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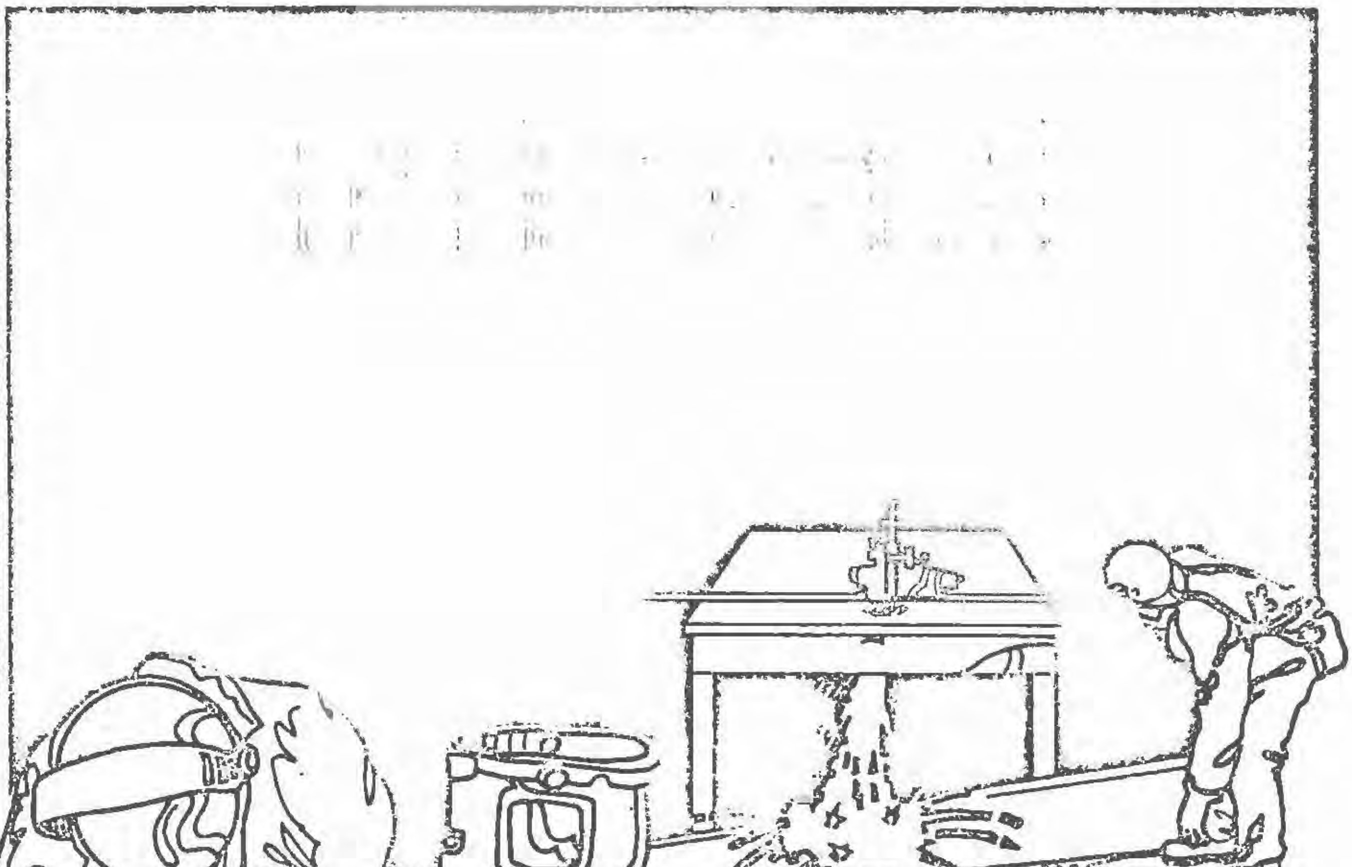

Health Hazard Evaluation Report

HETA 80-119-1103
AQUA-CHEM, INC.
MILWAUKEE, WISCONSIN

HETA 80-119-1103
MAY 1982
AQUA-CHEM, INC.
MILWAUKEE, WISCONSIN

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I. SUMMARY

In April 1980, the National Institute for Occupational Safety and Health (NIOSH) received a confidential request for a Health Hazard Evaluation at Aqua-Chem, Inc., Milwaukee, Wisconsin to evaluate reported health effects due to working under high pressure sodium lighting (including a reported excess incidence of heart attacks). Concern was also expressed by workers about welding fume exposures. About 164 workers were involved in production at this facility.

Aqua-Chem, Inc. develops, designs and manufactures specialized fluid processing systems. The majority of assembly is done using a variety of welding procedures. The metals used in largest quantity are carbon steel, stainless steel, and copper nickel. The main production area is almost exclusively illuminated with high pressure sodium vapor lamps.

The initial survey was conducted June 13, 1980 with the follow-up survey on December 2-5, 1980. Personal breathing zone air samples were obtained for measurement of welding fumes and carbon monoxide. Sodium lighting was assessed with direct reading instrumentation for ultraviolet radiation (actinic and near), luminance, and illuminance. A medical and work history questionnaire was administered to 52 employees.

Environmental sampling demonstrated the following full shift exposure levels: cadmium - mean 0.025 mg/m^3 (0.0-0.05), NIOSH 0.04 mg/m^3; chromium - mean 0.34 mg/m^3 (0.01-2.3), NIOSH criteria 0.025 mg/m^3; copper - mean 0.12 mg/m^3 (0.00-1.8), OSHA standard 0.1 mg/m^3; iron - mean 0.86 mg/m^3 (0.03-7.4), ACGIH 5 mg/m^3; magnesium - mean 0.01 mg/m^3 (0.00-0.03), ACGIH TLV 10 mg/m^3; manganese - mean 0.17 mg/m^3 (0.00-1.6), ACGIH 1 mg/m^3; nickel - 0.17 mg/m^3 (0.01-1.4), NIOSH 0.015 mg/m^3; total fume - mean 2.4 mg/m^3 (0.46-5.1), ACGIH 5 mg/m^3; carbon monoxide - 27 ppm (20-42), NIOSH 35 ppm. Maximum optical radiation levels measured were: actinic ultraviolet irradiance - none detected; near ultraviolet irradiance - 0.5 uW/cm^2 (ACGIH 1.0 mW/cm^2); luminance 50,000 fL (ACGIH 2920 fL); illuminance 500 Lux (IES 100-1000 Lux). (Source of evaluation criteria applied are indicated by acronym.)

Medical questionnaire data indicated that 24 of 37 welders but only 1 of 15 non-welders had experienced episodes compatible with metal fume fever, a syndrome that typically includes fever, chills, chest tightness, shortness of breath, headaches, muscle aches, and metallic taste. The questionnaire data did not substantiate the expressed concern about cardiovascular disease among current workers. Many workers reported inadequate lighting in the plant, but no adverse health effects related to lighting were documented.

Based on the results of this survey, NIOSH concluded that a health hazard from overexposure to welding fumes of Cd, Cr, Cu, Fe, Mn, and Ni and total fume existed at Aqua-Chem, Inc. Questionnaire data indicated that workers may have experienced episodes of metal fume fever associated with exposure to welding fumes. No health effects directly attributable to high pressure sodium vapor lighting used in the plant were detected.

Recommendations addressing ventilation and procedures for reducing worker exposures, suggested lighting modifications, and worker education are presented in Section IX.

KEYWORDS: SIC 3559 (Special Industry Machinery, Not Elsewhere Classified), welding, copper, nickel, chromium, iron, carbon monoxide, welding fumes, metal fume fever, cardiovascular disease, lighting, sodium vapor lamps, Lucalox®

II. INTRODUCTION

On April 23, 1980 the National Institute for Occupational Safety and Health (NIOSH) received a confidential request for a Health Hazard Evaluation at Aqua-Chem, Inc., Milwaukee, Wisconsin. NIOSH was asked to investigate a reported excess incidence of heart attacks and other health effects that were thought to be related to welding fume exposures or to working under high pressure sodium lighting. The employees considered to be at risk were welders and assemblers.

On June 13, 1980 an initial survey was conducted which consisted of an opening conference, walk-through survey, and interviews with company and labor representatives. Informal interviews with employees indicated the need for further investigation of cardiovascular disease, of acute illness episodes suggestive of metal fume fever, and of headaches, fatigue, and other health effects attributed by workers to sodium vapor lighting. Refusal of the company to permit the administration of confidential employee interviews during regular working hours (as part of the follow-up survey) necessitated obtaining a warrant in order to complete the evaluation. The follow-up survey, conducted December 2-5, 1980, included an assessment of the sodium vapor lighting, administration of medical and occupational history questionnaires, and environmental monitoring for welding fumes and carbon monoxide. Employee representation was provided by Local 124 of the International Brotherhood of Boilermakers, Iron Shipbuilders, Blacksmiths, Forgers, and Helpers. A consulting firm had been contracted by the company to do an industrial hygiene survey in late May 1980, prior to NIOSH's initial survey. An interim report was issued by NIOSH in July 1980 and later sampling results were made available in February 1981.

III. BACKGROUND

A. Environmental

1. Process Description:

Aqua-Chem, Inc., Water Technologies Division, formerly a wholly owned subsidiary of the Coca-Cola Company, is involved in the development, design, and manufacture of sophisticated evaporators and systems for heat transfer, reverse osmosis, and other specialized fluid processing. The size and complexity of the products varies from large multi-vessel evaporators capable of processing millions of gallons of water per day for cities to compact units for shipboard use. The entire process, from initial design to crating of the finished product for shipment, is conducted on the premises. The estimated length of time for production of a unit ranges from several weeks for a smaller, simpler unit to 4 months for a larger, complex unit. Parts are initially tack welded together and then completed with seam welds. Welding inside confined spaces is required for some units. The metals welded in largest quantity are carbon steel, stainless steel, and copper-nickel alloys. Any combination of these metals may be present in a finished unit. The maximum thickness of metal used was 5 centimeters.

Welding techniques include tungsten inert gas (TIG), metal inert gas (MIG) or gas metal arc (GMA), stick, and submerged arc. Automatic wire welders are used extensively. The main gases used to provide an inert atmosphere over the work are argon/nitrogen mixtures and carbon dioxide. Plasma and oxyacetylene cutting are also performed during part fabrication. All welders must be capable of welding on all 3 base metals.

2. Facility Description:

The main production areas occupied a large, open building with 3 bays, each of which measured 85 x 220 meters and averaged 11 meters in height. There were no local exhaust systems present in the welding areas. General ventilation was achieved via ceiling louvres located in the roof of the center bay. The only air movers observed were several man coolers and box fans.

3. Sodium Lamp Description:

In 1977 Aqua-Chem converted the existing mercury vapor lamps in North Plant #2 to high pressure sodium vapor lamps. There were 225 sodium vapor lamps in the area of the facility where reported adverse health effects occurred. Other artificial optical radiation sources in the same area included fluorescent lamps, cutting and welding processes, mercury vapor lamps and quartz heaters. In addition, the building was designed to permit sunlight to enter the work area. Figure 1 shows the approximate location of these sodium lamps. Lamps were mounted in standard parabolic reflectors. A detailed description of the lamps is presented in Appendix A.

The spectral emission of the sodium vapor lamp, as indicated in G.E. sales literature, is shown in Figure 3. Very little ultraviolet radiation (i.e., wavelengths less than 400 nanometers (nm) is produced. The spectrum contains wavelength emissions throughout the visible region, but the peak emissions occur in the region from about 575-610 nm.

IV. MATERIALS AND METHODS

A. Environmental: Industrial Hygiene

The environmental assessment of the production area consisted of 2 major activities: (1) evaluation of worker exposure to substances associated with the welding processes (i.e., welding fumes and carbon monoxide [CO]) and (2) measurement and evaluation of the high pressure sodium vapor lighting present in the area.

1. Welding Fume: Personal monitoring for welding fume exposure was conducted using preweighed polyvinyl chloride/acrylonitrile filters and mixed cellulose ester filters with personal sampling pumps calibrated at 1.5 liters per minute (Lpm). Filter cassettes were mounted high on the worker's collar to insure their placement inside the welding helmet and worker assistance was requested in keeping the cassettes inside the helmet when welding. Observation during personal sampling indicated few problems with cassettes outside the helmet during welding. The weighing of preweighed filters was done in duplicate and all filters were analyzed for cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), and nickel (Ni) using NIOSH analytical method P&CAM 173.[1] The limits of detection for the various metals by this method were: Cd-1 microgram (ug); Cr-3 ug; Cu-1 ug; Fe-3 ug; Mg-0.3 ug; Mn-1 ug; and Ni-4 ug.

2. Carbon Monoxide: Area carbon monoxide levels were monitored with an Ecolyzer Series 2000 connected to a strip chart recorder and also with several low flow sampling pumps connected to long-term direct reading CO detector tubes. Personal monitoring for CO exposures was also done using the low flow pumps (15-20 cubic centimeters per minute) and long-term direct reading detector tubes mounted in the individual's breathing-zone. Acetylene welding and cutting in the shop was not performed during the survey and as their use was reportedly minimal, acetylene was not considered as an interference.

B. Environmental: Optical Radiation

The following instrumentation was used to document levels of optical radiation produced by the sodium vapor lamps:

1. An International Light model 730A radiometer with 2 specially calibrated detectors was used to evaluate the ultraviolet radiation levels. Since the effectiveness of actinic UV radiation in causing biological effects varies with the wavelength, the potential effectiveness of a source is the integrated product of the irradiance of that source at each wavelength and the effectiveness factor at that wavelength. One detector was designed to read the actinic UV radiation (200 to 315 nm) in directly biologic effective units of microwatts per square centimeter (uW/cm^2), while the other measured near UV (320 to 400 nm) in units of milliwatts per square centimeter (mW/cm^2) with no biologic weighting function.

2. A Photo Research Spectra mini-spot photometer, with 1° field of view, was used to measure the luminance of lamps. Due to scale saturation when making these measurements, it was necessary to use additional filters. A Photo-Research Litemate/Spot-Mate Photometer was used to document the environmental illuminance in units of lux.

   All instruments had been calibrated by the respective manufacturer within 6 months and had been checked by NIOSH for compliance with calibrations. In addition to the above equipment, photographs were taken to document positions, size, and location of lamps in the facility.

   Lamp measurements were performed in the facility during regular working hours on December 3, 1980. The majority of measurements were performed in the area where most of the reported health effects had occurred. However, measurements were taken at sites throughout the facility. All lamp measurements in the west and center bays were made at an estimated detector to lamp distance of 11 meters, except in the stockroom where the distance was about 6 meters. Only the maximum result obtained for a given measurement was recorded. In many cases, over 10 individual measurements were made for each radiation quantity.

C. <u>Medical: Epidemiology</u>

The names of individuals to be interviewed were drawn from the October 3, 1980 list of 164 hourly employees. Workers from the main production area were divided into two groups: "welders" (welders, welder-fitters, and layout-fitters), and "non-welders" (assemblers, assembler-fitters, grinders, and cranemen), whose job responsibilities did not include welding. There was no sizeable group of production workers whose work area was not illuminated by high pressure sodium vapor lamps, although the cranemen were shielded from direct incidence of light by the roof of the operator's booth.

Thirty-seven welders and 15 non-welders were interviewed, based on random selection. Selection for participation in the medical study was independent of that used in determining workers to be monitored for occupational exposures.

The questionnaire was administered by the medical officer. Medical questions preceded smoking and work history questions. Questions relating to sodium vapor lighting inquired about visual acuity, visual perception, and medical symptoms. Other questions were asked regarding respiratory symptoms, chest pain, known cardiovascular disease, and symptoms of metal fume fever.

V. EVALUATION CRITERIA

A. Environmental

The criteria used in evaluating exposures identified in this investigation were obtained from the following sources: NIOSH Recommended Standards; the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's) for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981; the Illuminating Engineering Society Lighting Handbook (IES); and the OSHA General Industry Standards. Table I (in back) presents the applicable criteria for chemical contaminants as time-weighted averages (TWA) for a normal 8-hour workday (8-10 hours in the case of NIOSH standards) or 40-hour work week. Table II (in back) presents the evaluation criteria for physical agents applicable to the sodium vapor lighting measurements.

1. Bases of Evaluation Criteria for Metals:

The evaluation criteria for chrome, copper, and manganese are intented to prevent acute health effects including respiratory irritation (Cr, Cu); nausea and metal fume fever (Cu); and acute poisoning (Mn). The health effects of chronic exposures are considered in the standards for cadmium (kidney malfunction, pulmonary changes); chromium (irritation and ulceration of nasal mucosa, kidney and liver damage); iron (pulmonary changes appearing on X-rays); manganese fumes (chronic poisoning); and nickel (nasal or lung cancer). The criteria for magnesium and iron reflect the maximally acceptable levels for fumes considered less toxic. It is noted that they are frequently found in combination with more toxic materials.

The evaluation criteria for Cr (VI) and Ni in Table I were considered most appropriate for this study based on the following consideration. Chromium (VI) sensitivity among welders exposed to aerosols of Cr (VI) has been confirmed by patch testing with aqueous solutions of Cr (VI) as potassium dichromate derived from welding fumes.[2] Chromium (VI) oxide is considered to be the major constituent of the Cr fume generated during the observed welding processes. Questions concerning the-carcinogenicity of chrome-containing welding fumes have been raised in recent literature, but no definitive answer shown.[3,4] Therefore, the most restrictive criteria for a non-carcinogenic form of Cr (VI) has been chosen.[2]

The consideration of nickel as a carcinogen is based on its identification as a possible cause of nasal and lung cancer among nickel refinery workers. Although specific carcinogenic compounds have not been implicated, studies conducted among other groups of workers and with animal exposure to various nickel compounds (including nickel oxide) support the classification of nickel as a carcinogen.[5,6]

2. Basis of Recommended Carbon Monoxide Standard:

The primary effect of exposure to low concentrations of CO on workmen results from the hypoxic (reduced oxygen) stress associated with a reduction in the oxygen carrying capacity of the blood. Workers with significant cardiovascular disease, both detected and undetected, may be at risk of serious injury, and for these workers it is recommended that exposures not exceed 25 ppm.[7] The applied value of 35 ppm recommended by NIOSH is intended to provide protection for workers with chronic heart disease.[8] This value is used to limit carboxyhemoglobin formation to 5% in a nonsmoker engaged in sedentary activity at normal altitude.[9] Physical exertion and cigarette smoking may increase carboxyhemoglobin levels.

B. Medical

1. Metal Fume Fever:

Metal fume fever, also known as brass chills, welders' ague, copper fever, zinc fever, and Monday morning fever, is a syndrome that arises after respiratory exposure to the fume of any of several metals. Fume is generated when a metal is heated to above its melting point, typically in such settings as brass foundry work, welding, and acetylene or plasma arc cutting. Exposure to fumes of zinc, copper, and magnesium are the most common causes. Symptoms, such as thirst, metallic taste, dry mouth, and headache, occur about four to eight hours after fume exposure. Cough, chills with irregular fever, dyspnea, muscle pain, and a sense of weakness and fatigue may develop over the subsequent few hours. The illness is self-limited and usually resolves within 24-48 hours. Illness can occur after an individual's first exposure to fume. Exposure to fume within a day or so of initial exposure tends to elicit less severe symptoms, but repeat exposure after having avoided metal fume for a longer period makes the individual susceptible again to the intial symptoms. The name "Monday morning fever" is used among workers with Monday through Friday fume exposure who become ill after a Monday exposure, feel well for the rest of the work week, and become ill again the next Monday.[10,11,12]

2. Cardiovascular Disease:

The term "heart attack" typically indicates either an acute episode of heart muscle cell death from insufficient oxygen delivery to the muscle cells or else an acute impairment of the heart's pumping action from disruption of the mechanisms that coordinate its rhythmic beating. Such acute events usually occur within a context of cardiovascular disease, such as high blood pressure or occlusion of the heart's blood vessels. Known or suspected factors that influence the likelihood of developing cardiovascular disease include age, hereditary factors, diet, obesity, cigarette smoking, exercise, and emotional stress.[13]. Some chemical substances, such as carbon monoxide,[14] carbon disulfide,[15] and trichloroethylene[16] can cause acute events in individuals without known heart impairment and may contribute to the development of cardiovascular disease. Suspicion that a workplace factor is contributing to heart attacks is strengthened if there appear to be patterns in terms of time of day, day of week, time of year, location in plant, job title, or similarities of chemical or physical exposures among workers who have had heart attacks.[17]

3. Health Effects of Sodium Vapor Lighting:

There are few documented reports of complaints associated with exposure to high pressure sodium vapor lights generally refer to color and visual task distortions. Reports from schools[18,19] and industries[20,21] emphasize such effects as eye strain and/or pain, headaches, glare, and color balance. Recently a study was published on the effects of 70 watt high pressure sodium vapor lamp exposures on Sprague Dawley female rats.[22] This study reports evidence of somewhat increased body and adrenal gland weight. It must be noted that this study has been the subject of controversy,[23,24] and has not been confirmed by other investigators. Critical is the question as to what constitutes average normal organ weights under exposures to light considered normal to the animal species being tested, and whether the effect produced under the test conditions are spectral or intensity dependent.

In general, it does seem reasonable to speculate that spectral distribution of various optical radiation sources may influence various bodily functions. Whether or not that influence extends to sodium vapor lamps simply has not yet been decided in the scientific arena. The evidence to date suggests that there are no data available which show correlation between heart attack and exposure to sodium vapor lamps. Some of the other problems relating to these lamps can be minimized by use of diffusers, retro-reflectors, and mounting different lamp types (i.e., fluorescent, incandescent) in the same general work area, producing a mixture of different color temperatures. The sodium vapor lamp radiation does not seem to constitute a major optical radiation hazard when compared to the existing guideline values. It is noted, however, that these guidelines have been formulated with reference to potential skin and occular health effects. There is very little research reported on potential behavioral effects from exposure to such lighting sources. The high luminance value could be reduced considerably either by the use of diffusers on the fixtures indirect lighting arrangement or by using lower wattage lamps at short lamp to floor distance.

VI. RESULTS

A. Environmental: Industrial Hygiene

Tables III and IV present the individual personal and area sampling results for welding fume and CO exposures. Twenty-five employees were monitored for welding fume exposures, (23 welders, 2 crane operators). Six employees were monitored for CO exposures (2 of which were welding). The type of welding used most extensively during the survey was GMA or MIG welding. Semiautomatic welding equipment, which fed wire continuously to the welding process, was used by a majority of the workers. The main blanket gases applied during the survey were pure argon and argon/nitrogen mixes. Carbon dioxide was also used, but the application of this gas was limited during the time of the survey. The major welding rods or wires were steel wire and stainless steel wire. Copper nickel filler wire was also used. The following summary presents personal sampling results for welding fumes and carbon monoxide:

Substance	Detectable[1] % (#)	Mean[2] ± Standard Deviation	Range	Evaluation Criteria[3]	Exceeded % (#)
Cadmium	8 (2)	0.025±0.04	0.00-0.05	0.04 mg/m^3	4 (1)
Chromium	35 (9)	0.34 ±0.75	0.01-2.3	0.025 mg/m^3	20 (5)
Copper	100 (26)	0.12 ±0.35	0.00-1.8	0.1 mg/m^3	20 (5)
Iron	100 (26)	0.86 ±1.6	0.03-7.4	5 mg/m^3	4 (1)
Magnesium	100 (26)	0.01 ±0.007	0.00-0.03	10 mg/m^3	0 (0)
Manganese	100 (26)	0.17 ±0.35	0.00-1.6	1 mg/m^3	4 (1)
Nickel	46 (12)	0.17 ±0.40	0.01-1.4	0.015 mg/m^3	28 (7)
Total Fume	11 weights	2.4 ±1.6	0.46-5.1	5 mg/m^3	9 (1)
CO	100 (6)	27 ±7.6	20-42	35 ppm	17 (1)

1. 26 or 25 fume samples total. First value indicates percent of total samples taken. Second value equals actual number.
2. N=25, area sample excluded from fume values; N=6 for CO. Values given in mg/m^3, except for CO in parts per million (ppm).
3. See Table I (at back of report).

Twenty-two overexposures were documented for the 31 employees monitored. Among welders, 9 of 25 monitored (36%) had 1 or more overexposures and of these 9, 6 (67%) were overexposed to 2 or more metals. One of the 6 workers monitored for CO was overexposed. The maximum number of overexposures observed for any 1 worker was to 4 different metals.

Background CO levels in the production area averaged 22 ± 1 ppm of CO during the first shift. Monitoring done with the Ecolyzer during the second shift showed an average level of 13 ± 2 ppm with the lowest levels occurring later in the evening towards the end of the shift.

B. Environmental: Physical Agents

Values for the maximum optical radiation levels measured in the production area during this survey are shown below. The last column gives the current accepted optical radiation guideline value for the given quantity.

Maximum Recorded Optical Radiation
Levels from Sodium Vapor Lamps

Quantity	Measured Radiation	Location	Optical Guideline & References[1]
Actinic UV Irradiance	Nondetected	Floor of Marine Welding Area	0.1 effective $\mu W/cm^2$ (3)
Near UV Irradiance	0.5 $\mu W/cm^2$	Floor of Marine Welding Area	1.0 mW/cm^2 (3)
Luminance	50,000 fL	Stockroom	2920 fL (3)
Illuminance	500 Lux	Floor of Marine Welding Area	100-1000 Lux (27)

1. See Table II (at back of report).

The only measurement that greatly exceeded the guideline was the luminance quantity. However, a person would have to look straight up into the lamp reflector in order to exceed this guideline value.

C. Medical: Epidemiology

Thirty-seven welders and fifteen non-welders were interviewed. The ages of the two groups were similar. Five participants were women

(4 welders and 1 non-welder). The smoking histories of welders and non-welders were similar: 24 of 37 welders (65%) and 9 of 15 non-welders (60%) were current smokers. The ages of the current smokers and non-smokers were also similar.

1. Respiratory Symptoms Questions:

   Each study participant was asked about shortness of breath with exertion, cough in the morning, phlegm production in the morning, and wheezing or whistling in the chest (Table V).

   Current smokers reported significantly higher rates for shortness of breath, cough, and phlegm production than non-smokers. When controlled for smoking status, welders and non-welders reported similar rates for all symptoms except wheezing, which was significantly more often reported by the welders ($p<.05$).

2. Metal Fume Fever:

   Twenty-two of 52 workers (42%) reported having had an episode of chest tightness with cough, chills, and fever (fume fever). Welders were over eight times more likely to have reported such an episode (57%) than non-welders (7%) ($p<.001$ Fisher exact test). This excess was also found when controlled for current smoking status (i.e. smokers did not have any increased risk for fume fever).

   Welders reported having an episode of fume fever were also significantly more likely to report phlegm in the morning (Table VI: 52% versus 25%; $p<.04$) and wheezing (57% versus 13%; $p<.02$). They also reported more shortness of breath with exertion and more morning cough, although neither association was statistically significant.

3. Cardiovascular Problems:

   The reports of myocardial infarction and other cardiovascular conditions were more common in welders than in non-welders (Table VII). However, the number of workers reporting these conditions other than hypertension were small, and there were no statistically significant differences between the groups.

4. Eye Problems:

   Although a significant number of workers reported various visual problems in the plant (Table VIII), there were no statistically significant differences between the welders and non-welders.

5. Other Symptoms:

Seventeen percent of the participants reported a skin rash or irritation in the past, although there was no significant difference between welders and non-welders (Table IX).

However, both headache, an abnormal taste in the mouth, and nose irritation were reported significantly more often by the welders. The former two symptoms were significantly associated with reporting an episode of fume fever and may represent a manifestation of that symptom.

VII. DISCUSSION AND CONCLUSIONS

A. Welding Fumes and Gases: Exposures

The environmental sampling done at Aqua-Chem, Inc., indicated significant potentially toxic exposure to a variety of metals used in welding. The excessive exposures to nickel (28% of the samples taken) and to chromium (20% of the samples taken) is of particular concern due to their substantial toxicity. The workload and the gauge and composition of the base metals will determine the degree of exposure as well as work practice and adequacy of contaminant removal systems. However, considering the continuous nature of the welding procedures and the absence of contaminant removal systems, the exposures documented in this study should be considered representative of those normally encountered in this plant.

The majority of exposures were to Ni, Cu, and Cr fumes. These were generally experienced by workers welding on Monel (70% Ni/30% Cu alloy) and/or stainless steel during the workshift. Cadmium overexposure was documented for a welder who worked on a combination of the two alloys. Manganese exposures were documented for two welders who reported having worked with stainless steel.

Carbon monoxide concentrations in the plant approached or exceeded the NIOSH recommended exposure limits of 35 ppm/8-hour TWA. Personal samples ranged from 20 to 42 ppm. Crane operators, who occupied open crane cabs above the welding areas, had exposures of about 26 ppm. Area samples indicated background levels of about 22 ppm during the day shift and a decline to 13 ppm for the second shift, presumably as a result of decreased welding activity. Carbon dioxide use as a blanket gas was limited during the survey. Higher CO levels would be expected if there were more welding with CO_2 as a blanket gas, welding inside of confined spaces, and with more overall welding activity than occurred during the NIOSH survey.

Additionally, for an individual who works overtime at a task with continuing exposure, the acceptable level of exposure to potentially hazardous fumes and gases is considered to be lower than applicable standards established for an 8-hour day/40-hour work week. Such an individual will have a longer period of potentially harmful exposure and will therefore have less recovery time away from the exposure.[25]

B. Production Area Ventilation:

There was no ventilation for removal of welding fumes and gases from the production area. The unacceptability of general dilution ventilation is apparent from the previously discussed exposures. Several mancoolers and box fans were scattered around for dispersal of welding fumes and gases from the immediate work area. A problem encountered with their use was the displacement of blanket gases used to cover welds. Several large paddle fans were located in the top of the center bay with the stated purpose of mixing heated air inside the building during cooler weather. A downdraft hood in the cutting area appeared ineffective even when work was performed directly over the hood entrance.

Local exhaust ventilation for the removal of contaminants generated during the welding process is considered the most satisfactory method of control. Dilution ventilation is seldom successfully applied to fumes and dusts because (1) the high toxicities often encountered require extremely large quantities of dilution air; (2) velocity and rate of evolution are usually very high; and (3) data on the amount of fumes and dust production are very difficult if not impossible to obtain.[26] Additionally, with the use of local exhaust ventilation systems makeup air must be provided in sufficient quantity for the systems to operate properly.

The current makeup air system was extremely limited with respect to the size of the production area. Makeup air units were restricted to the north wall at the north end of the production area and no air distribution system was present outside of the units themselves. Numerous supplemental heaters and air movers were scattered about supporting the conclusion that air exchange and distribution by the makeup system was marginal at best. The increase in CO levels during the day shift, the stationary accumulation of fume above the area of activity, and the high background CO levels of the overhead crane operators indicate that air movement and exchange is not occurring.

It must be acknowledged that the work being performed at this plant will require a very flexible local exhaust system. Caution must be exercised in system selection since small, independent portable units, while capable of removing fume, may not remove CO. A central system can be effective in removing gaseous contaminants generated by the welding process as well as fumes.

C. Confined Spaces:

No provisions for removing contaminants from confined spaces were observed other than box fans and an "air sucker" - a metal cylinder with a compressed air connection used on occasion as an exhausting unit.

The absence of active means for removing contaminants and the lack of defined confined spaces operating procedures in this plant creates additional concern over exposure of workers to toxic materials. Discussions with workers supports this concern. Confined spaces refers to an object or area which by design has limited openings for entry and exit; may have unfavorable natural ventilation which could contain or produce dangerous air contaminants; and which is not intended for continuous employee occupancy. These include storage tanks, compartments of ships, process vessels, pits, silos, vats, degreasers, reaction vessels, boilers, ventilation and exhaust ducts, sewers, tunnels, underground utility vaults, and pipelines.[27]

A Class B confined space has the potential for causing injury and illness, if preventive measures are not used, but is not immediately dangerous to life and health.[27] Classifications are determined by the most hazardous condition of entering, working in, and exiting a confined space. The large vessels, inside which welding is done, are considered a Class B confined space involving hot work and the generation of toxic fumes. Potential for oxygen deficiency should also be considered, and this could result in a change to a more hazardous class of the confined space.[27]

D. Respiratory Protection:

Three types of respiratory protection were being utilized - disposable dust masks; half-masks with high efficiency dust, fume, and mist cartridges; and powered air purifying helmets. There was no formal respiratory protection program. There was no maintenance facility for cleaning respirators and decisions about the use of respiratory protection were left largely to the individual employees. Bearded employees were observed wearing respirators

The powered air purifying helmets would reduce welding fume exposures but would be ineffective for gases and vapors. High efficiency filters used on the half-masks were also ineffective for gases and vapors; however, properly used they could offer protection against welding fume exposures. The single use dust masks were ineffective for welding fume exposures. Work performed in confined spaces would require supplied air respirators in the absence of sufficient contaminant removal and makeup air.[27]

E. Welding Fumes and Gases: Medical Study

The most prominent medical finding of this evaluation was the high prevalence of metal fume fever among the welders at Aqua-Chem (57% of the interviewed welders). These episodic (and often recurrent) episodes of fume fever were most likely associated with high exposure to fumes in specific welding processes. After the initial episode or episodes of fume fever, workers reported the ability to prevent further episodes by avoiding such high exposure through the use of protective equipment or work practice changes. The poor control of occupational exposures at Aqua-Chem (described above) undoubtedly contributed to the occurrence of metal fume fever among the welders.

The higher prevalence of some chronic respiratory symptoms among the welders reporting episodes of metal fume fever is disturbing. There is very little information on the chronic effects of recurrent metal fume fever. Whether these chronic symptoms represent the effects of metal fume fever or the effects of chronic exposure to high levels of welding fume is difficult to discern.

The data collected in the study do not suggest an unusual occurrence of cardiovascular disease among the workers at Aqua-Chem. The prevalence of hypertension among the workers is consistent with general population estimates. The small number of workers reporting other cardiovascular problems and the overall small number of workers at the plant precludes any more definitive study of this issue. However, high exposure to carbon monoxide, which appears to be occurring at the plant (based on the industrial hygiene data), could contribute to the occurrence of heart attacks or angina (chest pain) in workers with underlying cardiovascular disease.

F. Effects of Sodium Vapor Lighting:

Although a large proportion of the workers interviewed reported eye strain (38%) and other visual disturbance, the exposure monitoring did not indicate any lighting exposures exceeding any of the current recommended guidelines for lighting. The lack of a non-exposed control group and the high level of concern about the sodium vapor lighting among the workers makes any association between exposures and the reported symptoms difficult to substantiate.

It has been well documented in past NIOSH studies that the optical radiation levels from the welding processes exceeded that from the sodium vapor lamps. Moreover, the presence of the rich blue welding light helps produce a better color and reduce some of the glare situations. None of the above discussion should negate the fact that workers may not like or may not be accustomed to the type of factory light now available. However, not liking the light color is not necessarily equivalent to its being potentially hazardous.

VIII. CONCLUSIONS

Based on the results of this survey, NIOSH concluded that a health hazard from overexposure to welding fumes of Cd, Cr, Cu, Fe, Mn, and Ni and total fume existed at Aqua-Chem, Inc. Questionnaire data indicated that workers may have experienced episodes of metal fume fever associated with exposure to welding fumes. No health effects directly attributable to high pressure sodium vapor lighting used in the plant were detected.

Recommendations addressing ventilation and procedures for reducing worker exposures, suggested lighting modifications, and worker education follow. Recommendations submitted by the consultant industrial hygiene firm addressing ventilation, confined spaces procedures, and development of a respiratory protection program had generally not been acted upon at the time of our follow-up survey. In retrospect, NIOSH's recommendations for the correction of problems associated with welding procedures (Section IX) are in agreement with those previously submitted to the company by the consultant.

IX. RECOMMENDATIONS

1. Local exhaust systems, either of a portable or permanent type should be installed. Accompanying this should be an evaluation and necessary modifications of the makeup air supply systems. The installation of local exhaust would reduce the requirements for general makeup air. Local exhaust ventilation is considered the best solution in confined spaces. A necessary consideration in the selection of portable units is the contaminant to be removed. High efficiency particulate filters would be ineffective for gases and vapors. Reevaluation of welding fume exposures and CO levels would be necessary following the installation of ventilation controls and makeup air systems.

2. A formal confined spaces entry and operations procedure should be developed for work inside of the larger, land base units and during any other tasks requiring workers to occupy an area not normally intended for human occupancy.

3. High luminance values could be reduced either by the use of diffusers on all lamps or by reducing the lamp wattage. Mounting different lamp types in the production area would produce a mixture of different color temperatures alleviating the intense yellow characteristic of high pressure sodium vapor lights.

4. Development and institution of an adequate respiratory protection program based on environmental surveillance and in accord with 29 CFR 1910.134. Use of respiratory protection should be considered temporary and reserved for infrequent and nonroutine operations where potential overexposures may occur. The use of supplied air respirators for use in confined spaces may be applicable in the absence of compatible local exhaust systems.

5. Development of joint management-union education programs to address worker concerns and needs regarding materials used, health effects of contaminants generated in the workplace, work practice, proper use and selection of personal protective equipment and engineering controls, as well as more effective use of the management-labor safety committee are recommended.

6. A medical surveillance program should be developed to periodically screen workers for the potential medical effects of occupational health exposures. This program should include periodic physical examinations, pulmonary function tests, and other appropriate medical testing.

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XI. AUTHORSHIP AND ACKNOWLEDGEMENTS

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XII. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report are currently available, upon request, from NIOSH, Division of Standards Development and Technology Transfer, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

Copies of this report have been sent to:

1. Local 124 of the International Brotherhood of Boilermakers, Iron Shipbuilders, Blacksmiths, Forgers, and Helpers.
2. The International Brotherhood of Boilermakers, Iron Shipbuilders, Blacksmiths, Forgers, and Helpers.
3. Aqua-Chem, Incorporated.
4. U.S. Department of Labor (OSHA), Region V.
5. NIOSH, Region V.

For the purpose of informing the 160-exposed employees, the employer shall promptly post the determination report for a period of 30 days in a prominent place near where exposed employees work.

FIGURE 1

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HE 80-119

Figure 1. SCHEMATIC OF NORTH PLANT =2 AT AQUA-CHEM SHOWING RELATIVE LOCATION OF LIGHTING FIXTURES

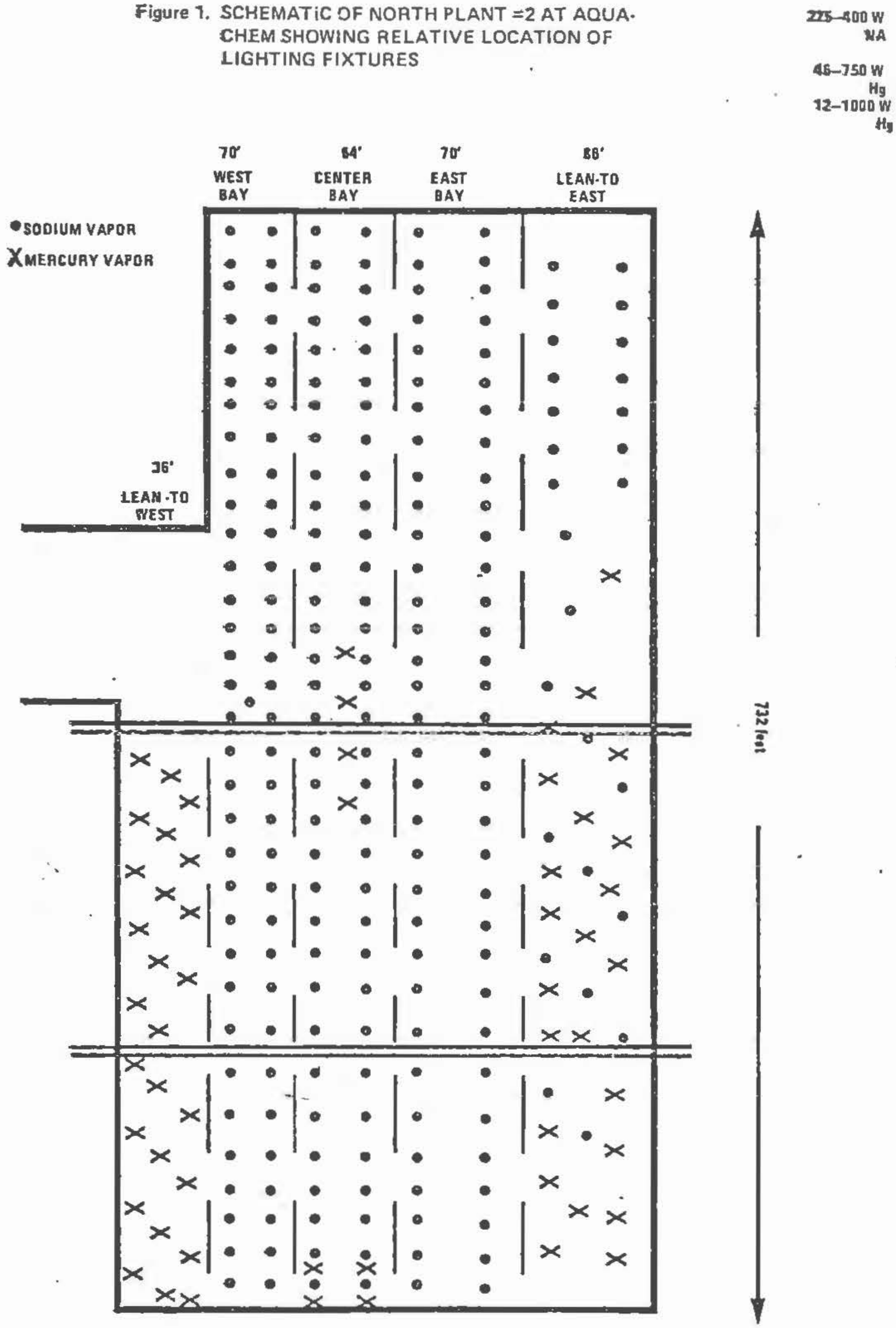

FIGURE 2

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HE 80-119

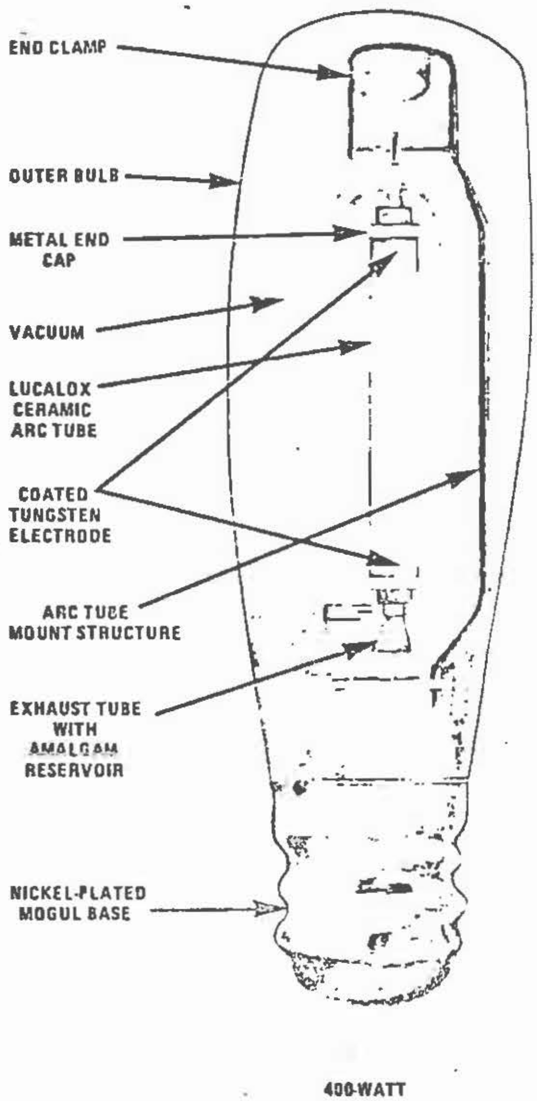

Figure 2. NOMENCLATURE OF LAMP

FIGURE 3

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HE 80-119

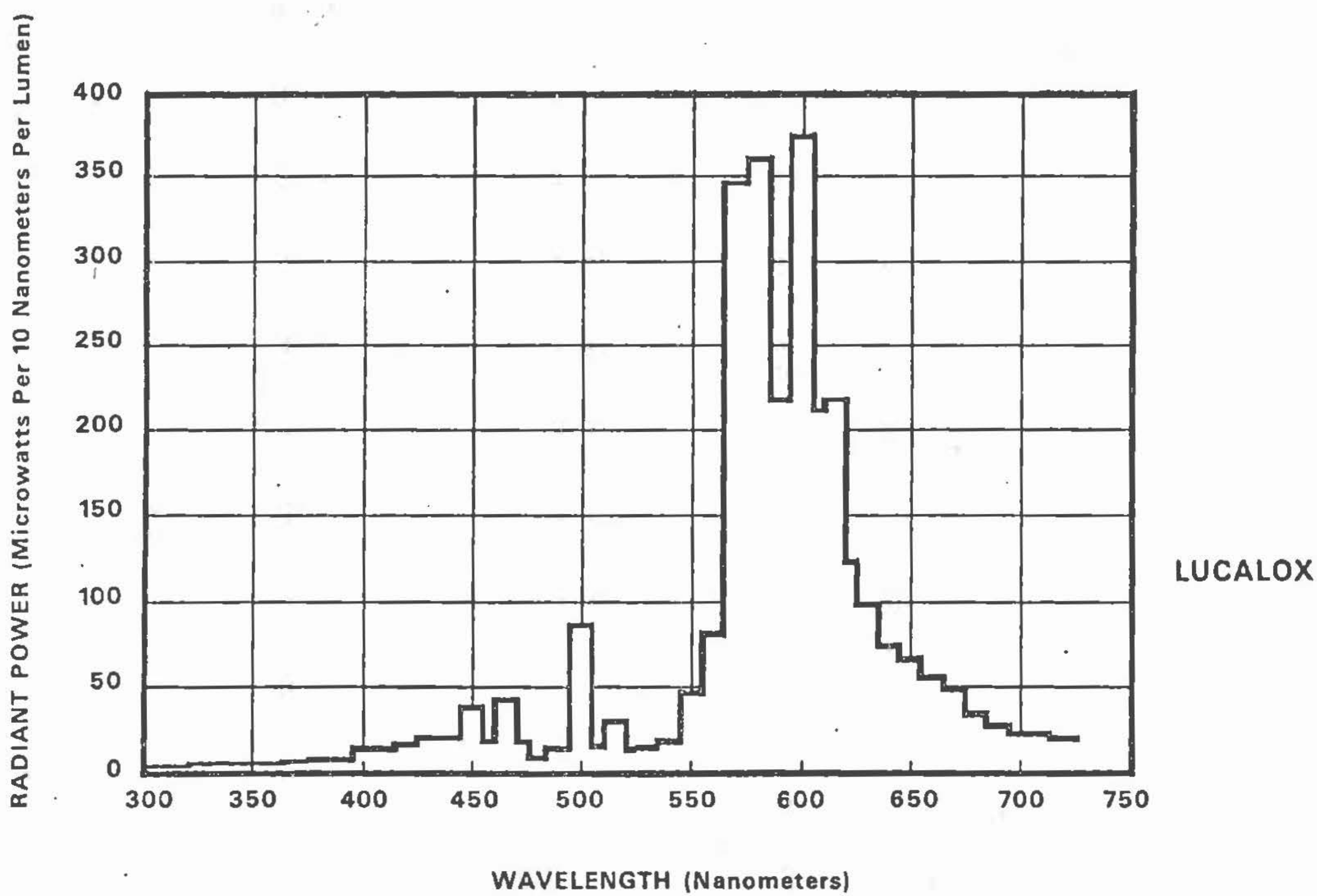

Figure 3. TYPICAL SPECTRAL EMISSION OF 400W HIGH PRESSURE SODIUM VAPOR LAMP

TABLE I

Evaluation Criteria for Chemical Contaminants

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

Substance	Recommended Environmental Exposure Limits (mg/m^3)[1] and Source[3,4]		Health Effects[5]	OSHA PEL[2] (mg/m^3)
Cadmium Oxide Fume (as Cd)	0.04 C=0.2	NIOSH	Severe pulmonary irritant; emphysema; chronic cadmium poisoning.	0.1 C=0.3
Chromium (water soluble Cr VI compounds as Cr)[6]	0.025 C=0.05	NIOSH	Severe upper respirator irritant.	0.1
Cooper Fume (as Cu)	0.1 0.1	OSHA	Upper respirator irritation; metal fume fever (an influenza-like illness).	0.1
Iron Oxide Fume (as Fe	5 STEL=10	ACGIH	Siderosis (a benign penumoconiosis or respiratory condition associated with inhalation of particulate.	10
Magnesium Oxide Fume (as Mg)	10	ACGIH	Mild eye, nose irritant.	15
Manganese Fume (as Mn)	1 STEL=3	ACGIH	Manganism (central nervous system effects of chronic Mn intoxication); metal fume fever.	C=5

(continued)

TABLE I (continued)

Substance	Recommended Environmental Exposure Limits (mg/m^3)[1] and Source[3,4]		Health Effects[5]	OSHA PEL[2] (mg/m^3)
Nickel (insoluble and inorganic compounds as Ni)	0.015	NIOSH	Respiratory irritation from fume; nasal and lung cancer.	1[8]
Welding Fumes (N.O.C.)[7]	5	ACGIH	Toxicity of component metals must be considered individually.	----
Carbon Monoxide	40 (35) C=229 (200)	NIOSH	Insufficient oxygen to tissues, impairment of central nervous system function.	55 (50)

1. Values are given as time-weighted averages (TWA's) over a normal 8-hour workday in the units milligrams per cubic meter (mg/m^3). Additionally, applicable values for CO in parts per million is shown in ().
   C=Ceiling concentration not to be exceeded.
   STEL=Short Term Exposure Limit, considered a maximal allowable concentration, not to be exceeded at any time during the 15-minute excursion period.
2. OSHA Safety and Health Standards (29 CFR 1910.1000).
3. NIOSH Criteria for a Recommended Standard...Occupational Exposure to ______.
4. ACGIH TLV's=Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981.
5. Proctor, N. and J. Hughes. Chemical Hazards of the Workplace.
6. NIOSH Criteria for a Recommended Standard...Occupational Exposure to Chromium (VI).
7. N.O.C.=Not Otherwise Classified.
8. NOTE: OSHA nickel standard is given for the metal and soluble compounds as Ni.

TABLE II

Evaluation Criteria for Physical Agents

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

Physical Agent	Exposure Guideline[1] and Sources[2,3]		Health Effects
Actinic UV[4] Irradiance (200-315 nm)	0.1 effective uW/cm^2	ACGIH	Erythema, keratoconjunctivitis (welder's flash, sand-in-eye, etc.), cataracts in animals. Eye is organ of primary concern.
Near UV Irradiance (320-400 nm)	1.0 mW/cm^2	ACGIH	Possible thermal or photochemical injury to the skin and eyes.
Luminance	50,000 fl	ACGIH	
Illuminance	500 Lux	IES	

1. Values are given for periods of exposure greater than 1000 seconds. Units are: microwatts per square centimeter (uW/cm^2); milliwatts per square centimeter (mW/cm^2); footlumens = fL; Lux = the International System unit of illumination.
2. ACGIH TLV's = Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981.
3. IES = Illuminating Engineering Socity Lighting Handbook.
4. UV = Ultraviolet radiation with wavelength indicated in nanometers (nm).

TABLE III

Metal Fume Exposures

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

Sample Description				Exposure Concentrations (mg/m^3)							
Date/ Shift	Location	Job Classification	Sample Duration (min)	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Tota Fume
12-3-80/1	Land Base W/B[1]	Welder A	489	N.D.[2]	0.12	0.04	1.6	0.02	0.25	0.05	5.1
	Land Base W/B	Welder A	478	N.D.	0.07	0.06	1.6	0.02	0.35	N.D.	4.5
	Land Base W/B	Welder Fitter[4]	471	N.D.	N.D.	1.8	0.18	0.02	0.06	0.25	3.8
	West Bay	Crane Operator	474	N.D.	N.D.	0.01	0.12	0.00	0.02	N.D.	0.4
	Marine Weld C/B[1]	Welder Fitter A	442	N.D.	0.02	0.03	0.21	0.01	0.02	0.01	2.2
	Marine Weld C/B	Layout Fitter A	389	N.D.	N.D.	0.04	0.21	0.01	0.03	0.02	1.4
	Marine Weld C/B	Layout Fitter B	396	N.D.	N.D.	0.01	0.15	0.01	0.02	N.D.	1.5
	Marine Weld C/B	Layout Fitter B	421	N.D.	N.D.	0.02	0.28	0.01	0.03	N.D.	1.1
	Marine Weld C/B	Welder B	428	N.D.	N.D.	0.04	0.14	0.01	0.01	0.01	*[3]
	Marine Weld C/B	Layout Fitter A	390	N.D.	0.01	0.01	0.24	0.01	0.03	N.D.	0.5
	Davis Area C/B	Welder B	461	N.D.	N.D.	0.01	0.72	0.01	0.25	N.D.	2.5
	Davis Area C/B	Layout Fitter B	525	N.D.	N.D.	0.04	1.7	0.01	0.20	N.D.	3.4
	Center Bay	Crane Operator	292	N.D.	N.D.	0.01	0.13	0.01	0.02	N.D.	*
	E/B[1]	Welder Fitter B	387	N.D.	N.D.	0.01	0.32	0.02	0.04	N.D.	*
12-4-80/1	Marine Weld C/B	Layout Fitter A	249	0.05	N.D.	0.16	0.12	0.01	0.02	0.04	*
	Marine Weld C/B	Layout Fitter B	531	0.00	N.D.	0.08	0.21	0.01	0.02	0.01	*
	Marine Weld C/B	Welder Fitter A	370	N.D.	N.D.	0.14	0.18	0.00	0.02	0.02	*
	Marine Weld C/B	Layout Fitter B	283	N.D.	N.D.	0.08	0.17	0.01	0.02	0.01	*
	Marine Weld C/B	Welder B	161	N.D.	N.D.	0.08	0.12	0.01	0.02	N.D.	*
	Davis Area C/B	Welder A	411	N.D.	0.51	0.10	4.2	0.03	1.6	0.18	*

(continued)

TABLE III (continued)

Sample Description				Exposure Concentrations (mg/m^3)							
Date/ Shift	Location	Job Classification	Sample Duration (min)	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Total Fume[5]
-4-80/2	Land Base W/B	Welder A	401	N.D.	0.03	0.01	0.42	0.01	0.08	N.D.	*
	Land Base W/B	Welder Fitter B	364	N.D.	N.D.	0.03	0.65	0.00	0.10	N.D.	*
	Burning Area W/B	Burner A[6]	225	N.D.	2.3	0.22	7.4	0.01	0.98	1.4	*
	West Bay-Crane	Area Sample	545	N.D.	N.D.	0.00	0.03	0.01	0.00	N.D.	*
	Marine Weld C/B	Welder A	424	N.D.	0.01	0.05	0.19	0.00	0.02	0.01	*
	Davis Area C/B	Welder B	418	N.D.	0.01	0.02	1.0	0.01	0.25	N.D.	*
aluation Criteria (See Table I) in mg/m^3:				0.04	0.025	0.1	5	10	1	0.015	5

W/B = west bay; C/B = center bay; E/B = east bay.
N.D. = values below analytical limits of detection.
Total Fume represents the total welding fume exposure and will be greater than the sum of the individual metal fume exposures listed.
Worker was provided with powered air-purifying respirator helmet.
* = preweighed filters not used, total fume not measured.
Wore dust, mist, and fume half-mask respirator. Cassette clipped on respirator strap inside helmet.

TABLE IV

Environmental Carbon Monoxide Levels

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

December 3-4, 1980

Date/Shift	Location	Job Classification	Sample Duration (min)	CO Exposure (ppm)
12-3-80/1	Land Base W/B[2]	Welder A	393	42
	West Bay	Crane Operator	473	26
	Center Bay	Crane Operator	397	26
12-4-80/1	West Bay	Crane Operator	410	26
	Center Bay	Crane Operator	209	23
	Marine Weld C/B	Layout Fitter B	557	20
	Area Sample Description			
12-3-80/1	Outside, top of union office (8' above floor) 09:50-17:30[3]		460	23±2 (range 21-29)
12-4-80/1	Inside union office		393	22
	Outside union office on pillar		530	42[4]
	Land base area-on unit near welder using Argon/Nitrogen mix[3]		360	21±2 (range 17-25)[5]
12-4-80/2	Land base area-on unit near welder using Argon/Nitrogen mix[3]		300	13±2 (range 8-18)[5]
Evaluation Criteria (See Table I) in ppm:				35

1. ppm = parts per million.
2. W/B = west bay; C/B = center bay.
3. Background measurements obtained with Ecolyzer Series 2000.
4. Value suspect.
5. [illegible]ursions observed during the time an arc was [illegible]k and appearing on the strip chart were not included in values reported. Excursions frequently exceeded the scale (0-50 ppm) and generally [illegible]

TABLE V

Respiratory Symptoms

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

	Welder			Non-Welder		
Symptom	Smoker (24) #/(%)	Non-Smoker (13) #/(%)	Combined (37) #/(%)	Smoker (9) #/(%)	Non-Smoker (6) #/(%)	Combined (15) #/(%)
Shortness of breath on exertion	12 (50%)	3 (23%)	15 (41%)	3 (33%)	0 (-)	3 (20%)
Morning cough	7 (29%)	1 (8%)	8 (22%)	3 (33%)	0 (-)	3 (20%)
Morning phlegm production	8 (33.3%)	2 (15%)	10 (27%)	4 (44%)	0 (-)	4 (27%)
Wheezing/Whistling in chest	10 (42%)	4 (31%)	14 (38%)	2 (22%)	0 (-)	2 (13%)
Fume fever episode	15 (63%)	6 (46%)	21 (57%)	1 (11%)	0 (-)	1 (7%)

TABLE VI

Association Between Fume Fever Episode and Other Respiratory Symptoms Among Welders

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

Symptom	Welders With an Episode of Fume Fever (21) (#/%)	Welders Not Reporting an Episode of Fume Fever (16) (#/%)
Shortness of breath on exertion	11 (52%)	4 (25%)
Morning cough	7 (33%)	1 (6%)
Morning phlegm production	9 (43%)	1 (6%)
Wheezing or whistling in the chest	12 (57%)	2 (13%)

TABLE VII

Cardiovascular Disease

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

Condition	Welders (37) #	%	Non-Welders (15) #	%	Combined (52) #	%
History of heart attack	2	(5%)	0	(0%)	2	(4%)
Past or present high blood pressure	6	(16%)	3	(20%)	9	(17%)
History of irregular heart beat	3	(8%)	0	(0%)	3	(6%)
Chest pain made worse by exertion and relieved by rest	4	(11%)	2	(13%)	6	(12%)

TABLE VIII

Eye and Visual Symptoms

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

Symptom	Welders (37) #	%	Non-Welders (15) #	%	Combined (52) #	%
Eye strain/glare while in plant	16	(43%)	4	(27%)	20	(52%)
Impaired ability to see in the plant	19	(51%)	7	(50%)*	26	(51%)*
Possible safety hazard due to lighting	5	(14%)	0	(0%)*	5	(10%)*
Decreased work quality due to lighting	12	(32%)	7	(50%)*	19	(37%)*
Abnormal color perception	2	(5%)	1	(7%)	3	(6%)

* One person did not answer these questions.

TABLE IX

Other Symptoms

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

Symptom	Welders (37) #	%	Non-Welders (15) #	%	Combined (52) #	%
Skin rash or irritation	6	(16%)	3	(20%)	9	(17%)
Ringing in ears	19	(51%)	5	(36%)*	24	(47%)*
Abnormal taste in mouth	25	(68%)	4	(29%)*	29	(57%)*
Headache	23	(62%)	1	(7%)	24	(46%)
Nose irritation	17	(46%)	4	(29%)*	21	(41%)*
Throat irritation	14	(38%)	5	(36%)*	19	(37%)*

* One person did not answer this question.

APPENDIX A

Sodium Vapor Lamp Description

Aqua-Chem, Inc.
Milwaukee, Wisconsin
HETA 80-119

The Lucalox® lamp was introduced to the market in 1965.[30] The lamp has one of the highest light-producing efficiencies of any commercial source of white light. The construction, operation, and radiation characteristic of Lucalox® lamps is unlike that of other high intensity high pressure sodium discharge lamps. Figure 2 shows the parts of the lamp. The 400 watt Lucalox® lamp produces light with an efficacy of 125 lumens/watt (l/w). This compares with values of about 80 l/w for fluorescent, 50 l/w for mercury, and 15-20 l/w for incandescent bulbs.

The success of the Lucalox® lamp in delivering a high l/w value is due to a new ceramic material, combined with a means of sealing the tube to contain a high temperature discharge of metallic sodium. The ceramic used is Lucalox®, an acronym representing "translucent aluminum oxide". This material can withstand very high temperatures (i.e., 1300°C). However, unlike other ceramics, Lucalox® has a high transmittance (92%) for visible wavelengths, is difficult to crack or weaken, and has a high resistance to the extremely corrosive effects of hot sodium.

The end caps of the Lucalox® tube are formed of niobium and are sealed in such a way as to withstand the expansion and contraction experienced in turning the lamp off and on. The niobium and coiled tungsten electrode are imbedded with oxides to withstand the sodium atmosphere.

The design of the Lucalox® lamp does not readily permit the use of a starting electrode, so the tube is filled with xenon and mercury in addition to sodium. (The mercury is inserted in the form of an amalgam with the sodium.) The ballast contains a special starting device to ionize the xenon across the main-electrode gap by means of a short, high-voltage pulse on each cycle or half-cycle. A typical starting pulse has a peak voltage of 2500V for about 1 microsecond. Because the pulse is so brief, very little energy is involved, but the xenon is ionized sufficiently for the much lower full-wave voltage of the ballast to strike and maintain the arc, and warm-up begins. Most ballasts are designed so that the starting pulse ceases once the arc has formed.

In the process of attaining full output, it is possible for one to observe several phases of vaporization in the arc by rating the light color. At first, a very dim, bluish-white glow is produced by the ionized xenon; this quickly gives way to a brighter blue mercury glow. As the brightness increases, there is a shift to monochromatic yellow (characteristic of sodium at low pressure and temperature). As the pressure and temperature builds up, the lamp spectrum broadens.

NOTE: Lucalox is a registered trademark of the General Electric Company.

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