ENVIRONMENTAL RESEARCH 11, 140–150 (1976)

Shipyard Health Problems[1]

BENJAMIN G. FERRIS, JR.

Department of Physiology, Harvard School of Public Health, 665 Huntington Avenue, Boston, Massachusetts 02115

AND

HARRY HEIMANN

Environmental Sciences Laboratory, Mount Sinai School of Medicine, 100th St. and 5th Avenue, New York, New York 10029

"Thought given to the design at the start can eliminate much that is dangerous during construction" (10).

This entire conference will be concerned with the many problems affecting the health of shipyard workers. Each category or type of exposure will be considered in a great deal of detail. It is not our intention to summarize the conference before it starts, but rather to indicate where much of the concern has been directed in the past, to indicate some of the areas for present and future concern, and to indicate by example some of the techniques that might be used to assess the adequacy of any health protection program in a shipyard.

The opening quotation from the ILO Encyclopedia on Occupational Health and Safety refers only to ship construction or building. It is, however, a very broad statement and can be applied to any health program. When we speak of shipyards, we speak not only of those yards that do new ship construction, but also of those that do ship repairing, and of those that do the breaking up or scrapping of ships. Some selected problems associated with these latter activities will be discussed. In any of these, planning for safety in the blueprint stage cannot be too strongly stressed. Safety must be a part of the initial design. As a corollary, it is a responsibility of the management to establish and support safety in production and a responsibility of the worker to comply with these necessary requirements.

This conference recognizes that shipyard work involves special hazards to safety and health. It must not be forgotten, however, that shipyard workers are exposed to most of the potential work hazards that are common to many aspects of the construction industry. Table 1 gives the incidence of injuries recorded in a shipyard during a year in which only limited personal protective equipment was worn. This tabulation emphasizes the need for safety glasses, hard hats, and protective shoes and clothing—basic items in any safety program.

Let us now consider some of the special health and safety problems. Since ships must remain watertight under adverse conditions, such as storms or enemy action,

[1] Supported in part by Grant ES-00002 from the U.S. Public Health Service and by Grant OH-00310 National Institute for Occupational Safety and Health, P.H.S., H.E.W.

Copyright © 1976 by Academic Press, Inc.
All rights of reproduction in any form reserved.

TABLE 1
INCIDENCE OF SHIPYARD INJURIES 1967[a]

	Rate/1000 employees
Eyes	2,426
Hand	1,241
Leg - foot	893
Strains - sprains	599
Burns - scalds	299
Scalp	225
Back	224
Welding – fumes	222
Face	149
Trunk	149
Other	132
	6,559

[a] From ILO (10). Rates are per annum, presumably in a British shipyard when protective equipment, such as helmets for welders, was used only if needed for work.

space on ships is compartmentalized. These compartments must be airtight and watertight. In addition, there are a great many essential parts of the ship such as pipes and electric wiring that have to be fitted into restricted areas. Constructing the compartments and installing the equipment requires working in confined spaces, under cramped conditions, and frequently with inadequate ventilation.

These conditions can lead to a greater tendency for injuries from falls and slips. Welding and/or cutting may be required in these areas. Noxious fumes and gases can be generated, and hazardous concentrations can develop. Even with good ventilation there may be great difficulty in controlling the level of exposure.

These confined spaces also can become hot and humid, either because of poor ventilation or because of the work being done, such as welding. These conditions, in turn, can put significant heat stress on the worker and he may suffer heat cramps, heat stroke, or even heat exhaustion. Again, adequate ventilation is needed.

Another problem in the confined spaces is noise. The metal surroundings have poor absorptive qualities but good reflective qualities. The overall effect can result in a significant sound pressure level that can be detrimental to the worker's hearing.

A further factor is that the confined and cramped spaces make movement into and out of them difficult. This becomes a very real problem in the case of an emergency, such as fire or explosion, or the release of toxic fumes or gases into those areas.

Formerly, shipbuilding was done virtually in the open. This has changed somewhat now as many compartments are built under cover in the yard or elsewhere and are then assembled into the ship. Much of the work, however, is still done out-of-doors; thus, during the winter, workers may be exposed to severe climatic conditions such as cold, wind, and rain, and yards in the northeastern part of the

United States may have much snow and ice, as well, in the winter. This in turn can lead to the potential hazard of slips and falls. On the other hand, virtually all of ship breaking is an outdoor activity comprising all of the above hazards, as well as the increased risk associated with demolition work.

Shipyard work requires the use of large amounts of special materials and processes that are generally recognized as occupational hazards that can produce disease. Ships' hulls and bulkheads are generally made of steel. These pieces are cut to specific sizes and shapes and then welded into place. Much of the steel superstructure is being replaced by aluminum to conserve weight. The welding of aluminum requires the use of inert-gas-shielded arcs. These, in turn, tend to produce more oxides of nitrogen, ozone, and ultraviolet than the nonshielded arcs. When such welding is required in confined spaces, heavy exposures can result. In addition, the various coatings on the welding rods may contribute potentially toxic materials to these exposures such as fluorine compounds, asbestos, silica, etc.

Cutting of steel or aluminum is the major activity in ship breaking, but it also occurs in ship repair or construction. The steel is likely to be covered with various paints to protect it from corrosion or to act as an antifouling substance. These substances may contain lead, chromium, or mercury which can be volatilized off the surface during cutting or welding. The lead-poisoning hazard from this activity is well recognized (19). The application of these paints presents a potential hazard, especially if sprayed onto the surfaces (19). If applied with a brush or roller the hazard is probably minimal.

Ships require large amounts of thermal insulating materials for cold water pipes and refrigeration units, as well as for steam and heating pipes. Insulation is also placed under open decks to minimize solar heat transfer below decks, and is especially necessary under flight decks of aircraft carriers. Fire-resistant materials are generally selected because of the hazard resulting from fires on board ship. Asbestos has been one of the most generally used materials because of its favorable characteristics. Its use, however, is diminishing as other materials have been developed that can replace it. These newer materials are magnesia bricks, fibrous glass products, and rock wool. To date there is little evidence that these latter substances are a hazard. Asbestos, on the other hand, is hazardous because of its capacity to product chronic lung disease and cancer. Its use may still be required in some areas where it is the only known adequate material. It is still present in many of the ships afloat and it does cause a problem when repair work is done and the old insulation material is ripped out. It is a problem at the time of scrapping of these ships. Perhaps the most dramatic example of this problem during renovation work was one faced by the British Royal Navy a few years ago. This involved removing three inches of crocidolite asbestos from beneath the flight deck of the *Ark Royal*, Britain's largest aircraft carrier. The hazard was recognized. The solution was to encase the men who were removing the material in ventilated plastic suits. The material was removed after wetting it thoroughly, and in order to minimize exposure to others it was promptly bagged in plastic bags for safe disposal. The area was then vacuumed to remove the residual contaminating material. This was a tremendous job but one that apparently was accomplished with minimal risk to the workers doing the work and others also working on board ship.

Exposures to X rays or radioisotopes may become more of a problem in the future. Many ship specifications require X-ray inspections of part or even all welds on the ship. This means extensive use of X radiation. Usually only a small number of skilled workers are involved but the potential hazard exists and a sound radiation protection program is indicated. The further development of nuclear power for use in ships will also mean an increase in this potential hazard. At present, this is limited almost entirely to military vessels but it may not be so in the future. Some work on this potential problem has been reported (9, 15).

Another area that may present problems in the future is the use of epoxy compounds or other similar materials to cover or coat interior surfaces. Problems such as sensitivity or dermal reaction may occur at the time of application. They may also present a problem at the time of repairs if they are burned off. The pyrolysis products of certain plastics such as Teflon can produce significant pulmonary symptoms (13). We must not forget that there may be other unrecognized toxic substances lurking in the holds and recesses of ships.

Many shipyards, especially repair yards, have almost a job-shop character. They may have a number of separate operations such as forging, plating, acid cleaning baths, degreasers, etc. Each of these has its special problems which are no different because they are carried on in a shipyard. Another problem found in repair yards is that a number of trades may be working simultaneously and exposure may be shared. For example, pipe fitters, welders, and pipe coverers all can be working in close proximity and only the pipe coverer may be wearing respiratory protection because he is handling asbestos. However, the men working nearby can be almost as heavily exposed as the pipe coverer himself if he did not wear a mask. New ship construction can be handled more like an assembly line so the exposure of other workers is less of a problem but significant exposures can occur and should be recognized as a possibility.

The Harvard School of Public Health has been studying shipyard workers for a long time. To demonstrate some of the problems in such studies I shall discuss two categories of workers—welders and pipe coverers.

Professor Philip Drinker became interested in the health and safety of welders over 40 years ago. He and his colleagues showed that zinc oxide caused metal fume fever (22) and that the zinc oxide could be produced in the process of welding on galvanized steel. During World War II, Professor Drinker was Chief Health Consultant to the United States Maritime Commission. Based on those experiences he wrote an article on shipyard health problems (3), particularly as related to conditions during the war when the sudden large increase in shipyards and in workers created a need for housing and medical care for the worker and his family.

As a result of this association he and his colleagues quantitated the effect of eye flash from arc welding (12) and recommended methods to protect nonwelders from this exposure. The effect of ultraviolet light on the eye had been documented many years before (24). Professor Drinker *et al.* also showed (23) that the fumes and gases generated in welding whether filtered or not, were toxic to animals. In that report they noted that studies by Russian workers had measured sufficient amounts of ozone and oxides of nitrogen around welding areas to cause irritation of lungs. A second paper in the series (25) reported a fatal case in a welder who had been working on galvanized steel in a confined space. This report also noted that a similar fatality had occurred earlier in Germany and it was thought to be due to exposure to oxides of nitrogen. Both of these deaths are interesting in the light of recent studies that have indicated that the pathogenicity of various bacteria is enhanced and macrophage activity is diminished by relatively low concentrations of ozone or oxides of nitrogen (1, 8). These deaths occurred before the development of antibiotics. The first case definitely had a pneumococcus pneumonia; the second seemed more like the progressive development of pulmonary edema. Thus these two cases may well demonstrate the ways in which welding fumes and gases might be toxic. On the other hand a study of pneumonia in the ship building industry during World War II (2) showed that welders had a morbidity rate and case fatality rate about the same as many other trades in the industry. This later study, however, occurred when antibiotics were available and in use.

Since that time a number of studies have been made in welders without showing evidence of a definite increased morbidity or decreased pulmonary function (7, 11, 18, 21), although one report (18) did point out that in a yard doing repair work all three categories (pipe coverers, pipe fitters, and welders) studied had some reduction in pulmonary function probably because they all had some exposure to asbestos. The concentration of gases and various metal oxides were reported (18) and were in the range or slightly lower than those that had been reported in earlier studies (4, 20). Since the more recent measurements were made inside the welding helmet, these values should be compared with comparable sites of measurement in the earlier studies which showed that there were higher concentrations outside the helmet. The earlier studies also documented the increased production of ozone and oxides of nitrogen by the inert-gas-shielded metal arc welding.

Exposures to welding fumes and gases and ultraviolet can be hazardous, but the evidence to date indicates relatively little disease, perhaps because of protective measures employed. This does not mean we should relax our vigilance or lower our control procedures. If and when more exotic metals or fluxing compounds are introduced into welding we may well see effects from these substances.

Another group of workers that commanded Professor Drinker's attention was pipe coverers handling primarily amosite asbestos (6). At that time, during World War II, it was believed that asbestos fibers of 15–75 μm were the important ones and that the very fine particles were not important. Because of this when they made their aerometric measurements only the relatively large particles were counted to assess the men's exposures. They pointed out the variety of operations done by pipe coverers and that, therefore, there was a considerable variety of exposure. They used a Konimeter for their analyses. Some of the areas showed high total dust count but virtually all counts of asbestos (fibers) were below 5 mppcf. They surveyed some 1074 men in four different shipyards by means of a chest X ray. The results of this survey are presented in Table 2, where the number of cases and rates are presented by the different yards and by the number of years

TABLE 2

RELATIONSHIP BETWEEN LENGTH OF EXPOSURE AND PREVALENCE OF ASBESTOSIS[a,b]

Shipyard	Years in shipyard pipe covering			
	0 – 2	2 – 5	5 – 10	10+
Navy A				
Exposed	26	13	8	3
Affected	0	0	0	0
Percentage	0	0	0	0
Navy B				
Exposed	225	435	67	22
Affected	0	0	0	0
Percentage	0	0	0	0
Contract C				
Exposed	0	105	45	17
Affected	0	0	0	1
Percentage	0	0	0	6%
Contract D				
Exposed	26	118	5	9
Affected	0	0	0	2
Percentage	0	0	0	22%
TOTAL				
Exposed	277	671	125	51
Affected	0	0	0	3
Percentage	0	0	0	6%

[a] Fleischer *et al.* (6).

[b] Rates really higher since no cases in those less than 20 years of exposure, and we do not know actual numbers in the group.

worked. The authors pointed out that the rate of asbestosis by X ray in the 1074 men surveyed was low and that this exposure had done little harm in this population from the time since the start of exposure. They did indicate that three cases occurred in men with more than 20 years of exposure. If we examine Table 2 in more detail we can see that the risk of developing asbestosis is only in that group with 10 or more years of exposure. The overall average rate in this group is 6% and varies from 22 to 0% for the various yards. Since the authors noted that their cases occurred only in those with 20 or more years of exposure, we should have had the size of that population in order to estimate the risk more precisely. In any case, it is certainly greater than 6% and may well be more than 22%. It would seem that at that time there was not, unfortunately, an adequate appreciation of the importance of duration of exposure or duration after start of exposure for the development of asbestosis. As can be seen in the table, 95% of the population had less than 10 years of exposure.

Some 20 years after this survey, we had the opportunity to resurvey one of the yards (16, 17) that was involved in new ship construction. We were fortunate in being able to use the same Konimeter that was used in the previous survey to measure the concentration of dust in the air. In addition, we used other procedures that have become recognized as more satisfactory. The results from our

Konimeter gave values comparable to those obtained some 20 years previously and, since the materials used and the general techniques of handling them had not changed, we believed we had reasonably good estimates of the exposures of these subjects over that period. The values for asbestos fibers were in general less than 5 mppcf by the Konimeter and values obtained by the midget impinger (the instrument used in setting the semi-official threshold limit value) ranged from 10.0 to 0.8 mppcf with a weighted average of 5.2 mppcf. Thus levels were very close to what was considered to be safe at that time.

Our resurvey involved a more detailed protocol than that done by Professor Drinker and his colleagues. Ours included chest X rays, a standard questionnaire, simple tests of pulmonary function, diffusing capacity of the lung, physical examination of the chest by auscultation, and examination of the fingers for clubbing. From the results of these we decided whether or not a diagnosis of "asbestosis" should be made. There were 101 pipe coverers and 94 pipe fitters as controls who had been matched by age and years worked with the pipe coverers. Figure 1 summarizes the findings of our 1965 survey. It is apparent that asbestosis was never diagnosed in persons with less than 10 years of cumulative exposure and that in those with 20 years or more of cumulative exposure the rate was 38%. One of our controls was diagnosed as "asbestosis" in 1965, since the films were read without knowledge of the men's occupation or history, but is not included in the figure. He had a history of smoke inhalation some 30 years previously, had developed pulmonary fibrosis, and was not an asbestotic. These results then tend to confirm our interpretation of the earlier survey by Professor Drinker *et al.* Our conclusion from this study was that the suggested threshold limit value was too high, as men were developing asbestosis even though exposed to so-called "safe" levels. All this was done without a consideration of the ultramicroscopic particles which were not counted by our methods.

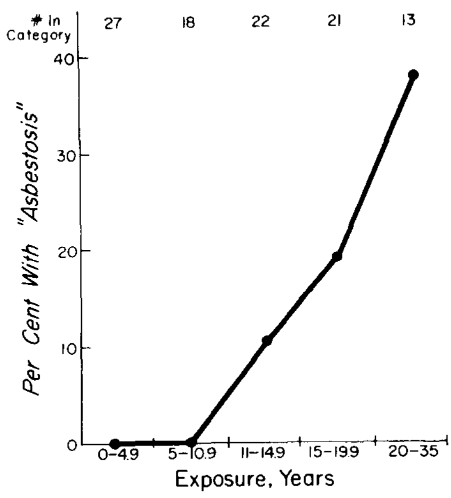

FIG. 1. Relationship between asbestosis and years of exposure in a shipyard doing new construction.

More extensive studies on the diffusing capacity of the lungs of this group (17) showed that the men handling asbestos had a greater impairment in this function than the men in the control group. A 3-year follow-up on them indicated that the diffusing capacity of the lung seemed to be a more sensitive indicator of later respiratory impairment than the simple tests of pulmonary function.

Since then a further follow-up and survey have been done using similar methods. All the analyses have not been completed to date but a summarization of outcome is presented in Table 3. As in most prospective studies the number available drops. Those lost to follow-up were primarily men who had had relatively brief periods of exposure and who had been laid off by the yard. It is apparent that the pipe coverers are suffering a higher mortality than the pipe fitters. Some of this has been due to mesothelioma. In addition, more of them are developing asbestosis by our criteria, again underscoring the latency of this disease.

It also has been possible to do a resurvey of one of the yards engaged in repair work that had been surveyed earlier by Professor Drinker. The methods of the resurvey were similar to those reported above (5). It was much more difficult to characterize the level of exposure of this population because of the wide range of activities in the shop and on shipboard. Total dust concentrations ranged from a high of 132 mppcf during tear out to 0.6 mppcf in the general shop. Mean values ranged from 57 to 3 mppcf. The higher values occurred during sawing, tearing out, and mixing cement, all of which were intermittent. On a time-weighted average, daily exposures were probably close to 5 mppcf. Fiber counts on samples showed mean values of 0.3–2.9 fibers per milliliter.

Changes in chest X rays consistent with definite asbestosis were noted in 10 out

TABLE 3

	1965	1967	1972
Pipe Coverers			
Number seen	101	84	78
"Asbestosis"[a]	11	13	8
Lost to follow-up			
Moved		14	14
Refused		0	1
Deceased		3	8
Controls-Pipe fitters			
Number seen	94	71	70
"Asbestosis"	1	2	1
Lost to follow-up			
Moved		23	18
Refused	(7)	0	0
Incomplete			2
Deceased	0	4	

[a] Criteria: Presence of three or more of the following: 1. dry crackling rales at the bases in two or more sites; 2. X ray changes on chest film consistent with advanced or moderately advanced asbestosis; 3. finger clubbing; 4. dyspnea on climbing one flight of stairs or less; 5. vital capacity less than 80% of predicted. (Unpublished data: R. L. H. Murphy, E. A. Gaensler and B. G. Ferris, Jr.)

of 61 pipe coverers and in none of the pipe fitters or welders. In addition, the prevalence of these changes seen by X ray increased with age, from 13.6% for those pipe coverers under 45 years of age to 18% for those pipe coverers 45 years of age or more.

Table 4 summarizes the results of the simple tests of pulmonary function. All of these tests as compared with a control group of pipe fitters from a yard engaged in new ship construction are low. The two populations did not differ significantly in age, height, or smoking habits so we think they are comparable and that the decrease in pulmonary function may reflect a general exposure of the men at the repair yard to small amounts of asbestos. On the other hand, measurement of the diffusing capacity (Table 5) only showed a decrease in the pipe coverers who were definitely exposed to asbestos. It should also be noted that cigarette smoking also produced a decreased diffusing capacity. Similar results have been seen by Marr (14).

TABLE 4

PULMONARY FUNCTION: REPAIR-SHIPYARD WORKERS COMPARED WITH PIPEFITTERS ENGAGED IN NEW SHIP CONSTRUCTION

	Number	Forced vital capacity (FVC) (liters)	Forced Expiratory volume ($FEV_{1.0}$) in 1 sec (liters)	Peak Expiratory flow (PEF) (l pm)
Pipe coverers	61	3.75	2.94	502
Pipe fitters	63	3.79	2.90	484
Welders	61	3.95	3.02	495
Pipe fitters—new ship	94	4.34	3.55	526

TABLE 5

CARBON MONOXIDE DIFFUSING CAPACITY: REPAIR-SHIPYARD WORKERS COMPARED WITH PIPE FITTERS ENGAGED IN NEW SHIP CONSTRUCTION

	Number	CO diffusing capacity (mm/min/mm Hg)
Pipe coverers		
Nonsmokers	10	22.2
Smokers	17	21.5
Pipe fitters		
Nonsmokers	12	25.9
Smokers	11	20.3
Welders		
Nonsmokers	12	24.5
Smokers	21	22.9
Pipe fitters—new construction		
Nonsmokers	33	25.69
Smokers	30	22.47

These results from the repair yard also tend to confirm those seen at the yard doing new construction, namely that even at these relatively low levels of exposure we can still expect to have cases of asbestosis after 20–30 years of exposure. For these reasons we are in accord with the proposed reduction in the threshold limit values. Some changes have already taken place in the shipyards, since from 1965 fiber glass products have been replacing asbestos in shipyards. It should be emphasized, however, that asbestosis can have a long latent period and we may still see cases developing which are, in fact, reflecting earlier exposure. The same observations have been made on the carcinogenic properties of asbestos, and mesotheliomata have occurred in persons with a year or so of exposure some 20–25 years previously.

It would thus seem prudent to continue to follow these various populations of workers in the shipyards to see whether new diseases develop and whether they are continuing to show evidence of exposures from their past.

Further studies should also be directed toward the effect of the small particles. These have been virtually ignored up to this time. It may well be that these will turn out to be the more important factors in the causation of disease.

SUMMARY

Shipyard health problems are similar to those of construction generally with the modification created by the inherent need to work in confined spaces. It is the latter fact that creates special conditions aggravating the hazard for occupational diseases and accidents.

We have considered some special problems (welding and asbestosis exposure) studied by colleagues at our Institution in the past and have brought some of these data up-to-date.

REFERENCES

1. Coffin, D. L., Gardner, D. F., and Holzman, R. S. (1968). Influence of ozone on pulmonary cells. *Arch. Envir. Health* **16**, 633–636.
2. Collen, M. F., Dybdahl, G. L., and O'Brien, G. (1944). Pneumonia in the ship building industry. *J. Indust. Hyg.* **26**, 1–7.
3. Drinker, P. (1944). Shipyard health problems. *Indust. Hyg. Toxicol.* **26**, 86–89.
4. Ege, J. D., Jr., and Silverman, L. (1945). Determination of welding fumes in ship construction. *Naval Medical Bull.* **44**, 1309–1320.
5. Ferris, B. G., Jr., Ranadive, M. V., Peters, J. M., Murphy, R. L. H., Burgess, W. A., and Pendergrass, N. P. (1971). Prevalence of chronic respiratory disease asbestosis in ship repair workers. *Arch. Envir. Health* **23**, 220–225.
6. Fleischer, W. E., Viles, F. J., Jr., Gade, R. L., and Drinker, P. (1946). A health survey of pipe covering operations in constructng naval vessels. *J. Ind. Hyg. Toxicol.* **28**, 9–16.
7. Fogh, A., Frost, J., and Glorg, J. (1969). Respiratory symptoms and pulmonary function in welders. *Ann. Occup. Hyg.* **12**, 213–218.
8. Gardner, D. E., Holzman, R. S., and Coffin, D. L. (1969). Effects of nitrogen dioxide on pulmonary cell populations. *J. Bacteriol.* **98**, 1041–1043.
9. Goren, S., and Thornton, J. H., Jr. (1960). The inhalation hazard from dust-producing operations in the repair of ships with low level radioactive contamination. *Amer. Ind. Hyg. Assoc. J.* **21**, 71–79.
10. Hill, R. N. (1972). Shipbuilding. In "Encyclopedia of Occupational Health and Safety." ILO Vol. II, pp. 1303–1305. Geneva.
11. Hunnicutt, T. N., Cracovaner, D. J., and Myles, J. T. (1964). Spirometric measurement in welders. *Arch. Environ. Health* **8**, 661–669.

12 Kinsey, V. E., Cogan, D. G., and Drinker, P. (1943). Measuring eye flash from arc welding. *J.A.M.A.* **123**, 403–404.

13. Lewis, C. E., and Kerby, G. R. (1965). An epidemic of polymer-fume fever. *J.A.M.A.* **19**, 375–378.

14. Marr. W. T. (1964). Asbestos exposure during naval vessel overhaul. *Indust. Hyg. J. 25*, 264–268.

15. Miles, M. E., Mangeno, J. J., and Burke, R. D. (1971). Environmental monitoring and disposal of radioactive wastes from U.S. Naval nuclear-powered ships and their support facilities, 1970. *Radiol. Health Data Rep.* **12**, 235-244.

16. Murphy, R. L. H., Jr., Ferris, B. G., Jr., Burgess, W. A., Worcester, J., and Gaensler, E. A. (1971). Effects of low concentrations of asbestos. Clinical, environmental, radiologic, and epidemiologic observations in shipyard pipe coverers and controls. *New England J. Med.* **285**, 1271–1278.

17. Murphy, R. L. H., Jr., Gaensler, E. A., Redding, R. A., Belleau, R., Keelan, P. J., Smith, A. A., Goff, A. M., and Ferris, B. G., Jr. (1972). Low exposure to asbestos. Gas exchange in ship pipe coverers and controls. *Arch. Environ. Health* **25**, 253–264.

18. Peters, J. M., Murphy, R. L. H., Ferris, B. G., Burgess, W. A., Ranadive, M. V., and Pendergrass, H. P. (1973). Pulmonary function in shipyard welders. An epidemiologic study. *Arch. Environ. Health* **26**, 28–31.

19. Rieke, F. E. (1969). Lead intoxication in ship-building and shipscrapping 1941–1968. *Arch. Envir. Health* **19**, 521–539.

20. Silverman, L., and Gilbert, H. (1954). Working conditions ambient to inert-gas-shielded metal-arc welding. *Welding J.* **33**, 1–12 (Research suppl.).

21. Stanescu, D. C., Pilat, L., Gavrilescu, N., *et al.* (1967). Aspects of pulmonary mechanics in arc welders' siderosis. *Brit. J. Ind. Med.* **24**, 143–147.

22. Sturgis, C. C., Drinker, P., and Thomson, R. M. (1927). Metal fume fever I. Clinical observations on the effect of the experimental inhalation of zinc oxide by two apparently normal persons. *J. Indust. Hyg.* **9**, 88–97.

23. Titus, A. C., Warren, H., and Drinker, P. (1935). Electric welding I. The respiratory hazard. *J. Indust. Hyg.* **17**, 121–128.

24. Verhoeff, F. H. and Bell, L. (1916). The pathological effects of radiant energy on the eye. *Proc. Amer. Acad. Arts Sci.* **51**, 630–818.

25. Williman, F. L. (1935). Electric welding II. An acute fatal pneumonia following electric welding of galvanized iron in a confined space. *J. Indust. Hyg.* **17**, 129–132.