U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES ■ Public Health Service
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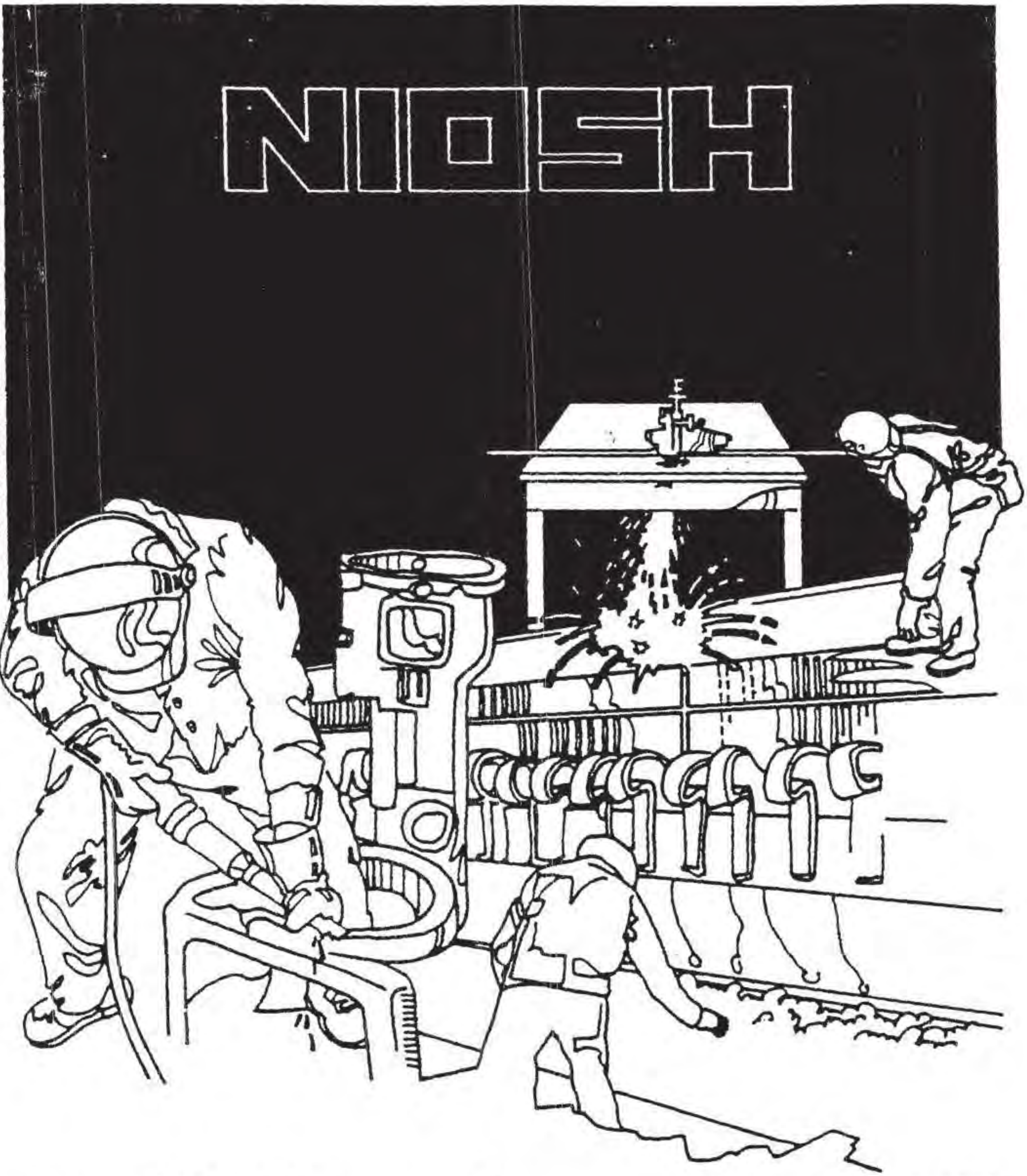


# Health Hazard Evaluation Report

HETA 84-082-1713
AIR FORCE GUIDANCE
AND METROLOGY CENTER
NEWARK AIR FORCE STATION
HEATH, OHIO

# PREFACE

The Hazard Evaluations and Technical Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, state, and local agencies; labor; industry and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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NEWARK AIR FORCE STATION
HEATH, OHIO

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## I. SUMMARY

On December 7, 1983, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation at the Aerospace Guidance and Metrology Center (AGMC), Newark Air Force Station, Newark, Ohio. The request listed the possible hazard as "eyestrain through microscope work." Other reported symptoms included musculoskeletal problems, cervical and lumbar strain, stiffness, pain, and nerve compression.

To determine if health complaints were related to work practices and work conditions, NIOSH researchers conducted site visits on March 19, 1984 and March 27-29, 1985. After the first site visit, a symptom survey was conducted among all workers involved in the maintenance of aerospace guidance devices. From this survey, low-and high-symptom workers were selected for an eye examination. At the time of the second visit, examinations of vision and the anterior segment of the eye were completed on 61 workers. NIOSH investigators also studied work practices, illumination, and workstation dimensions.

The proportion of examination subjects who used corrective lenses was not greater than would be expected among individuals of the same age in the US population. The proportion of subjects who had damaged cells on the surface of the eye (as indicated by uptake of fluorescein stain by the cornea or conjunctiva) was within clinical expectations, and the proportion of subjects with an unstable tear film was not significantly greater than has been reported elsewhere. However, these AGMC subjects had a greater mean eye redness score than a control group, but the degree of eye redness was not severe.

The high-symptom (HS) group included a greater proportion of women. Moreover, workers in the HS group also spent more time using acetone and using the microscope than the low-symptom (LS) group. Forty-three percent of the HS group, but only 14% of the LS group used the microscope 6 hours or more daily (odds ratio = 4.5). The LS and HS groups did not differ, however, on any of the three objective measures of external eye irritation, i.e. tear break-up time, eye redness, or stain uptake by damaged cells in the cornea and conjunctiva.

Neither uptake of stain by the cornea nor tear break-up time were credibly predicted by any of the work or visual variables that were examined. Eye redness scores were greater among men than women, and were associated with increased hours of isopropyl alcohol use and age.

As noted above, the HS group reported longer acetone use, and eye redness was associated with isopropyl alcohol use. However, the results of air sampling carried out by NIOSH investigators in 1979 showed that the workplace was in compliance with the OSHA permissible exposure limits.

The illumination produced by the microscope light sources was well within the levels recommended as safe by the American Conference of Governmental Industrial Hygienists. However, the illumination was quite variable, due in part to variation in the placement of the lamp within the illuminator and in the focussing of the illuminator. Area illumination was generally adequate, although there were areas of low illumination within each room. Problems with solder smoke, glare, and microscope cleaning and maintenance were also observed.

Most workers bend forward, flexing the neck and back, to use the microscope. The short optical path of the type of microscope in use at AGMC, along with the angle of the eyepieces, does not allow an erect posture with the work at the level of a conventional table top. The recommendation was made that the work should be placed on a slant stand that would elevate the work and rotate it toward the worker.

Based on these results, it is concluded that there was not a health hazard due to microscope use at the Air Force Guidance and Metrology Center. However, there was evidence of eye irritation and musculoskeletal discomfort associated with prolonged microscope use, that may be disturbing to workers and interfere with their work. Recommendations are made for alterations in work stations and work practices to minimize irritation and discomfort associated with microscope work.

KEYWORDS: SIC 7699 (Repair Shops and Related Services, Not Elsewhere Classified), microscope, eye irritation, posture, illumination

## II. INTRODUCTION

On December 7, 1983 NIOSH received a request for a health hazard evaluation at the Aerospace Guidance and Metrology Center (AGMC), Newark Air Force Station, Newark, Ohio. The request was submitted by a representative of the American Federation of Government Employees, Local 2221. The request listed the possible hazard as "eyestrain through microscope work." The symptoms were described as "musculoskeletal problems associated with chronic use of microscope tending to optical strain, cervical and lumber strain, stiffness, pain, nerve compression and ergonomic concerns."

In response to this request, NIOSH conducted site visits on March 19, 1984 and March 27-29, 1985, and NIOSH personnel trained in physics and ergonomics collected data on work practices, illumination, and work stations. The 1985 visit included eye examinations of selected workers by contract optometrists. A brief interim report was provided in the form of a letter to the requestor, dated April 12, 1985, with copies to several management personnel.

## III. BACKGROUND

### A. Processes

AGMC is divided into two major departments. Workers in the maintenance department maintain and rebuild a variety of guidance devices for use in aircraft and missiles. The work involves dismantling, cleaning, soldering, reassembling, and testing these devices. Workers use a variety of solvents, as well as solder and flux. Much of the work is carried out under low-power microscopes (7x-30x), which are almost entirely cycloptic stereo microscopes manufactured by American Optical, now Reichert Scientific Instruments. Each microscope pod is mounted on an adjustable stand containing at least one external variable light source. Many of the workers are in "clean rooms" with carefully controlled airborne particulate levels, temperature, humidity, and ventilation. Approximately 650 workers, all civilians, are employed in the maintenance department.

The metrology department maintains secondary standards for a variety of physical measurements, and provides specialized technical services, including calibration of tertiary standards used at other Air Force installations. The metrology department was not included in this investigation

### B. Previous environmental data

The maintenance department was investigated in 1979 by NIOSH, at the request of the Department of Justice, in connection with the government's defense of a suit by the union for environmental differential pay (NIOSH, 1979). Extensive industrial hygiene measurements were made at that time. The breathing-zone samples showed low-level exposure to a number of solvents, several of which are eye irritants. The highest concentrations, expressed as time-weighted averages over several hours, are shown in Table 1. In most cases, these were several times the median concentration.

All the concentrations measured in 1979 were below the OSHA permissible exposure limits, the NIOSH recommended standards, and the American Conference of Government Industrial Hygienists (ACGIH) threshold limit values. None of the 140 air samples showed concentrations of a single material greater than one-third of its threshold for eye irritation. Most workers were exposed to 1,1,2 trichloro- 1,2,2 trifluoroethane (Freon 113), 1,1,1-trichloroethane, and isopropyl alcohol. However, Freon 113 is not considered an eye irritant (ACGIH, 1980).

On March 19, 1984, NIOSH investigators visited AGMC and observed the work in several areas. The workers interviewed during the initial walkthrough reported a variety of symptoms, such as headaches, eye pain, blurred vision, and back pain.

## IV. MATERIALS AND METHODS

### A. Symptom survey

In order to obtain a more complete assessment of the symptoms, a short symptom survey was prepared for distribution to all maintenance department workers (included as Appendix A). The questions included age, sex, work area, job category, and the presence or absence of nine symptoms. During June, 1984, the surveys were distributed by the mail with the assistance of the union to the 646 workers in the guidance-device maintenance department.

### B. Eye examination

Workers were selected for the examination on the basis of two criteria: 1) having high or low eye-symptom scores on the June, 1984 survey and 2) working in March, 1985 at AGMC on the day shift, so that they would be available for the examination. Many workers were not available because either they worked on other shifts or no longer worked at AGMC. Examination subjects were selected proceeding from the extremes of the eye-symptoms scores, and continuing toward the middle of the distribution until 75 subjects were identified. Using this method, the low-symptom subjects were selected from the lowest 27% of the eye-symptom scores, and the high-symptom subjects were selected from the highest 41% on the same scores. Each of the 75 workers selected for the examination received a letter that explained the study and requested their participation, along with a consent form, and a questionnaire.

We intentionally selected more high- than low-symptom examination subjects to increase the probability of finding objective pathology. This choice was based on the assumption that if objective pathology were present, it would occur in some, but not all of the high-symptom workers.

As shown in Table 2, the 75 workers selected for study included 40 from the high-symptom group and 33 from the low-symptom group. Two workers were also included who did not have a high eye-symptom score, but reported specific problems that warranted further evaluation (breaking a blood vessel in the eye, and deterioration in vision since starting work at AGMC). Of the 75 workers who were selected, one had been transferred to another shift before the date of the examinations, nine were on leave at the time their examination was scheduled, and seven declined to be examined. However, one of the low-symptom subjects who declined to be examined did submit a completed questionnaire. We were able to locate three replacements for workers who informed us before the times of their examinations that they were not willing to be examined. Thus, a total of 62 workers returned completed questionnaires, and 61 of these were examined.

Each subject selected for the eye examination completed another, more detailed, self-administered questionnaire about his or her work and visual history (included as Appendix B). The work history portion of the questionnaire included questions on duration of employment at AGMC; specific job title and duties; years in that job; daily duration of microscope use, soldering, work in laminar flow ventilation, and use of several chemicals; smoking habit; age; and sex.

At the time of the examination, each subject was also asked how many hours he or she had used the microscope during that day. The chemicals selected for inclusion on the questionnaire were those that had been found frequently (at any concentration) in the 1979 air sampling data.

The visual history portion of the questionnaire inquired about seven visual and ocular symptoms: eyestrain, burning, dryness, and itching of the eyes, other eye irritation, blurred vision, and double vision. For each symptom, the subject was asked if he or she ever experienced the symptom, how many days a week the symptom was experienced, how severe the symptom was, and what time of day the symptom was usually first experienced. The subjects were also asked about the use of corrective lenses while viewing through the microscope and at other times.

A team of optometrists examined each subject to detect objective evidence of external eye irritation, as well as visual problems that might explain subjective eye strain. This examination included assessment of muscle balance, refraction for near and distance vision, assessment of color vision, examination of the external eye, photography of both eyes, and slit lamp examination of the cornea (including "break-up" time of the tear film).

The day shift at AGMC is 8am to 4pm. Examinations were conducted between 10am and 4pm, so that the examinations represent the condition of the eyes during the workday. Informed consent was obtained immediately before the examination.

Subjects were informed that the examination was not a complete eye examination. For example, intraocular pressure was not measured. Workers were informed during the examination of any abnormalities that were found, including refractions that are widely divergent from their corrective lenses. A summary of his or her findings was provided to each examination subject, and, if the subject so requested, to a health-care professional designated by the subject.

Specific measurements included the following:

Corneal staining: A small amount of fluorescein dye, followed by a small amount of rose bengal dye, was introduced into the eye. Each of these dyes will penetrate injured or dead cells in the cornea or conjunctiva, resulting in a prominent stain. For statistical analysis, all subjects who demonstrated staining with either dye in either eye were reported as having corneal staining.

Tear break-up time is the time from a blink, which renews the tear film, until the first gap is noted in the film of tears over the eyes. Fluorescein dye was placed in the eye and the subject was told to keep his or her eyes open. A stop watch was used to measure the time from the last blink until the first gap in the tear film was noted. A break-up time of thirty seconds was recorded for subjects who did not develop a gap in their tear films by that time. A decreased break-up time indicates an unstable tear film, which may be due to an inherent dry eye condition or external eye irritation.

Eye redness: Each eye was photographed, and the degree of redness was rated subjectively by one rater. Eye redness is related to fatigue, irritation, time of day, and sleep the night before. Redness was rated on the following scale:

| | |
|---|---|
| 0 | none |
| 1 | light redness |
| 2 | medium redness |
| 3 | heavy redness |
| 4 | extreme redness (conjunctivitis) |

Each eye was rated to .5 units on the above scale. The score for each subject was the mean of the scores for the two eyes.

Vertical phoria is defined as a muscle imbalance that tends to turn the eyes in different directions (in a vertical plane), which is not apparent when the two eyes are looking at the same object. Vertical phoria is measured by the vertical movement of one eye when the other eye is covered. All values are measured in prism diopters and expressed as positive numbers, regardless of the direction of movement.

Phoria is a muscle imbalance that tends to turn the eyes in or out, which is not apparent when the two eyes are looking at the same object. This value was calculated from the horizontal movement of one eye when the other is covered, while the subject is looking at an object 1 m from his or her eye, with a lens that requires no focusing in the subject's eye. (Many microscopes, including those in use at AGMC, use converging eyepieces, so that the image appears to be 1 m from the subject.) The values are measured in prism diopters. Outward movement (exophoria) is recorded as a positive number, and inward movement (esophoria) as a negative number.

Stereoacuity is defined as the ability to see fine difference in depth using binocular vision. This ability was measured with the subject's current spectacles and a test card placed at a distance of 40 cm. The results are expressed in seconds of arc, and low values indicate greater acuity. The test yields ten possible results from 20 to 500 seconds of arc.

Near point of convergence is the distance from the bridge of the nose to the point at which an object approaching the eye first appears double, or the subject deviates one eye from fixation. This test was conducted with the subject wearing his or her own spectacles.

Astigmatism is defined as an unequal curvature of the refractive surfaces of the eye. Subjects were classified as astigmatic if they needed a correction of 0.5 diopters of cylinder or more in both eyes. (Cylinder is the second number in an ordinary glasses prescription.) This classification was based upon the subject's condition while viewing through the microscope. That is, subjects who do not wear corrective lenses while viewing through the microscope were classified according to the prescription determined during the examination, and subjects who use corrective lens while viewing through the microscope were classified according to the difference between those lenses and the prescription determined by the examination.

Spherical errors (nearsightedness and farsightedness) are refractive errors in which the focal point of the image formed by the lens of the eye is in front or behind the retina. Subjects were classified according to their correction while viewing through the microscope. Subjects with a spherical equivalent error of +0.75 diopter or more in both eyes were classified as hypermetropic (farsighted), and subjects with a spherical equivalent error of -0.75 diopters or less were classified as myopic (nearsighted). All other subjects were classified as emmetropic (having normal vision).

Anisometropia is defined as the condition in which the refractive errors of the two eyes are different. Subjects were classified according to their correction while viewing through the microscope. They were classified as anisometropic if the difference in their spherical equivalent errors was 0.75 diopters or more, or if the difference in their cylindrical errors (astigmatism) was 1.00 diopters or more.

Deficient color vision: Two different color vision tests were used. All examination subjects were asked to identify numbers formed by colored dots on pseudoisochromatic plates. Subjects who read nine or less of the 14 plates correctly were asked to arrange a set of 15 colored circles in order of their hue (the Farnsworth Dichotomous Test). Subjects who failed both tests were classified as having deficient color vision.

Inadequate fusional reserve was defined for this study as fusional reserve, or vergence, that is less than twice the subject's phoria. Fusional reserve is the ability to converge or diverge eyes in order to form a single image even though the image is presented to the subject's two eyes at slightly different angles. This ability was tested by placing a prism in front of one eye, while the subject looked at an object at a distance of 40 cm, and was measured in the direction (either inward or outward) of the subject's phoria. In practical terms, inadequate fusional reserve means that the subject's ability to move his or her eyes to form a single binocular image is not large enough compared to subtle imbalances in his eye muscles. Such a person may be more likely to experience visual fatigue.

Eye pigmentation: Examination subjects were rank ordered on the degree of pigmentation in their right eyes. Blue eyes were ranked lowest, followed by green, hazel, and brown. Two observers independently ranked the degree of pigmentation. Ranking was used rather than color categories because the categories are not distinct and the degree of pigmentation follows a continuum. Since light passes through the iris as well as the pupil, we would expect subjects with blue eyes (and little pigmentation) to be more frequently affected by pathology or discomfort due to the level of light reaching the retina.

C. Evaluation of illumination and optical conditions

Light levels were documented in two ways. Luminance or brightness levels were measured with a Photo Research Spectra mini-spot photometer having a 1 degree field of view. The values obtained could be expressed in units of candela/$cm^2$. Illumination levels were obtained from a Photo Research System 500 photometer that measured in units of lux. The measuring instruments had been calibrated by the manufacturer within the previous six months.

In addition, densitometer techniques were used to estimate the light levels at the exit pupil of the microscope and record any glare problems. Latent image emulsions for densitometry were obtained using a 35mm Mamiya Sekor single lens reflex recorder mounted on a tripod.

One microscope from AGMC was sent to the manufacturer, Reichert Scientific Instruments, for an evaluation of its mechanical function. The microscope was selected by AGMC management from an area where its absence would not impede output. It was compared to a unit of a similar model from current production.

D. Ergonomic survey

To provide a basis for evaluating the possible contribution of workstation design to postural discomfort, the physical dimensions of twelve workstations in three areas were measured, and workers using these workstations were photographed. These areas were selected to include a variety of workstations, and are not a random sample of the workstations at AGMC. The inclination of the head was measured from these photographs, and angles of the upper back (T1-L1) and lower back (L1-S5) were measured from the estimated position of the respective landmarks under normal clothing in the photographs.

## V. EVALUATION CRITERIA

### A. Symptom survey

The responses from this survey were compared to those of medical pathologists at the Armed Forces Institute of Pathology (AFIP). These pathologists also use microscopes during a major part of the workday, and several pathologists had complained of musculoskeletal problems, which they attributed to microscope use. Approximately 100 of these pathologists were given a survey similar to the one used at AGMC, including identical questions on the presence of symptoms.

### B. Eye examination

The first step in analyzing the eye examination results was to evaluate the prevalence of abnormal test results. We compared the use of corrective lenses by AGMC examination subjects to that of subjects of the same age in the first National Health and Nutrition Examination Survey (NHANES) (Roberts, 1978). The prevalence of corneal staining was compared to the expected prevalence, based on the professional judgment of the optometrist. Eye redness was compared to that of a control group comprised of 23 men and women, ages 25-65, who did not wear contact lenses. The control subjects were photographed at the Ohio State University (OSU) College of Optometry during the afternoon. Their photographs were scored in the same manner by the same rater as the photographs of AGMC subjects. Tear break-up time was compared to a published normal group (Lemp and Hamill, 1973).

The remaining eye measurements were of factors that might influence the relationship between microscope use and outcome variables, rather than indicate the effect of microscope use. These measures included phoria, stereoacuity, convergence, astigmatism, anisometropia, color vision, fusional reserve, and eye pigmentation. They were treated as potential covariates or confounding variables. If they were related to an outcome variable, they were included in the evaluation of the relationship of other variables to that outcome. For example, workers with astigmatism might experience more visual symptoms than other workers, and this effect must be accounted for when evaluating the effect of microscope work on visual symptoms.

Secondly, factor analysis was used to determine how the symptoms were inter-related. Thirdly, simple bivariate statistics were used to compare the low- and high-symptom groups with regard to measures of eye irritation, work, and visual function. Simple bivariate statistics were also used to test the relationship of work variables to corneal staining, tear break-up time, and eye redness.

Finally, multivariate methods were used to determine if the associations found in the simple statistics were independent, or a reflection of relationships to other work and visual variables. The methods used for this analysis are described in detail in Appendix C.

C. Evaluation of illumination and optical conditions

For periods of exposure lasting more than about 3 hours, ACGIH recommends a threshold limit value of 10 milliwatts/$cm^2$/steradian for blue light (ACGIH, 1984). Other wavelengths of light are converted to an equivalent dose of blue light by a hazard function, which gives the greatest weight to wavelengths between 415 and 475 nm. The threshold limit value was selected to avoid damage to the retina, the light-sensing portion of the eye.

The general lighting in work areas should be from 500 to 1000 lux. This level of illumination is adequate for tasks with normal visual requirements (Commission Internationale de l'Eclairage, 1975). For tasks with higher visual requirements, task lighting of 1000 to 7500 lux is needed. Older individuals require more light than younger individuals for the same task (Konz, 1979).

In previous studies, NIOSH has demonstrated that the retinal irradiance (illustrated in Figure 1) while looking through a low-power stereo microscope is less than .0001 times the ACGIH Threshold Limit Value (Landkrohn, 1984). The irradiance depends on the spectrum of light produced by the light source, the position of the eye, the magnification power, the position of the lamp in the illuminator, and whether the light passing through the microscope is reflected or direct. Typical microscopes do not transmit ultraviolet or visible light wavelengths shorter than 400 nm (Figure 2). As magnification is increased, the intensity of the transmitted light is decreased (Figure 3).

Often the lamp is not centered within the microscope illuminator. In a study by Landkrohn (1984), rotating the beam within the illuminator produced luminance ranging from 100,000 to 277,000 candela/$m^2$--a variation of 2.8 times (Figure 4). When the beam was passed through a microscope, luminance differed by a factor of 8.9 times. This wider variation may be the result of the small aperture of the microscope objective lens, making it more sensitive to positioning of the lamp filament as it moves in and out of the field of view.

There is a lower transmission of reflected than direct light through the microscope. (AGMC workers use reflected light.) Note that in Figure 5 the shortest wavelength reflected is about 410 nm, and that for all wavelengths, except those with peak transmission, there is less transmission, hence a greater margin of safety, in the reflected than in the direct condition.

## D. Ergonomic Survey

There are number of published guidelines for workstation design (Ayoub, 1973; Konz, 1979; Grandjean, 1981), although none of them specifically addresses the constraints of a microscope workstation. Chairs should be adjustable for height over the range of 38 to 53 cm. When properly adjusted, they should allow the workers to sit with their thighs horizontal and feet flat on the floor. The base of the chair should have five points and a diameter greater than that of the seat.

For precision work, the work surface should be high enough to allow close inspection without excessive head inclination. Acceptable head inclination is 17 to 29 degrees (Grandjean, 1981). A lower height for elbow support (70 to 78 cm) is desirable, with support for the work and hands at a higher level.

The workstation dimensions were also compared to anthropometric surveys of United States Air Force men in 1965 and women in 1968 (Webb Associates, 1978). The popliteal height is measured from the footrest surface to the underside of the thigh with the lower leg vertical (dimension "a" in Figure 6). It should correspond to the height of the chair pan minus the thickness of the shoe. The elbow rest height is the height of the tip of the elbow above the seat with the subject seated erect and the upper arm vertical (dimension "b" in Figure 6). It should correspond to the height of the table above the chair pan. The seated eye height is measured from the sitting surface to the inner corner of the eye with the subject seated erect (dimension "c" in Figure 6). It should correspond to the height of the microscope ocular lens above the chair pan.

## VI. RESULTS

### A. Symptom survey

Four hundred and twenty-two (65 %) of the AGMC workers returned surveys. The characteristics of the respondents are summarized in Table 3. No data were collected on the characteristics of the non-respondents.

Table 4 shows the symptoms reported from the list. Sixty-seven (67%) of the AFIP pathologists returned surveys. In both the AGMC and AFIP surveys, if workers marked positive responses, but no negative responses, it was assumed that blank responses were negative. If any negative answers, or no positive answers, were marked, blank responses were not included in calculating percentages.

While all symptoms are more common at AGMC than at AFIP, the percentages are difficult to compare because the populations and jobs differ so greatly. Nevertheless, it is apparent that burning or itching eyes, blurred vision, eye pain, and redness of the eyes were many times more common at AGMC than at AFIP.

The symptoms were factor-analyzed to determine if they represented a smaller number of core factors. The analysis suggested two underlying factors--eye symptoms and musculoskeletal symptoms. Headache was weighted on both scales. This analysis must be interpreted cautiously, since the responses were yes or no, rather than continuous variables following a normal curve, as the analysis assumes. The eye-symptom factor increased with age, and the musculoskeletal-symptom factor was greater in women, but neither factor was related to job title or work area.

One hundred and twenty-seven (30 %) of the respondents offered additional comments about health problems or environment complaints. Many of these comments mentioned more than one problem or complaint. Those mentioned by ten or more workers are shown in Table 5.

### B. Eye examination

Sixty-one workers were examined. Their characteristics are shown in Table 6. Their age, sex distribution, and jobs are similar to the entire group that answered the first survey (shown in Table 3). Because of the small numbers of examination subjects, instrument workers and instrument mechanics were grouped together for the analysis, and compared to all other workers. The workers came from 21 different work areas, but only Clean Rooms 10 and 11, considered together, gave a large enough number to use for analysis.

The amount of time spent in various activities, and using various chemicals is shown in Table 7. The mean time includes subjects who reported no time in that activity or using that chemical. Sufficient numbers of workers reported using Freon 113, 1,1,1-trichloroethane (Chlorothane-Nu), isopropyl alcohol, and acetone for further analysis. One subject inquired about tetrachloroethylene, and immediately recognized the synonym "perk" (an abbreviation of perchloroethylene). Perhaps if this synonym had been included on the questionnaire, more workers would have reported its use. Thirteen subjects reported using a total of six other chemicals. None of these six chemicals was reported by more than five workers.

Twenty-seven of 61 examination subjects reported that they used corrective lenses for distance viewing, including 24 who used corrective lenses all the time. This was not significantly more than the 20.0 that would be expected, based on the NHANES data ($p>.1$). Thirty-three of the subjects reported that they used corrective lenses for reading and close work, including those who use corrective lenses all the time (31.2 expected, $p>.7$).

Thirty-five of the 36 examination subjects who use corrective lenses at any time brought the lenses to the examination. There was no difference between the distribution of correction in those lenses and that expected in subjects with the same age distribution (mean ridit for minus correction=.549, $p>.3$).

Corneal staining, eye redness, and tear break-up time were used as objective indicators of irritation to the cornea. Although symptoms are the best indicators of irritation, these objective measures were also used because they are not influenced by individual differences in the perception or reporting of irritation.

Nine examination subjects had corneal staining, indicating damage to the corneal cells, and in every case it was classified as "a light stain." (Light staining is usually not persistent, and has no clinical implication for the individual.) Six subjects stained only with fluorescein, one stained only with rose bengal, and two stained with both dyes. One contact-lens wearer was not examined for corneal staining. In the opinion of the examining optometrist, the incidence of staining found in this population was similar to the level that would be expected in the general population.

Photographs were available to rate the eye redness for at least one eye of 60 of the 61 examination subjects. The mean eye redness was 1.15 units, where 1.0 corresponds to light redness and 2.0 corresponds to medium redness. This is significantly more than the mean eye redness of the OSU control group, which was .85 units ($p=.05$, two-tailed t-test). The analysis did not control for any demographic variables. This difference suggests that the AGMC group had somewhat more eye irritation than would be expected, although the difference is not large enough to be clinically significant.

Tear break-up time was successfully measured on 57 subjects. Two subjects were excluded because their contact lens wear might affect their tear stability, and two were not able to refrain from blinking long enough to complete the test. Three subjects had a break-up of time of less than 10 seconds, and six had a break-up time of 10-14 seconds. In the published normal group, no subjects had a break-up time of less than 10 seconds, and four of 50 had a break-up time of 10-14 seconds. Ninety percent of the published group had a break-time of 15 to 34 seconds. The proportion of AGMC workers having break-up times of less than 15 seconds was twice that found in the published normal group, but this difference was not statistically significant ($p>.2$).

For each symptom, the median time of reported onset was late morning or early afternoon. For five of the seven symptoms, the majority of the examination subjects reported onset during this period.

The symptoms reported by the examination subjects chosen for high-symptom levels were factor analyzed to determine if there were groups of symptoms that tended to occur together. This analysis was attempted with the frequency, and the severity of symptoms, the product of frequency and severity, and the log of one plus the product of frequency and severity. The strongest factor pattern was found using the product of the frequency and severity scores. Only one factor had an eigen value greater than one. When it was used, the weights of each of the normalized symptom scores were similar. When two factors were retained, the factors were not intuitively meaningful. The division of the symptoms into a visual symptom score and an irritation symptom score did not yield any additional associations beyond those found in the comparison of the low- and high-symptom groups.

The examination subjects were scored on the single factor that emerged in the factor analysis described above. For further analysis, the subjects were divided into those with standardized factor scores of less than -.75 (low-symptom) or more than -.75 (high-symptom). This dividing point was chosen to maximize the number of subjects that would be classified as low- or high-symptom in agreement with the classification from the 1984 symptom survey. Subjects who were classified differently by this factor than by the 1984 symptom survey were excluded from the comparisons of low- and high-symptom groups. Twenty-eight of 35 high-symptom subjects and 21 of 25 low-symptom subjects were retained. The comparison of the symptom groups is based on these 49 subjects.

A summary of the multivariate analysis of the eye examination results is presented here. The bivariate results and the detailed multivariate analysis are included in Appendix C.

The low-symptom and high-symptom workers were compared on the basis of self-reported work exposures and visual function as measured by the examination. The high-symptom group included a higher proportion of women than the low-symptom group. Workers in the high-symptom group also reported more time using the microscope and using acetone. These differences persisted when all three of these variables were considered together, as shown in Table 8. The low-symptom and high-symptom groups did not differ on any of the three objective measures of external eye irritation: Tear break-up time, eye redness, or corneal staining.

The odds ratio, reported in Table 8, is a measure of the relative probability that subjects with a given characteristic are in the high-symptom group. An odds ratio greater than 1.0 indicates that subjects with that characteristic are more likely than subjects without that characteristic to be in the high-symptom group, and an odds ratio less than 1.0 indicates that subjects with that characteristic are less likely than subjects without that characteristic to be in the high-symptom group. The odds ratio for average microscope use is significant, even though it is close to 1.0, because it is multiplied by the average hours of microscope use raised to the fifth power.

The distribution of reported hours of microscope use by subjects in low- and high-symptom groups is shown in Figure 7. Both the regression equation and Figure 7 indicate that the most important difference is in the proportion of each group who use the microscope for 6 or more hours daily. Forty-three percent of the high-symptom group, but only 14% of the low-symptom group used the microscope 6 hours or more daily (odds ratio = 4.5).

The distribution of hours of acetone use is shown in Figure 8. Sixty-seven percent of the high-symptom group, but only 32% of the low-symptom group used acetone 1 or more hours daily.

If the high-symptom group had tended to overestimate their microscope use, the overestimation would be expected to be greater for more abstract responses, such as average microscope use, than for more concrete responses, such as hours of microscope use the day of the examination. We compared the proportion of time each subject reported using the microscope before the examination and the proportion of time that he reported using the microscope on an average day. The proportion of time using the microscope before examination was calculated as the hours the subject reported using the microscope before the examination divided by the hours from 8 am to the time of the subject's appointment. The proportion of time using the microscope on an average day was calculated as the hours the subject reported using the microscope on an average day divided by 8 hours. The proportion of time using a microscope on an average day explained 38% of the variation in the proportion of time using the microscope before the examination ($p=.0001$). This relationship was not influenced by membership in the low- or high-symptom group ($p=.47$).

Examination subjects with corneal staining, an indicator of damage to the cells of the surface of the eye, used isopropyl alcohol more than subjects without staining (see Table 9). A lower proportion of the subjects with corneal staining were women. On the day of their eye examinations, they had used the microscope less before their examinations, but reported about the same hours of microscope use on an average day. If microscope use before the examination were excluded from the logistic regression because of its paradoxical effect, neither isopropyl alcohol use nor sex would remain significant.

Tear break-up time was not significantly related to any of the variables examined, but subjects with darker eyes tended to have less stable tear films.

As shown in Table 10, women had less eye redness than men. This association was not affected by cigarette smoking (not shown). Eye redness was associated with increased hours of isopropyl alcohol use and with age. As shown in Figure 9, workers who used isopropyl alcohol for 6 hours or more daily had a mean eye redness score of 1.56 units, while workers who used isopropyl alcohol for 4 hours or less daily had an eye redness score of 1.05 units.

C. Evaluation of illumination and optical conditions

Light levels were measured on four microscopes in the Test Pad area, 14 microscopes in Area 41A23, and 15 microscopes in Clean Room 12. The NIOSH team observed the use of microscopes by workers from the day and evening shifts. The magnification used in these microscopes varied from 7x to 20x. There were one or two illuminators on each microscope, and almost half the eyepieces had homemade spectacle shields.

The average area illumination levels were 625 lux in the Test Pad area, 786 lux in 41A23, and >700 lux in Clean Room 12. Although the average room lighting was adequate, parts of these work areas were not adequately illuminated. In the Test Pad area, a number of workers were seated at a long table with a shelf mounted over the table. The shelf obstructed the area lighting, and one of the workers had mounted a fluorescent lamp under the shelf to provide additional task lighting. In area 41A23 light fixtures were not installed on one side of the room. As a result, the workers in that part of the room required more task lighting, and many of the workers used more than one illuminator with the microscope.

The microscope illuminators in the Test Pad area produced light ranging from 2,220 to 3,090 lux, depending on the location of the source relative to the work and the voltage setting of the illuminator. In area 41A23, those illuminators set on the lowest voltage setting produced 1,000 to 14,500 lux, while those set on the highest voltage setting produced 1,700 to 32,400 lux. There was a difference of at least 10 times in the illumination produced by different illuminators of the same type, at the same distance, and on the same voltage setting. This variation was due to a number of factors, including the variation in the placement of bulbs within the illuminator housing, and in the focussing of the illuminator beam.

The illuminator focussing adjustment allows the worker to select a small, bright area or a larger, more diffuse area of illumination. Many of the illuminators were sharply focussed, with a bright image of the coiled filament projected onto the work table. The effect of illuminator focussing is illustrated in Figure 10.

Bright light was emitted through vents in housings of some of the illuminators. When the illuminator was placed in its receptacle in the microscope stand, the vents were close to the operator's eyes, and were the source of considerable glare. Some of the housings also became quite hot when the illuminators were operated at the highest voltage, and could present a burn hazard to the worker's skin.

In each of the three areas where light measurements were made, many of the microscopes had dust on their optical surfaces, and a few had broken parts. One microscope, according to a service sticker affixed to it, had not been serviced for 10 years. Microscope repairs were made in-house or by a contractor. None of the technicians involved in repair were aware of any collimation checks being made, even when lenses were remounted. Workers reported using a variety of cleaning methods, and seemed unsure of the appropriate method.

The microscope sent for optical evaluation performed within expected tolerances. The optical coatings were heavily scratched and stained, but this resulted in, at most, a subtle loss of image quality. The complete report is attached as Appendix D.

Many of the workers solder electronic components using the microscope. In the Test Pad area, each worker to which the NIOSH team spoke complained of the smoke produced during soldering, and all sought better smoke removal systems. In area 41A23, the workers were able to hold the soldering iron in such a way as to minimize, but not eliminate, the drift of smoke into their eyes.

The pig-tailing operation in Clean Room 12 was clearly the most visually demanding task we saw. Workers counted coils of extremely fine gold wire that they stretched across an accelerometer and soldered into place. The wire was exceedingly difficult to see, even with very intense illumination. Furthermore, the illumination created intense glare off the reflective accelerometer case.

The problem of glare off metal components is illustrated in Figure 11. In most cases, the glare level can be reduced by the use of a shadow box placed on the microscope. However, many workers do not use these devices.

D. Ergonomic survey

As shown in Table 11, the height of the chair pans, as they were being used, varied from 43.6 to 54.6 cm, and the table top heights varied from 70.3 to 81.2 cm. At 10 of the 12 workstations, a microscope was being used. The center of the ocular lens was 56.2 to 68.9 cm above the chair pan.

All of the workers who were using the microscope inclined their heads forward (mean 29 degrees). Nine of ten workers inclined their heads 26 to 43 degrees. The exception inclined her head 10 degrees. The inclination of the upper back was 3 to 26 degrees (mean 15 degrees), and the inclination of the lower back was -2 to -25 degrees (mean -10 degrees). Many of the workers sat forward on their chairs, away from the back support.

The microscope eyepieces were tilted at an angle of 60 degrees from the horizontal plane of the microscope. Workers decreased this angle by rotating the entire microscope toward themselves by up to 14 degrees. However, this adjustment also rotated the plane of focus, so that a flat object placed on the table top is not in focus throughout the entire field of view.

In the workstations examined, the chair pan height roughly corresponds to the popliteal height plus the thickness of the shoe sole and heel. The table top height is slightly more than the height recommended for elbow support. The height of the ocular lens of the microscope above the chair pan (56.2 to 68.9) is less than the range of seated eye height.

A variety of chairs were in use. The older chairs had fabric covering, a four-point base without casters, and height adjustment by rotating the chair on its screw-type post. The newer models had a pneumatic height adjustment and plastic covering. They had four- or five-point bases with or without casters. The chairs with casters move very easily on the smooth floors. Some of the workers mentioned that they had fallen from the new chairs, which they attributed to the casters.

## VII. DISCUSSION AND CONCLUSIONS

### A. Eye examination

The eye examination demonstrated no major ocular pathology in workers at AGMC. Both the increased eye redness, compared to a control group, and the high level of complaints in AGMC workers suggest eye irritation. However, the redness score was no higher in high-symptom than in low-symptom AGMC workers.

High-symptom subjects were more likely to be women, to use the microscope 6 or more hours daily, and to use acetone 1 or more hours daily. It is well known that men are less likely to report symptoms than women (Hunt, McEwen, and McKenna, 1984). The odds ratio for sex is large, but it is not clear whether this difference is due to reporting or biological differences between men and women.

Symptoms were more frequent in examination subjects who reported prolonged microscope use. For 5 hours or less of daily microscope use, there is no increase in the proportion of subjects in the high-symptom group. However, the odds that a subject belonged to the high-symptom group was 4.5 times greater among workers using the microscope 6 hours or more daily than among workers using the microscope 5 hours or less daily. We found no evidence that members of the high-symptom group estimated their hours of microscope use in a manner that was different from the low-symptom group.

These findings suggest that symptoms are the result of prolonged microscope use, while shorter periods of use have little or no effect on symptoms. This hypothesis is also supported by the reports of most subjects that their symptoms began in the late morning or early afternoon, rather than in the early morning.

The odds ratio for symptoms of eye strain in workers who use the microscope for prolonged periods can also be calculated from an investigation similar to ours in an electronics plant (Soderberg *et al.*, 1983). The odds of having moderate or severe symptoms that occurred at least weekly among workers who used the microscope more than 75% of the workday were 3.6 times the odds among workers who used the microscope 75% or less of each workday. This is only slightly less than the odds ratio we found.

Microscope use may be associated with eye symptoms because of the ocular accommodation, that is focussing by the eye, that occurs during the use of optical instruments (Hennessy, 1975; Ostberg and Moss, 1984). While there is no optical necessity for the eyes to accommodate while an individual looks through a microscope, there are several reflexes that cause accommodation during microscope viewing. These reflexes include involuntary accommodation when an individual looks through a small aperture, looks at an image without any indication of its distance, or when the eyes converge, as is required by many microscopes.

We did not expect, and we did not find, that nearsightedness or farsightedness had any effect on visual or ocular symptoms (see Appendix Table C1). The focussing of the microscope inherently corrects for a broad range of spherical errors. However, others have found that microscope workers with uncorrected astigmatism are more likely than other workers to have visual symptoms (Soderberg, et al. 1983), but we were unable to confirm this association. Focussing the microscope does not correct astigmatism--it must be corrected by spectacles or contact lenses--and we expected that the blurring that results from uncorrected astigmatism would increase symptoms. Further work is needed to clarify this point.

More high-symptom subjects used acetone 1 hour or more daily. However, no difference was apparent among those who used acetone for longer periods.

Our examination subjects were selected for comparison of the low- and high-symptom groups. For the analysis of the objective measures of eye irritation, the low-and high-symptom groups were pooled. However, low- and high-symptom subjects were not selected at the same rate, and the sample did not include subjects with eye-symptom scores between the 27th and 59th percentiles on the first symptom survey. Thus, the combined sample is not a probability sample of the entire population of maintenance department workers. On the other hand, the low- and high-symptom groups did not have different levels of objective signs of irritation (Appendix Table C1). Thus, while the pooled sample is not ideal for the analysis of corneal staining, tear break-up time, and eye redness, it seems to adequately reflect the entire maintenance department work force for this purpose.

In the pooled sample, subjects with injured cells on the surface of the eye, as indicated by corneal staining, used isopropyl alcohol more than subjects without corneal staining. Subjects with corneal staining used the microscope less before their eye examination, but reported about the same hours of microscope use at other times. A lower proportion of the subjects with corneal staining were women. We are unable to explain how microscope use might protect against corneal staining, or why the effect of microscope use before the examination was not reflected in an association with usual microscope use. The negative association between corneal staining and microscope use before the examination seems to be due to chance. In that case, it should be removed from the multivariate equation, which also makes the associations of corneal staining with isopropyl alcohol use and sex no longer significant in the logistic model. Thus, none of the variables we examined credibly predicts corneal staining in this population.

Tear break-up time was unrelated to any of the variables under study. Eye redness scores were greater in men and were positively related to isopropyl alcohol use and age. The increased risk associated with isopropyl alcohol use was evident only in subjects who used isopropyl alcohol for 6 hours or more daily. However, even at this level the increase in eye redness was not remarkable. The subjects who reported using isopropyl alcohol 4 hours daily or less had an eye redness score of 1.05 (light redness), and the subjects who reported using isopropyl alcohol 6 hours daily or more had an eye redness score of 1.56 (light to medium redness).

The 1979 NIOSH air sampling data show that this workplace was clearly in compliance with the OSHA permissible exposure limits. As shown in Table 1, no single material that was measured was found in any sample at more than one-third of the threshold for eye irritation. However, acetone and isopropyl alcohol are known eye irritants at higher levels, and our data suggest that they may contribute, along with other factors, to eye irritation in this workplace.

Neither time spent soldering nor time spent working in laminar flow ventilation was associated with signs or symptoms of eye irritation. However, it was the impression of several workers, and of the NIOSH team, that both these factors could contribute to eye irritation in some situations.

In summary, the NIOSH investigators found no evidence of eye injury or disease as a result of work at AGMC. Staining and a short tear break-up time, which are specific indicators of effects on the cornea or tears, were neither altered in this population, nor consistently associated with any measures of workplace exposure. Symptoms and eye redness, which are nonspecific indicators of eye irritation, were greater at AGMC than in other populations, and eye symptoms were related to time spent using the microscope. Both eye symptoms and redness were related to chemical use, although different chemicals were involved in each case. The association of nonspecific indicators of irritation with microscope and chemical use suggests some interventions that might decrease irritation.

B. Evaluation of illumination and optical conditions

Area illumination was generally adequate in the rooms NIOSH studied in detail. However, there were darker areas within those rooms that need more illumination.

Task lighting under the microscope was quite variable. If workers use more than one microscope, this variation may require the worker to frequently adjust the lighting. At AGMC, glare is primarily the result of light from vents in the illuminator housings and reflections off machined metal parts. Inappropriate lighting and glare may contribute to discomfort and decreases in productivity and quality of output (Konz, 1979).

Work under the microscope can be most clearly seen with bright, even illumination. This is obtained by slightly de-focussing the illuminator, so that the filament coils cannot be visualized. When an image of the filament is projected onto the work, light and dark bands will distort the contrast and relief of the work.

Incandescent lamps are the most frequently used illumination source for low-power microscopy, both at AGMC and in other settings. However, as shown in Figure 2, much of the electromagnetic energy emitted by these lamps and transmitted through the microscope is infrared (wavelengths greater than 800 nm), rather than visible light (380 to 760 nm). Energy in the infrared spectrum cannot be seen, but it heats the surface of the eye, and therefore probably dries the eye to some degree. It is not known whether this effect contributes to eye irritation.

Other illuminators may be useful in certain situations. Fluorescent ring illuminators provide an even, cool illumination, without shadows. Fluorescent illuminators are not as bright as some other illuminators, but would be adequate for most applications at AGMC. Their color characteristics are somewhat different from incandescent lamps, but fluorescent lamps are actually closer than incandescent lamps to those of sunlight, so that after habituation their color will be perceived as normal. Fiberoptic light sources with tungsten-halogen lamps provide very bright illumination in a ring, or on adjustable supports that can be directed as needed to reduce glare or highlight relief. However, if accidentally directed into another worker's eye, they might pose a retinal hazard. Ring and fiberoptic light sources are available from many sources, including Reichert Scientific Instruments.

Microscope maintenance also seems to be a problem. The microscopes were not cleaned in a consistent fashion. The collimation of the microscopes is not verified when repairs are made, such as remounting lenses, that may affect collimation.

C. Ergonomic survey

While chair height is appropriate, and table height is only slightly above the recommended height, the low ocular lens height indicates that most workers will have to bend down to view through the microscope. This is consistent with the forward inclination of the upper back. This posture is narrowly constrained by the workstation dimensions, and requires prolonged muscle activity (Kumar and Scaife, 1979). Some workers may experience back and neck pain due to such prolonged forward bending (Hunting, Grandjean, and Maeda, 1980).

This working posture is in large part dictated by the length of the optical path of the microscope and the angle of the eyepieces. The length of the optical path, the distance from the ocular lenses to the object that is being viewed, is fixed by the design of the microscope. In most low-power stereo microscopes this dimension is 25 to 30 cm, and the eye pieces are angled at 60 degrees above horizontal. To permit an erect working posture with the hands at elbow level, the optical path should be about 50 cm, and the eyepieces should be no more than 30 degrees above horizontal. However, no economical microscope is made with these dimensions.

The most practical solution to this problem is to elevate and rotate the work on a slant stand (see Figure 12). The surface of the slant stand should be inclined upward at angle of 30 degrees. The stand should have one or more lips in the center to keep the work from sliding off the stand, or a holding jig mounted on the stand. The slant stand must also be wide enough to support the worker's hands on either side of the work. The forearms could be supported on the sides of the lower part of the stand. The microscope would also be tilted toward the workers at an angle of 30 degrees. This angle would match that of the slant stand, so that a flat piece of work would be in focus throughout the field of view of the microscope. Supplies, especially liquids, could be placed on the flat table surface beside the work.

Where such a slant stand is not practical, it may be appropriate to provide workers who have back pain with a microscope that permits a more erect posture. One such microscope is manufactured by Wild in Switzerland. These microscopes have an optical path of about 45 cm, and eyepieces that are elevated at 45 degrees above horizontal.

Falls from chairs may be related to the base of support as well as upholstery and caster characteristics. With many chairs having a four-point base, it is possible to sit on the edge of the chair, but have the center of gravity outside of the base of support. The chair will tip and slide away, and the worker may not realize that the tipping of the chair initiated his fall. This problem does not occur with a five-point base of adequate diameter.

VIII. RECOMMENDATIONS

1. Workers should not use the microscope for longer than 5 to 6 hours in any workday. Workers should perform various duties, and microscope use should be spread over a workday, so that workers do not spend long, uninterrupted periods at the microscope.

2. Training courses should include more education regarding the cleaning and use of the microscope, the use of illuminators and shadow boxes, and techniques to avoid visual and musculoskeletal strain. Specific points should include the following:

   a. Workers should be instructed to set the focus control at the highest point at which a clear image is produced. Because of the interaction of microscope focussing and ocular accommodation, the image may appear to be in focus over a range of focus settings. The lowest amount of ocular accommodation is required when the microscope focussing is set at the highest setting that produces a clear image.

   b. When using the microscope, workers should look away from the microscope every few minutes, and focus on an object at least 20 feet away, to avoid prolonged accommodation.

   c. Illuminators should be focussed to provide bright even light, without projecting the image of the coils of the filament.

   d. Shadow boxes should be used more frequently to decrease both shadow and glare.

   e. Optical surfaces of the microscope should be cleaned when dust is apparent with a cotton swab and a small amount of distilled water or alcohol. Eyepieces should be kept in the microscope to prevent the accumulation of dust in the body of the microscope. (Cleaning methods are discussed in more detail in Appendix D).

   f. Workers should be instructed in the operation of the controls of their chairs. They should readjust the height periodically, and adjust the back rest whenever they change positions, so that the chair provides lumbar support even if the worker is sitting forward in the chair.

3. Workers with correction for astigmatism should use their spectacles while viewing through the microscope. (Lenses are corrected for astigmatism if the second number in the optical prescription is 0.5 or greater.) Workers with spectacles should have "high eye point" objectives, which have a high exit pupil (shown in Figure 1). They should also use commercially-available eye shields, which fit around the eye piece, to protect their spectacles from scratches. These shields provide better protection for spectacles than the homemade shields we saw in use.

4. Workers who do not wear spectacles and find that laminar flow ventilation is irritating to their eyes may benefit from using plain safety glasses when they work in laminar flow ventilation.

5. Contact lenses may interact with occupational exposures to increase eye irritation, and their use may not be appropriate in all work areas. (Few of the workers we examined used contact lenses). Workers who do use contact lenses should be encouraged to seek appropriate professional care if they have any signs or symptoms of eye irritation.

6. Chemical exposures should be kept as low as possible. Although chemical exposures were well below the OSHA permissible limits in 1979, our data suggest that chemical exposures, particularly to acetone and isopropyl alcohol, may contribute to eye irritation. We noted evidence of attempts to minimize the use of open beakers and other sources of chemical vapors. Additional measures may be helpful, such as weighted covers that will not stand open, or covers with small holes, only large enough to permit entrance of a small brush or swab. Any container that is not being used at the moment should be completely covered.

7. Ventilation in areas where soldering is performed should be examined. Increases in both area and workstation ventilation may be useful in reducing exposure to soldering fumes.

8. Slant stands should be provided to elevate and rotate the work under the microscope. Several slant stands should be made according to the design shown in Figure 12 and evaluated by the workers after a few weeks of use. If the slant stands are found to be helpful, they should be modified according to any recommendations made during the evaluation, and provided to all workers.

9. Both chair height and the horizontal position of the back support should be quickly adjustable with, for example, pneumatic controls. The chair must allow adjustment to the dimensions of each worker, as well as easily accommodate changes of posture during a shift.

10. Chairs with five-point bases, rather than four-point bases, should be purchased because of their greater stability. The base of support should be larger than the chair pan. Cloth surfaces, where compatible with particle control, should be selected to avoid workers slipping off the chairs. Rollers with greater rolling friction than those currently in use may also be necessary.

11. If workers of approximately the same height use a given workstation on different shifts, the table should be set to the appropriate height. If necessary, tables can be elevated with blocks. If workers of different heights use a workstation, tables should be set for taller workers, and shorter workers should be provided with sloping footrests, which allow workers to set chair height so that the hands are at a comfortable level while their feet are supported above the level of the floor. Tables with crank-operated screw adjustment may be appropriate for some workstations, if they are stable and introduce no perceptible vibration into the field of view of a microscope on the highest magnification.

12. Workers should be encouraged to maintain a high level of physical fitness. In another worksite, microscopists with severe neck and shoulder pain reported that physical exercise, along with changes in their workstation, was useful in controlling their pain. The exercise they used included swimming and weight-lifting. Exercises to stretch neck and back muscles during the workday may also be beneficial.

13. The pig-tailing operation should be redesigned to reduce the glare. This might be accomplished with fiberoptic illumination that could be directed onto the coils from a low angle, spectacles with polaroid or color filters to reduce transmission of glare, or a video system that would display the work on a large screen.

14. Microscopes should be recollimated whenever any optical components, such as lenses or prisms, are replaced or repaired, or when other repairs are made that influence the orientation of the two optical paths to each other. Recollimation is not necessary on a routine basis.

15. The external incandescent lamps should be aligned and checked for output when illuminator bulbs are replaced.

16. Area illumination should be increased in areas of shadow and in corners of rooms that are less intensely illuminated than the rest of the room.

## IX. REFERENCES

American Conference of Governmental and Industrial Hygienists. Documentation of the threshold limit values, 4th ed. Cincinnati, Ohio: American Conference of Governmental and Industrial Hygienists, 1980.

American Conference of Governmental and Industrial Hygienists. Supplemental documentation. Cincinnati, Ohio: American Conference of Governmental and Industrial Hygienists, 1982.

American Conference of Governmental and Industrial Hygienists. Threshold limit values for chemical substances and physical agents in the work environment and biological exposure indices with intended changes for 1984-85. Cincinnati, Ohio: American Conference of Governmental and Industrial Hygienists, 1984.

Ayoub MM. Work place design and posture. Human Factors 15:265-268, 1973.

Commission Internationale de l'Eclairage. Guide on Interior Lighting. Paris: Commission Internationale de l'Eclairage, 1975. (CIE publication no. 29).

Grandjean E. Fitting the task to the man. London: Taylor & Francis Ltd., 1984.

Hennessy RT. Instrument myopia. J Optical Soc Amer 65: 1114-1120, 1975.

Hunt SM, McEwen J, and McKenna SP. Perceived health: age and sex comparisons in a community. J Epidem Commun Health 38:156-160. 1984.

Hunting W, Grandjean E, and Maeda K. Constrained postures in accounting machine operators. Appl Ergonom 11:143-149, 1980.

Konz S. Work Design. Columbus, Ohio: Grid Publishing, 1979.

Kumar S and Scaife WGS. A precision task, posture, and strain. J Safety Res 11: 28-36, 1979.

Landkrohn KJ. Transmittance Levels of Optical Radiation Through Several Types of Microscope in Common Use. MS Thesis, Department of Environmental Health, School of Medicine, University of Cincinnati, 1984.

Lemp MA and Hamill JR. Factors affecting tear film breakup in normal eyes. Arch Ophthalmol 89:103-105, 1973.

National Institute for Occupational Safety and Health. Criteria for a recommended standard for occupational exposure to tetrachloroethylene (perchloroethylene). Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1976. (DHEW (NIOSH) publication no. 76-185, NTIS publication no. PB-266-583/A08).

National Institute for Occupational Safety and Health. Criteria for a recommended standard--Occupational exposure to Ketones. Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1978. (DHEW (NIOSH) publication no. 78-173, NTIS publication no. PB-81-225-278).

National Institute for Occupational Safety and Health. Technical Assistance, No. TA 79-46. Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1979.

National Institute for Occupational Safety and Health. Registry of Toxic Effects of Chemical Substances, 1983 supplement to the 1981-82 edition. Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1984. (DHHS (NIOSH) publication no. 84-101).

Ostberg O and Moss CE. Microscope work--ergonomic problems and remedies. In: Proceedings of the International Conference on Occupational Ergonomics, Volume 1: Research reports and case studies, Attwood DA, McCann C, Sugarman RC, eds. Human Factors Conference, Inc., Rexdale, Ontario, Canada, pp 420-406, 1984.

Roberts J. Refraction status and motility defects of persons 4-74 years, United States, 1971-1972. Hyattsville, MD: National Center for Health Statistics, 1978. (Vital and health statistics, series 11: Data from the National Health Survey, no. 206) (DHEW publication no. (PHS) 78-1654).

Soderberg I, Calissendorff B, Elofsson S, Knave B, and Nyman KG. Investigation of visual strain experienced by microscope operators at an electronics plan. Appl Ergonom 14:297-305, 1983.

Webb Associates. Anthropometric source book, Volume II: A handbook of anthropometric data. Washington, DC: National Aeronautics and Space Administration, 1978. (NASA reference publication 1024).

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## XI. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report ar currently available upon request from NIOSH, Division of Standards Development and Technology Transfer, Publication Dissemination Section, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), 5285 Port Royal, Springfield, Virginia 22616. Information regarding its availability through NTIS can be obtained from NIOSH Publication Office at the Cincinnati address. Copies of this report have been sent to:

1. Authorized Representative of Employees, Local 2221, American Federation of Government Employees
2. Aerospace Guidance and Metrology Center, Newark Air Force Station
3. Surgeon General, United Stated Air Force Logistics Command
4. NIOSH, Region V
5. OSHA, Region V

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table 1

Maximum chemical concentration, breathing zone samples

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
TA 79-46
September 27 & 28, 1979

| Material | Highest time-weighted average concentration | Threshold for eye irritation* | OSHA permissible exposure limits** |
|---|---|---|---|
| 1,1,2 Trichloro-1,2,2 trifluoroethane | 1264 $mg/m^3$ | none established | 7600 $mg/m^3$ |
| 1,1,1-Trichloroethane | 803 | 2440 $mg/m^3$ | 1900 |
| Isopropyl alcohol | 87 | 980 | 980 |
| Tetrachloroethylene | 168 | 670 | 670*** |
| Toluene | 26 | 1125 | 750 |
| Acetone | 124 | 1200 | 2400**** |
| Methyl ethyl ketone | 117 | 885 | 590 |

* from NIOSH, 1983 and ACGIH, 1980 and 1982

** 29 Code of Federal Regulations, part 1910.1000 (1985)

*** NIOSH (1976) recommends a maximum of 340 $mg/m^3$

**** NIOSH (1978) recommends a maximum of 600 $mg/m^3$

Table 2

Workers selected and examined, by symptom group

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| | High-symptom group | Low-symptom group | Significant symptoms | Total |
|---|---|---|---|---|
| Originally selected | 40 | 33 | 2 | 75 |
| Not examined: | 8 | 8 | 1 | 17 |
| Transferred to evening shift | | 1 | | 1 |
| On leave | 4 | 4 | 1 | 9 |
| Declined examination | 4 | 3 | | 7 |
| Selected and examined | 32 | 25 | 1 | 58 |
| Replacement subjects | 3 | | | 3 |
| Total examined | 35 | 25 | 1 | 61 |

Table 3

Characteristics of respondents to the symptom survey

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
June, 1984

| | | |
|---|---|---|
| Mean age | | 39.9 years |
| Sex: | Men | 77 % |
| | Women | 23 % |
| Job: | Instrument workers | 58 % |
| | Instrument mechanics | 20 % |
| | Electronics workers | 5 % |
| | Electronics mechanics | 9 % |
| | Optical instrument workers | 6 % |
| | Machinists and mechanical parts repairer | 2 % |

Table 4

Percentage of respondents reporting eye and musculoskeletal symptoms in symptom surveys

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
Armed Forces Institute of Pathology
Washington, D. C.
HE 84-082
1984

| | AGMC | AFIP | Ratio |
|---|---|---|---|
| Number of respondents | 422 | 67 | |
| Eyestrain | 77 % | 30 % | 3 |
| Burning or itching eyes | 63 % | 13 % | 5 |
| Blurred vision | 53 % | 8 % | 7 |
| Eye pain | 41 % | 9 % | 5 |
| Redness of eyes | 60 % | 4 % | 15 |
| Headache | 60 % | 15 % | 4 |
| Neck pain | 64 % | 18 % | 4 |
| Back pain | 55 % | 21 % | 3 |
| Shoulder or arm pain | 47 % | 19 % | 3 |

Table 5

Additional symptoms reported by 10 or more respondents 1984

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
June, 1984

| Symptom | Number |
| --- | --- |
| Dry skin and rash | 18 |
| Tension, stress, and nervous conditions | 13 |
| Dizziness and light-headedness | 13 |
| Complaints about chemical exposure (no specific effects) | 12 |
| Nausea and upset stomach | 10 |

Table 6

Characteristics of examined subjects

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| | | |
|---|---|---|
| Number (N) | | 61 |
| Mean age | | 40.8 years |
| Sex: | Men | 79 % |
| | Women | 21 % |
| Job: | Instrument workers | 56 % |
| | Instrument mechanics | 18 % |
| | Electronics workers | 8 % |
| | Electronics mechanics | 13 % |
| | Optical instrument workers | 2 % |
| | Machinists and mechanical parts repairer | 3 % |
| Work Area: | Clean rooms 10 and 11 | 21 % |
| | Other areas | 79 % |
| Tenure: | at AGMC | 8.8 years |
| | in the specific job | 5.1 |

Table 7

Number of examination subjects reporting
one or more hours of various activities and use of various chemicals;
and mean daily duration of activities and chemical usage

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Activity or chemical (as shown on the questionnaire) | Number reporting one or more hrs | Percent | Mean daily duration (hrs/day) |
|---|---|---|---|
| Microscope use: average | 57 | 92 | 4.5 |
| before the exam, on the same day | 36 | 58 | 1.9 |
| Soldering | 47 | 76 | 2.9 |
| Work in laminar flow ventilation | 34 | 55 | 2.2 |
| Freon 113 | 43 | 69 | 3.3 |
| 1,1,1-Trichloroethane (Chlorothane-Nu) | 24 | 39 | 1.6 |
| Isopropyl alcohol | 41 | 66 | 2.3 |
| Tetrachloroethylene | 4 | 6 | 0.3 |
| Toluene | 7 | 11 | 0.5 |
| Acetone | 33 | 53 | 2.6 |
| Methyl ethyl ketone | 2 | 3 | 0.1 |
| Other chemicals: (written in) | 13 | 21 | 0.8 |

Table 8

Variables independently associated with membership in the high-symptom group, using multiple logistic regression

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Odds ratio | p |
| --- | --- | --- |
| Sex (women/men) | 17.79 | .02 |
| Average microscope use (hours/day, raised to the fifth power) | 1.0002 | .02 |
| Acetone use (1 or more hours/day) | 8.35 | .01 |

Table 9

Variables independently associated with corneal staining, using multiple logistic regression

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Odds ratio | p |
| --- | --- | --- |
| Sex (women/men) | 6.61 | .05 |
| Average isopropyl alcohol use (hours/day) | 1.39 | .03 |
| Microscope use before the examination (hours) | 0.50 | .03 |

Table 10
Variables independently associated with eye redness, using multiple linear regression

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Slope | p |
|---|---|---|
| Sex (women/men) | -0.67 | .0003 |
| Average isopropyl alcohol use (hours/day, raised to the sixth power) | .000002 | .009 |
| Age | .02 | .02 |

Table 11

Workstation dimensions and anthropometric norms

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| | Chair pan height (above the floor) | Table top height (above the floor) | Table top height (above chair pan) | Ocular lens height (above chair pan) |
|---|---|---|---|---|
| Minimum | 43.6 cm | 70.3 cm | 22.6 cm | 56.2 cm |
| Maximum | 54.7 | 81.2 | 34.2 | 68.9 |
| Mean | 48.5 | 78.0 | 29.4 | 63.4 |
| n | 12 | 12 | 12 | 10 |
| | **Popliteal height** | | **Elbow rest height** | **Seated eye height** |
| 10th percentile (women) | 38.8 cm | | 19.5 cm | 69.8 cm |
| 90th percentile (men) | 47.7 | | 27.2 | 83.9 |

Figure 1

Relationship between microscope and retinal image

HE 84-082

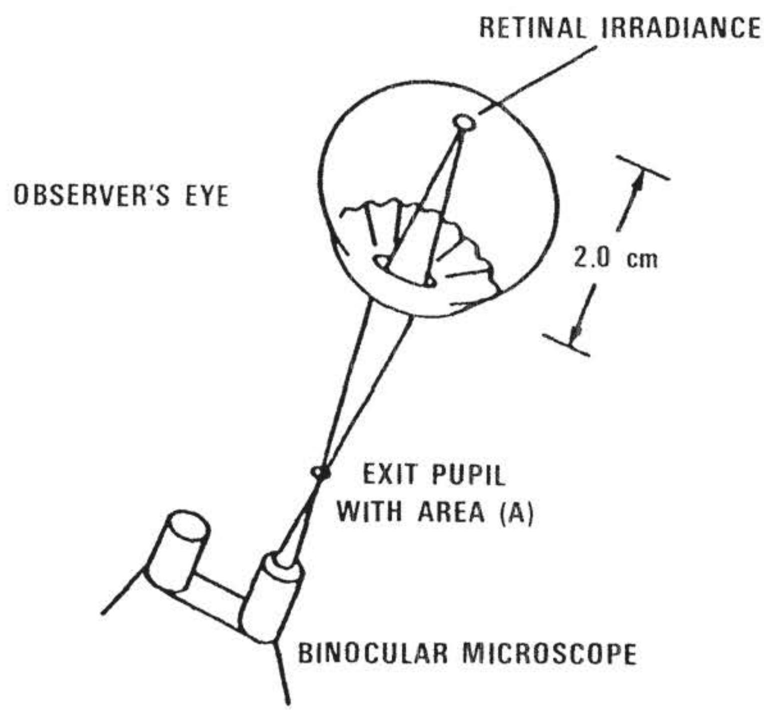


Figure 2

Transmittance of incandescent source output through the Bausch & Lomb cycloptic microscope

HE 84-082

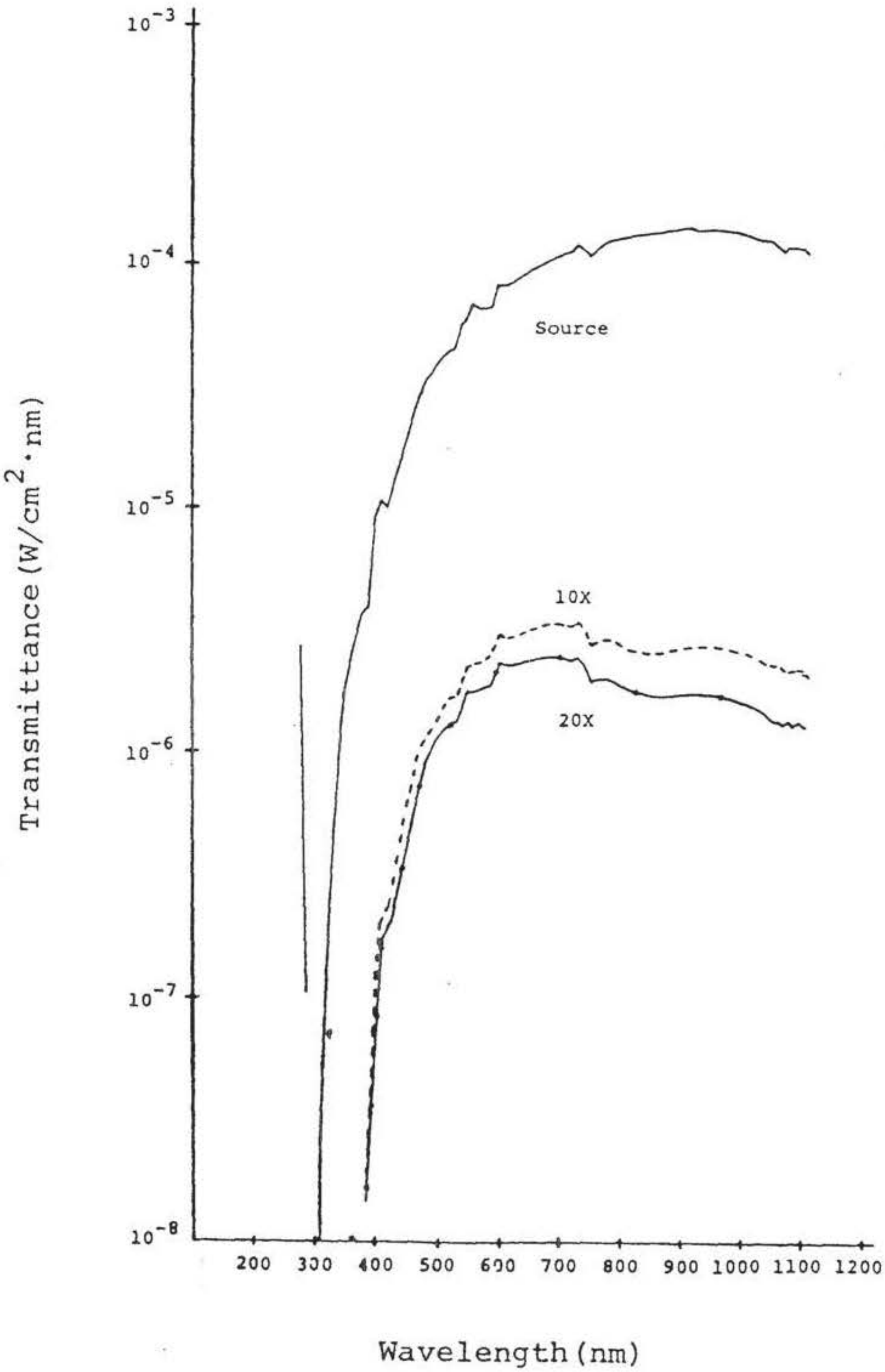


Figure 3

Percent transmittance at different magnifications
of Bausch & Lomb cycloptic microscope with incandescent source

HE 84-082

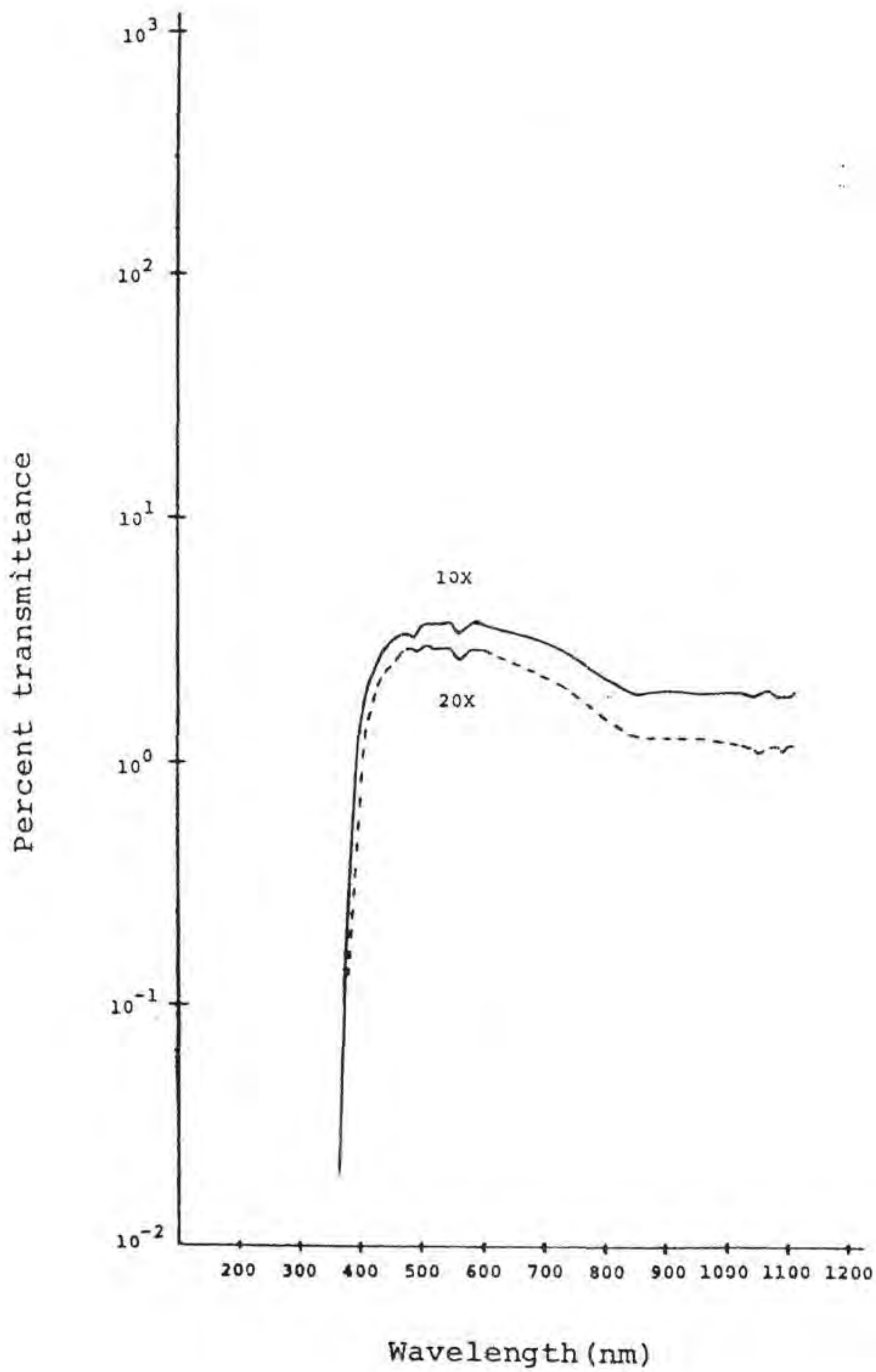


Figure 4

Lamp filament position and variation in incandescent source output (in candela/$m^2$) as a result of beam rotational orientation. Upper reading was obtained directly from source while lower reading refers to corresponding luminance transmitted through Bausch & Lomb dissecting microscope (10X). Hash mark on circle represents rotational position of source housing index mark at which luminance was measured.

HE 84-082

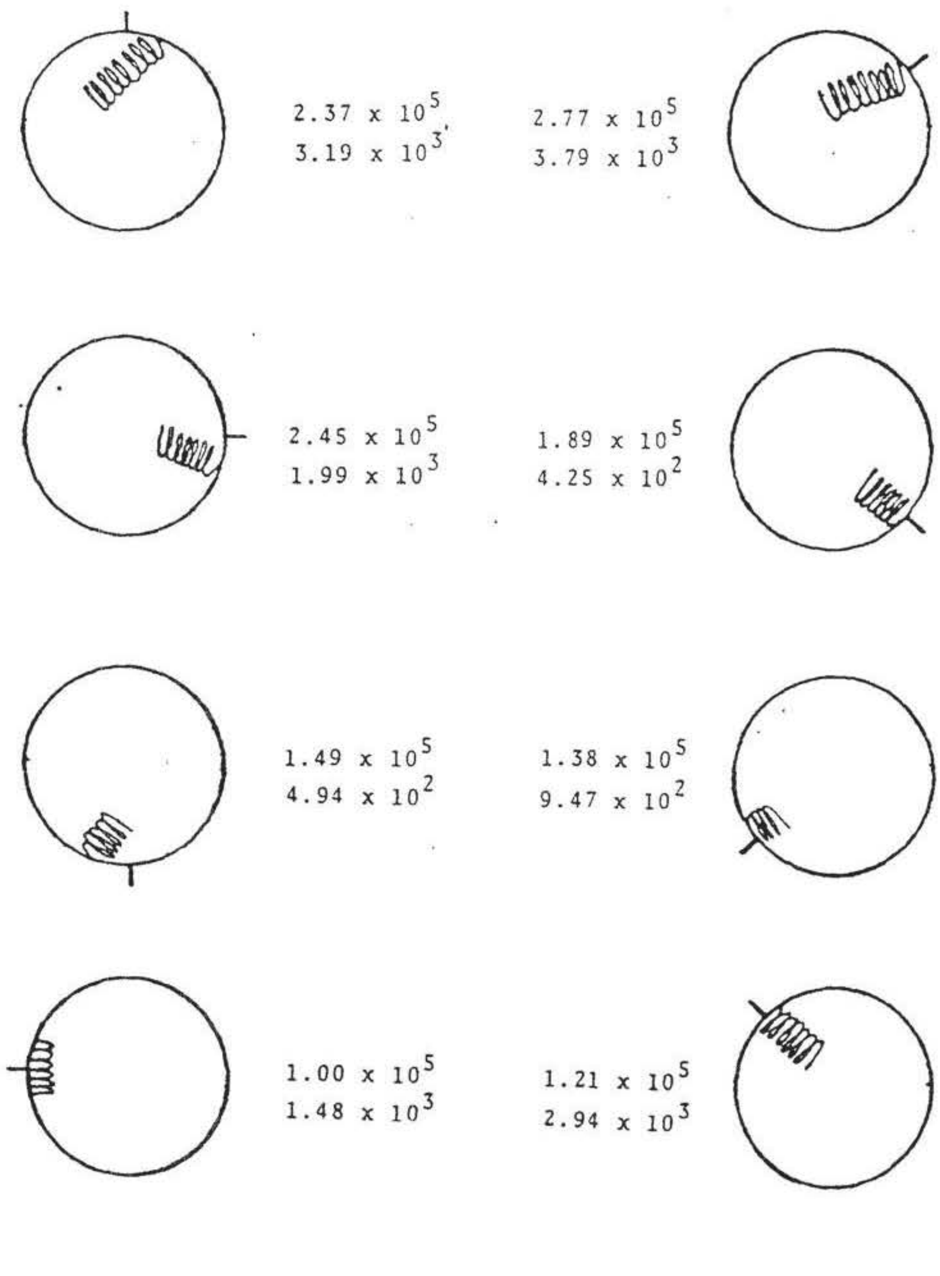


Figure 5

Normalized percent transmittance of direct versus reflected incandescent source output through Bausch & Lomb dissecting microscope (10X).

HE 84-082

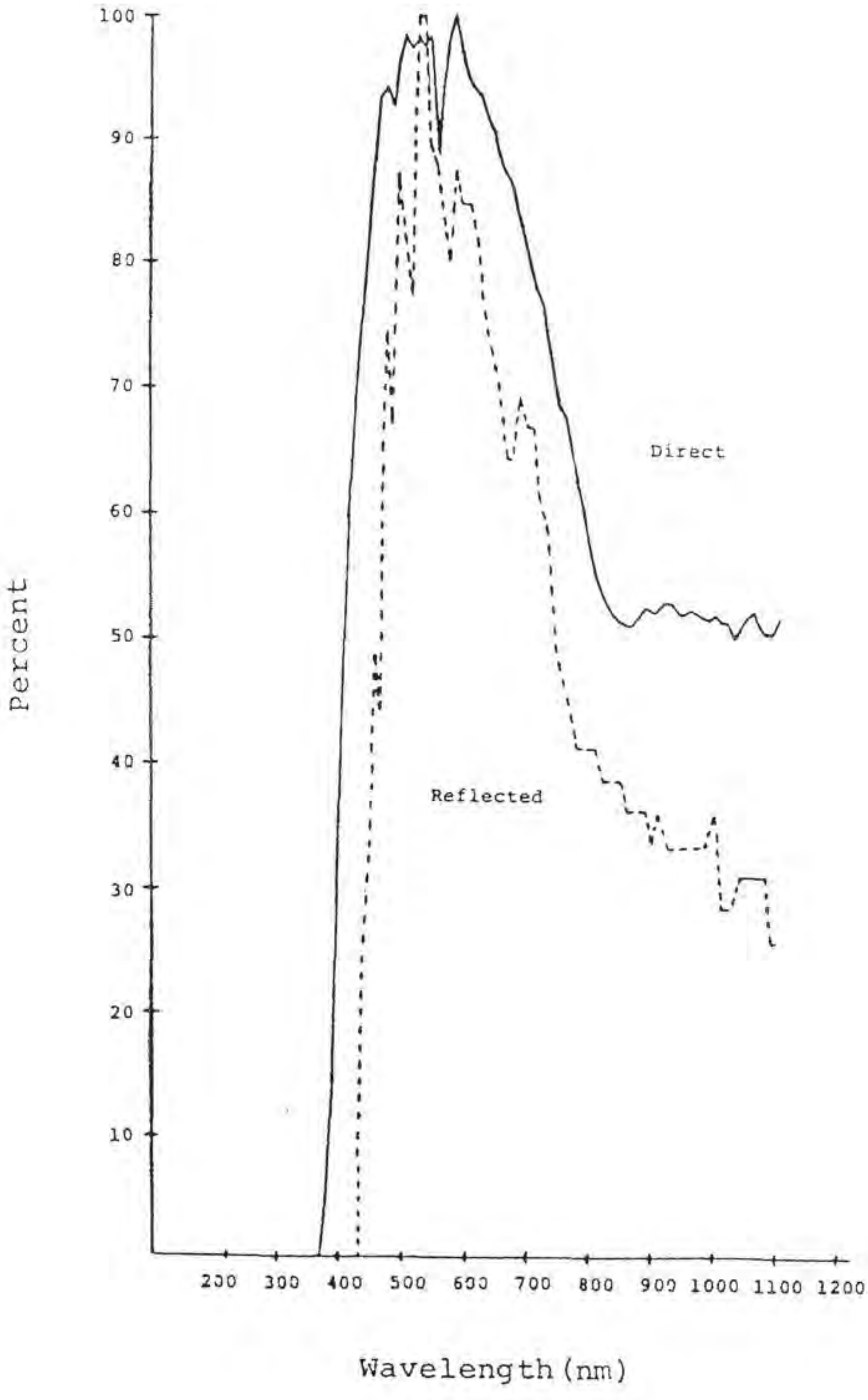


Figure 6

Anthropometric dimensions used for comparison to workstation dimensions: a. popliteal height, b. elbow rest height, c. seated eye height.

Redrawn from Webb Associates, 1978.

HE 84-082

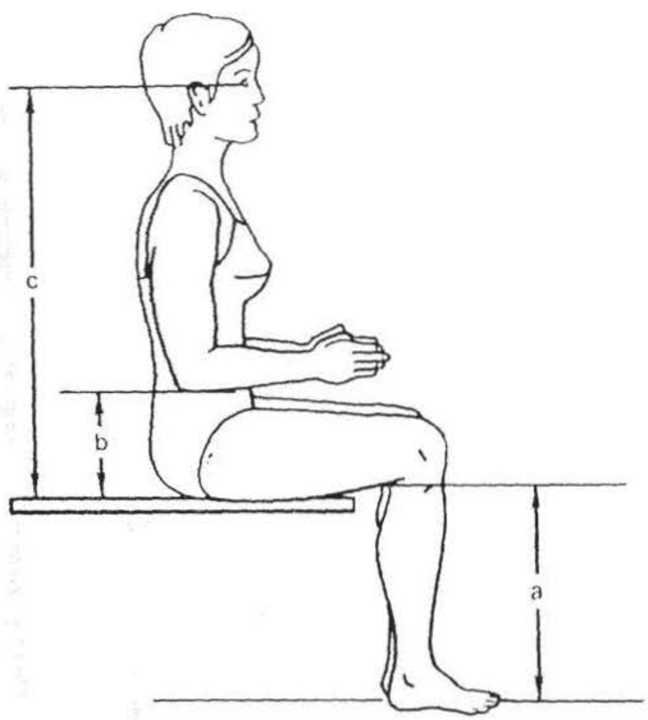


Figure 7

Percent of examination subjects reporting various durations of daily microscope use, by symptom group

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

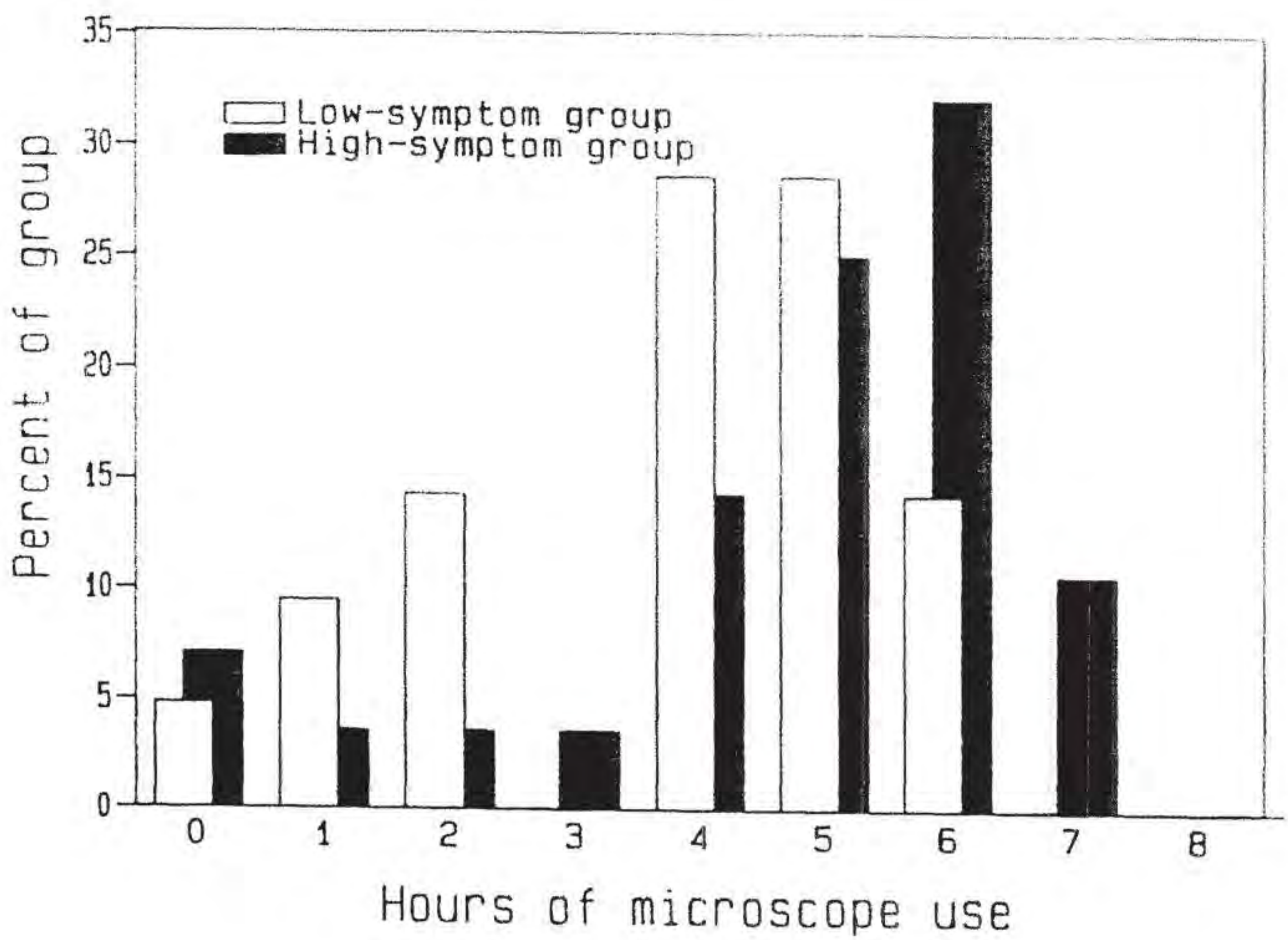


Figure 8

Percent of examination subjects reporting various durations of daily acetone use, by symptom group

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

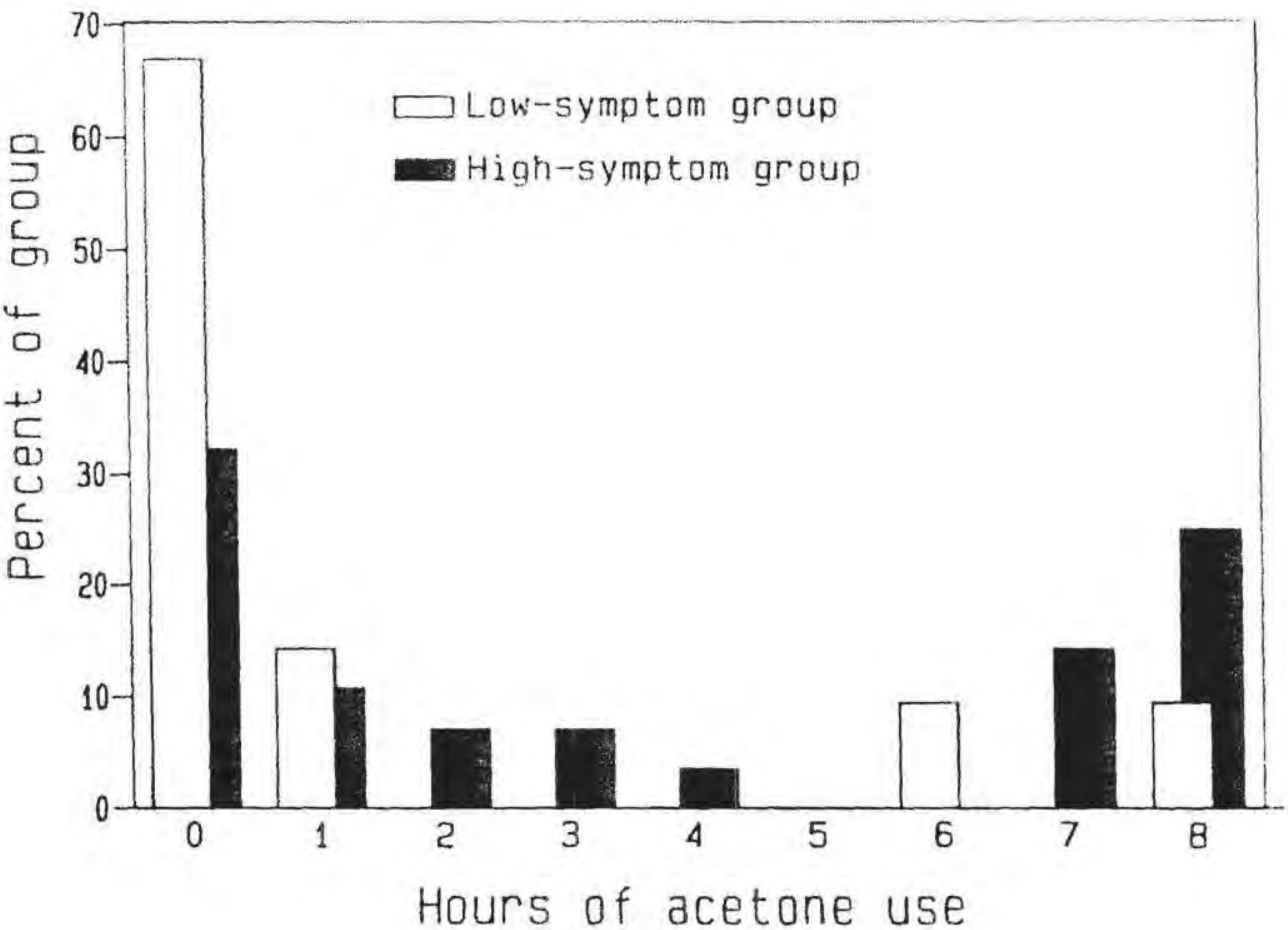


Figure 9

Eye redness score by daily isopropyl alcohol use. Each dot represents one subject; the curve shows the fitted relationship from Table 10.

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

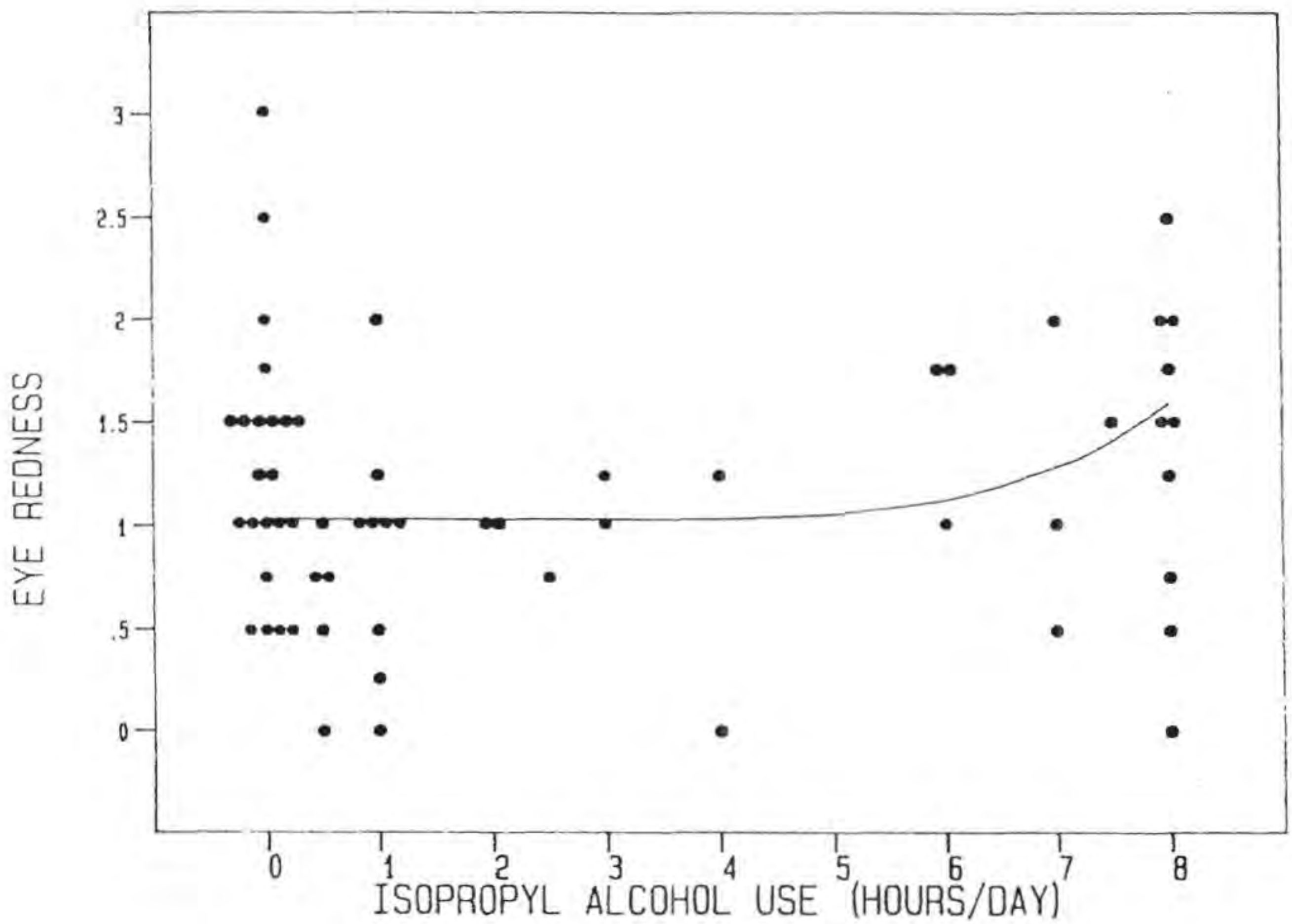
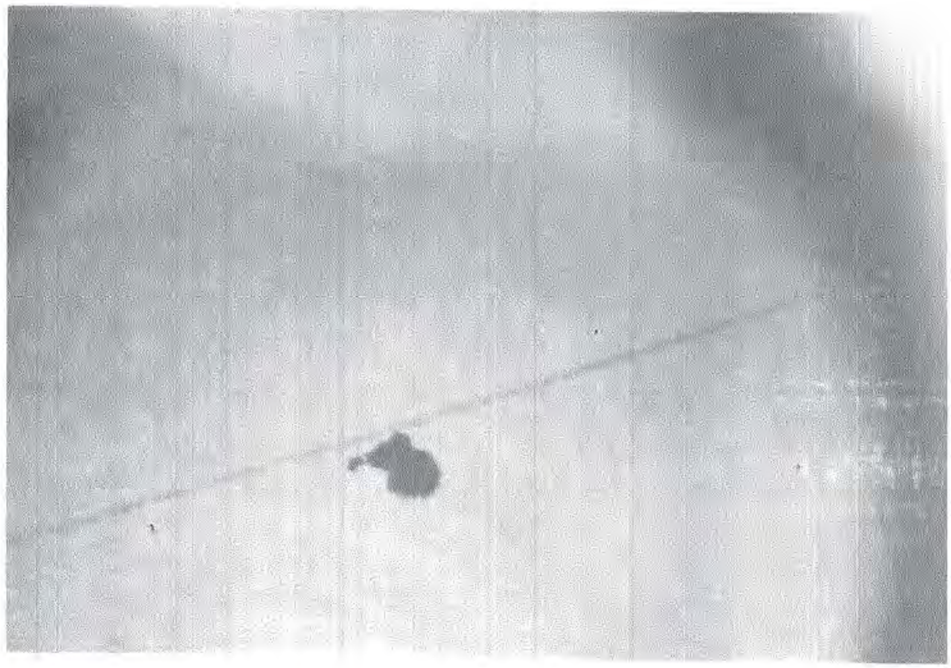


Figure 10

Further examples of lighting patterns.
A. Uniform B. Non-uniform, showing image of lamp filament.

HE 84-082

A.



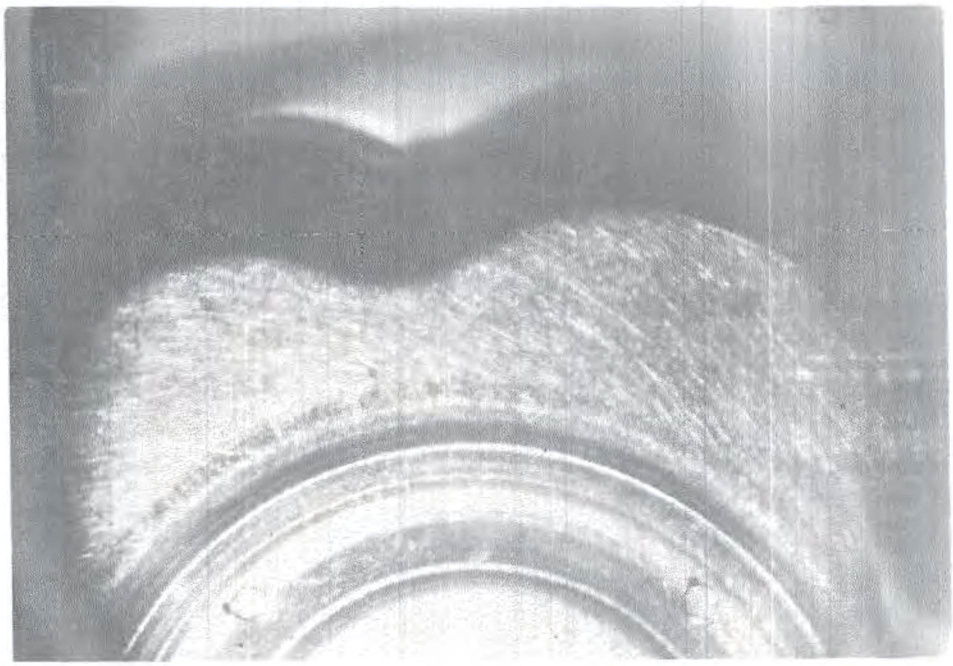
B.

Figure 11

Effect of the shadow box. A. View through the microscope without shadow box
B. View through the microscope with shadow box.

HE 84-082

A.



B.

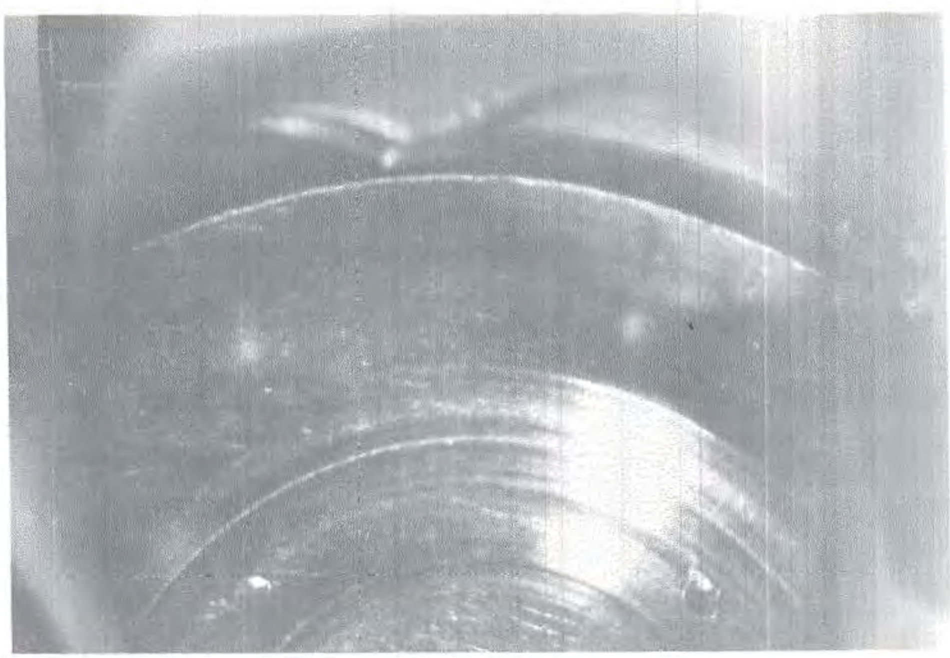
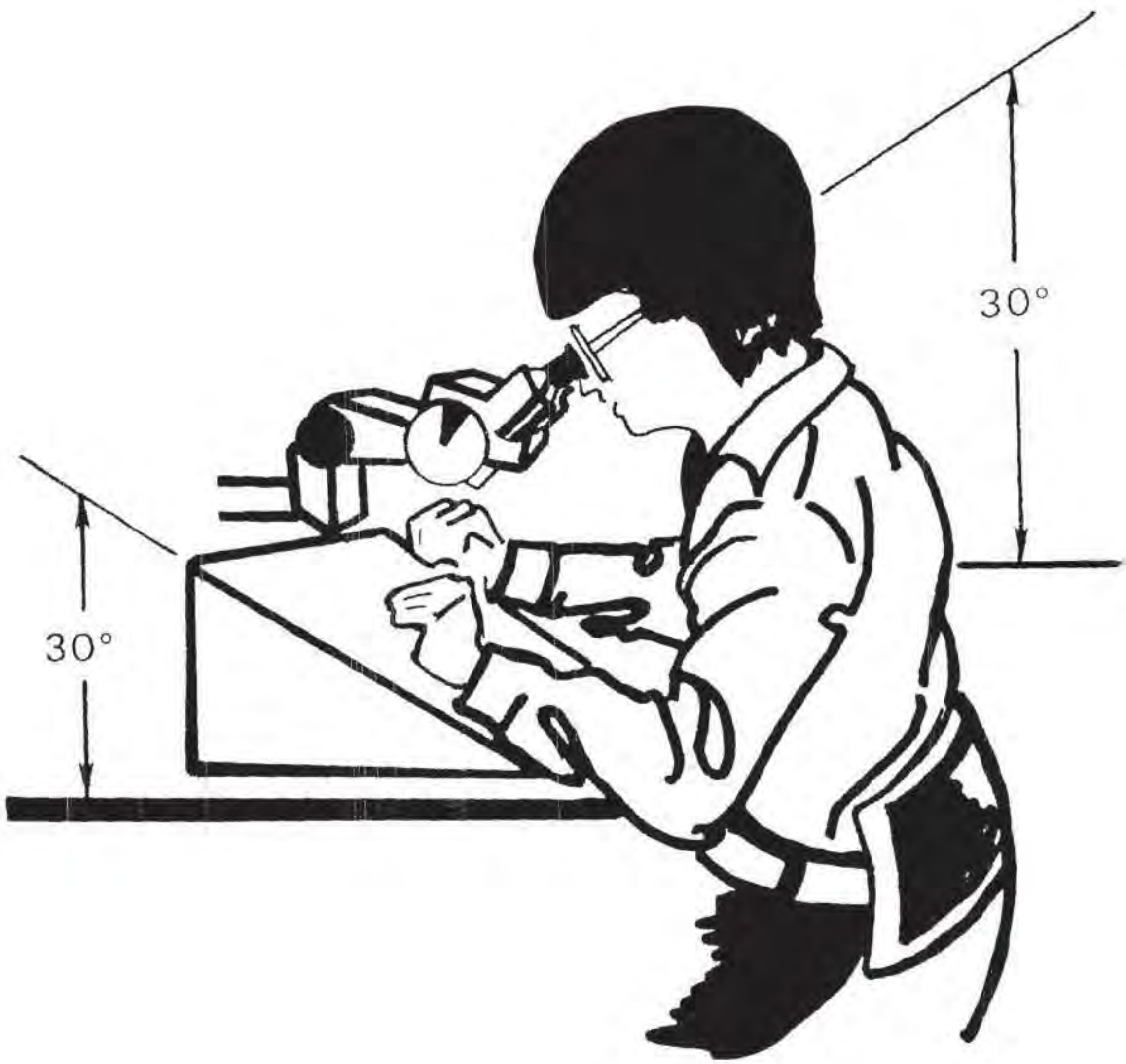


Figure 12.

Proposed slant stand to elevate and rotated work under a microscope

HE 84-082



# APPENDIX A

1984 symptom survey
HE 84-082

(Please Print)

# NEWARK AIR FORCE STATION
# PRELIMINARY QUESTIONNAIRE

| | | OFFICE USE |
|---|---|---|
| SOCIAL SECURITY NUMBER (Optional): | ☐☐☐ - ☐☐ - ☐☐☐☐ | (1-9) |
| NAME: ______ (Last) ______ (First) ______ (MI) | | |
| AGE (# years): | ☐☐ | (10) |
| SEX: | 1 __ Male 2 __ Female | (11) |
| WORK AREA (OR CLEAN ROOM NUMBER): ______ | | ☐☐ (12-13) |
| JOB TITLE: ______ | | ☐☐ (14-15) |

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

DURING YOUR USUAL WORK ACTIVITY, OR SOON AFTER YOU LEAVE WORK, DO YOU <u>FREQUENTLY</u> SUFFER FROM ANY OF THE FOLLOWING SYMPTOMS?

| | | | |
|---|---|---|---|
| 1. EYESTRAIN | 0 __ No | 1 __ Yes | (16) |
| 2. BURNING OR ITCHING OF THE EYES | 0 __ No | 1 __ Yes | (17) |
| 3. BLURRED VISION | 0 __ No | 1 __ Yes | (18) |
| 4. EYE PAIN | 0 __ No | 1 __ Yes | (19) |
| 5. REDNESS OF EYES | 0 __ No | 1 __ Yes | (20) |
| 6. HEADACHE | 0 __ No | 1 __ Yes | (21) |
| 7. NECK PAIN | 0 __ No | 1 __ Yes | (22) |
| 8. BACK PAIN | 0 __ No | 1 __ Yes | (23) |
| 9. SHOULDER OR ARM PAIN | 0 __ No | 1 __ Yes | (24) |
| | | SCORE ☐ | (25) |

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

PLEASE WRITE HERE COMMENTS ABOUT OTHER HEALTH PROBLEMS THAT YOU HAVE:

______________________________________________

______________________________________________

CARD | 0 | 1 | (79-80)

# APPENDIX B

1985 work and visual history.
HE 84-082

1-3 ___ ___ ___ Name ______________________________

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH)
CENTERS FOR DISEASE CONTROL
U.S. PUBLIC HEALTH SERVICE
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES

WORK AND VISUAL HISTORY

1. How long have you worked at the Aerospace Guidance and Metrology Center?

4-7 ___ ___ years ___ ___ months

2. What is your exact job title?

______________________________

8,9 ___ ___

3. What are your specific duties?

______________________________

______________________________

10-19 ___ ___ ___ ___ ___ ___ ___ ___ ___ ___

4. How long have your worked <u>at this job</u>?

20-23 ___ ___ years ___ ___ months

5. What is your work area?

______________________________

24,25 ___ ___

6. On the average, how many hours a day do you use a microscope?

26 ___ hours

7. On the average, how many hours a day do you solder?

27 ___ hours

8. On the average, how many hours a day do you work with laminar flow ventilation?

28 ___ hours

9. On the average, how many hours a day do you use each of the following chemicals?

| | hours | chemical |
|---|---|---|
| 29 | ___ | Freon 113 |
| 30 | ___ | 1,1,1 Trichloroethane or methyl cholorform (Chlorothane-Nu) |
| 31 | ___ | Isopropyl alcohol |
| 32 | ___ | Tetracholoroethylene |
| 33 | ___ | Toluene |
| 34 | ___ | Acetone |
| 35 | ___ | Methyl ethyl ketone |
| | | Other chemicals (please specify) |
| 36 | ___ | ______________________________ |
| 37,38 | | ___ ___ |

10. How long has it been since you've had a complete eye examination?

39-42 ___ ___ years ___ ___ months

11. Are you under professional care for any visual or eye problem (other than fitting glasses or contacts)?

43 1. yes (please specify ______________________________)
2. no

12. At work when you are <u>not</u> using a microscope, do you usually wear glasses or contact lenses?

44
1. yes
2. no (If no, skip to question 15.)

13. What type of glasses or contact lenses do you use?

45
1. regular prescription glasses
2. reading glasses
3. bifocal or trifocal glasses
4. nonprescription safety glasses
5. hard contact lenses
6. soft contact lenses (specify type ________________________________)

46
14. Do use this eyewear while viewing through the microscope?

1. yes
2. no

15. Have you even been trained how to properly focus a binocular microscope to insure both eyes are in focus simultaneously?

47
1. yes
2. no

16. Do you smoke tobacco?

48
1. yes
2. no (If no, skip to question 18)

17. Do you smoke at work?

49
1. yes, throughout the day
2. only during breaks and lunch hour
3. no

18. When were you born?

50-55
__ __   __ __   __ __
month   day   year

19. What is your sex?

56
1. male
2. female

20. A. While on the job, do you ever have eyestrain?

4 1. yes
2. no (If no, skip to question 21.)

B. In a typical work week, how many days do you have eyestrain?

5 1 2 3 4 5

C. Using the scale below, how severe would you rate this eyestrain?

6 1. barely noticeable
2. somewhat noticeable
3. moderately distracting
4. quite distracting
5. severely distracting

D. When during your workday does this eyestrain typically first appear?

7 1. before coming to work
2. during early morning
3. during late morning
4. during early afternoon
5. during late afternoon
6. after work

E. Is there a task at work or environmental factor which you feel causes most of your eyestrain?

8 1. yes (please specify ______________________________)
2. no

21. A. While on the job, do your eyes ever burn?

9 1. yes
2. no (If no, skip to question 22.)

B. In a typical work week, how many days do your eyes burn?

10 1 2 3 4 5

C. Using the scale below, how severe would you rate this burning?

11 1. barely noticeable
2. somewhat noticeable
3. moderately distracting
4. quite distracting
5. severely distracting

D. When during your workday does this burning typically first appear?

12 1. before coming to work
2. during early morning
3. during late morning
4. during early afternoon
5. during late afternoon
6. after work

E. Is there a task at work or environmental factor which you feel causes your eyes to burn?

13 1. yes (please specify ________________________________________)
2. no

22. A. While on the job, do your eyes ever feel dry?

14 1. yes
2. no (If no, skip to question 23.)

B. In a typical work week, how many days do your eyes feel dry?

15 1 2 3 4 5

C. Using the scale below, how severe would you rate this dryness?

16 1. barely noticeable
2. somewhat noticeable
3. moderately distracting
4. quite distracting
5. severely distracting

D. When during your workday does this dryness typically first appear?

17 1. before coming to work
2. during early morning
3. during late morning
4. during early afternoon
5. during late afternoon
6. after work

E. Is there a task at work or environmental factor which you feel causes your eyes to feel dry?

18 1. yes (please specify ______________________________)
2. no

23. A. While on the job, do your eyes ever itch?

19
1. yes
2. no (If no, skip to question 24.)

B. In a typical work week, how many days do your eyes itch?

20
1 2 3 4 5

C. Using the scale below, how severe would you rate this itching?

21
1. barely noticeable
2. somewhat noticeable
3. moderately distracting
4. quite distracting
5. severely distracting

D. When during your workday does this itching typically first appear?

22
1. before coming to work
2. during early morning
3. during late morning
4. during early afternoon
5. during late afternoon
6. after work

E. Is there a task at work or environmental factor which you feel causes your eyes to itch?

23
1. yes (please specify ______________________________________________)
2. no

24. A. While on the job, have you ever experienced any eye irritation that does not fall into one of the above categories?

24 1. yes
2. no (If no, skip to question 25.)

B. In a typical work week, how many days are your eyes irritated?

25 1 2 3 4 5

C. Using the scale below, how severe would you rate this irritation?

26 1. barely noticeable
2. somewhat noticeable
3. moderately distracting
4. quite distracting
5. severely distracting

D. When during your workday does this irritation typically first appear?

27 1. before coming to work
2. during early morning
3. during late morning
4. during early afternoon
5. during late afternoon
6. after work

E. Is there a task at work or environmental factor which you feel irritates your eyes?

28 1. yes (please specify ______________________________)
2. no

25. A. While on the job, do you ever experience blurred vision?

29 1. yes
2. no (If no, skip to question 26.)

B. In a typical work week, how many days do you experience blurred vision?

30 1 2 3 4 5

C. Using the scale below, how severe would you rate this blurred vision?

31 1. barely noticeable
2. somewhat noticeable
3. moderately distracting
4. quite distracting
5. severely distracting

D. When during your workday do you typically first experience blurred vision?

32 1. before coming to work
2. during early morning
3. during late morning
4. during early afternoon
5. during late afternoon
6. after work

E. Is there a task at work or environmental factor which you causes your blurred vision?

33 1. yes (please specify ______________________________)
2. no

26. A. While on the job, do you ever experience double vision?

34 1. yes
2. no

B. In a typical work week, how many days do you experience double vision?

35 1 2 3 4 5

C. Using the scale below, how severe would you rate this double vision?

36 1. barely noticeable
2. somewhat noticeable
3. moderately distracting
4. quite distracting
5. severely distracting

D. When during your workday do you typically first experience double vision?

37 1. before coming to work
2. during early morning
3. during late morning
4. during early afternoon
5. during late afternoon
6. after work

E. Is there a task at work or environmental factor which you causes your double vision?

38 1. yes (please specify ______________________________)
2. no

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

* Bring this form and the "Consent to Participate" to your examination. *
* If you ever use glasses or contact lenses, be sure to bring a copy of *
* your latest lens prescription and the date of that examination. *

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

APPENDIX C

Detailed statistical analysis of the eye examination results
HE 84-082

## A. Statistical methods for the multivariate analysis

Only variables that could be readily interpreted were included in the multivariate analyses. We did not include variables, such as work area, which were likely to be indicators of other variables that could be directly related to symptoms, such as time at the microscope or exposure to specific chemicals. Freon 113 was not included in any of the multivariate analyses, because experimental evidence indicates that it is not an eye irritant (ACGIH, 1980), and hours of use of freon was correlated with hours of use of a number of other chemicals that do cause eye irritation at high concentrations.

Variables with $p<.10$ were included in the multivariate models, along with interaction terms and quadratic terms for continuous variables. For the computation of the higher-order terms involving continuous variables, the mean was subtracted from each observation of the continuous variables. All the terms to be included in the multivariate analysis were considered together, and terms with $p>.05$ were removed one at a time, beginning with the greatest p. Linear terms were not removed until all the higher-order terms involving that variable had been removed. A $p<.025$ for the higher-order term was required to keep a linear and a higher-order term involving the same variable if the linear term was associated with a $p>.05$. Similarly, both a linear and higher-order term involving the same variable were kept if the linear term had a $p<.025$ with the higher-order term in the equation, and a $p>.05$ without the higher order term in the equation.

After the nonsignificant terms were removed from the model, the curves described by the combination of linear and quadratic terms were examined. U-shaped or mound-shaped relationships between a work exposure and a health effect are difficult to interpret, since a longer exposure would not be expected to have an effect opposite to a shorter exposure. These non-monotonic curves were replaced by monotonic curves of the form $a * x^b$, which were fit to the data with nonlinear regression. If these new curves were also significantly related to the particular effect, they replaced the linear and quadratic terms in the equation. This substitution did not affect the probability of accepting a false hypothesis, since the decision to include a variable in the model was based on the linear and quadratic terms.

## B. Detailed analysis of eye examination results

The 21 low-symptom and 28 high-symptom workers who continued to report symptoms at these levels were retained for a comparison of these two groups. The groups were compared on the basis of self-reported work exposures and visual function as measured by the examination. These results are shown in Table C1. The high-symptom group spent more time using Freon 113, Chlorothane-Nu, and acetone than the low-symptom group. The high-symptom group included a higher proportion of women and subjects with inadequate fusional reserve. The high-symptom workers also used the microscope about an hour more each day, but this difference was not quite statistical significant.

Logistic regression was used to determine which variables, with $p<.10$ in the bivariate correlations, independently predicted membership in the high-and low-symptom groups. These results are shown in Table C2. Terms involving Chlorothane-Nu and fusional reserve were not independently related to symptom group. Sex, microscope use, and acetone use were independently associated with membership in the high-symptom group. Both the linear and quadratic terms for hours of acetone use were retained because p for the linear term was $<.025$ with both terms in the equation, but greater than .05 with the quadratic term removed.

However, Table C2 shows an association between microscope use and the odds of membership in the high-symptom group that reaches a minimum at 3 hours of daily microscope use, an association between acetone use and the odds of membership in the high-symptom group that reaches a maximum at 5 hours of daily acetone use. The best fit with a monotone function was obtained with hours of microscope use raised to the 5.14 power and hours of acetone use raised to the .0000194 power. The later function is 0 for 0 hours of acetone use, quickly rises, and is nearly level for 1-8 hour of acetone use. For simplicity, the hours of microscope use was raised to the fifth power and a acetone use was dichotomized into less than 1 and 1 or more hours of daily acetone use. As shown in Table C3, both of these terms remained significant when they replace the linear and quadratic terms in the logistic model. This model fit the data slightly better than the model shown in Table C2.

Although the factor analysis of these data did not suggest any useful division of the symptoms, the data from AFIP and other NIOSH studies suggests that eye symptoms can be divided into those suggestive of irritation and those related to vision. We divided the symptoms reported on our questionnaire along these lines. Burning eyes, dry eyes, itching eyes, and other forms of eye irritation were considered as one factor, and eye strain, blurred vision, and double vision as another. The summary score used for this analysis was the sum of the log of one plus the product of frequency and severity for the symptoms in each of the two categories of symptoms. This score was approximately normally distributed. The only variables independently associated with the visual symptom score were microscope use and sex. Only sex was independently related to the irritation score.

The work exposures and personal characteristics of examination subjects with and without corneal staining are shown in Table C4. Visual function variables were not included because there is no reasonable connection between them and irritation on the surface of the eye. Subjects with corneal staining used the microscope less before the examination and reported that they used isopropyl alcohol during more hours of an average workday compared to subjects without corneal staining. Subjects with corneal staining also used freon more than subjects without corneal staining, and a lower proportion of them were women, although these two associations did not reach statistical significance.

Logistic regression was used to determine which variables, with $p<.10$ in the bivariate correlations, independently predicted presence or absence of corneal staining. As shown in Table C5, all three variables included in the model were significant. Interactions and quadratic terms were not examined because of the small number of subjects with corneal staining. If microscope use before the examination were excluded from the logistic regression, neither isopropyl alcohol use nor sex would remain significant.

We analyzed the relationship of eye redness and tear break-up time to various job variables among all the examined workers. Measures of visual function were not included in these comparisons, because there is no reasonable mechanism by which deficiencies of visual function might cause external eye irritation. As shown in Table C4, tear break-up time was not significantly related to any of the variables examined, but a negative association with eye pigmentation approached significance.

Women had less eye redness than men (Table C6). Eye redness was also related to age, time using the microscope, and time using isopropyl alcohol, but these associations did not quite reach statistical significance. Work in laminar flow ventilation was negatively associated with eye redness.

As shown in Table C7, multiple linear regression was used to examine the simultaneous contribution to eye redness of the variables with $p<.10$ in the bivariate correlations. Age and work in laminar flow ventilation were not independently related to eye redness. Women had less eye redness than men. Eye redness increased directly with increasing hours of microscope use. It was associated negatively with the linear term and positively with the quadratic term for hours of isopropyl alcohol exposure.

The relationship between isopropyl alcohol use and eye redness was U-shaped, with a minimum at 4 hours of daily isopropyl alcohol use. The best fit with a monotone function was found when hours of daily isopropyl alcohol use was raised to the 5.70 power. For simplicity, hours of daily isopropyl alcohol use was raised to the sixth power. As shown is Table C8, this term was significantly related to eye redness. However, the fit was not as good as that obtained with the linear and quadratic terms. In this model, average daily hours of microscope use was no longer significant, and was replaced in the model by age.

Table C1
Mean and number of subjects examined (n) for visual and work variables, by symptom group
Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Continuous variables (compared with t-tests) | Low-symptom mean | n | High-symptom mean | n | p |
|---|---|---|---|---|---|
| Average microscope use (hours/day) | 3.8 | (21) | 4.8 | (28) | .08 |
| Soldering (hours/day) | 2.3 | (21) | 3.1 | (28) | .26 |
| Work in laminar flow ventilation (hrs/day) | 1.7 | (21) | 2.9 | (28) | .16 |
| Use of Freon 113 (hours/day) | 2.1 | (21) | 4.5 | (28) | .01 |
| Use of Chlorothane-Nu (hours/day) | 0.6 | (21) | 2.3 | (28) | .01 |
| Use of isopropyl alcohol (hours/day) | 1.6 | (21) | 2.1 | (28) | .45 |
| Use of acetone (hours/day) | 1.6 | (21) | 3.7 | (28) | .03 |
| Age (years) | 39 | (21) | 42 | (28) | .40 |
| Tenure at AGMC (years) | 7.7 | (21) | 9.9 | (28) | .25 |
| Tenure in job (years) | 4.0 | (21) | 5.9 | (28) | .14 |
| Vertical phoria | 0.25 | (20) | 0.32 | (28) | .57 |
| Phoria at 1 m (degrees, +=exo, -=eso) | +3.0 | (20) | +1.5 | (28) | .30 |
| Stereoacuity (seconds of arc) | 81 | (20) | 61 | (28) | .54 |
| Near point of convergence (cm) | 4.8 | (20) | 4.2 | (28) | .60 |
| Tear break-up time (seconds) | 21 | (20) | 21 | (24) | .98 |
| Eye redness (arbitrary units) | 1.13 | (19) | 1.06 | (28) | .73 |
| Eye pigmentation (mean rank of 60) | 30 | (19) | 30 | (28) | .99 |

| Categorical variables (compared with chi-squared test or, indicated by *, with Fisher's exact test) | Low-symptom percent | n | High-symptom percent | n | p |
|---|---|---|---|---|---|
| Instrument workers and mechanics | 71 | (21) | 79 | (28) | .56 |
| Work in Clean Room 10 or 11 | 10 | (21) | 29 | (28) | .15* |
| Smokers | 48 | (21) | 43 | (28) | .74 |
| Women | 5 | (21) | 39 | (28) | .01 |
| Deficient color vision | 5 | (20) | 7 | (27) | 1.00* |
| Inadequate fusional reserve | 25 | (20) | 54 | (28) | .05 |
| Corneal staining | 10 | (20) | 19 | (27) | .68* |
| Wear glasses at the microscope | 20 | (20) | 14 | (28) | .71* |
| Wear bifocals at the microscope | 10 | (20) | 7 | (28) | 1.00* |
| Wear contact lenses | 0 | (20) | 7 | (28) | .50* |
| Astigmatic | 40 | (20) | 25 | (28) | .27 |
| Anisometropic | 15 | (20) | 11 | (28) | .68* |
| Hypermetropic | 15 | (20) | 14 | (28) | .97 |
| Myopic | 15 | | 18 | | |
| Emmetropic | 70 | | 68 | | |

Table C2

Multiple logistic regression model of membership in the high-symptom group

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Retained | Odds ratio | p |
|---|---|---|---|
| Sex (women/men) | Yes | 24.88 | .01 |
| Average microscope use (hours/day) | | | |
| Linear | Yes | 2.14 | .01 |
| Quadratic | Yes | 1.27 | .03 |
| Average acetone use (hours/day) | | | |
| Linear | Yes | 1.71 | .02 |
| Quadratic | Yes | 0.87 | .10 |
| Average Chlorothane-Nu use (hours/day) | | | |
| Linear | No | | |
| Quadratic | No | | |
| Inadequate fusional reserve | No | | |
| Interaction with microscope use | No | | |

Table C3

Multiple logistic regression model of membership in the high-symptom group using monotone functions

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Odds ratio | p |
|---|---|---|
| Sex (women/men) | 17.79 | .02 |
| Average microscope use (hours/day, raised to the fifth power) | 1.0002 | .02 |
| Acetone use (1 or more hours/day) | 8.35 | .01 |

Table C4

Comparisons of examination subjects with and without corneal staining, with the mean and number of subjects used for each comparison (n)

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Variable | Staining mean | n | No staining mean | n | p |
|---|---|---|---|---|---|
| Continuous variables (compared with t-tests) | | | | | |
| Microscope use: average (hours/day) | 4.8 | (9) | 4.5 | (51) | .73 |
| before the exam, on the same day (hours) | 0.8 | (9) | 2.1 | (51) | .01 |
| Time of examination (24 hour time) | 1257 | (9) | 1254 | (51) | .93 |
| Soldering (hours/day) | 3.3 | (9) | 2.8 | (51) | .64 |
| Work in laminar flow ventilation (hrs/day) | 3.2 | (9) | 2.8 | (51) | .26 |
| Use of Freon 113 (hours/day) | 5.0 | (9) | 3.0 | (51) | .09 |
| Use of Chlorothane-Nu (hours/day) | 2.0 | (9) | 1.5 | (51) | .65 |
| Use of isopropyl alcohol (hours/day) | 4.1 | (9) | 2.0 | (51) | .04 |
| Use of acetone (hours/day) | 3.9 | (9) | 2.4 | (51) | .19 |
| Age (years) | 41 | (9) | 41 | (51) | .88 |
| Tenure at AGMC (years) | 7.2 | (9) | 8.8 | (51) | .49 |
| Tenure in job (years) | 4.7 | (9) | 5.0 | (51) | .87 |
| Tear break-up time (seconds) | 18 | (9) | 21 | (51) | .31 |
| Eye redness (arbitrary units) | 1.25 | (9) | 1.13 | (51) | .61 |
| Eye pigmentation (mean rank of 60) | 32 | (9) | 31 | (50) | .90 |

| Categorical variables (compared with 2-tailed Fisher's exact test) | percent | n | percent | n | p |
|---|---|---|---|---|---|
| Instrument workers and mechanics | 67 | (9) | 77 | (51) | .68 |
| Work in Clean Room 10 or 11 | 33 | (9) | 20 | (51) | .39 |
| Smokers | 33 | (9) | 43 | (51) | .72 |
| Women | 44 | (9) | 16 | (51) | .07 |
| Wear glasses at the microscope | 44 | (9) | 20 | (51) | .19 |

Table C5

Multiple logistic regression model of corneal staining

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Retained | Odds ratio | p |
|---|---|---|---|
| Sex (women/men) | Yes | 6.61 | .05 |
| Average isopropyl alcohol use (hours/day) | Yes | 1.39 | .03 |
| Microscope use before the examination (hours) | Yes | 0.50 | .03 |

Table C6

Correlates of tear break-up time and eye redness, with correlation coefficient (r), probability (p), and number of subjects used for each comparison (n)

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082 March 27-29, 1985

| Variable | Tear break-up time | | | Eye redness | | |
|---|---|---|---|---|---|---|
| Continuous variables: | r | p | n | r | p | n |
| Microscope use: average (hours/day) | .04 | .76 | (57) | .23 | .08 | (62) |
| before the exam, on the same day (hours) | .03 | .83 | (57) | .12 | .36 | (62) |
| Time of examination | .00 | .99 | (57) | -.01 | .96 | (62) |
| Soldering (hours/day) | .01 | .92 | (57) | -.01 | .92 | (62) |
| Work in laminar flow ventilation (hrs/day) | -.20 | .14 | (57) | -.25 | .05 | (62) |
| Use of Freon 113 (hours/day) | -.05 | .73 | (57) | .15 | .25 | (62) |
| Use of Chlorothane-Nu (hours/day) | -.09 | .50 | (57) | .05 | .72 | (62) |
| Use of isopropyl alcohol (hours/day) | -.16 | .23 | (57) | .24 | .06 | (62) |
| Use of acetone (hours/day) | -.08 | .57 | (57) | .15 | .27 | (62) |
| Age (years) | -.11 | .42 | (57) | .24 | .07 | (62) |
| Tenure at AGMC (years) | -.13 | .34 | (57) | -.06 | .64 | (62) |
| Tenure in job (years) | -.07 | .62 | (57) | -.12 | .38 | (62) |
| Eye pigmentation (mean rank of 60) | -.26 | .06 | (56) | -.06 | .66 | (60) |
| Categorical variables (compared with t-tests) | mean | p | n | mean | p | n |
| Instrument workers and mechanics | 20 | .88 | (42) | 1.15 | .94 | (46) |
| Other job categories | 21 | | (15) | 1.16 | | (14) |
| Work in Clean Room 10 or 11 | 23 | .14 | (12) | 1.33 | .26 | (13) |
| Work in other areas | 10 | | (45) | 1.10 | | (47) |
| Smokers | 21 | .62 | (23) | 1.30 | .12 | (25) |
| Nonsmokers | 20 | | (34) | 1.04 | | (35) |
| Men | 21 | .11 | (46) | 1.27 | .01 | (47) |
| Women | 18 | | (11) | 0.73 | | (13) |
| Corneal staining | 18 | .31 | (9) | 1.25 | .61 | (9) |
| No staining | 21 | | (48) | 1.13 | | (50) |
| Wear glasses at the microscope | 20 | .92 | (14) | 1.16 | .94 | (14) |
| Do not wear glasses at the microscope | 21 | | (43) | 1.14 | | (46) |
| Wear contact lenses at the microscope | | | (0) | 1.12 | .96 | (2) |
| Do not wear contacts at the microscope | 21 | | (57) | 1.15 | | (58) |

Table C7

Multiple linear regression model of eye redness

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Retained | Slope | p |
|---|---|---|---|
| Sex (women/men) | Yes | -0.66 | .0003 |
| Average microscope use (hours/day) | | | |
| Linear | Yes | 0.09 | .02 |
| Quadratic | No | | |
| Average isopropyl alcohol use (hours/day) | | | |
| Linear | Yes | -0.11 | .02 |
| Quadratic | Yes | 0.04 | .001 |
| Age | | | |
| Linear | No | | |
| Quadratic | No | | |
| Average duration of work in laminar flow (hours/day) | | | |
| Linear | No | | |
| Quadratic | No | | |
| Interaction with isopropyl alcohol use | No | | |

Table C8

Multiple linear regression model of eye redness, using monotone functions

Air Force Guidance and Metrology Center
Newark Air Force Station, Heath, Ohio
HE 84-082
March 27-29, 1985

| Term | Slope | p |
|---|---|---|
| Sex (women/men) | -0.67 | .0003 |
| Average isopropyl alcohol use (hours/day, raised to the sixth power) | .000002 | .009 |
| Age | .02 | .02 |

# APPENDIX D

Optical evaluation of a microscope from AGMC
HE 84-082

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