NECROSIS OF THE JAW IN WORKERS EMPLOYED IN APPLYING A LUMINOUS PAINT CONTAINING RADIUM*

WILLIAM B. CASTLE, M.D., KATHERINE R. DRINKER, M.D., AND CECIL K. DRINKER, M.D.

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

THE investigations which are reported in this paper were begun at the request of the president of the company involved, and were conducted in the factory of this company and in the Harvard School of Public Health. It would have been impossible to make the observations we are placing on record without the complete co-operation of the executives and employees of the corporation in question and it is a pleasure to acknowledge this co-operation in a thorough examination, which, when coupled with the publication of the results, confronts the medical profession with a most interesting and novel problem.

SUMMARY OF CASES OF NECROSIS OF THE JAW

Our work began following receipt of a letter dated March 12, 1924, giving an account of two cases of necrosis of the jaw—one fatal case and one existing case, supposedly on the mend.

Careful inquiries and investigations made during two visits to the plant have enabled us to trace the following instances of chronic disease processes occurring in the jaw-bones of employees engaged in the application of luminous paint.

CASE 1.—Miss A., employed for four years and four months, ending in 1922, developed a necrosis of the jaw and later died.

CASE 2.—Miss B., employed for approximately two years and seven months, ending in 1921, developed, following the extraction of a tooth, a rapidly progressing necrosis of the jaw, not improved by curetting eight or nine times. Miss B. finally died as a result of this disease process.

CASE 3.—Miss C., employed from 1917 to 1920, inclusive, developed, following the extraction of a tooth, about December, 1923, progressive necrosis of the jaw, necessitating the removal of much of her left upper jaw and two blood transfusions. This patient died of chronic sepsis late in 1924, approximately one year after the extraction of the tooth.

CASE 4.—Miss D., employed for a period of six and one-half years, ending in 1923, began to fail in health three years before cessation of employment. Her symptoms were extreme fatigue and weakness with pallor. She continued her work in spite of increasing ill health and in October, 1923, developed a toothache with local swelling of the face. In December, 1923, she had an upper and a lower right molar pulled, a piece of decayed bone coming out with one of these teeth. She then stopped work. Normal healing of the jaw did not ensue; instead, a discharge of pus began and persisted. Later, two other teeth at some distance became affected and were extracted. When examined in May, 1924, she had, in addition to the process in the lower jaw, a

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new sinus in the upper jaw communicating with the antrum, as shown by X-rays. Her appearance was very bad; she had lost much weight and was very pale. Her blood, on microscopic examination, showed a profound anemia. She complained of pain in the bones of her face, had considerable inconvenience from the discharge of foul pus in her mouth and was forced to spend much of her time in bed. She said, however, that of late she had felt a little better—a statement not in accord with her appearance nor with the new septic process. At the time of examination this girl was in an extremely serious condition.

X-ray films made May 7, 1924, showed necrosis of the right upper maxilla with a great deal of clouding of the antrum and an apparent tendency to extend into the nose. The necrosis was not yet great enough to cause loss of all the teeth, but the condition of the antrum and the tendency of the process to extend upward toward the skull made one fear the possible onset of meningitis.

Case 5.—Miss E., who left employment in 1919, had a left lower molar extracted in 1923. The wound apparently healed normally. Six months later a sinus appeared at the site of the extracted molar and drained pus profusely for some months. X-rays taken after admission to a local hospital in March, 1924, showed evidence of a chronic infectious process in the jaw in the region of the extracted tooth. This patient left the hospital after five days, unrelieved and with a diagnosis of chronic osteomyelitis of the jaw, possibly due to phosphorus poisoning. She was, however, reported in May, 1924, to have recovered satisfactorily.

Here, then, is a series of five cases of necrosis of the jaw—necrosis not at all like the ordinary infections of the jaw which do occasionally follow the extraction of a tooth. Instead of a localized process which heals either of itself or after the establishment of drainage, we have a chronic, progressive rotting away of the bone, which is essentially different from an ordinary infectious process or from tuberculosis of the bone, but resembles very closely the necrosis of the jaw resulting from phosphorus poisoning. In our opinion, so great an incidence among these employees of this unusual disease process in the jaw cannot be a coincidence but must be dependent on some type of bone damage occasioned by the employment.

Analysis of Possible Toxic Agents

In view of the excellent general hygienic conditions of the work in the particular factory, it seemed at once advisable to study the special ingredients used in the luminous material.

The base of the luminous paint contains no phosphorus but consists of a luminous zinc sulphide containing minute traces of copper combined with small amounts of radium bromide, probably changed later into radium sulphate. The radium bromide is intimately mixed with the zinc sulphide. The vehicle is varied and the paint is applied with fine brushes.

As we learned from the dial painters that until six months before our investigation it was their universal practice to point their brushes in their mouths, we have considered the possibility of brushes or of vehicle as a source of difficulty. Bacteriologic studies of twelve brushes have been negative for anthrax. The bacteria cultured from the brushes were Bacillus subtilis, Staphylococcus albus, and a gram-negative nonsugar fermenting bacillus—harmless air-borne organisms which may be found normally in the mouth. Gum Acacia, the usual vehicle for the luminous material, is of course entirely nontoxic by mouth. We may now

consider the constituents of the luminous powder itself.

Zinc.—Zinc, in the opinion of practically all recent authorities, is in itself nonpoisonous (1) (2). So-called "poisonous" actions are due to the local irritant effects of soluble salts. Zinc sulphide is an insoluble salt and has never been the cause of any kind of poisoning. It is not reasonable to suppose that this salt would be readily absorbed or, if so, that it would be toxic in the relatively small quantities involved. We are, fortunately, able to instance additional proof of this in the operations of the New Jersey Zinc Company. In a part of the works in which zinc sulphide is made the employees are exposed to it in large quantities in a finely divided form. They must inhale and swallow it, as well as have a liberal contact with it through the skin. These workers have been observed over many years and exhibit no unusual pulmonary, skin, or digestive disturbances which might be due to local effects; certainly no cases of necrosis of the jaw have occurred as a result of their very ample exposure to zinc sulphide.

The zinc sulphide employed is, to be sure, not identical with that just mentioned. Its molecular state has been changed by "roasting" so that it is photosensitive. It is also, we find, more insoluble than the nonluminous sulphide in common inorganic reagents. This would tend to diminish any possible local effects—of which we found none in the plant under investigation—and make it more difficultly soluble for the organism. Lastly, if it were dissolved and absorbed by the organism it would change its chemical form, becoming probably a chloride or eventually a phosphate, and in this form would be identical with the soluble product from ordinary zinc sulphide that had been absorbed. If such a solubility does take place, the presence of soluble zinc in the organism, even where the exposure is many times greater than at the plant studied, is harmless, judging by the good health of the employees of the zinc sulphide department of the New Jersey Zinc Company and by a large general experience with the problems of zinc poisoning.

Copper.—It is hardly conceivable that the minute traces of copper present in the paint are significant as a toxic agent.

Radium.—There is a great deal of material in the literature on the effects of radium on animals and on men. In individuals working in the manufacture of radium apparatus and in clinical workers with this substance, the important symptoms of overexposure to radium are disturbances of the male and female sex organs, skin changes, and changes in the blood. These changes occur in persons who are exposed to radium externally but not in such a way as to be able to absorb any of the element itself.

Disturbance of menstruation in the female and sterility in the male are clearly recognized. And in the work of Mottram (3) (4), Gudzent and Halberstaedter (5), Williams (6), Pfahler (7), and others there is ample evidence of a disturbance of the blood functions following overexposure to radium. This disturbance consists in a change in the white cells of the blood, a diminution in number and an alteration in the proportions of lymphocytes

and of polymorphonuclear cells. The red cells may also be affected, and there is evidence in some cases of a change in the ability of the bone marrow to manufacture these cells. At least five deaths[1] due to failure of the blood-forming organs have been reported as associated with overexposure to radium or X-rays (7)[2] (8). The presence of changes in the white cells may be uncombined with other damage, and an individual showing these changes may be in good health, but the weight of opinion at present is in favor of regarding the occurrence of even minor deviations from the normal among radium workers as evidence of overexposure to radium. This index has already found a basis in practice in the London Radium Institute, where the blood film is used as a means of determining the need of vacations or of increased protection.

In regard to the distribution and time during which radium in various forms will stay in the body, there is a mass of evidence which is often contradictory. From it clearly emerges the fact, however, that reliable workers have shown that, except for emanation, both soluble and insoluble salts of radium once in the system may remain for a considerable period, even longer than a year in the case of insoluble salts intravenously injected (9) (10) (11).

[1] Since the writing of this article other cases of death from pernicious anemia following exposure to radium have been reported. See, for example, Weil and Lacassagne: Pernicious Anemia from Radium. Abstr. from Bull. Soc. méd. d. hôp., 1925, *49*, 535, in Jour. Am. Med. Assn., 1925, *84*, 1786.

[2] The five cases mentioned are summarized in this reference.

Pertinent facts in regard to the effect of radium on bone have been demonstrated by other writers. We have found in the literature no reports of cases of necrosis of the bone occurring among radium workers as the result of overexposure to radium during the course of their work. It has been demonstrated experimentally, however, that X-rays, which are similar to but less penetrating than gamma-rays, will delay or prevent the union of a fracture by delaying the normal production of callus (12). Exposure to X-rays will also disturb the growth of bone (13). Gamma-rays themselves, in a local application of radium in the course of treatment of cancer of the tongue, have produced in a sound jaw a necrosis (14) similar to those with which we are concerned, similar even to the extent that in one of the four jaw-bones so radiated, and to all intents normal, necrosis followed only after the extraction of a tooth. That radium, if absorbed, might have a preference for bone as a final point of fixation is to be anticipated from the similar chemical nature of radium, calcium, barium, and strontium. Strontium has been shown to be deposited by replacement of calcium in bone (15) (16), which has for its basic substance a calcified matrix, so it is not surprising to find that a considerable fraction of radium remaining in the body following the intravenous or intramuscular injection of both soluble and insoluble radium salts becomes fixed in the skeleton (17) (18). Intratracheal injections of the luminous paint into cats made by the authors have shown just such a deposition and fixation of radium in the hard bone. Radium

once deposited in bone would be in a position to produce peculiarly effective damage. In the first place, all of the weakly penetrating radiation would be absorbed with intense local damage. And, secondly, the more penetrating gamma-rays would be, to a large extent, changed into easily absorbed secondary radiations characteristic of the calcium atom. The effectiveness of a unit of radium inside a bone would be many thousand times greater than the same amount outside of the bone and the soft tissues as well, because of the enormously greater proportion of radiations absorbed in the bone. The alpha particles and many of the beta and gamma-rays from an external source would never take effect in the bone at all, either because of their very distance away from the bone or because of their being absorbed by the soft tissues.

It thus appears as if the only constituent of the luminous material which can do harm must be the radium. The profound effect of radium even in minute quantities on living cells is too well known to require more than mere mention. In addition, experimental evidence is not wanting to show that there may be a selective deposit of radium in bone, and that the effects of radiations of the sort emitted by radium may prevent both bone growth and the repair of fractures. A necrotic process in the jaw-bone itself, like that occurring in the employees with whom we are concerned, has been reported in four instances following the use of radium in the mouth for therapeutic effect on cancer of the tongue.

Conditions Observed at the Plant

We found the girls employed in painting in a large, well-lighted room. The fact that the powder to be used in mixing the luminous paint is issued to the workers in very small amounts (1 to 2 gm.) in small containers as required, made it seem, at first glance, as if the possibility of dissemination of the material was very slight. Yet the clothes and the persons of many of the workers were said to be luminous in the dark following exposure to light.

By means of this "flash" test and examination in the dark-room, we were able to show that the air of the workroom must contain zinc sulphide. Dust samples collected in the workroom from various locations (tables, chandeliers, wall beams, etc.) and from chairs not used by the workers were all luminous in the dark-room. The hair, faces, hands, arms, necks, the dresses, the underclothes, even the corsets, of the dial painters were luminous. One of the girls showed luminous spots on her legs and thighs. The back of another was luminous almost to her waist. Dust from the machine shop below the painting room was luminous, and the same property was exhibited by office girls and by others about the plant not employed in the paint room. This, we think, is evidence that the powdered base was being carried in suspension about the paint room and even beyond its confines. Some quantitative notion of the rate of deposition is gained from the fact that dresses worn in the painting room for only a few hours exhibited luminosity in the dark following exposure to light. Dust samples collected from various places

recently oiled were luminous and showed traces of radium when examined later in Boston. These traces of radium, while necessarily minute, were definitely present.

The fact that the luminosity which developed after exposure to light faded away in the dark was merely an expression of the fact that the temporary response of the sulphide to light was far greater than the permanent luminosity produced in the sulphide by the radium. In our opinion, the luminosity, for example, in the skins of the workers, was due to paint which was present in such small quantities as not to be seen unless flashed. There can be no comparison between the amount of luminous paint persisting in the skin after vigorous washing and the rather thick streak of the paint on the dial of a watch. The transiency of the luminosity was not a proof that the skins did not contain radium, but merely that they did not contain enough radium to confer spontaneous visible luminosity. The same reasoning is applicable to the dust samples, which were not spontaneously luminous.

TABLE 1.—SUMMARY OF BLOOD FINDINGS IN TWENTY-TWO RADIUM WORKERS AS CONTRASTED WITH THE BLOOD FINDINGS IN NORMAL PERSONS

BLOOD FINDINGS			RADIUM WORKERS	NORMAL PERSONS
			%	%
Red blood cells		below 4 million	6	0
		between 4–6 million	75	100
		above 6 million	19	0
White blood cells below 7 thousand			27	0
Blood films	Polymorphonuclear cells	between 60–72%	55	100
		below 60%	45	0
		below 55%	32	0
	Lymphocytes	between 20–25%	18	100
		above 25%	64	0
		above 35%	27	0
	Mononuclear cells	between 3–8%	41	100
		above 8%	59	0
	Abnormal red cell forms		36	0
No blood abnormalities			0	100

By means of dental films, we endeavored to determine roughly the amount of gamma-radiation in the plant. Pfahler (7) has established the fact that any fogging of a sealed dental film within two weeks is evidence of an overexposure to radium or to X-rays. Films placed in various spots in the

plant—storeroom, telephone operator's room, office, etc.—all showed slight but definite fogging within one to two weeks. Films in the painting room showed distinct fogging at the end of two and three days, those at the weighing room end being the darkest.

In an attempt to determine whether or not radium had shown any effects on the personnel, we investigated the general health of the employees and their personal hygiene in the plant; we also examined the teeth and the blood of a representative group of workers. In all, twenty-two individuals from various parts of the plant were examined, fourteen of whom we considered to have had a long or an extensive exposure to radium or to the luminous paint, and eight of whom we considered to have had a slight exposure. Thirteen of these individuals were employed in painting or were working in the room with the painters. Nearly all of the workers reported themselves to be in good health. The general conditions of work were good and did not seem to produce fatigue, eyestrain, or other cause of complaint except a persistent luminosity of the persons of the workers.

Table 1 gives a summary of our findings in the bloods of the twenty-two persons examined, as compared with normal findings. The significance of these findings is that no blood was entirely normal, and that the findings characteristic of exposure to radium or to X-rays in excessive amount (3) (4) (5) (6) appeared in many of the blood films examined. The chief features observed were a reduction in the white cell count, a decrease in the percentage of polymorphonuclear cells, and an increase in the percentage of lymphocytes. These same findings were noted in some instances in previous reports by the Life Extension Institute on the health of these workers, but the Institute did not appear to have been aware of their meaning. If we consider only the fourteen cases with the greater exposure, instead of the mixed group of twenty-two, the percentage of blood abnormalities among the employees is markedly increased.

Conclusions

As a result of the observations and examinations already outlined, we are led to the following conclusions in regard to the necroses of the jaw under investigation. In the absence of any demonstration of the toxic properties of brushes, solvents, or zinc sulphide, the well-recognized biologic activity of radium causes us inevitably to regard it with suspicion. We have not been able to find accounts of necrotic processes in the bones of persons similarly employed elsewhere. We have, however, undoubted proof of excessive exposure to radiation in these workers, as evidenced by the abnormal condition of their bloods and by the fogged dental films. There is, in addition, evidence of an air-borne route by which radium itself may be absorbed. How it is exactly that these two processes—external radiation or a slow, long-continued absorption of minute quantities of radium—alone or in combination, have produced the bone destruction, we are unable at present to demonstrate. In view, however, of the descriptions of the effects of radium on bone already in the literature, in view of the overexposure to radiation which we demon-

strated in the plant studied, and finally, in view of the possibility of an actual absorption of radium through inhalation, we believe that radium has in some way caused these necroses of the jaw, as an effect hitherto not observed under these conditions of exposure.

Recommendations for Protection of Workers

This brings us to the question of recommendations for the relief of the conditions in the plant under observation, and for the future protection of similar workers. The recommendations are directed at the two sources of danger: the clearly demonstrated overexposure to gamma-radiation, and the less obvious, but probably more serious, possibility of the absorption of emanation or of radium itself.

Protection from gamma-radiation in such occupations must be improved. This necessity in the plant studied is clearly demonstrated by the fogging of all films to a greater or less degree in less than two weeks, no matter where the films were placed in the plant. The method employed will vary with the particular conditions of exposure, but will depend essentially on a proper screening of employees from the effects of concentrated sources of radiation (6) and on the prevention of the gradual deposition of radium-bearing dusts in their vicinity.

The absorption of the radium element itself must proceed in the group studied from the absorption of the luminous powder. There are three possible routes of absorption: the skin, the digestive tract, and the lungs. We do not believe that the skin is a favorable channel for absorption, in a situation of this sort, but it is certain that there was luminous powder in the skins of the workers which could not be removed by ordinary means.

The discontinuance, six months previous to the investigation, of the practice of pointing brushes in the mouth stopped what must have been a means of introducing relatively considerable amounts of luminous powder into the digestive tract. At the time of our study, paint smeared on the fingers of the operators during the process of pointing the brushes might possibly have been absorbed through the skin, or, after careless washing have reached the workers' mouths with their food. If the radium in the luminous paint is present as an insoluble salt, the digestive tract in an exposed worker is probably not a very great source of absorption; but it is, nevertheless, a possible route which, in the absence of definite knowledge, we cannot afford to neglect.

The inhalation of insoluble particulate matter into the lungs is an efficient means of securing its absorption (19) (20). The inhaled particles are held in the lung as in a reservoir from which they may gradually be dissolved and carried about the body. Our studies on the luminosity of objects and of workers in the plant proved the presence of dust, though it was not visible, in the air—dust presumably containing radium—which could certainly be breathed into the lungs. To this source of absorption, all those in the painting room were obviously exposed.

Similarly, persons engaged in the handling of larger quantities of luminous powder were exposed to absorption of radium by this route. The

man who weighed and issued the powder to the painters told us that the substance was extremely light, that it blew about if he breathed on it, and that to prevent losses it needed to be dampened slightly. This man had been employed about two weeks when we examined his blood, but, in spite of what would seem almost certainly a short exposure, we found suspicious alterations in the number and proportion of types of his white blood cells. The girl previously employed at this work is said to have noticed luminosity of nasal discharges in her handkerchief after blowing her nose.

Statements as to the facility with which the powder may be dispersed have been confirmed by us in experimental studies on the rate of settling after suspension in a chamber by means of an air blast. Once suspended, the material settled out very gradually and there was a demonstrable quantity still in the air at the end of forty-five minutes. We have also measured by means of the microscope the size of the particles in the powder. Eighty-three per cent. of the component particles are less than 4 microns in diameter, the majority of these being under 2 microns. Particles of this size will remain suspended for hours even in perfectly still air (21). According to observations made at this laboratory, the average size of particles of a similar mineral dust which had floated for two hours in still air was 3 to 4 microns, and many of them were as large as 6 or 7 microns.

Accordingly, in order that these modes of exposure to radium, or its emanation, should be avoided, in the handling of this powder or other similar preparations, we recommend the following: The mixing of radium with zinc sulphide and the manipulations necessary in the further handling of the radium-containing material should be carried out under a hood by a gloved operator in a room entirely separate from any workrooms. The material in a dry state should be mixed with the vehicle of the paint under a hood and in a separate room before being given out in small quantity to the painters. The painters should always work at desks covered with large sheets of paper to catch any dropped paint, and the papers should be burned and replaced with fresh ones each day. The workers should wear high-necked, long-sleeved work aprons which should be washed weekly. The ideal method of protecting the hands of the painters from possible skin absorption and of reducing the high degree of skin luminosity, so objectionable to the women, would be to require the wearing of thin rubber gloves. In surgical practice the wearing of such gloves is not found to be an impediment to the performance of delicate or long-continued operations, after the slight time required for becoming accustomed to their use. We, therefore, suggest that gloves be provided and that all workers be strongly urged to wear them. Workers unwilling to wear gloves should be required to wash their hands promptly after discontinuing work at lunch time and at 5 o'clock. The washroom should be provided with good stiff nail brushes and with an abrasive soap—a brush and a cake for each basin—and with individual paper towels. Furthermore, the workroom should be thoroughly scrubbed—walls, ceiling, desks,

floors, etc.—at least every two months. The weighing room should be made entirely separate and should be equipped with a proper hood in order to abolish the dust hazard. The possible danger from emanation is diminished, but not entirely removed even by these precautions so long as any radium is not hermetically sealed.

To be certain that such precautions are really efficacious, because of the serious nature of the disease process involved, we urgently recommend provision for competent and systematic medical supervision of the situation. Regular examinations of all workers, including examinations of the blood, and the routine carrying of a dental film at intervals ought to be instituted as procedures designed to determine whether or not employees are unduly exposed to radium. It is certainly advisable to employ enforced vacations in the cases of persons showing significant blood changes (22) (23). It is also an essential precautionary measure to have systematic examination and care of the teeth of all workers.

At the time of our investigation, a considerable number of the employees required dental attention. In the case of certain workers, extraction of teeth which needed to be removed had been refused for fear of initiating a necrosis of the jaw. This introduces a most difficult question and one that needs an answer. It is unfortunately not an easy problem nor one which removal from work for a considerable period will solve; for we know that more than three years after discontinuing work with luminous paint, Miss C. developed a severe necrosis following the extraction of a tooth. There is, to our knowledge, no way of determining for certain which individuals may or may not have a similar experience. Our opinion is that the best way out of the difficulty lies in getting the teeth of these workers in the best shape possible, without extractions in the case of persons long exposed. After this, it is within the province only of a competent dental surgeon, who knows thoroughly the facts in each case, to decide on the removal of teeth which require this procedure. We can only suggest, in general, conservatism in the matter, and in the contemplation of the removal of a tooth the clear understanding of the possible risks by both dentist and worker.

Summary

As a result of a careful examination, a novel condition affecting five workers with radium paint is described. The amounts of radium in this paint are extremely minute, so slight as to cause no one in this plant or in other plants employed in similar work to consider the possibility of a radium hazard. Blood examinations coupled with the use of photographic films have, however, demonstrated an overexposure to radium, and this overexposure is of peculiar type since it also permits the inhalation of particulate material containing a radium salt. The literature on radium indicates that under such circumstances radium is deposited in bone, and our own injection experiments verify this. Furthermore, clinical literature presents cases of jaw necrosis (one following tooth extraction) in patients who have received heavy treatment with radium

for mouth cancers. It seems necessary, therefore, to consider that the cases described have been due to radium. This is not finally proved, but since the remedial measures proposed are of general as well as specific import, it is felt that the safest course at the present time is to treat the situation in this light. It seems advisable to present an account of the situation without awaiting absolutely definite conclusions.

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BOOK REVIEWS

HYGIENE AND PUBLIC HEALTH. By *George M. Price*, M.D., Author of "A Handbook on Sanitation," "Tenement-House Inspection," "Hygiene and Sanitation for Nurses," "The Modern Factory," Director, Joint Board of Sanitary Control, Director, Union Health Center, New York City. Third edition, thoroughly revised. Cloth. Pp. 306 with index. Philadelphia and New York: Lea & Febiger, 1924.

The author of this book attempts to present in very condensed form an epitomized survey of hygiene and public health. Since the entire volume, including index, comprises but 306 pages, no topic is treated with any but the extremest brevity.

The chapter headings are: Housing Hygiene, Child Hygiene, School Hygiene, Industrial Hygiene, Public Water Supply, Foods, Meat Foods, Milk Supply, Disposal of Waste Matter, Public Nuisances, The Prevention of Infectious Diseases, and Federal Hygiene.

At the conclusion of each chapter is a list of questions to which answers are found by referring to the heavy type of the paragraphs in the text preceding.

While the book is technical in scope, it is popular and elementary in style, with no references but with a good index. The elementary student of public health may find it a useful reference text or dictionary of public health and hygiene.—*Philip Drinker.*

THE MEDICAL ASPECTS OF CHEMICAL WARFARE. By *Edward B. Vedder*, Lieut. Colonel, M.C., U. S. A. With a chapter on the Naval Medical Aspects of Chemical Warfare. By *Duncan C. Walton*, Lieut. Commander, M.C., U. S. N. Cloth. Pp. xvi, 327 with illustrations, appendix, and index. Baltimore: The Williams & Wilkins Company, 1925.

"There has been and there still is considerable prejudice against the use of gas in warfare." This prejudice, according to the author, apparently proceeds from three sources: first, because the use of gas was started by the Germans in violation of their existing treaty obligations; second, because it is a new weapon and shares the criticism usually leveled at new weapons; and third, because it is "barbarous and inhumane."

To the first two criticisms, the author takes no exception, but on the third, by statistics from the British and American armies, he shows at some length that death and permanent disability from gas were far less than from gunshot and explosives. "Gas causes a smaller proportion of deaths than other weapons. Only 1.73 per