OCCUPATIONAL HAZARDS OF THE RADIOLOGIST, WITH SPECIAL REFERENCE TO CHANGES IN THE BLOOD [1]

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THAT the practice of radiology entails certain hazards to health and life was forcibly impressed on its practitioners many years ago, but not until a large number of radiologists had suffered or died from radiodermatitis and cancer. Rolleston says that according to Ledoux-Labard there have been a hundred victims of cancer among radiologists. To this long roll of professional sacrifice is added from time to time the name of some pioneer who sustained his injuries in the early days, but was granted a postponement of the inevitable result. It was soon learned that this danger could be averted by the ordinary precautions which are now habitually employed. So effective are these methods in the prevention of skin lesions that the radiologist has apparently been lulled into a false sense of security from all harm. His serenity is not due to ignorance, but to an unwarranted optimism in the face of his abundant knowledge. He is fully aware that an intact skin may cover a multitude of internal changes wrought by irradiation. These changes are the expected result of radiotherapy; they are found at the necropsy table, are substantiated by experiments on animals, and are demonstrated conclusively by the microscope and the test tube. The literature on deep irradiation effects is overwhelming, both in magnitude and complexity, and the references here appended constitute but a small fraction of the total.

Studies which are almost fascinating in interest have been made of irradiation effects on virtually every organ and tissue of the body, including the digestive tract, blood, bones, heart, lungs, liver, pancreas, eyes, brain, nerves, kidneys, spleen, gonads, and ductless glands. Findings have not always agreed, nor is this surprising in view of the different conditions under which the tests were made. Notwithstanding discrepancies and contradictions, it is impressive to note that alterations of some sort were found almost constantly, and that in many instances they were produced by moderate or even minute amounts of irradiation.

Among generally accepted facts and theories the following are especially pertinent to the present theme, and will bear repetition, however familiar they may be:

1. Radium and the X-rays produce biologic effects which are essentially alike.

2. These effects vary according to the amount of irradiation, and range from stimulation to destruction (36, 44, 46, 64, 85, 87). Although supported by a great preponderance of evidence, the occurrence of stimulation has been denied by Pordes and others. Holzknecht insists that the X-ray is like curare, and that even in small amounts it is destructive, never stimulative.

3. Cells differ in sensitiveness to irradiation, and certain varieties are especially susceptible. Easy vulnerability of the sperm cells is well established. Lymphocytes, endothelium of blood and lymph vessels, immature cells, and cells in the process of mitosis are highly sensitive.

Susceptibility of the blood and the hematopoietic system to irradiation has been shown convincingly by experiments on animals and by tests of patients and radiologic workers. Levin regards the lymphocyte as the most sensitive cell in the animal organism, and asserts that the greater the square surface of entry of the rays, the more severe is the general effect on the blood. Béclère found that in some persons even a single application of the rays causes a permanent change. As might be expected from varying technical factors, the experimental re-

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sults are not uniform. In general, however, they show that the circulating lymphocytes are increased in number by small doses (41, 55, 77), and decreased in number by large (41, 64, 67). Among radiologic workers there is frequently an increase of lymphocytes, either absolute or relative (1, 7, 24, 58, 78), but with severe or long-continued exposure a reduction may occur (7, 54). The polymorphonuclear count is usually diminished, absolutely or relatively (1, 53, 54, 58, 78), although this may be preceded by an initial increase (76, 84). Marked increase of the cosinophiles has been found in radiologic workers (58, 78, 84, 86). The red cells are more resistant than the white, but restoration is slower (4). Radiologic changes in the erythrocytes run the gamut from a slight increase in number and augmentation of the color-index (1, 15, 30, 84) to diminution and hemolysis by intense doses (29, 60). Most investigators have found hastening of coagulation (44, 47, 57) although the opposite has been reported (65). Reduction of blood pressure is a common finding (15, 58, 88), various alterations of the blood chemistry have been noted (9, 10, 28), and histologic changes in the bone marrow are well-confirmed experimentally (24, 25, 51, 80).

Evidence is increasing that the intestinal mucosa is markedly sensitive. In dogs, Hall and Whipple produced a necrosis of the epithelium lining the intestinal crypts. Mottram observed that very small doses of radiation, less than would be required to affect the testes or skin, altered the production of intestinal mucus. Intestinal ulceration following deep therapy is by no means unknown.

The mooted matter of personal idiosyncrasy has a bearing on hypersensitiveness to radiant energy, and while this factor has perhaps been exploited unduly, it has some basis in fact.

4. Irradiated cells have a lowered resistance to other unfavorable influences, including trauma and possibly certain infections. Moreover, as Loeb has pointed out, "chain reactions" may occur, one effect giving rise to another, with ultimately severe results.

5. Radiologic workers, so far as they themselves are concerned, are inclined to lay too much stress on the difference in effect of hard and soft rays, and to assume, quite inconsistently, that hard rays, regardless of their aggregate amount, are unlikely to affect the operator. With respect to the skin there is admittedly a difference between hard and soft rays. Martius has shown that rays with a wave length of 0.56 have nearly four times as great an effect as rays with a wave length of 0.325. On the other hand, only hard rays can reach the deeper tissues, and hard rays are in daily use for that purpose. Hall and Whipple found not only that the intestines of dogs were gravely affected by hard rays, but that fatality increased in ratio to the spark gap. Mottram considers it probable that the gamma rays of radium have a destructive action on bone marrow which relatively soft beta rays may not possess. Regaud is cited by Withers as asserting that gamma rays and X-rays of very short wave length are "elective poisons" for nuclear chromatin.

6. The cumulative effect of radiation, which the radiologist guards against so zealously in therapy, cannot be ignored in estimating the chances of injury to himself. Cells affected by the X-rays or radium and re-exposed before sufficient time has elapsed for complete restoration to normal, are altered on an ascending scale, and in the case of hypersensitive cells it is logical to assume that even minute doses frequently repeated may have momentous consequences to their growth and function.

7. By analogy it may be reasoned that radiant energy, like certain drugs, may set up an increase of cellular resistance. This is indicated empirically by the decreasing responsiveness of newgrowths to irradiation. Warren and Whipple have found a suggestion of increased tolerance of dogs to subsequent X-ray exposures. Loeb offers the hypothesis that new cell races

which are more resistant than their ancestors may develop. The fact that many radiologists have been exposed for years, yet survive in apparent good health, is an item of corroboration.

However, the profession cannot safely emphasize the hypothesis of immunization, for there is also evidence that an opposite condition, that of anaphylaxis, may develop in patients. Granting that either immunization or anaphylaxis may occur, the exact circumstances likely to induce one or the other effect are not known.

8. To the foregoing premises is to be added the fact that radiologists are not and cannot be shielded completely from irradiation while pursuing their vocation. Protection can only be relative, and the gamma rays of radium and X-rays of short wave length penetrate ordinary barriers appreciably. The fluoroscopist and the dispenser of radium and high voltage therapy are especially exposed. Even with customary safeguards, some degree of scattered and secondary irradiation is inevitable. Moreover, not all radiologists are scrupulous in the exercise of care, and some of them are daring to the point of recklessness. Admitting that with routine measures of protection the radiologic worker receives only minimal doses, these are repeated day after day through the years. Even if their effect is only stimulative, the results of long-continued stimulation are to be reckoned with.

In view of these data the injuries to radiologic workers which may eventually come to light offer a broad theme for conjecture. But the radiologist, confident of his defense against radiodermatitis, and quite unterrified by the chance of emasculation or lesser damage, waits for absolute proofs that more serious dangers threaten him. Such proofs have begun to appear, and, in consonance with the results of experimental research, lesions of the blood and at least one authentic case of intestinal injury lead the van.

INTESTINAL INJURY

With regard to intestinal injury, only a single case, that of the English radiologist, Barclay, is of sufficient gravity and sufficiently confirmed to warrant recording. After twelve years of work, including much screening without an apron, Barclay had several diarrheic attacks with loss of weight. Mucous casts were noted in the stool on a few occasions. On ceasing work the attacks disappeared in three weeks, and on returning to duty they recurred in from eighteen to twenty days. This cycle was confirmed eight or nine times. Since using additional protection he has been comparatively free from such troubles.

It would be interesting to know whether or not the gastro-intestinal complaints of certain other colleagues have any relation to their occupation. For example, an associate of many years recently had a severe hematemesis and diarrhea, the latter recurring on several occasions. A Western radiologist gives a similar history. In both instances a thorough physical and radiological examination failed to reveal an adequate cause. While no definite relation to irradiation has been established in either case, a systematic study of radiologists from this standpoint might develop valuable information.

FATALITIES FROM DISEASE OF THE BLOOD

No less than six deaths from aplastic anemia have occurred among radiologic workers.

The first, a classic and oft-repeated story, was that of Dr. Tiraboschi (18), an Italian roentgenologist, who, after fourteen years' service with little or no means of protection, died of a "profound essential anemia" in 1914. Three years prior to this he had a severe nervous breakdown, but was able to resume his duties after six months. Although he showed an increasing pallor and complained of loss of strength his nutrition was good, and he continued to work until his death. Among other abnormalities, necropsy revealed extreme testicular atro-

phy, diminution and hardening of the spleen, and pronounced alterations in the marrow of the ribs.

Next in chronologic sequence were the three cases in radium workers reported by Mottram (53) in 1920. One of these, a woman aged thirty-six years, had been engaged in the work for eight years, during which time she was in excellent health. Pallor developed after a holiday of two months. Her red cell count and hemoglobin progressively diminished; there was definite leukopenia and anisocytosis, and death occurred after seventy-three days. Another was a man aged thirty-three years, a worker with radium for three years. He, too, was taken ill after a month's holiday, and the blood picture was similar to that in the preceding case. Death ensued after three months. The last case of the trio was a man aged fifty years who had worked with radium for ten years. His fatal illness was of short duration. The diagnosis of aplastic anemia was supported by the blood findings.

Dr. Ironside Bruce, of England, was the fifth victim (40). Bruce was in his early forties, and had been engaged in radiology for about eighteen years. He was of good physique, had lately gained in weight, and his general health was never better. In October, 1920, a blood count, made quite accidentally, showed a slight diminution of the red cells and hemoglobin. From that time until his death, in March, 1921, the red cells, hemoglobin and white cells steadily diminished. Low blood pressure, a relative lymphocytosis and a poikilocytosis were other features.

The sixth death recorded was that of Dr. Nordentoft (24), a Danish radiologist who had employed X-ray therapy for twelve years and was not always careful in taking precautions. Some years ago he noted testicular atrophy. In November, 1921, he complained of fatigue, and an examination of the blood disclosed a slight reduction of the red and white cells. Several months later he again became weak and dyspneic. At this time diminution of red cells was marked: anisocytosis, microcytosis and poikilocytosis were also pronounced. Demoralization of the blood picture rapidly became extreme, and he died within another month.

Dr. F. M. Sylvester, of Oak Park, Illinois, writes the following interesting letter:

"About two years ago, I was doing some research work towards the establishment of a so-called lethal cancer dose. At this time I was working with a kilovoltage varying from 160 to 280. My protection consisted of a booth of one-inch pine covered with one-eighth inch lead and quarter-inch beaver board. This booth was completely covered, with the exception of the floor, which had no protection. The booth was approximately eight feet from the tube. I was spending on an average of four hours an evening in this booth, with the tube in constant operation during this time.

"The first manifestation of illness was the usual tired, weary sensation. As these symptoms became more pronounced, I naturally suspected the X-ray, and made several tests around through other parts of my laboratory to see if I was getting irradiation either from radium or from other machines. These tests proved negative to such an extent that I felt satisfied that there was perhaps another cause. In the meantime an anemia developed, the red count dropping from 5,200,000 to less than 4,000,000. I now made several tests with an iontoquantimeter within the booth, and found that radiation was coming in through the floor. In fact, this was to such an extent that an eight by ten film could be fogged in eight minutes' time operating with a kilovoltage of anything above 200 k.v. I immediately had the floor of the booth covered, and at Dr. Darnell's suggestion, walled off a room, and covered the same with one-eighth inch lead. This room was utilized for the patient, thereby giving me a protection of the one-eighth inch lead on the booth, as well as the one-eighth inch lead in the treatment room.

"I now found, on tests, that there was no further evidence of perceptible radiation. The damage, however, in my case had been done, and the red count dropped to 2,500,000. At this time I was confined to my bed and my life despaired of. Relative to blood changes, there were several things of interest that we noted. The blood pressure, which normally had been 130 systolic, fell to 105. (This, by the way, has never come back beyond 110.)

"The alkaline reserve at the beginning showed a relative increase. This gradually fell, as you can see by enclosed charts, and has never returned to a normal point."

Six blood counts made between June 15 and August 21, 1922, tell a graphic story of Dr. Sylvester's illness, and are tabulated herewith:

TABLE 1

DATE	JUNE 15	JUNE 29	JULY 5	JULY 18	JULY 28	AUG. 21
Erythrocytes	5,200,000	3,900,000	3,000,000	2,500,000	3,500,000	4,200,000
Leukocytes	8,000	6,500	5,000	8,000	7,000	8,000
Hemoglobin %	80	65	55	41	61	70
Color index	1.25	1.00	1.09	1.21	0.84	1.14
Coagulation time	4 min.	3 min.	2.5 min.	5 min.	4 min.	3 min.
Erythrocytes						
Color	normal	pale	pale	pale	pale	pale
Size	normal	small	small	small	small	normal
Shape	normal	crenated	crenated	crenated	oval	oval
Poikilocytes	0	+	+	+	0	0
Polychromatophilia	0	+	++	++	0	0
Basophile granulation	0	0	0	+	0	0
Microcytes	0	+	+	+	+	0
Macrocytes	0	0	0	0	0	0
Microblasts	0	0	+	+	0	0
Normoblasts	0	+	0	0	0	0
Megaloblasts	0	0	0	0	0	0
Howell's Particles	0	0	0	+	0	0
Lymphocytes						
Sm. mononuclear %	27	30	30	14	24	23
Lg. mononuclear %	6	8	14	10	8	10
Transitionals %	2	0	0	0	0	0
Neutrophiles						
Mononuclear %	0	0	0	0	0	0
Polynuclear %	63	60	54	70	65	56
Eosinophiles %	1	2	2	3	3	1
Myelocytes %	0	0	0	0	0	0
Basophiles %	1	1	0	3	0	0
Mast cells %	0	0	0	0	0	0
Free nuclei %	0	0	0	0	0	0
Alkaline reserve %	7.6	7.8	6.4	6.1	7.0	7.3
Hydrogen-ion %	6.3	6.2	6.1	6	6.3	6.7

punctilious as to protection and sometimes omitted wearing an apron. During the last year he complained of extreme exhaustion at the end of the day's work. Early in 1924 a blood count, made casually, showed signs of a lymphatic leukemia. Shortly afterward he discovered some swelling of the cervical and inguinal lymph nodes. He came to the Mayo Clinic in February and the existence of the leukemia was confirmed. Blood counts, details of which are tabulated herewith (Table 2), revealed 25,000 to 30,000 leukocytes, 96 per cent

LYMPHATIC LEUKEMIA

The chief stimulus for reviewing this subject was the recent death of Dr. Walter Mills, of St. Louis. Dr. Mills was forty-six years old and had been engaged in clinical roentgenology of the digestive tract for about fourteen years. The volume of his work was large and consisted chiefly of fluoroscopic examinations. He was not

of which were lymphocytes. The red cells numbered 4,220,000 to 4,600,000 and the hemoglobin was 65 to 70 per cent.

TABLE 2

	February 4	February 6
Hemoglobin, %	70	65
Erythrocytes, millions	4.60	4.22
Leukocytes	25,800	30,400
Lymphocytes, %	96.5	96.5
Neutrophiles	2.0	3.5
Platelets	240,000	310,000
Anisocytosis	slight	slight
Poikilocytosis	slight	slight
Polychromatophilia	slight	slight
Coagulation time (Bogg)	6 minutes	

Shortly after coming to the Clinic, Dr. Mills developed appendicitis, and operation became imperative notwithstanding the unfavorable circumstances. Death followed three days later.

Various interpretations of Mills' case are obvious. Exposure to the X-rays may have had no causative relation to the leukemia. Indeed, the X-rays may have mitigated the disease. On the other hand, the X-rays are capable of causing malignant lesions of the skin and may have induced this malignancy of the blood. Further, Mills' father died from cancer, so that the hereditary factor, emphasized by Slye, was present. At all events, the case is worthy of publicity for future consideration.

Only two references to a possible relation between exposure to irradiation and lymphatic leukemia were discovered in the literature. One was a statement in 1911 by von Jagic and his collaborators, as follows: "Several years ago a Vienna roentgenologist died of lymphatic leukemia. At the same time it was announced that a practicing roentgenologist of Munich had passed out with the same disease. One of us (Schwarz) had the opportunity of observing a case of leukemia in a chemist who had been occupied for a long time in the production of radium. Recently we have received the news that an American roentgenologist had also fallen a victim to this disease." Unfortunately, von Jagic gives no specific details, and the identity of the American roentgenologist referred to is unknown to us. However, his language is declarative regarding two of the cases, and is entitled to credence. In a late paper, Amundsen (24) states that the lymphocytes of radiologic workers are regenerated very rapidly, and the over-production may be regarded as an attempt to compensate for the leukopenia. Hence, he says, "the cases of lymphatic leukocythemia that are reported as having occurred among radiologists may no doubt be interpreted as a lymphocytic regeneration overshooting the mark."

In this connection, it might be pointed out that deaths of radiologists are often reported without any information as to the cause. For the welfare of the profession, it is to be hoped that in future the records of all such deaths will be given in detail, and with due attention to the occupational phase.

INJURIES AND FATALITIES FROM ELECTRIC CURRENTS

Besides the effects of radio-activity, the roentgenologist is exposed to another hazard, that of electric shock. Rare, indeed, is the roentgenologist who has not witnessed or been the target of such shocks. Fatalities to patients have happened, and records of most of these can be found in the annals of medical jurisprudence. The death of Dr. Jaugeas, December 2, 1919, (13) should not be difficult to recall. Dr. Clatus Cope, a dentist of Seymour, Indiana, was electrocuted July 16, 1920. Doubtless this list is not complete, for personal accidents are not indexed as carefully as scientific papers.

THE PERSONAL EQUATION

Injuries and fatalities to radiologists from cancer, aplastic anemia, lymphatic leukemia and electric shock thus assume

considerable proportions. The reaction of the profession to them will be determined by the personal equation. The optimist and the pessimist can each find strong arguments in the whole array. In the one view, dermatitis and cancer belong to ancient history, irradiation has not been proved with mathematical precision to be a cause of aplastic anemia or lymphatic leukemia, and accidents are always possible to those who work with electric currents. In the other view, radio-activity is so dangerous that its employment should be left entirely to those who are willing to assume the most extraordinary risks.

As usual, the truth is probably between these extremes. In that case, the optimists, who seem to be in the majority, must be roused to a proper sense of their unnecessary jeopardy. Fear that the eligibility of radiologists for life insurance might be impaired by too much publicity has perhaps inspired a certain modesty of opinion in the past. But this attitude is shortsighted, for with open recognition of his perils the radiologist will employ more effective means to avert them.

PREVIOUS WARNINGS

Warnings of hidden dangers to radiologists have not been lacking. Von Jagic and his associates made examinations of several roentgenologists in 1911 and showed that blood changes had occurred. Portis published the results of similar tests in 1915. Later, the deaths of Tiraboschi and Bruce were made the occasion of urgent admonition by editorial writers. Five years ago Mottram began to write extensively for the benefit of radium workers, and his efforts were seconded by Pinch. In 1920 and again in 1921, de Courmelles emphasized the gravity of the situation. In 1922, Caffaratti, Amundsen and Pfahler each gave serious attention to the subject of hematic changes in radiologists. Last year Faber reported the death of Nordentoft, and again cautioned other workers. Hemler, in 1922, and Shearer, in 1923, wrote of the hazard from electric shock and the methods of avoidance.

Pfahler's paper deserves more than passing mention. He canvassed the radiologists of America to learn whether they were sustaining hematic changes or other injury, and received many replies. In general, the professional workers had a slight leukopenia and a relative increase of lymphocytes. A few had an increase of eosinophiles. Twelve had delayed clotting of the blood. Systolic blood pressure was decreased, as a rule. While in most instances the changes in the blood picture were only slightly beyond normal limits, Pfahler regarded them as probably significant of excessive irradiation and as danger signals. In the main, nurses and lay assistants seemed intact, but ten of them had blood changes or other abnormalities, or were receiving excessive exposure. Many of the roentgenologists reporting to Pfahler complained of marked fatigue from their work, but Pfahler believes that similar fatigue would follow equal activity in other occupations. It is noteworthy, however, that radium workers have also complained of fatigue.

PREVENTION OF INJURY

Viewing all this evidence, even in the most liberal light, the conclusion is inescapable that many radiologists are being harmed in their daily work and are menaced by graver injuries. To avert these injuries it is necessary, first of all, that the radiologic worker be impressed so thoroughly with his danger that he will take adequate precautions. Either the methods of protection now in common use are not effective, or the worker is careless in their application. As Pfahler and others have said, not only the means of protection but the will to use it is requisite.

It is needless here to review protective measures at length, for the principles are familiar and easily applied. It might be emphasized, however, that the worker should be shielded not only from direct rays, but also from secondary irradiation

which may reach him from any angle. For the radiographer efficient protection can be secured by simple means, but in fluoroscopy and radiotherapy more elaborate measures are required. Protection from irradiation and prevention of electric shocks have been given more attention of late by the manufacturers of X-ray apparatus.

Even with all practicable safeguards, a certain degree of exposure cannot be evaded. Laboratories doing a large volume of work should, therefore, have a reserve personnel to permit alternation of service or frequent holidays. Workers should repeatedly be cautioned to receive the least possible amount of irradiation consistent with the performance of their duty. Modern life, regardless of occupation, has an abundance of risks, and additions are superfluous. Besides taking all reasonable precautions, workers should have frequent medical examinations.

One of the first maxims learned by the physician is "*non nocere*" (harm not), and he is seldom faithless to it with regard to his patients. Is his own body less worthy of care?

BIBLIOGRAPHY

1. AMUNDSEN, P.: The blood picture of radiologists. Tidsskrift for den Norske Laegeforening, 1922, 862. Abst., Jour. Roentgen Soc., 1923, XIX, 25.
2. AMUNDSEN, P.: Blood anomalies in radiologists and in persons employed in radiological service. Acta Radiologica, 1924, III, 1-7.
3. BARCLAY, A. E.: A danger of the Coolidge tube for screen work. Editorial, Arch. Radiol. and Electroth., 1921, XXV, 225-227.
4. BECLERE, M.: Que dôit-on espèrer et que peut-on craindre de l'emploi, en radiotherapie profonde, de rayons très penetrants. Arch. d'electr. méd., 1921, XXXI, 225-237.
5. BORDIER, H.: Biochemische Strahlenwirkung mit besonderer Berücksichtigung der Roentgenstrahlen. Fortschr. a. d. Geb. d. Roentgenstrahlen, 1913, XX, 202-220.
6. BORDIER, H.: Sur un cas d'anemie mortelle. Bull. et mém. Soc. radiol. méd. de France, 1921, IX, 158-160.
7. CAFFARATTI, M.: Quantitative Veraenderungen der Blutelemente bei Roentgenologen und Personnel in Roentgen Instituten. La Radiol., Medica, August, 1922. Abst., Fortschr. a. d. Geb. d. Roentgenstrahlen, 1923, XXX, 382.
8. CONTREMOULINS, M. G.: A propos de la protection des tiers contre les rayons X. Arch. d'electr. méd., 1921, XXXI, 314-315.
9. CORI, C. F.: Biological reaction of X-rays: The influence of X-ray treatment on the complement content of the blood of cancer patients. Am. Jour. Roent. and Rad. Ther., 1923, X, 830-834.
10. CORI, C. F., and PUCHER, G. W.: Biological reactions of X-rays: Effect of radiation on the nitrogen and salt metabolism. Am. Jour. Roent. and Rad. Ther., 1923, X, 738-745.
11. CUMBERBATCH, E. P.: Fatal leucopenia following X-ray treatment. Arch. Roentg. Ray, 1913-1914, XVIII, 187.
12. DAVID, O., and HIRSCH, A.: Experimental studies on the adrenalin content of the suprarenals following roentgen irradiation. Klin.-therap. Wchnschr., 1923, 790. Abst., Am. Jour. Roent. and Rad. Ther., 1923, X, 1010.
13. DE COURMELLES, F.: Accidents des rayons X et du radium. Arch. d'electr. méd., 1921, XXXI, 289-298.
14. DE COURMELLES, F.: Hygiene et securité du radiologue. Radiopathie et radiotherapie. Arch. d'electr. méd., 1920, V, 177-186.
15. DESJARDINS, A. U., and MARQUIS, W. J.: Blood count and blood pressure in high voltage therapy. Radiol., 1924, II, 252-259.
16. DESJARDINS, A. U.: Protection against radiation. Radiol., 1923, I, 221.
17. DESSAUER, F.: The cause of the action of X-rays and gamma rays of radium upon living cells. Jour. Radiol., 1923, IV, 411; also Strahlentherapie, 1923, XVI, 208. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 122.
18. EDITORIAL: The autopsy of a radiologist. Arch. Roentg. Ray, 1914, XVIII, 393-394. (Data from La Radiologia Medica, February, 1914.)
19. EDITORIAL: Arch. Radiol. and Electroth., 1921, XXV, 338-339.
20. EDITORIAL: Arch. Radiol. and Electroth., 1921, XXV, 193-194.
21. EDITORIAL: Arch. Radiol. and Electroth., 1920, XXIV, 341.
22. EDITORIAL: The dangers in working with radium and X-rays. How the problem is being met. Radium, 1921, XVII, 53-60; London Correspondent of Jour. A. M. A., 1921, LXXVI, 1412.
23. ENGEL, K.: Ueber Roentgenschädigungen in der medizinischen Radiotherapie. Deutsch. med. Wchnschr., 1907, XXXIII, 22-24.
24. FABER, K.: Anemie pernicieuse aplastique mortelle chez un specialiste des rayons roentgen. Acta Radiologica, 1923, II, 110-115.
25. FRAENKEL, E., and BUDDE, W.: Histologische, zytologische and serologische Untersuchungen bei roentgenbestrahlten Meerschweinen. Fortschr. a. d. Geb. d. Roentgenstrahlungen, 1913, XX, 355-363.
26. FALCONER, E. H., MORRIS, L. M., and RUGGLES, H. E.: The effect of X-rays on bone marrow. Am. Jour. Roent. and Rad. Ther., 1924, XI, 342-351.
27. GIRAUD, M., GIRAUD, G., and PARES, G.: La crise hemoclasique du mal des irradiations penetrantes. Presse méd., 1921, XXIX, 746-748.
28. HALL, C. C., and WHIPPLE, G. H.: Roentgen-ray intoxication; disturbances in metabolism produced by deep massive doses of the hard roentgen rays. Am. Jour. Med. Sc., 1919, CLVII, 453-482.
29. HAUSMANN, W., and KERL, W.: Zur Kenntniss der biologischen Radiumwirkung. Strahlentherapie, 1921, II, No. 3. Abst., Fortschr. a. d. Geb. d. Roentgenstrahlen, 1921-1922, XXVIII, 275.

30. HEIM, K.: Blut Veraenderungen bei der Grossfelderbestrahlung. Arch. f. Gynaek., 116, II, 291. Abst., Fortschr. a. d. Geb. d. Roentgenstrahlen, 1923, XXX, 613.
31. HEMLER, W. F.: High tension electric shocks in roentgenologic practice. Am. Jour. Roent., 1922, IX, 365-370.
32. HENKEL, M., and GUEFFROY, H.: Blutgerinnung bei Tiefentherapie. Zentr. f. Gynaek., 1923, No. 11. Abst., Fortschr. a. d. Geb. d. Roentgenstrahlen, 1922, XXIX, 534.
33. HIRSCH, E. F., and PETERSEN, A. J.: The blood with deep roentgen-ray therapy; hydrogen-ion concentration, alkali reserve, sugar and nonprotein nitrogen. Jour. Am. Med. Assn., 1923, LXXX, 1505-1507.
34. HOLZKNECHT, G.: Gibt es ein Reizwirkung der Roentgenstrahlen? Muenchen. med. Wchnschr., 1923, LXX, 761-762.
35. HUSSEY, R. G., and THOMPSON, W. R.: The effect of radium emanations on solutions of trypsin. Jour. Radiol., 1923, IV, 260.
36. IVY, A. C., ORNDOFF, B. H., JACOBY, A., and WHITLOW, J. E.: Studies of the effect of X-rays on glandular activity. Jour. Radiol., 1923, IV, 189-199.
37. KLEIN, J.: The rapidity of sedimentation of erythrocytes before and after roentgen irradiation. Strahlentherapie, 1923, XVI, 233. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 128.
38. KROENIG, B., and FRIEDRICH: The principles of physics and biology of radiation therapy. London, W. Heinemann, Ltd., 1922. Review in Arch. Radiol. and Electrother., 1922-1923, XXVII, 216-217.
39. LACASSAGNE, A., and LAVEDAN, J.: Histologic modifications of the blood after experimental radiations. Paris méd., 1924, XIV, 97. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 269-270.
40. LARKINS, F. E.: A case of acute aplastic anemia. Arch. Radiol. and Electrother., 1921, XXV, 380-382.
41. LAZARUS-BARLOW, W. S.: Some biological effects of small quantities of radium. Arch. Radiol. and Electrother., 1919-1920, XXIV, 1-12.
42. LEITSCH, A.: The immediate effects of X-rays on the blood lymphocytes. Arch. Radiol. and Electrother., 1921-1922, XXVI, 122-128.
43. LEVIN, I.: Action of radium and the X-rays on the blood and blood-forming organs. Am. Jour. Roentgenol., 1922, IX, 112-116.
44. LEVY-DORN, M., and WEINSTEIN, S.: Zum Verhalten des Blutdruecks nach Roentgenbestrahlung. Fortschr. a. d. Geb. d. Roentgenstrahlen, 1921-1922, XXVIII, 175-178.
45. LITTLE, C. C., and BAGG, H. J.: The occurrence of two heritable types of abnormality among the descendants of X-rayed mice. Am. Jour. Roent. and Rad. Ther., 1923, X, 975.
46. LOEB, L.: The effects of roentgen rays and radioactive substances on living cells and tissues. Am. Jour. Roentgenol., 1922, XIV, 497-498.
47. MAHNERT, A., and ZACHERL, H.: The influence of roentgen rays on the body fluids and metabolism of the human organism. Strahlentherapie, 1923, XVI, 163. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 125.
48. MARTIUS: The biological effects of X-rays of different wave lengths. Strahlentherapie, XIV, 558. Abst., Arch. Radiol. and Electrother., 1922-1923, XXVII, 382.
49. MARTIUS: Experimental studies of the action of roentgen rays. Arch. f. Gynaek., 1923, CXX, 193. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 124.
50. MAYOR, J. W.: Studies on the biological effects of X-rays. Am. Jour. Roent. and Rad. Ther., 1923, X, 968-974.
51. MOTTRAM, J. C.: Histological changes in the bone marrow of rats exposed to the gamma radiations from radium. Arch. Radiol. and Electrother., 1921, XXV, 197-199.
52. MOTTRAM, J. C.: Some effects of exposure to radium upon the alimentary canal. Arch. Radiol. and Electrother., 1923, XXVIII, 28-31.
53. MOTTRAM, J. C.: The red cell blood content of those handling radium for therapeutic purposes. Arch. Radiol. and Electrother., 1920, XXV, 194-197.
54. MOTTRAM, J. C., and CLARKE, J. R.: The leukocytic blood content of those handling radium for therapeutic purposes. Arch. Radiol. and Electrother., 1919-1920, XXI, V, 345-350.
55. NAKAHARA, W.: Studies on X-ray effects. III. Changes in the lymphoid organs after small doses of X-rays. Jour. Exper. Med., 1919, XXIX, 83-87.
56. NAKAHARA, W., and MURPHY, J. B.: Studies on X-ray effects. The biological action of small doses of low frequency X-rays. Jour. Exper. Med., 1922, 475. Abst., Jour. Radiol., 1922, III, 251.
57. PAGNIEZ, RAVINA, and SOLOMON: Action des rayons de Roentgen sur la coagulation du sang. Bull. et mém. Soc. radiol. méd. de France, 1921, IX, 256-258.
58. PFAHLER, G. E.: The effects of the X-rays and radium on the blood and general health of radiologists. Am. Jour. Roentgenol., 1922, XIV, 647-656.
59. PICCALUGA, N.: The action of roentgen rays on the reducing capacity of normal tissue and of newgrowths. Strahlentherapie, 1923, XVI, 245. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 125.
60. PINCH, A. E. H.: A report of the work carried out at the Radium Institute from January 18, 1919, to December 31, 1919. Arch. Radiol. and Electrother., 1920, XXV, 50-62.
61. PORDES, F.: In explanation of the action of X-rays is it necessary to assume functional and growth stimulation? Arch. Radiol. and Electrother., 1923, XXVIII, 89-93.
62. PORTIS, M. M.: Blood changes in workers with the roentgen ray, and apparatus for protection. Jour. Am. Med. Assn., 1915, LXV, 20-21.
63. RISSE: Some blood changes during roentgen and radium action. Arch. f. Gynaek., 1923, CXX, 181. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 127.
64. ROLLESTON, H.: Acute constitutional symptoms due to radiation. Jour. Roentgen Soc., 1923, XIX, 5-18.
65. RUSS, S.: The immediate effects of X-rays on the blood lymphocytes. Arch. Radiol. and Electrother., 1921-1922, XXVI, 146-149.
66. RUSS, S., CHAMBERS, H., and SCOTT, G. M.: The local and generalized action of radium and X-rays upon tumor growth. Arch. Radiol. and Electrother., 1921-1922, XXVI, 129.
67. RUSS, S., CHAMBERS, H., and SCOTT, G. M.: Further observations of the effects of X-rays upon lymphocytes. Arch. Radiol. and Electrother., 1921, XXV, 377-380.

68. Russ, S., Chambers, H., Scott, G. M., and Mottram, J. C.: Experimental studies with small doses of X-rays. Lancet, 1919, CXCVI, 692-695.
69. Schall, W. E.: The stimulating and paralyzing effect of X-rays. Arch. Radiol. and Electrother., 1923, XXVIII, 124-125.
70. Shearer, J. S.: Possible dangers in connection with the use of the X-rays and how to avoid them. Am. Jour. Roent. and Rad. Ther., 1923, X, 240-246.
71. Simons, A.: Experimenteller Beitrag zum Problem der Wachstumsteigernden Wirkung der Roentgenstrahlen auf normales menschliches Gewebe. Fortschr. a. d. Geb. d. Roentgenstrahlen, 1923, XXX, 300-301.
72. Slye, M.: The inheritability of spontaneous cancer in mice and its application to cancer in man. Jour. Radiol., 1922, III, 453-464.
73. Soiland, A.: Protection to the operator from unnecessary radium radiation. Jour. Radiol., 1922, IX, 683.
74. Strauss, O.: The effect of roentgen rays on intracellular and metabolic processes. Strahlentherapie, 1923, XVI, 195. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 126.
75. Strauss, O.: Different degrees of sensitiveness to roentgen rays. Fortschr. a. d. Geb. d. Roentgenstrahlen, 1924, XXXI, 428. Abst., Internat., Survey Roent. and Radiother., 1924, VII, 271.
76. Taylor, H. D., Witherbee, W. D., and Murphy, J. B.: Studies on X-ray effects. I. Destructive action on blood cells. Jour. Exper. Med., 1919, XXIX, 75-82.
77. Thomas, M. M., Taylor, H. D., and Witherbee, W. D.: Studies on X-ray effects. II. Stimulative action of the lymphocytes. Jour. Exper. Med., 1919, XXIX, 75-82.
78. von Jagic, N., Schwarz, G., and von Siebenrock, L.: Blutbefunde bei Roentgenologen. Berl. klin. Wchnschr., 1911, XLVIII, 1220-1222.
79. von Mikulicz-Radecki, J.: Roentgen irradiation and rapidity of sedimentation of blood corpuscles. Arch. f. Gynaek., 1923, CXX, 187. Strahlentherapie, 1923, XVI, 223. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 128.
80. Warren, S. L., and Whipple, G. H.: Roentgen-ray intoxication. Jour. Am. Med. Assn., 1923, LXXXI, 1673-1675.
81. Warren, S. L., and Whipple, G. H.: Roentgen-ray intoxication. II. The cumulative effect or summation of X-ray exposures given at various intervals. Jour. Exper. Med., 1923, XXXVIII, 725-730.
82. Warthin, A. S.: The changes produced in the kidneys by roentgen irradiation. Am. Jour. Med. Sc., 1907, CXXXIII, 736-746.
83. Warthin, A. S.: An experimental study of the effects of roentgen rays upon the blood-forming organs, with special reference to the treatment of leukemia. Internat. Clin., 1906, s. XV, IV, 243-277.
84. Westman, A.: Alterations du sang chez les malades traités par les rayons X et par le radium. Acta Radiologica, 1921-1923, I, 349-357.
85. Wickham, L.: Modifications histologiques produites par les rayons X sur les tissues. Arch. d'electr. méd., 1913, XXII, 433-447.
86. Wintz, H.: Injuries from roentgen rays in deep therapy. Am. Jour. Roent. and Rad. Ther., 1923, X, 140-147.
87. Withers, S.: Certain biological principles of radiation therapy. Am. Jour. Roent. and Rad. Ther., 1923, X, 776-781.
88. Wolmershauser, O.: The behavior of blood pressure and leukocytes during roentgen irradiation and their relation to the vegetative nervous system. Strahlentherapie, 1923, XVI, 235. Abst., Internat. Survey Roent. and Radiother., 1924, VII, 129.

DISCUSSION

Dr. H. J. Ullmann (Santa Barbara): Reference was made to a statement by Hall and Whipple regarding the decreased lethal dose when a longer "gap" was used. If one will refer to this article, square the gaps and compare with the lethal doses, he will find that the doses are inversely proportional to these squares. The authors were evidently not familiar with the physical laws governing X-ray output when they assumed that rays generated by a higher voltage were more lethal, for no allowance is made for the increased intensity produced by this increased voltage. When such an allowance is made no difference in the lethal effect is found.

Dr. Albert Soiland (Los Angeles): I believe that Dr. Carman's paper should be given great thought and consideration. There is no one phase of the work we are doing that is more important to us, both physically and from a medico-legal aspect, than protection—and that means not only to ourselves and our technicians, but to the patients we undertake to treat or examine. I have presented this subject on former occasions and am always glad of an opportunity to reiterate, because I believe it is the most important radiological subject we have to deal with to-day. Many years ago, when Dr. Carman was even younger than he is to-day and I used to visit him, I found him sitting behind his fluoroscope, with his bare hands palpating many patients daily. Also, many years ago when Dr. James T. Case was young and handsome, he was doing his fluoroscopic work on the overhead table, which he assumed was fully protected. On one visit I took his fluoroscope and walked around the table with it and had no difficulty in observing the leg bones of Dr. Case as he stood over the table. However, I see that he is still alive and I guess he is

now keeping out of harm's way. In New York last week I saw something which bordered on sheer neglect. I went to one of the large hospitals where deep therapy was being done by someone who is highly intelligent and, I presume, knows every detail of the work. He was operating two high voltage tubes in rooms where open wooden doors with no lead protection permitted the attendants and waiting patients to absorb whatever direct and scattered radiation came their way. In the light of present-day knowledge of the biologic reactions to radiation, this is inexcusable. We should all take to heart what Dr. Carman has said and impress upon ourselves the necessity of protection against every form of unnecessary radiation.

DR. G. E. PFAHLER (Philadelphia): I want to emphasize what Dr. Carman and Dr. Soiland and Dr. Ullmann have said. There is nothing so important to us to-day, and really so important to the advancement of this science, as this question of protection. We must not, on this question of protection, limit ourselves entirely to the roentgenologist, but extend our consideration to the patient. These high voltage machines that are being distributed through the country and installed in some of the hospitals, without the thought of even having a technician do the work, without the supervision of a trained radiologist, make those of us who know the dangers very fearful. We must not imagine that we get protection, especially from these high voltage rays, by simply standing an alleged screen up in front of us. I tried this out very thoroughly in my own laboratory,—not with a screen but by the following process. I placed my high voltage tube under a concrete floor sixteen inches thick; I covered the top of the concrete floor with a quarter of an inch of lead; the only communication from the basement was a small door, and one had to pass around the hallway in order to get up. I thought that that would give protection, because the only rays that came to the room were the beams of rays that passed through the patients. We soon learned, however, that we had rays not only all over this room but in the neighboring rooms, and we did not get protection until we leaded all of the rooms and doors about the space in which we had only a column of rays coming through. When I see, as we all can see, deep therapy equipment with simply a glass bowl around the X-ray tube, and see patients and physicians and assistants walking around this glass bowl, assuming that they have protection, it just makes one shudder. As Dr. Soiland has well said, a wooden door is no protection,—you must have the leaded wall complete to the ceiling and all the air shut off, because the air itself will carry this radiation through to the adjoining room.

Now test yourselves, as I suggested in my paper to which Dr. Carman kindly referred. Put some dental films in the place where you are standing, and leave them there for a time until you think they are fogged, and test it out. Carry a dental film in your pocket and see how long you can carry it until it becomes fogged. You would be surprised at yourself, when you are working around either radium or X-rays, no matter how careful you are. Then make further tests by examining your blood from time to time.

All these things furnish indices of danger. We must all be more careful, not only in protection against the rays, against the electrical dangers, but also in getting sufficient rest, for we are adding to this over-exhaustion the intense work we are doing, and we must overcome the products of waste in our body plus this radiation effect.

DR. L. T. LEWALD (New York): I think that each laboratory should be inspected according to the regulations of the Board of Health in New York City.

The Board needs support just like this, however, for there is the other side to it: a physician claims, by right of his license, that he can use *any* means *he* sees fit to treat patients, and we have to prove that he

has not that right, for the public must be protected, and even the individual himself. The Board needs your support of the code recently passed, and if New York City goes into court on this problem, as it might on a case such as Dr. Soiland has mentioned, it will have to be tried out. The orders of the Board can be carried out under the police regulations of the city, and the only stumbling block is the question of whether we are going to have the support of the medical profession itself. When it comes to a question as to what the Board of Health may adopt as a standard for adequate protection, we might insist upon these suggestions which were made to-day, which will be brought to the attention of the New York Board of Health. For any violation of the code, even though a laboratory has a license, that license may be revoked. I am sure we will have the support of the court in this matter, if we have the support of the profession. The New York City Code governing this matter follows:

X-RAY LABORATORIES REGULATED

At a meeting of the Board of Health of the Department of Health of New York City, held January 26, 1922, the following resolution was adopted:

Resolved, That Article 7 of the Sanitary Code be amended by adding thereto a new section to be numbered 107, to read as follows:

Section 107. No person shall maintain, operate or conduct an X-ray laboratory or advertise or hold out to the public that an X-ray laboratory is maintained, operated or conducted, wherein radiographs are taken, diagnoses made or human beings examined or treated by X-rays, without a permit therefor issued by the Board of Health, or otherwise than in accordance with the terms of said permit and with the Regulations of the said Board.

Regulation 3. Precautions against danger.—Every X-ray laboratory shall be so constructed as to confine within the operating room the rays emanating from the machine and it shall be equipped with suitable and necessary appliances and devices at all times when the X-ray machine is in operation for the proper protection of patients, operators and all other persons or property adjacent, contiguous to or coming in contact with the electrical or other current or force or spark generated or incident to the operation and use of the X-ray machine.

Regulation 4. Permits may be revoked in the discretion of the Board of Health.

DR. J. D. SOUTHARD (Fort Smith, Ark.): It seems to me this is one of the most important questions we can possibly consider, and as I have listened to the discussions of the leaders in our profession, giving their experience, it has occurred to me that we ought to at least appoint here at this time, a committee of three men, such as Dr. Carman, Dr. Soiland, and Dr. Pfahler, to formulate something like a minimum of precaution to be taken by every one in the work that we are doing—something as easily practicable and simple as possible—and submit it to this association and let it be published, and then that we all should resolve in our own minds that we will comply with it. I am a new member and do not know whether anything of this kind has been or is being done or not.