MEDICAL ASPECTS OF RADIATIONS USED IN INDUSTRY *

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Present knowledge of the potential danger of many varieties of radiation, and of the measures necessary to safeguard industrial workers against such danger, is based first upon the actual experience of early research workers in this field, and, second, upon preventive measures instituted by various medical bodies for personnel engaged in x-ray and radium therapy.

The radiations with which industry is chiefly concerned are x-rays, infra-red, light, and ultra-violet rays, radium, and to a much smaller extent, ultra-short waves.

X-rays

The story of the injuries received by pioneers in the x-ray field is a sad one, so well known that only brief reference need be made to it. It is interesting to note, however, that Röntgen himself, who discovered x-rays in 1895, escaped injury chiefly because most of his experiments were photographic only, and also because he used x-ray tubes placed in a zinc box and protected by lead screens.

Reports of soreness of the eyes, dermatitis and loss of hair began to come in about 1896, but even in 1899 it was still believed by many authorities that these were due to chemical or electrical conditions in the skin or, as in the case of Dr. Hall Edwards who eventually died of x-ray cancer, to the developer used. The first case of x-ray cancer in a workman employed in making x-ray tubes, and developing from a lesion on the back of the hand, was described in 1902; but Dr. Hall Edwards' reports on his own injuries in 1904 provide the classical description of this fatal condition. The redness of the skin, transverse lines on the brittle nails, cracks of the epithelium, warty growths, sores which would not heal, and the very severe pain, finally necessitating amputation of fingers and forearm, form a picture which was to be repeated in other unfortunate victims before the necessity for suitable preventive measures was fully recognized.

Injuries due to X-rays. Injuries to the skin are perhaps the best known signs of x-ray damage, perhaps because they are so obvious, especially in the acute stage. An x-ray burn may consist only of a patch of acute erythema, which gradually dis-

appears in the course of a few weeks, but it may go on to necrosis and ulceration which is extremely difficult to heal. It is probable, however, that a single burn never initiates cancer. Chronic x-ray dermatitis is a different and entirely characteristic pathological condition, involving processes of both atrophy and regeneration. Side by side with atrophic loss of the epidermal appendages and obliteration of small blood vessels, leading to areas of necrosis beneath the epidermis, goes reparative proliferation of surrounding tissues. The clinical signs of this combination of atrophy and repair are thickening of the epidermis, hyperkeratosis, cracks, with degenerative changes in the deeper tissues—in other words, a pre-cancerous condition.

There are also the later skin reactions, appearing only some time after exposure has ceased, even as long as several years after. These may consist of telangiectases, areas of pigmentation and atrophy, localized thickenings and warts, generally on the dorsum of the hand, or later ulceration due to obliterative endarteritis and lymphangitis.

The *blood changes* caused by excessive exposure to x-rays are shown first of all by the white cells. A gradually increasing leucopenia, sometimes preceded by a transient leucocytosis, is the most constant diagnostic sign. The leucopenia is often accompanied by a lymphopenia, since the lymphocytes are specially sensitive to x-rays, or sometimes by a relative lymphocytosis. If this condition is detected at an early stage and the subject removed from exposure, it is entirely curable, but if allowed to progress it may culminate in severe and even fatal depression of the bone marrow—aplastic anaemia. Cases of leukaemia as the final stage have also been reported, but there appears to be some doubt as to the direct connection between the condition and general x-ray radiation. There seems no scientific reason, however, why leukaemia should not be the end-result of an aplastic marrow, possibly as an over-compensatory regenerative process. We do know that benzol poisoning, which characteristically causes aplasia of the bone marrow, does at times end fatally, with the bone marrow in a condition of hyperplastic leukaemia; and, in fact, benzol leukaemia, though not nearly so common as benzol anaemia, is a recognized clinical entity.

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With regard to the *generative organs*, sterility has been known to occur in some male radiographers when protection has been inadequate. Some of these cases have eventually recovered. In female radiographers and nurses the percentage of sterility has been found to be high, and there is said to have been a rather high percentage of developmental defects in any children born, but the evidence is not conclusive.

Industrial Uses. The use of x-rays for detecting flaws in castings and other metal articles and in diffraction processes is constantly increasing and the voltage of the apparatus varies considerably. For small castings of light alloys the range is usually from 30 to 100 kilovolts; for heavy large castings, such as bomb-carriages, from 100 to 200 kv. and in some cases up to 400 kv. In America much more powerful installations—up to 1000 kv.—are used, but have not yet been introduced into this country.

The chief danger to x-ray operatives arises when the work is chiefly screening, rather than photography. Protection from the direct beam can, of course, be afforded by lead screening of the tube. The danger of *scatter radiation* is less obvious and therefore often less carefully guarded against, and it has not been unusual, until fairly recently, to find x-ray rooms littered with numerous articles awaiting examination, all acting as contributory sources of scatter radiation.

Preventive Measures. The measures at present recommended to all users of industrial x-rays are based on the original recommendations of the British X-ray and Radium Protection Committee, which was formed in 1921 with the object of preventing casualties to x-ray and radium workers. These formed the basis of the International Recommendations adopted at Stockholm in 1928 by the Second International Congress of Radiology. They included general hygienic conditions for x-ray rooms—size, ventilation, temperature and layout of the apparatus; protection of the x-ray tube by a sufficient thickness of lead or its equivalent; the use of mirrors; provision of screens for fluorescent work; protection against scatter radiation by placing the operator outside the x-ray room behind walls containing the necessary lead or its equivalent; protective clothing; a working week of not more than 35 hours with four weeks' holiday a year; and periodical blood examinations. These recommendations are designed to limit the exposure received by the operator to what is considered the tolerance dose of one R per week, and to detect the earliest signs of injury.

Application to Industrial X-ray Exposure.—These preventive measures apply with equal force to the protection of industrial x-ray operatives, though they are not at present statutory. Naturally, a continuous check is kept by the Factory Department on the conditions obtaining in the x-ray industrial field. It has to be remembered that, even with a well installed and well protected x-ray apparatus, the human factor comes into play more

markedly with the industrial worker, who is less likely to be aware of the danger and more likely to take liberties with it, than with the trained medical radiographer. X-ray burns, for instance, should not occur with a fully protected installation and lead rubber gloves, but even where these conditions have been fulfilled and where advice and instructions have been given, they have occurred, because the worker has been unable to realize that putting his uncovered hands in the track of an invisible ray even for a short time could do any harm.

It will be appreciated that the work in factories differs from that in hospitals; longer hours and more continuous spells may have to be worked, and the risk of scatter radiation may be greater. The Chief Inspector of Factories decided therefore, in 1942, after consultation with representatives of various interested bodies, to have a preliminary survey made of the actual conditions of exposure in factories using x-rays. A circular letter was sent to managements inviting them to co-operate in a scheme by which the National Physical Laboratory undertook to measure the dosage revealed by dental films worn for one week by the operatives. If these showed evidence of a dosage greater than the tolerance dose of one R per week, the National Physical Laboratory would investigate the plant, and the operative in question would be asked to undergo a blood examination. In this way it is hoped to link up actual exposure with the condition of health of the workers. The results so far have been very encouraging with regard to the dosage which industrial x-ray workers on the whole are receiving. In nearly all the large number already investigated the dosage varied from 0.1 to 0.3 R per week—well below the tolerance dose.

Infra-red Rays and Light

Certain industrial occupations, such as welding or brass foundry work, involve exposure to all three varieties of radiation—infra-red, light, and ultra-violet; in glass manufacture it has been shown that infra-red is the chief harmful component; and in electro-welding the light and ultra-violet rays form the greater hazard. Exposure to excessive light, as in gazing at bright objects, may cause transient scotomata which disappear on rest and can be prevented by wearing suitable glasses such as those prescribed by the British Standard Specification Pamphlet No. 679. Infra-red radiations physiologically produce vasodilatation of the skin vessels, and stimulation of cell activity, thus promoting healing and tissue repair. They do not penetrate very far before being converted into heat, but some do penetrate the dermis and may cause an actual rise of body temperature. In excessive dosage they produce severe metabolic disturbance, skin burns and lesions of the eye.

Industrial Exposure and Injury. The chief processes in which excessive exposure to infra-red radiation is likely to occur are foundry work, welding, glass manufacture, and some varieties of furnace work. Heat cramps are, of course, a

severe metabolic effect which includes the inevitable dehydration of the tissues and loss of salt. The provision of saline drinks is a well-recognized preventive measure for the heat colic from which those who work in excessive heat frequently complain.

On the *skin*, infra-red rays produce an erythema which may amount to severe burning, followed by pigmentation which is sometimes permanent and may also be accompanied by chronic inflammatory changes.

Changes in the *blood* are not so well recognized as a consequence of infra-red radiation but some authorities believe that severe and continuous exposure may cause anaemia and leucopenia.

Cataract.—The industrial injury which is the chief recognized effect of infra-red radiation, and which is subject to compensation, is cataract following exposure to molten glass or red-hot metal. Historically, glass-workers' cataract is of great interest. It has been observed in Germany since 1896, and in 1903 Dr. Robinson, surgeon to the Sunderland and Durham County Eye Infirmary, published a paper drawing attention to the frequency of cataract in bottle finishers in the glassworks of that district. This was followed up by Sir Thomas Legge, who compared the incidence of cataract in glass workers with that of a large number of operatives who were not glass workers and who showed that changes in the lens were in fact about five times as frequent in glass workers between 30 and 40 years of age, twice as frequent between 41 and 50, and three times as frequent over 50.

The character of the cataract differs from that of the ordinary senile variety in that it always commences at the posterior pole of the lens and involves the cortex, whereas in senile cataract the characteristic change usually develops in the form of radiating lines from the periphery, the central pupillary area remaining free. The explanation given by Robinson of the difference was that the posterior pole was practically the optical centre where the principal rays from the furnace crowd together, cross, and pass on without refraction. That it was the infra-red rather than the ultra-violet rays which were responsible for the cataract was shown by Sir William Crookes during his researches on suitable protective glasses; he found heat rays in far greater abundance than ultra-violet in the radiations from molten glass.

Ultra-Violet Rays

Modern knowledge of the effects of ultra-violet rays is really due to Finsen. It is rather curious that Finsen should at first have devoted his studies entirely to the harmful effects of ultra-violet radiation and only later, in 1897, turned his attention to their beneficial action in the treatment of lupus vulgaris.

The physiological effects of ultra-violet rays are exerted chiefly on the skin, the superficial blood vessels and the haematopoietic system in general. The erythema produced only appears after a latent

period of from 4 to 12 hours and lasts for a time depending on the severity of the exposure. The degree of pigmentation produced, now known to be a protective reaction, is not directly related to the intensity of the erythema. The effects on the *blood* are seen in an increase in the number of red cells, and a slight increase in the total white corpuscles for which the lymphocytes rather than the polymorphs are responsible. There is also an increase in blood platelets and serum calcium.

Industrial Uses and Injuries. There are many modern industrial processes in which ultra-violet rays are used, as it were, deliberately, for their revealing power, just as x-rays are. The examination of golf balls to detect defects in the painting and under-coating, the examination of blue-prints and razor blades, of linen marked with invisible ink, and of luminized dials, are some examples of this type of use. In these processes there is very little risk of injury to the eyes since both lamps and personnel are usually well protected and, also, since many of this kind of apparatus emit not true ultra-violet but 'near' ultra-violet with a wavelength of 3000 to 4000 A.U. The destructive effects of ultra-violet radiations on the eye tissues is greater the shorter the wavelength; that is to say, it rises sharply between 2000 and 2400, is more gradual from 2400 to 2900, and is almost negligible when the wavelength is greater than 3000 A.U. The chief trouble arises when ultra-violet rays are emitted during processes for which they are not specifically desired, such as electro-welding. The eye injuries caused by excessive ultra-violet radiation show themselves, like the skin erythema, after a latent period of some hours. They begin with symptoms of severe conjunctivitis, smarting, lachrymation, photophobia and sometimes chemosis. In severe cases the cornea may become inflamed and corneal ulceration and iritis may follow. Many authorities believe also that the lens may be injured and that cataract may be a final result, as it is of infra-red radiation.

Prevention. The most logical and successful prevention of injury to the eyes by infra-red, actinic or ultra-violet rays, is the provision of either spectacles or screens of glass which intercept the wavelength in question. For processes involving exposure to these wavelengths eye protective glasses are available, designed according to the British Standard Specification. These glasses are graded according to the proportion of the different radiations absorbed by them and are suitable for different types of work—for example, Grade A for lead-burning, lead-brazing and melting furnaces up to about 1600° C., Grade B for acetylene welding, Grades C and D for metal-arc lamps, and Grade E for carbon-arc lamps used in carbon-arc welding and cutting. For protection against ultra-violet radiation alone, for example from a distant arc, Crookes' special glass is suitable. It absorbs very little visible light but all the dangerous ultra-violet. A detailed description of all the various glasses will be found in the B.S.S. pamphlet on 'Protective Glass for Welding, 1936, No. 679.'

Radium

The credit for the actual discovery of radium goes, of course, to the Curies, who isolated it in 1898, though Becquerel had previously shown that uranium gave off active radiation.

Injuries due to Radium. The first evidence that this potent substance might cause injury to living tissue was shown, as in the case of x-rays, by skin lesions. Pierre Curie suffered from radium dermatitis, but the best-known example of its acute effect was the burn received by Becquerel in 1901. He carried a tube containing some decigrammes of impure radium chloride in his waistcoat pocket for six hours, and was surprised later to find a patch of acute erythema on his abdominal wall, followed by ulceration which took over a month to heal.

Much more serious consequences followed exposure to radium in America from 1917 to 1924. The luminizers of New Jersey are the classical example of true radium poisoning, caused by the accumulation in the tissues of radium which had almost certainly been ingested, owing to the habit of the luminizers of pointing with their lips the brushes which they used for applying the luminous paint. The necrosis and in some cases sarcoma of the jaw which preceded death in 15 cases was no doubt partly due to local infiltration by this mode of entry, but probably also to the fact that the trabecular structure of the jawbone makes for low resistance to infection. Combined with these lesions of the jaw was severe aplastic anaemia. In ten other fatal cases there were malignant tumours of other bones. Dr. Robley Evans of Massachusetts Institute of Technology has also called attention to cases of rarefying osteitis with spontaneous fracture. It is noteworthy that only those luminizers who had been employed one to two years or longer were affected, and in many the disease did not show itself until as long as 5 or 6 years after they had ceased work.

These cases are the outstanding examples of radium poisoning due to the cumulative effect of radium deposited in the body, but other similar cases have occurred following the ingestion of radio-active medicaments such as radio-active waters containing as much as 2 microgrammes of radium in a two-ounce bottle. One case described by a pathologist who was present at the post-mortem examination was that of a man who had died of aplastic anaemia of apparently unknown origin. It was discovered, however, that he had drunk radio-active water for rheumatism for the past 12 years, and examination of the tissues showed the presence of a considerable amount of radium. It should be mentioned here that the natural radio-active water of some British spas contains only the most minute traces of radium and, of course, the human body normally contains traces of radio-active material.

In considering the injuries which may be caused by radium it is necessary to remember that all three types of radiation which it emits, as well as the radon gas which is constantly emanating from it,

have separate potentialities for harm. *Alpha particles*, which are the most destructive, are fortunately also the least penetrating and their entrance into the tissues from outside can be most easily guarded against. But in cases where radium has been deposited in the body, especially in the bones, either by ingestion or long-continued inhalation of radium dust, alpha particles can keep up a continuous bombardment of the bone marrow and other tissues, with serious results.

Beta particles are less destructive to tissue but have more penetrating power than alpha particles; they need several millimetres of metal or glass for complete screening. Their chief action is on the skin, causing radium dermatitis.

Gamma rays are a true radiation of great penetrating power; only half of their intensity is lost after passing through about 1.5 cm. of lead. Their chief action is upon the blood-forming organs, causing depression of the bone marrow, which if allowed to continue might lead to fatal aplastic anaemia.

Radon is a colourless gas, without taste or smell, which is being continuously formed from radium and which is itself continuously being transformed into the next radio-active element, radium A. It is obvious that prolonged and continuous inhalation of radon must in time add to the risks of damage from external radiation or ingestion of radium dust.

In considering the risks to health of radium workers, therefore, four possibilities must be borne in mind. (1) *True radium poisoning*.—This was seen in its worst form in the New Jersey cases. (2) *Respiratory lesions*.—These have been observed chiefly among the uranium workers in Joachimsthal in Bohemia, where the incidence of lung cancer is high. This disease, known locally as 'Bergkrankheit,' was at one time thought to be due to inhalation of either arsenic or other metallic particles, but more recent authorities have considered it due to inhalation of radon given off by the radium chloride in the uranium ore. (3) *Injury of the blood-forming organs*.—A gradual depression of the white cell count, leading in time to aplastic anaemia. (4) *Skin injury*.—Like x-rays, radium may produce an acute burn or patch of erythema, or a chronic dermatitis of atrophic character. It is believed, however, that chronic radium dermatitis is less likely to develop into skin cancer than the dermatitis caused by x-rays.

Industrial Uses. The chief use of radium in this country is the application of 'luminous compound' to aeroplane and watch dials, compasses, gun sights and various electrical instruments.

Luminous compound in its dry form is a powder consisting of zinc sulphide with a small admixture of radium or mesothorium, the usual proportion being 70 micrograms of radio-active substance per 1 gramme of compound. By far the greater part of the luminous compound in this country is used in the form of a paint, made by the addition to the powder of various mucilages and solvents; a small

amount is used dry. The reason for the addition of radio-active material to zinc sulphide, which is in itself phosphorescent, is to prolong the period of luminescence when any source of light is removed.

Prevention of Injury to the Health of Luminizers. The preventive measures for the luminizing industry are embodied in the Factories (Luminizing) Health and Safety Provisions Order of 1942, and the Amendment to the Order 1943. In addition to the statutory obligations imposed on both employer and employee by this Order, two further precautionary measures have been in use for some time. These are the six-monthly blood examinations of every luminizer, and estimations of the radon content of their exhaled air and of the air of the luminizing room. So far it would appear that strict enforcement of the provisions of the Luminizing Order and continual instruction to the luminizers themselves has prevented consequences of anything like the severity of the New Jersey occurrence. There have been no cases of fatal radium poisoning, none even of true aplastic anaemia, and the skin effects which have been observed have been slight and in most cases transient.

In order to prevent the occurrence of chronic dermatitis from direct contact with luminous compound or with radiation from open containers, a protective covering, consisting of a section of brass tubing with the oblique top filled in with a perspex lid through a small hole in which the applicator was inserted, was designed by Professor Mayneord of the Royal Cancer Hospital (see fig. 1). Most managers have accepted this appliance with great willingness.

Blood Examinations.—In no case has evidence of true aplastic anaemia been found. Slight leucopenia has occurred in comparatively few cases, nearly always in supervisors who usually weigh out and mix the luminous compound and who are therefore exposed to heavier dosage than the girls using small quantities of paint at a time. In all cases where leucopenia has occurred at successive blood examinations this has been brought to the notice of the Examining Surgeon who has then suspended the luminizer for three months; at the end of that time she is re-examined and only reinstated if her total white count has returned to normal. The red cells and haemoglobin have shown very little variation, except that during the first few months of employment the values are rather higher than one would expect in girls of this age and probable nutritional level. It is not at all unusual to find counts of 5 million r.b.cs. and over, and haemoglobin percentages of 100–102 per cent.

The most interesting and striking feature of the blood picture of a large proportion of these girls, especially during the first six months, is a high degree of relative lymphocytosis with a total white cell count of 6000–8000, or even higher. In these latter cases this amounts, of course, to an absolute lymphocytosis. In addition, the stained smears frequently contain immature cells such as premyelocytes, Türk cells, and even occasionally myelo-

CONTAINER IN USE

DETAILS OF CONTAINER

FIG. 1.—Mayneord's protective container.

blasts. Usually these abnormalities subside in the course of a year or eighteen months and the count remains normal for as long as they remain in employment. It has not been possible to follow their further development, because many of these girls have changed their work, or married, but in a very few cases who have shown this tendency at the beginning, and then become normal, and who have stayed on for a number of years, a trend towards a gradual lowering of the total white count has been observed. The statutory obligation under the

Amendment Order that all luminizers employed more than a year shall have three months of complete removal from exposure will no doubt prevent this trend towards a depressive effect from degenerating into a true leucopenia. Consultation with many haematologists as to the significance, if any, of the initial lymphocytosis and the presence of abnormal cells, appears to confirm the author's opinion, which is that it represents an initial stimulative effect of small doses of radio-active material. In itself the phenomenon is not necessarily harmful, but it must be remembered that hyper-stimulation over a long period might eventually produce depression.

Radon Estimations.—An attempt is being made here, as has already been done by Robley Evans in America to keep a further check on the health of luminizers by estimation of radon in their exhaled air, in order to ascertain whether in fact any radium is deposited in the tissues. Research is being carried out on these lines, under the direction of the M.R.C. by Professor Russ of the Middlesex Hospital, and it is hoped to make further use of the results, but there are great difficulties of technique and of arriving at definite conclusions. The method will, it is hoped, be a valuable adjunct to the prevention of serious effects.

A *dental film test*, similar to that for x-ray workers, is also being worked out by the National Physical Laboratory.

It will be seen, therefore, that while at present there is no reason to fear for the health of luminizers, it is very necessary in view of the cumulative effect of radium, and again taking into account the human factor which sometimes defeats the strictest regulations, not to relax a single precaution and to keep a constant watch on any developments that might arise. So far as the Factory Department is concerned, this is being done.

Short Waves

A brief reference must be made to 'short waves.' As in the case of x-rays and radium, most of our knowledge of the biological effects of this variety of radiation comes from the clinical field, where short-wave therapy has been in use for some time in the treatment of inflammatory conditions, rhinitis, asthma, sepsis and the results of trauma. In industry, short waves are not at present widely used. Before the war there was a gradually increasing manufacture of television receivers and of medical short-wave apparatus, and both these sources of short-wave radiation will no doubt increase during the post-war years. It is necessary, therefore, to have some idea what danger, if any, is to be apprehended if their use becomes more extensive.

So far the only symptoms complained of have been discomfort from sensations of heat, headache and drowsiness. It appears more than probable that these are entirely a heating effect, since in actual short-wave therapy, as in diathermy, heating of the tissues is a known and desired effect.

It has often been stated that the favourable effect of short-wave therapy is due chiefly to dilatation of capillaries, but recent observations, by means of special microscopic technique, of human capillaries while short-wave therapy was being carried out, showed that there was no marked alteration in the calibre of the capillaries; there was, however, a marked increase in the rate of blood flow, which probably accounted for the rapid subsidence of oedema and resolution of septic processes. It has been suggested that the chief danger to persons exposed to short waves might arise from their selective absorption by the body owing to the great variation in resistance of the various organs and tissues, and that over-heating of the blood might be associated first with the possibility of thrombosis, and second with damage to projecting parts of the body because of the reversal of the normal cooling process—that is to say, these parts would receive heat from the blood instead of having it taken away.

In actual practice, so far as all inquiries have shown, no such dangers have arisen, and the discomfort from overheating can be minimized by suitable precautions. These include: (1) Keeping out of the field as much as possible. Distant control of the apparatus is the obvious solution. (2) Using the apparatus in atmospheric conditions which best provide regulation of the body heat. This could, of course, be achieved by artificial movement of the air. (3) Suitable screening. At the same time it must be emphasized that beyond the physiological effects described little is known of any other biological or possibly cumulative properties of these rays, and if their use ever becomes an industrial problem of any magnitude a promising field of research and of vigilance will be open to the industrial medical officer.

Summary

X-rays. Used for detecting flaws in metal. Screening more dangerous than photography; 'scatter' radiation requires special precautions. Injuries—skin lesions (burns, dermatitis, pigmentation, warts, malignancy); blood changes (leucopenia, aplastic anaemia, even fatal leukaemia); sterility is rare. Prevention by limitation of exposure.

Infra-Red Rays. Injuries—heat cramps, skin erythema, cataract—in foundry and furnace work, welding, glass manufacture.

Ultra-Violet Rays. Injuries—conjunctivitis, corneal ulcer, iritis—in electro-welding. Prevention by spectacles or protective glass screens.

Radium. Used in luminizing. Injuries—due to alpha or beta particles, gamma-rays, or radon—causing true radium poisoning (jaw necrosis, bone malignancy, aplastic anaemia); respiratory lesions (including cancer); aplastic anaemia; dermatitis. Prevention by legislation; Mayneord's protective container; periodic blood examinations; radon estimations of exhaled air; dental film test.

Short Waves. Exposure in manufacture of television and therapeutic apparatus. Serious risk to health improbable.