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MEDICOLEGAL ASPECTS OF INJURIES FROM EXPOSURE TO X-RAYS AND RADIOACTIVE SUBSTANCES

CHARLES E. DUNLAP, M.D.*

INTRODUCTION

Roentgen rays¹ (x-rays) and radium were both discovered in the last years of the nineteenth century² and before 1900 it was well recognized that both these agents could produce burns of the skin. The applications of x-rays and radium to the diagnosis and treatment of disease followed with amazing rapidity and radiology was a well-established medical specialty by 1915. In more recent years, industrial and commercial applications have come into wide use particularly in the United States. Although the hazards of overexposure to radiation³ were recognized almost from the first and adequate protective measures were soon developed, accidental burns still occur with unfortunate frequency. Uhlmann⁴ saw 70 patients with radiation burns of the skin from 1938 to 1940. Forty of these injuries resulted from the use of x-rays for diagnostic or technical purposes and 30 occurred as a consequence of radium or x-ray therapy.

It is the purpose of this paper to discuss the principal hazards of overexposure and the effects of x-rays and radioactive substances on human tissues, excluding any consideration of the action of sunlight, infra red, ultra-violet and other forms of radiation. Several accessible reviews⁵ cover

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1. The term "Roentgen rays" is preferred in scientific writing to Röntgen's own term "x-rays." Röntgen's name, even in its anglicized spelling, is difficult for many Americans to pronounce. The preferred pronunciation, rünt'gen, usually gives way to rent'gen. Since scientific and lay readers are alike familiar with the meaning of "x-rays" this term will be used throughout.

2. Wilhelm Konrad Röntgen discovered and named x-rays in 1895 and the Curies isolated radium chloride in 1898.

3. The terms "radiation" and "irradiation" are often loosely used in their several different and overlapping meanings. In this paper "radiation" will be used to indicate the radiant energy itself and "irradiation" will denote the application of the rays to an object.

4. Uhlmann, E.: *Significance and Management of Radiation Injuries* (1942) 38 RADIOLOGY 445.

5. The seven articles below all bear the heading "Warren, S.: Effects of Ra-

the scientific and experimental aspects of the subject in greater detail than will be attempted here. However, a brief survey of the nature and physical properties of radiant energy will contribute to an understanding of the discussion to follow.

X-RAYS: NATURE, PRODUCTION, PHYSICAL PROPERTIES AND DOSAGE

X-rays are invisible electro-magnetic waves similar to light and falling within the same spectrum as radio waves, heat (or infra-red) rays, visible light and ultra-violet light.⁶ Like the other members of the spectrum, x-rays travel in straight lines at a speed of 186,300 miles per second and are partially or completely absorbed in the materials through which they pass. On absorption, the energy of the rays at first produces a temporary state of ionization (separation of atoms and molecules into electrically charged particles) but is soon released in the form of heat and chemical changes. The chemical and biological effects appear to be proportional to the amount of ionization produced.

The production of x-rays for medical use is carried out in large vacuum tubes somewhat similar to electric light bulbs but differing in that there

diation on Normal Tissues," although parts III, IV and XII were written by other authors and edited by Warren.

- (a) Warren, S.: *Effects of Radiation on Normal Tissues, I. Introduction: II. Effects on the Cell* (1942) 34 ARCH. PATH. 443.
- (b) id. III. Dunlap, C. E.: *Effects of Radiation on the Blood and the Hemopoietic Tissues, Including the Spleen, the Thymus and the Lymph Nodes* (1942) 34 ARCH. PATH. 562.
- (c) id. IV. Friedman, N. B.: *Effects of Radiation on the Gastro-intestinal Tract, Including the Salivary Glands, the Liver and the Pancreas* (1942) 34 ARCH. PATH. 749.
- (d) id. V. *Effects on the Respiratory System* (1942) 34 ARCH. PATH. 917.
- (e) id. VI. *Effects on the Cardiovascular System. VII. Effects on the Urinary System* (1942) 34 ARCH. PATH. 1070.
- (f) id. VIII. *Effects on the Gonads. IX. Effects on the Nervous System* (1943) 35 ARCH. PATH. 121.
- (g) id. X. *Effects on Organs of Special Sense. XI. Effects on Endocrine Glands. XII. Gates, O.: Effects on Bone, Cartilage and Teeth. XIII. Effects on the Skin. XIV. Effects on Striated Muscle. XV. Effects on the Germ Plasm and the Embryo* (1943) 35 ARCH. PATH. 304.
- (h) COLWELL, H. A., AND RUSS, S.: *RADIUM, X-RAYS AND THE LIVING CELL* (2d ed., 1924). London, G. Bell & Sons.
- (i) DUGGAR, B. M.: *BIOLOGICAL EFFECTS OF RADIATION* (1936). New York, McGraw Hill Book Co., Inc.
- (j) Rolleston, H.: *Critical Review: The Harmful Effects of Irradiation (X-rays and Radium)* (1930) 24 QUART. J. MED. 101.
- (k) Warren, S. L.: *The Physiological Effect of Roentgen Radiation upon Normal Body Tissues* (1928) PHYSIOL. REV. 92.
6. CLASSER, O.: *THE SCIENCE OF RADIOLOGY* (1933) Springfield, Charles C. Thomas.

is no continuous wire or electrical conductor through the x-ray tube. The tube contains two electrodes entering at opposite ends of the tube and separated by a gap within the vacuum. A current of electricity under high voltage is passed through the tube and leaps the gap between one electrode, known as the "cathode," and the other known as the "anode" or "target." On striking the anode a part of the energy of the stream of electricity is converted into invisible x-rays which pass out through the walls of the vacuum tube much as light passes out of an electric light bulb. It is important to remember that x-rays are true electro-magnetic waves and are in no sense the same as an electric current.

X-rays are cast out in all directions from the target of an x-ray tube but for most medical purposes it is desirable to use only a small beam which can be directed to a particular part of the body. It is therefore the practice in all modern equipment to surround the tube with a shielding layer of lead, or other absorbent material leaving only a small aperture through which the usable beam may pass. In this aperture it is customary to place filters which are usually thin layers of copper, aluminum or both. The filters absorb rays of longer wave length and allow most of the rays of shorter wave length and greater penetrating power to pass. The higher the voltage of the electric current used to generate x-rays the more penetrating the resulting rays will be. Therefore high voltages ranging from 100,000 to 1,000,000 volts are used in generating rays for the treatment of deep seated disease while lower voltages are suitable for taking x-ray photographs and treating superficial disease.

The accurate measurement of doses of radiation is a complex but important feature of all undertakings which involve the exposure of human beings. A physical unit of measurement known as the "roentgen" or "r" is in universal use for measuring x-ray doses but is less easily applied to other types of radiation. The roentgen is measured in terms of the amount of ionization produced in a measured volume of air through which the beam of x-rays is passing. Since all tissue changes resulting from exposure to radiation of these wave lengths are believed to be due to ionization, doses measured in term of ionization might be expected to give predictable degrees of biological effect. Within limits this is true and under the usual conditions of exposure it can be predicted that a dose of approximately 600 r, for instance, generated at 200,000 volts will produce a moderate reddening of the skin or "erythema" in a normal human subject. This same dose, however,

if administered at low intensity over a long period of time or in divided doses with intervening rest periods or to a very small area, will produce much less change in the tissues. Numerous technical factors such as the wave length of the radiation, the amount of filtration, the distance of the patient from the x-ray tube (skin-target distance), etc. complicate the problem to such a degree that only a person trained and experienced in radiological work can determine whether or not a dose of radiation stated in roentgens was suitable to the purpose for which it was employed.

Although there is no unit of biological dosage which will accurately represent the degree of tissue damage, an arbitrary and inexact unit known as the "erythema dose" is in common use. An erythema dose is the amount of radiation which will produce a slight reddening of the skin in the average human subject. It is obvious from the previous discussion that this dose does not bear a constant relationship to physical doses measured in roentgens. The erythema dose for single exposures may vary from about 300 r with very long wave-length or "soft" radiation up to as much as 1000 r in the case of "hard" radiation generated at 1,000,000 volts. The unit is also inexact in that one erythema dose of soft radiation produces less damage to deep seated structures than an erythema produced by hard, penetrating rays. However there is no more satisfactory standard by which to compare the biological effects of radiation of different quality (wave-length).

RADIUM AND RADON: PROPERTIES AND DOSAGE

Radium is a rare metallic element which emits radiation spontaneously without being supplied with electrical or other energy from an external source. Radium emits three types of radiation known as alpha particles, beta particles and gamma rays. Alpha and beta radiation have relatively little ability to penetrate tissues. Alpha particles are absorbed by an ordinary sheet of paper and the beta particles of radium penetrate tissues to an average depth of only about one centimeter ($\frac{2}{5}$ of an inch). Hence alpha and beta radiation find little use in medicine and are generally filtered off and eliminated by enclosing the radium in a capsule or needle of steel, gold or platinum. The medical importance of alpha and beta radiation lies chiefly in their deleterious effects on the health of persons who inadvertently swallow, inhale, or otherwise take radioactive substances into their

bodies.⁷ The gamma rays of radium are in all respects similar to "hard" x-rays, generated at about one million volts.

In the process of emitting radiation, radium spontaneously "decays" or breaks down into a series of elements of lower atomic weight, ultimately yielding lead. A sample of radium decays to half its initial radiant strength in a matter of 1690 years so that in terms of a human life-time its radiating power may be considered constant.

Radium has little use in the diagnostic of disease and is employed only in treatment. It is either put up in applicators and applied to the surface or natural cavities of the body or packed into hollow needles and inserted directly into the tissues.

Radium constantly emits a radioactive gas known as radon which when trapped and enclosed in sealed tubes may be used in a fashion similar to radium itself. Radon decays very rapidly, losing half its strength in 3.85 days. Radon tubes or "seeds" may therefore be left permanently within the body without exposing the tissues to a constant, unremitting bombardment of radiation throughout the patient's remaining life, as would be the case if radium were so used. Forty naturally radioactive elements are known to science but only radium and radon are used extensively in medicine. Thorium and some of its derivatives have found a limited use in diagnostic procedures as will be discussed in a later section.

The unit of radium dosage is the "milligram-hour" which is a dose equivalent to the energy emitted by one milligram of radium element in the course of one hour. The unit of radon dosage is the "millicurie-hour," an amount of radiation identical for all practical purposes with a milligram-hour of radium. The effect on human tissues of exposure to a given number of milligram-hours of radium is reduced in proportion to the amount of filtering material interposed between the radium and the tissue and is also

7. Medicolegal cases involving exposure to radioactive substances: *La Porte v. U. S. Radium Corp.*, 13 F. Supp. 263 (1935) (Occupational exposure); *Crawford v. Duncan*, 61 Cal. App. 647, 215 Pac. 573 (1923) (Medical treatment: Scars); *Scott v. Sciaroni*, 66 Cal. App. 577, 226 Pac. 827 (1924) (Medical treatment—over-exposure); *Vallat v. Radium Dial Co.*, 360 Ill. 407, 196 N. E. 485, 99 A. L. R. 607 (1935); *Ferguson v. Bellaire*, 197 Iowa 277, 197 N. W. 13 (1924) (Medical treatment: cancer); *Graham v. Updegraph*, 144 Kan. 45, 58 P. (2d) 475 (1936) (Medical treatment); *U. S. Radium Corp. v. Globe Indemnity Co.*, 13 N. J. Misc. 316, 178 a. 271, *aff'd* 116 N. J. Law 90, 182 A. 626 (1935) (Occupational exposure); *Pine v. Waterbury Clock Co., Inc.*, 245 App. Div. 605, 283 N. Y. S. 763 (1936) (Industrial); *Jacobs v. Grigsby*, 187 Wis. 660, 205 N. W. 394 (1925) (Medical treatment).

reduced as the square of the distance between the radium and the tissue. Tissue doses of radiation from radium and radon sources are very difficult to compute and have little meaning in terms of tissue damage unless they are interpreted by an expert. The tissue changes produced by x-ray, radium and radon are qualitatively the same.

CYCLOTRON RADIATION AND ARTIFICIALLY RADIOACTIVE SUBSTANCES

In recent years physicists have succeeded in rendering practically all of the known elements temporarily radioactive (capable of emitting radiation) by exposing them, or a precursor, to the enormous energies generated by the cyclotron ("atom-smasher").⁸ A number of these machines are in operation in the United States, the largest being at the Radiation Laboratory of the University of California at Berkeley. Artificially radioactive elements behave in most respects like their natural counterparts (isotopes) except that they emit radiant energy in a fashion very similar to the natural behavior of radium. Radiation is given off as a product of the spontaneous disintegration or "explosion" of individual atoms. Various radioactive isotopes disintegrate at different rates and the intensity and duration of the radiation differs for each isotope. With several exceptions only beta radiation is produced, which has relatively little ability to penetrate tissues.

Doses of radioactive isotope radiation are stated in millicurie-hours, the same unit used in the case of radon. However, the unit takes on a variable significance for different isotopes since it is computed on the basis of the number of atomic disintegrations occurring each second (1 millicurie = 3.5×10^7 disintegrations per second) regardless of the amount of radiation energy produced or the character of the radiation. Thus the units, although they have definite meaning to the physicist have little biological significance unless they are computed in terms of energy and penetration.

The cyclotron and its products have been used chiefly in the study of nuclear physics and experimental biology but a number of investigators are exploring the possibilities of treating human disease by introducing artificially radioactive substances into the body, either by mouth or by injection. Some degree of success has attended the use of radioactive phosphorus in treating a universally fatal tumor-like disease of the blood known

8. Aebersold, P. C.: *The Cyclotron: A Nuclear Transformer* (1942) 39 RADIOLOGY 513.

as leukemia,⁹ and other possibilities are being tested.¹⁰ As yet, radioactive isotopes find no place in the therapeutic armamentarium of the ordinary practicing physician. In the present state of knowledge concerning the immediate and ultimate effects of these substances no patient should be exposed to their action without having been informed of the experimental nature of the procedure.¹¹

A new cause of litigation may arise out of the hazard incurred by personnel working with or near cyclotrons and their radioactive products. Trained physicists, chemists and biologists might be expected to understand the dangers involved and to conduct their work with suitable caution. In practice many of them are amazingly obtuse to the possibilities of serious bodily injury and need to be protected from themselves by careful medical supervision. The same applies with even greater force to technical assistants of non-professional standing and to persons not engaged

9. *Leukemia*: The condition has been briefly defined as follows: "Leukemia is a fatal disease, considered by many to be neoplastic (tumor-like or similar to cancer) in nature, which arises primarily in the blood-forming organs, and is characterized by an extensive and abnormal proliferation (multiplication) of the leukocytes (white blood cells) and their precursors. Almost invariably at some time during the disease, immature white corpuscles appear in the circulating blood, frequently in great numbers; in most cases there is an associated anemia, often of a severe degree." CECIL, R. L.: *A TEXTBOOK OF MEDICINE*, (5th ed. 1940) at p. 1085 Philadelphia, W. B. Saunders Co. Various types of the disease are recognized, but the diagnosis is usually established very easily because of the characteristic changes one detects in the blood picture by a count of the white blood cells and by a study of a stained blood smear under the microscope. In an ordinary person we find somewhere between 6,000 and 8,000 white blood cells in a cubic millimeter of blood; in leukemia the count may increase to levels of 30,000 to 1,000,000 per cubic millimeter with a marked increase in one or more of the types of immature leukocytes.

10. Low-Beer, B. V. A.; Lawrence, J. H., and Stone R. S.: *The Therapeutic Use of Artificially Produced Radioactive Substances* (1942) 39 RADIOLOGY 573.

11. A physician who subjects a patient to experimental methods of treatment without making a full disclosure of the material facts so that the patient may assume or reject the risk may thereby become liable in damages for resultant injury.

Slater v. Baker, 2 Wils. K. B. 359, 95 E. R. 860; (Eng. 1767);

Kershaw v. Tilbury, 214 Cal. 679, 8 P. (2d) 109, 115 (1932);

Langford v. Kosterlitz, 107 Cal. App. 175, 290 Pac. 80 (1930);

Baills v. Boulanger, 4 D. L. R. 1083 (Alberta Sup. Ct., Canada, 1924).

In exceptional cases (extreme emergency requiring immediate surgery to forestall death or serious bodily injury where patient is unable to speak and legal representatives cannot be readily located) surgery may be performed without consent. The same rules would apply to similar cases involving experimental irradiation. See Smith, H. W.: *Antecedent Grounds of Liability in the Practice of Surgery* (1942) 14 ROCKY MT. L. REV. 233; Smith, H. W.: *Legal Responsibility in Surgical Practice*, a section in THOREK'S SURGICAL ERRORS AND SAFEGUARDS (4th ed., 1943). Philadelphia, J. B. Lippincott Co.

in radiological work who may occupy living or working quarters in the immediate vicinity without protection from scattered radiation.¹²

The character of the tissue damage produced by exposure to the direct beam emitted by the cyclotron¹³ (neutrons or deuterons) and by artificially radioactive elements appears to be identical for most practical purposes with the injuries resulting from exposure to x-rays or radium and hence these injuries can be discussed together in a later section of this paper.

NATURE AND HAZARDS OF NON-MEDICAL USES OF RADIATION

A number of industrial, commercial and experimental pursuits involve the hazard of exposure to dangerous doses of radiant energy. Safeguards against overexposure have been installed in many establishments where the hazard is great so that the actual number of serious accidents has so far been small. However, in any of these occupations uninformed personnel may neglect to take the prescribed precautions and become casualties to innocent carelessness. Several of the principal hazards are indicated under separate headings below.

1. *Manufacture of X-ray Tubes*

In order to attain the high vacuum essential to the proper functioning of an x-ray tube it is necessary to operate the tube in the factory during the process of pumping out the retained gases. As an unavoidable result of this process, x-rays are generated and are scattered throughout the chamber where the pumping is conducted. The hazard to employees is obvious and the methods of protection are adequate in the majority of factories.

2. *Detection of Flaws in Metal Castings and Welds by X-ray and Radium Photography*

Supervoltage x-rays (generated at 400 kilovolts or more) and the gamma rays of radium can penetrate to considerable depths in metals and

12. These warnings are very important as we enter the new era of atomic energy and intensive research in the field of nuclear physics. The new giant betatron to be installed at the University of Illinois at a cost exceeding a million dollars will be housed in a special structure, and surrounded by various operating safeguards. Since the full properties of the rays generated are still under investigation, elaborate precautions and warnings should be maintained in respect to personnel and it seems that all persons connected with such research should have risk of injury covered by adequate insurance.

13. Stone, R. S., and Larkin, J. C.: *The Treatment of Cancer with Fast Neutrons* (1942) 39 RADIOLOGY 608.

are being used extensively to photograph the internal structure of metallic castings and welds. Air bubbles and other defects in the metal are revealed as areas of decreased density. Enormous doses of radiation are used and the work is often conducted by engineers and workmen without medical supervision. Provision for the protection of personnel is frequently inadequate or non-existent, and serious consequences are to be anticipated unless the existing state of affairs is promptly remedied.

3. *Manufacture of Luminous Dials*

The luminous dial industry has provided most of the litigation which has arisen to date from industrial exposure to radiation. The paint used in the manufacture of luminous dials is composed chiefly of zinc sulphide rendered luminous by the addition of about one part in 40,000 of radium, mesothorium and radiothorium. The figures are painted on the dials by hand and it was formerly the practice of the workers to bring their brushes to a sharp point by drawing the bristles between their moistened lips. In this fashion minute amounts of radioactive material were taken into the mouth each day and small but definite amounts accumulated in the tissues of the body, chiefly in the skeleton. The bones of the victims were thus subjected to continuous bombardment by the alpha, beta and gamma radiation from the radioactive deposits. The nature of the poisoning and its medical consequences have been described in detail by Harrison Martland,¹⁴ Chief Medical Examiner of Essex Co., N. J., who followed many of the victims throughout their illness to death and autopsy.¹⁵ The course of events in briefest outline was as follows. The earlier cases were characterized by ulcerations of the gums, necrosis¹⁶ of the bones of the jaw and various grades of anemia.¹⁷ The later cases, which survived the poison-

14. Martland, H.: *The Occurrence of Malignancy in Radioactive Persons: A General Review of Data Gathered in the Study of the Radium Dial Painters, with Special Reference to the Occurrence of Osteogenic Sarcoma and the Inter-Relationship of Certain Blood Diseases* (1931) 15 AM. J. CANCER 2435.

15. *Autopsy*: Post mortem examination to determine the cause of death and the extent to which disease or injury has affected particular organs. The examination is a systematic one involving gross inspection of the main organs and also the taking of small samples of tissue for microscopic study. Oftentimes the microscopic changes are characteristic of a particular disease or injury and the pathologist is therefore able to determine the nature of the disease or cause which produced the patient's illness or death.

16. *Necrosis*: Death of tissue.

17. *Anemia*: A condition in which the red blood cells are deficient either in quantity or in quality. The deficiency in quality may consist in diminution of the amount of hemoglobin (which transports oxygen) or in diminution of the number of red blood corpuscles.

ing for periods of six years or more, exhibited chronic, crippling, destructive lesions of bone in many parts of the body which often developed after years of apparent good health. Mild anemias were often present. Among 18 deaths attributable to occupational poisoning with radioactive substances at least 5 were due to the development of osteogenic sarcoma (cancer of bone).¹⁸ The amount of radioactive material found in the bodies of the victims was only a few millionths of a gram but any doubt that the changes were produced by radioactive deposits has been resolved by experimental reproduction of the same chain of events in laboratory animals.¹⁹

4. *Manufacture and Handling of Radium Applicators and Needles*

The preparation of purified salts of radium from impure ores and the preparation of radium applicators and needles and luminous paint involves exposure not only to the radiations from the radium but also to radon gas in the room air and to the chance inhalation or ingestion of particles of radium. In practice, the injuries which are seen are usually confined to chronic burns of the finger tips although low grade anemias are occasionally encountered. Some exposure of the fingers is unavoidable in such work and the main protective measures are: 1. the elimination of all unnecessary exposure by the use of adequate lead shielding, long handled instruments and speed in dangerous operations; 2. the rotation of workers so that none spends too long a time at the more hazardous operations; and 3. careful medical supervision so that any worker showing evidence of the slightest radiation injury may be removed permanently from further exposure.

5. *Mining and Handling of Radioactive Ores*

Radium and other radioactive substances occur in very low concentrations in the natural ores from which they are obtained. No medical difficulties have been encountered among the miners of "pitchblende," the chief source of radium. However the workers in the cobalt mines of Schneeberg and Joachimsthal have suffered for many centuries from an obscure disease of the lungs more recently identified as cancer. Considerable radioactivity has been found in the waters of these mines and the evidence points

18. For court cases involving industrial or occupational exposure to radioactive substances, see n. 7 *supra*.

19. Dunlap, C. E.; Aub, J. C.; Evans, R. D., and Harris, R. S.: *Transplantable Osteogenic Sarcomas Induced in Rats by Feeding Radium* (1944) 20 AM. J. PATH. 1.

to inhaled radon as the probable cause of the lung cancers.²⁰ No cases of lung cancer among miners of radioactive ores have been reported from North America but the recent exploitation of the large radium deposits in the Great Bear Lake region of Northern Canada brings the potential hazard closer to the United States.

6. *Biological, Chemical or Physical Experiments With Radiation*

Many scientists although engaged in the study of radiation phenomena are not alive to the dangers of exposing themselves and their assistants to excessive doses. The greatest potential hazards are suffered by students of atomic physics since their work may involve the use of the enormous energies generated by the cyclotron and by supervoltage x-ray machines. As is so often the case where the dangers are great they are recognized and adequate protective measures are provided. The main problem is to induce scientists to take advantage of the available protection.

Chemists were seldom exposed to dangerous quantities of radiation before the advent of artificially radioactive elements. Many chemists are now engaged in the purification of these elements, the synthesis of radioactive compounds, and in other experiments involving their use. Some radioactive elements are relatively safe to handle since they emit radiation at low intensity. Others, particularly "short life" isotopes such as carbon (C^{11}) and Sodium (Na^{24}) are more dangerous to the chemist since they give off most of their energy at high intensity in a brief period of time. Almost the entire supply of radioactive isotopes has, until recently, been consumed in war research conducted for the most part under adequate supervision. When these substances again become available for general use they should be supplied only to investigators who understand protective measures against excessive radiation. Thus far no serious injuries to chemists have been reported as a result of working with artificially radioactive substances. The potential dangers have been exemplified by the burns and anemias suffered by chemists who have worked with radium and related compounds.²¹

Many types of radiation are employed in experimental biology among

20. HUEPER, W. C.: OCCUPATIONAL TUMORS AND ALLIED DISEASES (1942) 435. Springfield, Charles C. Thomas.

21. (a) Jaulin: *Rapport sur les Dangers des Rayons-X et des Substances Radioactives pour les Professionnels—Moyens de s'en Preserver* (1927) 11 J. RADIOL. ET D'ELECTROL. 193. (Abstracted in (1928) 19 AM. J. ROENTGENOL. 308.

(b) Hueper, W. C.: *op. cit. supra* n. 20 at p. 602.

the most popular being the radioactive isotopes. In biology these substances are generally used in minute amounts as "tracers" or "identification tags" on compounds and in this use they carry little danger to the experimenter. Work involving the experimental exposure of biological material to x-rays and radium is often conducted with little regard to the safety of the investigator, even in laboratories of high scientific standing.

7. *Casual Experiments With X-ray Equipment by Untrained Persons*

Old-fashioned x-ray equipment was complicated to operate and sufficiently forbidding in appearance to discourage the casual tamperer. Modern shock-proof apparatus of simplified operation and appearance, particularly fluoroscopic machines, present an almost insuperable temptation to an inquisitive layman. Any experimentally-minded citizen who has watched the machine in operation and has access to it in the absence of the radiologist may be impelled to "have a look at the bones." One look leads to another and the cumulative exposures soon exceeds the limits of tissue tolerance. A number of workmen in a large West Coast industry were seriously burned in a recent series of laymen's experiments conducted during the lunch hour with a fluoroscopic machine in the first-aid room. Responsibility for such accidents depends, of course, upon the circumstances but all rooms containing radiological apparatus should be kept locked in the absence of a responsible person and warning notices should be posted when indicated.

8. *X-ray Equipment Used in Sales Promotion*

In several of our larger retail stores one may find in the shoe department a simple looking device used for demonstrating to the customer the position of the bones of his foot within the new shoes. As the clerk pushes a button the customer places his foot in a slot near the bottom of the machine and gazes through the top at the fluoroscopic image of his foot. No report of injuries suffered from the use of these machines has been found but the potential hazard will be obvious from the subsequent discussion of the dangers of fluoroscopy. The skin and mature bones of the adult foot tolerate considerable radiation but the growing bones of children are subject to irremediable damage from much smaller exposures. The clerks are doubtless instructed to limit the time and number of exposures and the machines are probably safe when operated in strict accord with

the manufacturers' instructions. However no book of rules can curb uninformed human curiosity.²²

MEDICAL USES OF RADIATION

The medical uses of x-rays depend chiefly upon three important properties: 1. Their ability to penetrate deeply into and through tissues. 2. The fact that they are absorbed to a different degree in tissues of different atomic composition and density. 3. The remarkable but poorly understood changes they produce in the tissues which absorb them.

The practice of radiology as a medical specialty includes two distinct branches, diagnostic and therapeutic radiology. In diagnostic radiology advantage is taken of the penetrating power and selective absorption of x-rays. Structural abnormalities can be detected by passing x-rays through a part of the body and photographing the emergent beam to reveal the shadows of bones, opaque foreign bodies and other structures which absorb greater or lesser amounts of radiation (radiography, roentgenography or x-ray photography). The emergent beam can also be observed directly through a fluorescent screen which contains materials capable of transforming invisible x-rays into longer, visible wave lengths. By this technique (fluoroscopy) one may not only see some of the internal structures of the body but even follow the motions of such organs as the heart, the lungs, the stomach and the bowels. In diagnostic radiology every effort is made to minimize the tissue damage which results from the passage of the rays by using the smallest amount of radiation which will give an adequate photographic or fluoroscopic image.

Therapeutic radiology, on the other hand, involves the intentional production of changes in the tissues by exposure to relatively large doses of radiation in an attempt to affect favorably the course of disease. High voltage x-rays (100,000 volts to 1,000,000 volts) are used for the most

22. Query whether diagnostic use of X-ray, when applied to human beings for any purpose, including fitting of shoes, does not involve the practice of medicine. It has been held that making a pedographic imprint of the foot as an aid to fitting shoes, does not involve the practice of chiropody or podiatry without a license (*People v. Dr. Scholl's Foot Comfort Shops*, 277 N. Y. 151, 13 N. E. (2d) 750 (1938), reversing 252 App. Div. 842, 300 N. Y. S. 602 (1937) nor should the shoe salesman's action in pointing out manifest abnormalities of the feet and making passing remarks be construed as diagnosis, particularly since he referred the customer to a duly licensed chiropodist employed by the store.

In the Scholl case, however, no dangerous diagnostic instrumentalities were used such as would require medical supervision to eliminate or minimize risk of injury.

part but in some conditions such as cancer of the cervix of the uterus,²³ radium and radon have special advantages, used either alone or in conjunction with x-rays. Radiation therapy finds its widest application in the treatment of malignant tumors (cancers) but it has also been employed by reputable radiologists and with varying degrees of success in treating sundry skin diseases, pneumonia and other bacterial and virus infections, dysfunction of the endocrine glands (hyperthyroidism, hyperpituitarism, etc.), menstrual disorders and a host of other conditions too numerous to catalogue. Most of the therapeutic uses of radiation apart from the treatment of malignant tumors are still to some degree experimental and the doses which may be legitimately used should be small enough to carry little hazard of serious damage to normal tissues.²⁴

HAZARDS IN THE USE OF RADIATION

1. *Injuries to Patients During Diagnostic Procedures*

The x-ray machines used in diagnostic radiology are operated at low voltage (50 to 90 kilovolts) and produce soft radiation of relatively low penetrating power. As a result, the injuries from overexposure are almost exclusively burns of the skin, and damage to deep-seated organs is uncommon. The exposures used in taking x-ray photographs are so short that tissue damage practically never results.²⁵ Most of the accidents in diagnostic

23. *Uterus*: The hollow muscular organ, constituting a part of the female reproductive system, in which the fertilized ovum implants and develops into an embryo. It is a pear-shaped structure, about three inches in length, consisting of a broad, flattened part (body) above and a narrow, cylindrical part (cervix) below. The cervix connects the uterus above with the vagina below.

24. *Editor*: It is interesting to note that far more litigation in respect to X-ray burns appears to have arisen from therapeutic irradiation of skin diseases, such as eczema, than from treatment of cancer.

25. Courts have not been sufficiently aware of this important difference between diagnostic and therapeutic use of irradiation. It seems that diagnostic films properly made, considering the low voltage of the rays and the transient exposure required, should never result in burns; injury of the patient therefore raises an inference of negligence and the doctrine of *res ipsa loquitur* should be uniformly applied. The defendant physician might still be able to introduce affirmative evidence of his due care sufficient to eliminate the inference altogether or to make a disputed fact issue for submission to the jury. In case of therapeutic burns, on the other hand, one cannot say so confidently that production of a burn always proves negligence; in such a case, the doctrine of *res ipsa loquitur* should be applied circumspectly, if at all.

In general, the doctrine *res ipsa loquitur* (the thing speaks for itself) may be applied in tort cases to raise an inference that the defendant's negligence produced plaintiff's injury in cases where: the plaintiff has been injured in a manner he cannot explain, without fault of his own, by an instrumentality under the exclusive control of the defendant, the injury being such as would not have occurred except for the

radiology result from fluoroscopy.²⁶ During fluoroscopic examination the patient is exposed to the beam of x-rays for periods of a few seconds to several minutes depending upon the nature of the examination and the

negligence of the defendant in controlling or using the instrumentality. Courts of all the states do not give the same effect to the doctrine, there being three divergent views currently followed, namely: (1) That *res ipsa loquitur* enables the plaintiff to avoid an adverse directed verdict and thus to get his claim to the jury for determination of the defendant's negligence unless defendant's evidence, in the court's opinion, satisfactorily rebuts the inference (2) That it has the effect of requiring the defendant to "come forward with evidence of due care" to avoid having the court instruct a verdict against him; (3) That it operates to shift the burden of proof, so that plaintiff is relieved of proving negligence affirmatively and defendant must prove his absence of negligence (due care) by a preponderance of the credible evidence.

Some courts are not so ready to apply the doctrine of *res ipsa loquitur* to medical treatment as to other tort situations. This reluctance is based, in part, on the rules that a physician does not guarantee a cure and that a bad medical result alone does not prove negligence. In X-ray burn cases, some courts have bolstered their reluctance by assuming that the burn may have been due to sensitivity of the patient rather than to negligence in administering the irradiation. The factor of hypersensitivity of the patient is shown by Dr. Dunlap to be much overstressed; furthermore, the exposure required in making diagnostic films ordinarily should not burn a sensitive individual and lastly, in cases requiring prolonged treatment, there is no reason why the physician should not determine for himself, by initial small dosages, of irradiation, whether the patient is hypersensitive or not. By use of due care the physician should be able to determine hypersensitivity to X-ray irradiation; the patient cannot.

Even if a court is disposed to deny the applicability of the doctrine of *res ipsa loquitur* in a particular case of injury by X-ray or radium, it should be recognized that negligence may be affirmatively proven by medical study of the patient and of the nature of his burn. Available knowledge permits a competent expert to reason from result to cause, since the exposure factors which lead to burns are now understood. Courts (as in *Lett v. Smith*, 6 La. App. 248 (1927)) fall into error when they exclude such expert opinions on the ground that they really involve an indirect application of the doctrine of *res ipsa loquitur*; such opinions, in fact, are positive evidence based upon medical study and interpretation of cause-effect relationships. The New Jersey courts have perceived this distinction. See *Young v. Stevens*, 132 N. J. L. 124, 39 A. (2d) 115 (1944), a tort action against defendant, a roentgenologist, for X-ray burns resulting from allegedly excessive irradiation in treating plaintiff's pilonidal cyst. The appeal court, in affirming a judgment in plaintiff's favor, held that the trial court properly permitted a physician who had not attended plaintiff, but had examined him prior to trial, to testify as follows: "I have to say that by ocular proof, by touch, and by the remains of the material that has been destroyed or altered in form, that the dosage of X-ray given is many times the safety dosage which would produce only an erythema."

And see, *Christie v. Callahan*, 124 F. (2d) 825 (App. D. C. 1941).

26. For cases involving injuries allegedly due to fluoroscopy, see: *Routen v. McGehee* 186 S. W. (2d) 779 (Ark. Sup. Ct. 1945); *Johnson v. Black Co.*, 33 Cal. App. (2d) 363, 91 P. (2d) 921 (1939) (Fluoroscopic table broke); *Ballance v. Dunnington*, 241 Mich. 383, 217 N. W. 329, 57 A. L. R. 262 (1928); *Henslin v. Wheaton*, 91 Minn. 219, 97 N. W. 882, 64 L. R. A. 126, 103 Am. St. Rep. 504 (1904); *Gottschall v. Geiger*, 207 Mo. App. 89, 231 S. W. 87 (1921); *Evans v. Clapp*, 231 S. W. 79 (Mo. App. 1921); *Walsh v. Sisters of Charity of St. Vincent's Hospital*, 47 Ohio App. 228, 191 N. E. 791 (1933); *Cooper v. McMurry*, 194 Okl. 241, 149 P. (2d) 330 (1944); *King v. Ditto*, 142 Or. 207, 19 P. (2d) 1100 (1933); *Nelson v. Newell*, 195 Wis. 572, 217 N. W. 723 (1928).

dexterity and experience of the examiner. The intensity of radiation delivered (output) by different machines varies and can only be determined by direct measurements. A fair average figure would be in the neighborhood of 20 r per minute under ordinary operating conditions but this figure can be greatly increased by increasing the operating voltage²⁷ or amperage²⁸ or placing the patient closer to the x-ray tube. A dose of about 300 r of x-rays generated by fluoroscopic equipment will produce an erythema of the skin and such a reaction should be considered both undesirable and avoidable in fluoroscopic work. A high proportion of all accidental x-ray burns are incurred during fluoroscopy and they are attributable almost without exception to ignorance or carelessness on the part of the fluoroscopist. The specific procedures which are most likely to result in overexposure are attempt to set fractured bones and to remove foreign bodies under direct fluoroscopic vision. It is perfectly legitimate to check the position of fractured bones or to locate a foreign body under the fluoroscope but the practice of manipulating fractures or probing for foreign bodies under continuous or intermittent fluoroscopic control is so likely to result in overexposure that neither procedure is sanctioned in good radiological practice.²⁹

Radium is not used in diagnostic but thorium, another radioactive substance, has found a limited application in a few special procedures. Thorium is an element of high atomic number and hence will cast a shadow in an x-ray photograph even when it is present in very small concentrations. This property of thorium accounts for its use in diagnosis whereas the fact that it emits radiation itself is considered only as an incidental undesirable side effect. The possibility that injury might result from the small amount

27. *Voltage*: A volt is the unit of electrical pressure or electromotive force, being the force necessary to cause one ampere of current to flow against one ohm of resistance. An ohm is the electric resistance of a column of mercury one square millimeter in diameter and 106 centimeters long.

28. *Amperage*: An ampere is the unit used to measure the rate of transfer of electricity. International ampere is the unvarying electrical current which, when passed through a solution of silver nitrate in accordance with certain specifications, deposits silver at the rate of 0.001118 Cm. per second.

29. (a) *Danger of Setting Fractures and Removing Foreign Bodies Under the X-ray screen* (A Memorandum Circulated to the Emergency Medical Service and Published by the Permission of the Ministry of Health) (1941) 14 BRIT. J. RADIOL. 344.

(b) Leddy, E. T.: *The Dangers of Roentgenoscopy: Summary and Recommendations* (1937) 38 AM. J. ROENTGENOL. 924.

(c) Schatzki R.: *Diagnostic Roentgenology: Dangers Associated with Fluoroscopy*. (1942) 227 N. E. J. MED. 18.

of radiation emitted by commercial preparations containing thorium has been discounted by many physicians. However, the Council on Pharmacy and Chemistry of the American Medical Association reviewed the possible dangers of injecting one such compound (thorotrast) as long ago as 1932³⁰ and the Journal of the American Association recently commented, editorially, that "Most investigators advise that the material (thorotrast) be employed only in cases in which there is some serious reason for its use or in those in which early death may be reasonably expected."³¹ The majority of careful radiologists hesitate to introduce any long-life radioactive compounds into the tissue³² even though few serious injuries have been reported which are directly attributable to the injection of thorotrast or other thorium compounds.

2. *Injuries to Patients During Therapy (Overtreatment and Undertreatment)*

The liability of a physician for the occasional untoward results of radiation therapy should be balanced in each instance against the gravity of the disorder for which the patient was treated and the probable efficacy of radiation in relieving that disorder. Acne vulgaris ("pimples") of the face, for instance, often responds well to x-ray therapy but since the disease is not serious it should be treated conservatively and a physician is strictly accountable for producing a disfiguring burn by overzealous irradiation.³³ Malignant melanoma (a type of cancer) on the other hand is usually fatal regardless of the type of treatment. This is one of the forms of cancer in which radiation therapy is seldom of benefit and a physician should consider whether the meager hope of improvement outweighs the danger and discomfort of heavy irradiation.

30. Council on Pharmacy and Chemistry, American Medical Association: *Thorotrast* (1932) 99 J. A. M. A. 2183.

31. Queries and Minor Notes: *Visualization of Intrahepatic Lesions with Thorium Dioxide* (1941) 117 J. A. M. A. 1491.

32. (a) Jacobson, L. E., and Rosenbaum, D.: *Postmortem Findings and Radio-Activity Determinations Five Years after Injecting Thorotrast* (1938) 31 RADIOLOGY 601.

(b) Taft, R. B.: *Demonstration of Gamma Radiation from Living Patient Following Thorotrast Injection* (1937) 29 RADIOLOGY 530.

33. This is a very important principle not properly emphasized in litigation. If the patient's condition is not particularly serious, and reasonably effective alternative methods of treatment involving no risk of injury are available, whereas favorable results can be expected from X-ray therapy only by running some risk of inflicting a burn, it is probably negligent practice to subject the patient to the unnecessary risk of injury, at least without his knowledge and consent in advance. It is worth noting that many of the litigated cases involve burns resulting from the X-ray treatment of eczema, a skin condition.

Some malignant tumors (cancers) may either be cured or temporarily arrested in their growth by irradiation.³⁴ Proper treatment generally requires the administration of very large doses not only to the tumor mass but to a wide margin of adjacent normal tissue which might harbor extensions or metastases³⁵ of the growth.

The term "radiation burn" is usually reserved for tissue reactions of undesirable severity though in fact the doses used in routine tumor therapy produce a reaction (epidermitis) which any layman would describe as a burn. The skin within the field of treatment becomes red and swollen and the superficial layers may peel away leaving a raw, moist surface. This reaction heals but the skin often shows permanent changes of an atrophic nature³⁶ characterized by a smooth shiny surface, loss of hair and alterations in pigmentation (either loss of pigment or increased pigment). Most radiologists forewarn their patients when such changes are to be expected as the probable consequence of adequate therapy.³⁷

It is often difficult to evaluate the responsibility of the radiologist for producing skin damage of greater severity than he had intended. In handling diseases such as cancer which are invariably fatal when untreated a physician is warranted in employing the methods most likely to preserve life even though the treatment itself may be dangerous. No honest radiologist of wide therapeutic experience would deny that his treatments have on occasion led to permanent disfigurement, disability or even death which might have been avoided had he used a different technique. For more than forty years since radiation was first introduced into cancer therapy there has been a consistent and regular trend toward the use of more penetrating

34. Stewart, F. W., and Farrow, J. H.: *The Radiosensitivity of Tumors*, in I. PACK, G. T., AND LIVINGSTONE, E. M.: *TREATMENT OF CANCER AND ALLIED DISORDERS* (1940) 98. New York and London, P. B. Hoeber.

35. *Metastases*: Metastasis is the transfer of disease from one organ or part to another not directly connected with it. It may be due either to the transfer of pathogenic organisms as in tuberculosis or to transfer of cells, as in the case of malignant tumors. The tumor cells are transported from one site to another by way of the blood stream, in the circulating lymph contained in the independent network of lymph vessels or in the free fluid in such spaces as the abdominal and chest cavities.

36. *Atrophic nature*: i.e. characterized by atrophy, which involves a wasting or diminution in the size of a part resulting as a rule from interference with the normal processes of nutrition.

37. *Editor*: This would seem to be a very provident practice from a legal point of view and it is doubtless good medical management to apprise the patient in advance that such consequences may result rather than to have him become psychologically disturbed, or to lose confidence in his medical attendant, by having them appear without warning.

radiation given in larger doses. The prime result of this trend has been a steady increase in the percentage of cancer cures obtained by radiation. At the same time there has been an increase in the variety and possibly in the number of radiation injuries. In every large series of patients who have received "adequate" radium treatment for cancer of the cervix there are a few sad examples of painful or fatal radiation burns of the small intestine, rectum or bladder. Since there are no rigid criteria for determining the exact minimal dose of radiation necessary to destroy a tumor it is the considered practice of most radiotherapists to give as large a dose as can, in their best judgment, be tolerated by the normal tissues within the region exposed. A program of this character involves a large element of personal judgment, the margin of safety is necessarily narrow, and it is inevitable that in some instances "the treatment may succeed but the patient die." Each attempt is in some degree an individual experiment and the radiologist can not be held accountable for untoward results unless his treatment departs radically from the accepted practice of other competent radiologists and in a direction which carries increased risk.

The well-recognized danger of causing serious injury by over-dosage has led to abuses in the opposite direction. A physician is much more likely to be criticized or sued for the unfortunate results of overtreatment than for failure to give doses sufficient to control the disease. Inexperienced or timorous radiologists and particularly physicians without special radiological training are tempted to treat cancer with repeated and protracted exposures to ineffective "safe" doses so that death, when it comes will be a result of the primary disease and in no way attributable to the treatment. Undue conservatism in the radiation treatment of cancer is often the result of simple ignorance uncomplicated by motives of self-protection but it has certainly cost more lives than it has saved.³⁸

38. It seems clear that the gravity of the illness, and the degree of urgency in treating it by irradiation, are factors to be considered in determining whether or not resulting X-ray burns were inflicted negligently. When the alternatives are likely death of the patient or serious, irreversible injury of his health if intensive irradiation be withheld, and a chance for betterment or cure, coupled with a risk of inflicting a burn if irradiation be given, it seems to be good medical judgment for the physician to follow the course which involves the least risk. It might, in such cases, be medically inadvisable to disclose all the facts of a dread disease to the patient because to do so might undermine his morale and psychological resistance; it is believed that in a narrow range of cases the physician may have a legal privilege, on therapeutic grounds, to withhold the diagnosis and risk of impending death. In other cases, the physician might safeguard himself against later complaints by divulging to the patient in advance the necessity for prompt and vigorous treatment

Inadequate radiation therapy of cancer is disadvantageous to the patient in several respects. It delays the institution of effective treatment, it may cause apparent cure for a period of months or years during which time the growth can spread to other parts of the body and it may induce a

and that adequate irradiation may involve some risk of burn.

In *Hazen v. Mullen* 32 F. (2d) 394 (App. D. C. 1929), an experienced roentgenologist treated the patient for advanced tuberculous adenitis so far progressed that surgery upon the neck was impracticable and death appeared to be imminent if intensive irradiation were withheld. An X-ray burn resulted and in an action for damages a jury returned a verdict in plaintiff's favor. On appeal the judgment against the physician was reversed, the court being of the opinion that the giving of intensive irradiation involved the exercise of plausible medical judgment rather than negligent management of the case.

In *Blankenship v. Baptist Memorial Hospital*, 26 Tenn. App. 131, 168 S. W. (2d) 491 (1942) the plaintiff, a 35 year old married woman, brought an action for damages alleging that she sustained a painful incurable third degree burn of the abdomen as a result of defendant's negligent irradiation of a squamous cell carcinoma of the cervix. The evidence showed that the cancer was diagnosed in Aug. 1936; that her uterus, ovaries and tubes were then surgically removed (pan-hysterectomy); that in March 1937, a recurrence was treated by 1500 roentgens; that in Sept., 1938, a further recurrence was treated by 2100 roentgens administered through a round cone through four portals; that at time of trial 2½ years later, plaintiff's cancer apparently was still arrested but that a painful third degree burn resulting from the irradiation had not yet healed despite surgery; and that morphine had been required to relieve the pain arising from the burn. There was some evidence that plaintiff had become an addict to that drug.

X, the hospital roentgenologist who administered the irradiation in 1937 and 1938, testified that he used the large dosage through four portals, and was willing to risk a third degree burn because early death was otherwise to be expected. His position was that a third degree burn might be healed or cured by plastic surgery, and his course of action was supported by the testimony of other medical men. Another roentgenologist testified that it was bad practice to inflict a third degree burn in an effort to cure cancer, asserting that the painful burn was worse than the cancer and might itself become cancerous.

The appeal court held that the trial judge properly instructed a verdict in defendant's favor. If roentgenologists themselves, in a new field such as radiology, differ as to the proper course and philosophy of treatment in such a case, said the appeal court, it means that two methods of treatment are currently recognized, and at most, defendant's choice involved an error of judgment rather than negligence.

The true determinants of negligence in these cases would seem to be: (1) Gravity of the disease; (2) Imminence of death or of grave impairment of health by progression of the disease; (3) Known or presumed effectiveness of irradiation in relieving similar conditions; (4) Availability of treatment as effective as irradiation and involving a substantially smaller risk of injury; (5) Presence or absence of disclosure of risk to patient in advance of irradiation; (6) Whether effective treatment required administering irradiation in a manner involving risk of a burn; (7) Whether irradiation would probably cause painful burns without doing more than momentarily arresting advanced or widespread cancer; (8) Whether such a contrariety of opinion and practice exists that defendant can show his conduct of the case involved due care when tested by one currently accepted mode of treatment. All of these factors should be considered rather than any one alone.

If a doctor should be held liable, on the ground of negligence in such a case, an interesting problem arises as to the proper measure of damages. It would seem that no large verdict for inflicting a painful burn could be upheld in those cases

state known as "radioresistances" in which the tumor acquires the ability to withstand doses of radiation which would have destroyed it if given in the first place.

An example of the results of dilatory and misguided tactics is presented in a recent review by Warren Hoerr³⁹ of the fate of 500 patients with epidermoid carcinoma⁴⁰ of the skin. This malignant tumor is so accessible to effective surgical or radiological treatment that it can be cured in approximately 90 percent of cases by prompt and vigorous use of either method. In the 401 patients followed for 5 years or more Warren and Hoerr found that while the mortality for the whole group was 33%, 60% of those who had had prior radiation treatment died. The recognized effectiveness of adequate irradiation in curing epidermoid carcinoma of the skin is enough to indicate that the treatment received by many of these patients before coming to the hospital was insufficient. A patient with a tumor which offers a reasonable hope of cure by any method of treatment would appear to have just cause for action against a physician who allows the disease to progress to an incurable stage while administering ineffective doses of radiation.⁴¹

Physicians employing radium or x-ray in their work are dealing with dangerous tools and should be held accountable for injuries resulting from ignorance, carelessness, wantonness or poor judgment. However, the peculiar susceptibility of radiologists to successful actions for damages serves to

where the physician can prove that, but for the irradiation, the plaintiff would have died before the time of trial. In *Stoffberg v. Elliott*, (Sup. Ct., South Africa, Cape of Good Hope Provincial Division, 1922) So. African Law Reports (1923), C. P. D. 148, an analogous situation was involved. There the defendant was a visiting surgeon and he amputated the plaintiff's penis for advanced cancer, supposing that the hospital had procured pre-operative consent according to its usual routine. Through an oversight it had not done so and the patient sued the surgeon for assault and battery, seeking £10,000 in damages. According to the medical testimony, the patient would have died a horrible death in less than two years had surgery been withheld. The trial court rightly held the operation was a battery even though the surgeon acted bona fide under a mistaken belief that consent had been given. The judge, however, very properly instructed the jury that they were entitled to say whether plaintiff had suffered any damage at all. Under the charge given, the jury returned a verdict for the defendant.

39. Warren, S., and Hoerr, S. O.: *A Study of Pathologically Verified Epidermoid Carcinoma of the Skin* (1939) 69 S. G. & O. 726.

40. *Epidermoid carcinoma*: Cancer of the skin in which the cells tend to differentiate in the same way as the cells of the epidermis do.

41. Such an assumption is legally sound. A physician may be liable for injury to the patient's health or for aggravation of his disease caused by a negligent error in diagnosis, by administering the right treatment negligently, or by negligently withholding proper treatment.

discourage the use of full doses of radiation in the treatment of cancer. A more lenient attitude on the part of courts and juries toward burns incurred in the course of legitimate radiation therapy of cancer and a wider recognition that physicians who undertreat cancer are responsible for the death of many patients would appear to serve the interest both of justice and medical progress.

Serious burns resulting from the faulty treatment of non-malignant diseases require little comment. Except in the treatment of cancer, the use of dangerously large doses is improper. The chief offenders are physicians who have the courage to administer radiation therapy without being familiar with the doses tolerated by normal tissues and often without even measuring or computing the doses they apply. Another common error is the accidental failure of the radiologist or his technician to place the proper filters between the x-ray tube and the patient.⁴² The patient may thus be exposed to several times the calculated dose of radiation. A more complicated problem of responsibility arises when a burn results from applying a moderate dose to an area which has previously been irradiated by another physician. The cumulative effects of repeated irradiation are well-recognized and the physician would always ask a new patient specifically whether or not a lesion has previously been treated with x-ray or radium before applying such treatment himself. If the patient conceals the fact of previous irradiation the physician's responsibility is decreased since the presence of latent skin damage is often impossible to detect.⁴³

42. For cases involving alleged failure to use proper filters, see: *Legler v. Muscatine Clinic*, 207 Iowa 720, 223 N. W. 405 (1929); *Withington v. Jennings*, 253 Mass. 484, 149 N. E. 201 (1925); *Frederick v. Strouse*, 299 Pa. 268, 149 A. 318 (1930); *Kuehnemann v. Boyd*, 193 Wis. 588, 214 N. W. 326 (1927) (Held: removal of filter, under the evidence, appeared to be a valid exercise of the physician's judgment.)

43. The patient as well as the physician has duties in respect to medical conduct of his case. The patient is duty bound to disclose to his doctor all information called for in the course of history-taking, and to answer general questions as to his past illnesses or treatment. It may be that he has a duty to *volunteer* such major medical facts about himself as the average person would reveal to his physician in seeking medical aid. There is but little law on the subject but at any rate the principle is clear that conscious concealment or withholding of essential medical facts not otherwise ascertainable in the course of the usual medical examination, involves contributory negligence on the patient's part which will defeat a claim for such damages as result from his own non-disclosure.

Every physician, as a matter of routine, should ask the patient specific questions about his past exposure to X-ray, and in event there has been previous treatment, he should obtain a medical record of the total dosages previously given before proceeding further.

3. *Injuries to Radiologists and Their Assistants*

Protecting radiologists against occupational injury is quite a different problem from avoiding radiation injuries to patients. Radiologists are seldom foolish enough to expose themselves to a single massive dose of radiation but they are in constant danger of injury from the cumulative effects of many small exposures acquired over a period of years from repeated minor carelessness. By far the most common obvious injury is radiation dermatitis⁴⁴ of the skin of the hands resulting in most instances from manipulating patients during fluoroscopic examinations. Manipulation or palpation is necessary in several diagnostic procedures but should never be practiced without the protection of lead-rubber gloves. Occasionally radiologists are unwise enough to place their hands directly in a beam of radiation in an attempt to adjust the position of a patient during therapy. A single act of this sort may result in exposure to only a fraction of a roentgen but the effects are cumulative. Other burns of the hands, particularly of the finger tips, result from manipulating radium applicators and needles with the hands rather than with long handled forceps. A special hazard for dentists arises from the necessity of holding a small film within the patient's mouth while taking x-ray photographs of teeth. Careful dentists place the film in position and then have the patient hold it during the exposure.

Direct exposure to a beam of radiation is easily avoided, but professional radiologists are also endangered by the incidental radiation present in the vicinity of operating x-ray tubes or of radium. In the case of x-ray, a tube which is improperly shielded may permit the general escape of diffuse rays but even with the best of modern equipment a small proportion of the energy in the useful beam is dispersed in all directions from the body of the patient as secondary and scattered radiation. Scattered radiation is seldom of sufficient intensity to produce acute injuries nor is it concentrated in a fashion likely to cause localized skin damage. The results of chronic overexposure are generally limited to vague feelings of fatigue, headache and loss of appetite and specific damage to highly radio-sensitive tissues such as the testicles, ovaries and blood forming tissues. Sterility may result in either sex and anemias of various grades of severity

44. *Dermatitis*: Inflammation of the skin; radiation dermatitis, therefore, is an inflammation of the skin resulting from irradiation by X-ray or radioactive substances.

occur. Similar effects have followed chronic exposure to diffuse radiation from poorly shielded stores of radium.

Radiological technicians are subject to the same dangers as professional radiologists but often expose themselves in a slightly different manner. Technicians do not do fluoroscopic examinations and are hence spared one of the major risks. However, in taking x-ray photographs, particularly of children, some technicians hold the patient on the table and expose their bodies to scattered radiation and their bare hands to the direct beam. Technicians are often entrusted with administering routine therapy while the radiologist attends to other tasks and if the treatment room is poorly shielded they are subject to long exposures to small doses of scattered radiation. The preparation, threading, cleaning and sterilization of radium needles is usually delegated to non-professional employees and hence radium burns are seen more often on the fingers of nurses and technicians than doctors. It is of course the responsibility of those in charge of x-ray or radium installations to protect members of the staff from overexposure, first by making sure the apparatus is properly shielded and second by forbidding dangerous practices.⁴⁵

Routine medical examination of all personnel working in a radiological laboratory should be carried out at least 4 times a year and preferably once a month in order to detect early burns of the skin or changes in the red or white cells⁴⁶ of the blood. Any person showing even slight radiation changes should be removed from further exposure.

Under the best of conditions radiologists and their assistants are exposed to minute doses of radiation in the conduct of their daily work. Strict

45. This is legally correct. In the same connection it may be of interest to distinguish the liability of a manufacturer for injuries caused by defective apparatus and non-liability of a manufacturer for negligent use of adequate apparatus. Thus, one who presumes to use X-ray apparatus assumes the risk of knowing fundamental facts about its operation and dangers.

O'Connell v. Westinghouse X-ray Co., Inc., 261 App. Div. 8, 24 N. Y. S. (2d) 268 (1940) reversing judgment in plaintiff's favor in lower court. Surgeon set two fractures under X-ray beams of fluoroscope and burned his hands badly; held: his failure to know that intensity of rays increased with proximity to machine was contributory negligence as a matter of law and barred any recovery of damages in an action against the manufacturer.

46. *Red and white cells*: Red blood corpuscles contain hemoglobin and carry oxygen. The blood of the average male adult contains about five million red blood cells per cubic millimeter, that of the female about four and one half million per cubic millimeter. The white blood cells, of which there are different types, have various roles, acting both as scavengers and as combatants of bacteria, etc. Normally the blood of the average person contains between six and eight thousand white blood cells per cu. mm. of blood.

attention to the details of protection will reduce these doses to an amount readily tolerated by normal tissues. The "daily tolerance dose" or the amount to which a person may safely expose himself each day has been established by the International X-ray and Radium Protection Committee⁴⁷ as 0.2 roentgens. This figure is not based on experimental evidence showing that slightly larger daily doses are injurious but was arrived at arbitrarily as a dose so small that practically all radiologists would agree that it falls well within the limits of safety. Reduction of the daily dose to this small figure is desirable and is attainable even in a busy radiological practice. Although it is true that many radiologists have exposed themselves to larger doses for many years with no demonstrable ill effects, recent reports show a decided increase in the proportion of physicians among those suffering from radiation injuries. Further analysis reveals that the great majority of the physicians are general practitioners who "do a little x-ray work" rather than specialists in radiology.

Protection is grossly inadequate in many hospitals⁴⁸ and it should never be assumed that protective measures are satisfactory in any radiological installation regardless of the assurances of those who manufacture or install the equipment. Direct measurements should be made at regular intervals of the intensity of radiation at various points where personnel may be stationed. Measurements are best made with an ionization chamber but photographic film is a useful substitute. Small "dental films" may be placed in various positions about the laboratory or carried in the pockets of personnel. When the film is developed, a darkening sufficient to prevent reading ordinary print through the film indicates that it has been exposed to more than 0.4 r. Further practical details on protection may be found in the report of the International Committee previously cited.^{48a} Henshaw⁴⁹ has written an interesting theoretical discussion of the possible harmful effects of very small doses.

The three chief defenses of radiological workers against overexposure are, in the order of their importance, distance, speed and lead. Workers should always stay as far away from sources of radiation as possible; pro-

47. International Recommendations for X-ray and Radium Protection: Revised by the International X-ray and Radium Protection Committee at the Fifth International Congress of Radiology, Chicago, Sept.13-17, 1937, and introduced in (1938) 40 AM. J. ROENTGENOL. 134.

48. Scheele, L. A., and Cowie, D. B.: *Radiation Protection in Forty-five Hospitals*, (1941) 117 J. A. M. A. 588.

48a. See n. 47 *supra*.

cedures that necessitate a close approach to the x-ray tube or radium should be carried out as rapidly as possible and lead or other suitable shielding material should be used liberally so as to reduce scattered radiation to a minimum.

GENERAL PRINCIPLES OF TISSUE RESPONSES TO RADIATION

Before discussing the specific changes observed in tissues and their component cells as a result of exposure to radiation a few of the general principles of radiation reactions should be stated. These principles are not strict laws but merely brief summaries of the average experience of clinical and experimental radiologists. It might be pertinent to mention here that no poison or noxious substance is stored up in tissues that have been exposed to x-rays or radium so that no danger whatever is involved in handling patients or inanimate objects after they have been irradiated. The same applies of course to eating irradiated foods.

1. *Radio Sensitivity*

Any living cell can be destroyed by sufficiently large doses of radiation but all cells are not equally vulnerable. It is possible to classify the different types of cells, in a loose fashion, according to the doses of radiation they will successfully withstand. Any such classification is empirical⁵⁰ and since it disregards important variables other than dosage, is far from exact. One such classification is presented and discussed by Desjardins.⁵¹ Although it is true that various authors place some of the tissues in a slightly different order of radiosensitivity the general principle of specific tissue sensitivity is generally accepted. The following list is based on the inadequate available data and is intended to represent the approximate response of tissues exposed to divided doses of x-rays generated at 200 kilovolts.

Highly radiosensitive

(cells seriously injured or killed by doses of 600 r or less)

Lymphocytes⁵²

49. Henshaw, P. S.: *Biologic Significance of the Tolerance Dose in X-ray and Radium Protection* (1941) 1 J. NAT. CANCER INST. 789.

50. *Empirical*: Based on experience or trial and error.

51. Desjardins, A. U.: *A Classification of Tumors from the Standpoint of Radiosensitivity* (1934) 32 AM. J ROENTGENOL. 493.

52. Lymphocyte: A variety of white blood cell having a round nucleus normally present in the blood, lymph nodes, spleen, and other sites and often found in tissues affected by chronic inflammatory processes. Acute inflammations are usually characterized by the presence of a different type of leukocyte, the neutrophilic polymorphonuclear leukocyte which has a single but lobulated nucleus.

Bone marrow cells (myeloblasts, erythroblasts, megacaryocytes, etc.)

Germ cells (testicles and ovaries)

Moderately radiosensitive

(cells seriously injured or killed by doses of 600 r to 3000 r)

Salivary glands

Epithelium⁵³ of skin

Endothelium⁵⁴ of blood vessels

Bone (growing)

Epithelium of stomach and intestine

Connective tissue⁵⁵

Elastic tissue⁵⁶

Radioresistant

(cells show little damage unless dose exceeds 3000 r)

Kidney

Liver

Thyroid, Pancreas, Pituitary, Adrenal and Parathyroid glands

Bone (mature)

Cartilage

Muscle

Brain and other nervous tissue

Cells of the same type, which appear identical under the microscope, nevertheless show major differences in radiosensitivity. A lymph node,⁵⁷ for instance, is composed chiefly of lymphocytes and would show major damage to many cells after exposures to a dose of 600 r. However, many times this dose could be applied without destroying every lymphocyte present in the node.

2. Cell Differentiation

All cells of the body at some time pass through stages of development from a primitive undifferentiated state to the mature adult, differentiated

53. *Epithelium*: The covering of the skin and mucous membranes, consisting wholly of cells of varying form and arrangement.

54. *Endothelium*: The layer of simple cells which lines the inner surface of the walls of the blood vessels, the lymph vessels and the heart.

55. *Connective tissue*: The tissue which binds together and is the support of the various structures of the body.

56. *Elastic tissue*: Connective tissue made up of yellow, elastic fibers, frequently massed into sheets.

57. *Lymph node*: These nodes are ovoid structures arranged in groups and interposed throughout the lymphatic circulation. They act as filters to trap foreign substances and bacteria carried in the lymph stream. The lymphoid tissue is also credited with producing antibodies and white blood cells.

form. In general, cells which are immature and undifferentiated are more easily damaged by radiation than the mature cells of the same type. This probably accounts for the greater general radiosensitivity of the tissues of children. In adults some mature cells, such as nerve cells, remain permanently in the body throughout life but most others such as the epithelial cells of the skin are constantly dying and being replaced by new cells which differentiate from less mature forms. Thus even the tissues of adults contain many immature cells particularly in organs such as the sex glands, lymph nodes, spleen and bone marrow where new cells are rapidly produced as older ones are removed.

3. *Cell Reproduction*

Almost all cells in the human body multiply by a complicated process of division known as "mitosis." This process may take place even in cells which are fairly mature. It has been found that cells are particularly vulnerable to radiation damage during the process of mitotic division and hence tissues which are rapidly growing and contain many dividing cells are more radiosensitive than the same tissues in the resting stage (growing bone for example is quite easily damaged whereas mature bone is radioresistant).

4. *Impairment of Function Without Cell Death*

A single cell of the body often has a number of known functions and these several functions may be impaired in different degrees by irradiation without necessarily bringing about the death of the cell. The function most easily damaged appears to be the ability of the cell to reproduce by mitotic division but other functions such as secretion (salivary glands and thyroid gland) and locomotion (leukocytes⁵⁸ and macrophages⁵⁹) may be temporarily or permanently impaired.

5. *"Stimulating" Doses of Radiation*

For many years some radiologists have believed that it is possible to "stimulate" the activity of some organs, particularly the endocrine glands, by exposing them to very small doses of x-rays or radium. Although this belief rests on very tenuous evidence it is difficult to disprove. The great

58. *Leukocytes*: Any colorless ameboid cell mass, such as a white blood corpuscle, pus corpuscle, lymph corpuscle, or wandering connective tissue cell. A leukocyte consists of a colorless granular mass of protoplasm, having ameboid movements, and varying in size between 0.005 and 0.015 millimeters in diameter.

59. *Macrophage*: The name given by Metchnikoff to a large mononuclear wandering phagocytic (scavenger) cell which originates in the tissues. A phagocyte is any cell that ingests micro-organisms, other cells or particulate substances. In many cases, but not always, the ingested material is digested within the phagocyte.

majority of critical observers believe that direct stimulation of cells by x-rays or radium has never been demonstrated and that the observed effects in tissues are best explained as reactions to initial injury.

6. *Latent Period*

Human beings have no sensory organs capable of direct perception of x-rays or radium radiation. Exposure, even to large doses, produces no special sensation and the tissues show no immediate change. Some 24 to 48 hours after treatment a faint transient blush of the skin may appear and disappear but the first outspoken evidence of reaction is characteristically delayed for a week or two.⁶⁰ The time interval between exposure and the onset of the frank reaction is called the "latent period" and almost nothing is known about what is going on in the tissues during this time. The larger the dose of radiation the shorter the latent period will be but it always remains as a puzzling hiatus between cause and effect. The initial, primary damage must take place during the actual exposure to radiation and the later changes must be consequent to an obscure chain of biological events continuing through the latent period.

7. *Latent Tissue Injury*

Tissues exposed to radiation show characteristic reactions of a severity depending upon the size of the dose. The principal evidence of slight injury is a reddening of the skin resulting from a dilatation of small blood vessels. After a few weeks the redness (erythema) subsides and the skin returns to its normal appearance. Even microscopic examination of a portion of such skin may show no changes from the normal. However, permanent residual damage can be demonstrated in the irradiated tissue by again exposing the same area to a moderate dose of x-ray or radium. The skin which was previously exposed and apparently had recovered is much more vulnerable to injury by radiation than the neighboring normal skin. It is possible to produce a similar latent injury of the skin or other tissues by repeated exposures to minute doses, any one of which alone is too small to produce any perceptible tissue alteration. Small repeated exposures may ultimately lead to obvious tissue damage of insidious onset but intractable course. The effects of repeated exposures are always less than would be expected from the same total dose delivered at a single sitting, but there

60. This is an important observation, for oftentimes courts have been unaware of this characteristic latent period and have assumed that failure of a burn to appear at the time of irradiation is evidence that the patient was not overexposed. As Dr. Dunlap indicates, this assumption is erroneous.

is always some residual tissue damage after any significant exposure. These facts can be expressed in brief by saying that the effects of divided doses of radiation are cumulative but show incomplete summation.⁶¹

8. *Tissue Tolerance*

The maximum dose of radiation which a tissue can receive without losing its major function, becoming necrotic,⁶² breaking down or ulcerating is known as the "tissue tolerance dose." This dose cannot be stated in absolute terms for any tissue since the severity of the damage depends not only on the number of roentgens delivered but upon the area exposed, the penetrating power (wave length) of the radiation, the time over which the dose was administered and a number of other variables. Tissue tolerance is of major concern in all radiation therapy since unfortunate results will ensue if the dose exceeds the tolerance of the normal tissues which lie in the path of the rays.

9. *Local and Systemic Effects*⁶³

Most of the damage resulting from irradiation is localized to the skin and underlying tissue directly exposed to the beam of rays. In addition some patients subjected to heavy irradiation suffer generalized disorders affecting the whole body. Most important among these are (1) "Radiation sickness" characterized by loss of appetite, nausea, vomiting and depression, seldom lasting more than a day or two after exposure and (2) Blood changes which may be mild or serious and often progress for months after treatment.

10. *Individual Idiosyncrasy*

Human beings show a considerable degree of individual variation in their responses to identical doses of radiation. Children are in general more sensitive to the effects of the rays than adults and fair skin containing little pigment is more readily damaged than dark skin. The general effects such as blood changes and radiation sickness are subject to greater personal variation than are the local tissue changes. These individual variations although

61. *Editor*: For cases involving repeated dosages of irradiation, see, among others: *Hales v. Raines*, 162 Mo. App. 46, 141 S. W. 917 (1911); *Gross v. Robinson*, 203 Mo. App. 118, 218 S. W. 924 (1920); *Evans v. Clapp*, 231 S. W. 87 (Mo. App. 1921); *King v. Ditto*, 142 Or. 207, 19 P. (2d) 1100 (1933).

62. *Necrotic*: Dead.

63. *Systemic effects*: Effects which involve the body as a whole in contrast to a certain local member or part.

64. Desjardins, A. U.: *A Group of Persons Whose Skin and Subcutaneous Tissues are Unusually Sensitive to Roentgen Rays* (1943) 50 AM. J. ROENTGENOL. 636.

real are not so great or so common as was generally believed before accurate dosage measurements became practicable.⁶⁴ Severe radiation injuries are rarely attributable to individual idiosyncrasy but almost always represent the results of overdosage.⁶⁵

11. *Wave Length and Type of Radiation*

It would scarcely be profitable to consider the physics of production and absorption of the various types of radiation under discussion. It is enough to say that they all appear to exercise their effects on tissues primarily through a common mechanism known as ionization. The tissue changes are qualitatively indistinguishable regardless of what type of ionizing radiation is employed. X-rays of long wave length and the alpha and beta radiation of radium are readily absorbed and thus give up their energy and produce their greatest damage in the superficial layers of tissue. Much of the energy of penetrating, short wave length x-rays passes through the surface and is absorbed progressively in the deeper layers. Thus damage to the skin may be less while the injury extends to a greater depth in the tissues. The disparity of effect which follows exposure to various types of radiation arises principally from a difference in the distribution rather than in the fundamental character of the injury.

CHARACTER OF RADIATION INJURIES IN PARTICULAR TISSUES

Comparatively little is known about the fundamental nature of tissue reactions to radiation and even the mechanism by which radiant energy

65. As to duty of roentgenologist to investigate hypersensitivity by preliminary test dosages of irradiation before instituting full therapy, see n. 24, *supra*.

In the following cases, among others, the question of the patient's idiosyncrasy was raised or discussed: *Kuttner v. Swanson*, 59 Ga. App. 818, 2 S. E. (2d) 230 (1939); *Ballance v. Dunnington*, 241 Mich. 383, 217 N. W. 329, 57 A. L. R. 262 (1928); *Cooper v. McMurry*, 194 Okl. 241, 149 P. (2d) 330 (1944); *Rost v. Roberts*, 180 Wis. 207, 192 N. W. 38 (1923).

Under existing tort law, the lay actor's duty of care is to avoid conduct which involves undue risk of injury to persons nearby and unless the actor knows, or should know that one or more of these persons has a special infirmity, idiosyncrasy, or hypersensitivity, he is not negligent if his conduct involved no risk of injury to persons possessed of average physical and psychic resistance. But if the actor's conduct is wanton or willful, he may be liable for injury due to idiosyncratic reactions. Furthermore, if the actor's conduct involved negligence in respect to average persons, courts are prone to permit the idiosyncratic plaintiff to recover his full damages without any diminution being made in respect to his greater susceptibility to injury. These problems are discussed in Smith, H. W.: *Relation of Emotions to Injury and Disease: Legal Liability for Psychic Stimuli* (1944) 30 Va. L. Rev. 193.

The physician, as actor, is in a position somewhat different from that of the layman, as his professional training and medical relationship put him under a duty to discover such idiosyncrasies or hypersensitivity as may be detected by usual examinations.

injures cells is obscure. One of the most puzzling features is the long delay or "latent period" between exposure to radiation and the first appearance of obvious signs of tissue injury. Another is the fact that tissue damage, once initiated, is so often progressive for months or years without further irradiation.

During actual exposure to x-rays or radium, even in doses large enough to kill the tissues, a person experiences no heat, pain, or other warning sensation but once an excessive dose has been administered no treatment is known which will modify the evolution of the subsequent injury. The tissues at first retain their normal appearance and only after a lapse of ten to fourteen days does one expect to see the blush or erythema of the skin which marks the clinical onset of the radiation reaction. Then in relentless sequence the progressive features of the full reaction appear. If the exposure consists of very small repeated doses even the erythema is lacking and the damage is manifest as a slowly progressive tissue atrophy of insidious onset and course, similar in many respects to the spontaneous changes occurring in old age.

The general character of the reaction to radiation is quite similar in the different tissues of the body. At first edema, dilatation of blood vessels and slight inflammation are the prominent features but these gradually regress and give way to a chronic state of atrophy, fibrosis (diffuse scarring) and poor blood supply. The disabilities and the complications resulting from overexposure depend in large measure on which organs or tissues are affected, and the lawyer interested in litigation involving injury allegedly caused by irradiation should bear this in mind.^{65a}

1. *Skin*

Of all tissues the skin is the commonest site of radiation injuries as might be predicted from the fact that all radiation entering the body from without must pass through the skin. The severity of the skin damage depends principally upon the size of the dose administered but if the total dose is divided into several exposures with intervening rest periods, if the area ex-

65a. In a somewhat fuller version of the medical considerations discussed in the present paper, published in an issue of OCCUPATIONAL MEDICINE, Spring, 1946, detailed descriptions are given of the effects of excessive irradiation on skin; bone and cartilage; stomach and intestine; blood and blood-forming organs; sex organs and fertility; the eye; the brain and nervous tissue; lungs; liver; spleen and lymph nodes; pancreas; kidneys, ureters and bladder; heart and muscle. See, also, references cited in n. 5, *supra*.

posed is small or if the radiation is of short wave-length, the skin effect of a given dose will be decreased. After large doses the initial changes appear earlier, the evolution of the reaction is accelerated, the damage is more profound and healing is delayed or fails to take place.

The early reaction of the skin to x-rays and radium is similar in many respects to ordinary sunburn if one can imagine a sunburn that is not confined to the superficial layers of the skin but extends also into the deeper layers and into the underlying soft tissues. As in sunburn the reaction begins with an erythema often followed by edema,⁶⁶ blistering and sloughing away of the surface epithelium and subsequent persistent brown pigmentation. Severe damage to the deeper layers of the skin through which the surface cells must obtain their blood supply and nourishment does not occur in sunburn but explains in part the chronic, indolent, intractable nature of x-ray and radium burns.

The early erythema, edema, inflammation and desquamation⁶⁷ seen in x-ray and radium burns passes over gradually into the late stage with the appearance of atrophy, pigmentation, fibrosis, impairment of blood supply and occasional ulceration. At about the time that the erythema appears the hair in the exposed area falls out but if the dose has not exceeded one erythema the hair grows back in the course of a few months. Secretion of sweat and oil (sebum) by the skin glands is decreased and the skin surface becomes dry and scaly. This change, too, is reversible if the dose has not been greatly in excess of one erythema.

Microscopically one can follow the changes in greater detail. At the time that the erythema develops, some 10 to 14 days after exposure, it is possible to see the dilated capillaries which are responsible for the reddening of the skin. In addition there is an edema, or collection of excessive fluid, not only between the cells but actually within them, causing them to swell to greater size than normal. The epithelial cells of hair follicles, particularly at the growing root, and the secretory cells of the skin glands become swollen and many of them degenerate. The fibres of connective and elastic tissue, which give the skin its toughness and resiliency, become swollen, fibrillated⁶⁸ and fragmented and scattered inflammatory cells appear among

66. *Edema*: Swelling; the presence of abnormally large amounts of fluid in the intercellular tissue spaces of the body.

67. *Desquamation*: The shedding of epithelial elements, chiefly of the skin in scales or sheets.

68. *Fibrillated*: Broken into minute fibers or filaments.

the fibres. A most important change, seen in many of the small blood vessels, is an edema of the fibrous and elastic tissue in the vessel walls and a swelling and multiplication of the endothelial cells which line the lumens or internal walls of the blood vessels. As the erythema subsides this change may progress to the point of narrowing the lumens of many vessels and thus decreasing the flow of blood. After exposure to an "erythema dose" or less, these changes are for the most part reversible and the skin returns to its normal appearance in a month or two except for slight brown pigmentation which may last for many months.

Larger doses of radiation result in changes which are of the same character as those just described but are more profound and persistent. There is permanent loss of hair due to destruction of the hair follicles and the skin glands atrophy and disappear. The surface layer of epithelial cells becomes vacuolated⁶⁹ and sloughs off leaving only a few epithelial cells behind. These regenerate imperfectly to give an epithelial covering which is for the most part thin and atrophic but often shows local areas of abnormal thickening.

The smaller blood vessels undergo progressive damage throughout the course of the reaction. Early edema of the vessel walls and swelling of endothelial cells lining the lumens goes on to permanent fibrous thickening of the walls and multiplication of the lining endothelial cells. Complete occlusion of some vessels results while others show permanent dilatation (telangiectasis).⁷⁰ The dilated vessels may be seen through the atrophic surface epithelium as fine branching red lines. The total amount of blood flowing through the region is decreased and the part often has a dusky reddish-purple color (cyanosis).

The fibrous connective tissue undergoes a prolonged edema which does not regress normally but is slowly replaced by the ingrowth of new connective tissue cells and fibres. This gives the skin a stiff, boggy consistency sometimes described as "woody edema." After several months as the edema slowly subsides the deeper layers of the skin are replaced by dense, leathery, connective tissue containing relatively few living cells or blood vessels.

The skin is normally rich in nerves and nerve endings but since these structures are radioresistant they suffer little direct damage even from large

69. *Vacuolated*: Formation of vacuoles (spaces or cavities) in the protoplasm of a cell.

70. *Telangiectasis*: Dilation of the capillary vessels and minute arteries.

doses of radiation. Hence pain is not a prominent feature of most early radiation burns. However, as the slow fibrosis and scarring develops during the healing phase, nerve fibres are caught in the scar tissue and may give rise to persistent pain of unbearable severity.⁷¹ It is impossible to predict whether or not pain will appear, how severe it will be or how long it will last. Reactions of moderate degree such as those produced intentionally in radiation therapy of tumors are seldom painful. Severe skin burns that ulcerate are usually painful. The pain may be continuous or recurrent for months or years and may be either mild or so severe as to necessitate amputation of the part.

The cumulative effects of repeated small doses lead to changes similar to those following single massive exposures except that the initial phase of erythema and edema is not so obvious. Atrophy is more prominent than fibrosis, and the margins of the burn are not clearly defined. Skin burns produced by radium show the same general features as those following over-exposure to x-rays. Those which result from handling radium needles and applicators are located on the tips of the fingers and are frequently associated with dry, brittle, ridged fingernails and a partial loss of the sense of touch.

The gross appearance of late radiation burns is fairly distinctive but these burns cannot be distinguished with absolute certainty from those caused by heat, acids and other agents. The skin in the affected area is smooth, shiny, dry and tense. Hair is absent and irregular areas of increased and decreased pigmentation are present. Open ulcers⁷² or the white scars of previous ulcers may be seen and sometimes the smooth surface is broken by dry scaly elevations known as keratoses. Dilated blood vessels appear under the atrophic surface epithelium as an irregular network of fine red lines. On plucking up a fold of skin between the thumb and finger it is found to be tough, thick, inelastic and adherent to the underlying structures. Except for the thickening of the skin and the localization of the injury mild radiation changes may bear a striking resemblance to the spontaneous degeneration or "senile atrophy" seen in elderly people.

71. *Editor:* Pain is an important factor in assessment of damages and other complications may arise, or a need for surgery develop; for all these reasons, legal action should be postponed until the final results of the X-ray burn are apparent and all elements of injury can be evaluated.

72. *Ulcer:* An open sore rather than a wound; a loss of substance on a cutaneous or mucous surface, causing gradual disintegration and necrosis (death) of the tissue.

Radiation burns of the skin are disadvantageous in several respects. The burn is unsightly, may be painful, is easily injured, ulcerates readily, heals poorly, has limited resistance to infection and may give origin to cancer of the skin.⁷³ The appearance of the burn and the possibility of pain have already been discussed. A slight blow or bruise to the affected area easily breaks the surface and may serve to initiate a chronic progressive ulceration which heals slowly if at all. The damaged skin appears to have little resistance against bacterial invasion particularly during the phase of "woody edema" but also in the later atrophic stage. Thus, accidental injuries or surgical incisions with the area carry increased danger of destructive progressive infections.

The fact that skin cancer frequently arises in radiation burns is well attested by numerous cases and is recognized by all authorities. Leddy⁷⁴ reports that of 135 physicians who sought advice at the Mayo Clinic between 1919 and 1939 because of radiation burns, 39 (29 percent) already had cancers at the site of injury. Saunders and Montgomery⁷⁵ found cancer present in over 10 percent of a series of 259 chronic radiation burns of the skin most of which resulted from misguided therapy. It is significant to note, parenthetically, that only 33 of these patients received their burns as a result of treatment for deep seated cancer while 181 were injured during radiation therapy of miscellaneous benign skin disorders. These two articles indicate only the frequency with which cancer was found at the time the patients were examined and the authors do not estimate how many will ultimately develop cancer at the site of the burns.

Radiation cancers may arise at any time from 1½ to 30 or more years after the initial burn. They are frequently multiple and usually begin either

73. *Editor*: Courts have permitted the plaintiff, in actions for X-ray burns, to include as a factor of damage, proper evidence in respect to the risk of future cancer. *Coover v. Painless Parker, Dentist*, 105 Cal. App. 110, 286 P. 1048 (1930); *Gross v. Robinson*, 203 Mo. App. 118, 218 S. W. 924 (1920). Courts, in general, hold that damages may not be recovered in respect to future complications of present injuries unless medical witnesses testify that they are "reasonably certain to occur"; in some of the X-ray cases, the testimony was in terms of possibilities rather than of probabilities, and might have been excluded by timely objection interposed by the defendant. Most courts allow damages for mental anguish produced by apprehension of dread complications, which may reasonably be expected to result from an original injury inflicted through the defendant's fault.

74. Leddy, E. T., and Rigos, F. J.: *Radiodermatitis among Physicians* (1941) 45. AM. J. ROENTGENOL. 696.

75. Saunders, T. S., and Montgomery, H.: *Chronic Roentgen and Radium Dermatitis: An Analysis of 259 Cases* (1938) 110 J. A. M. A. 23.

at the margins of chronic radiation ulcers or in the "keratoses" previously described within the burned area. Under the microscope they are indistinguishable from spontaneous cancer of the skin and clinically they follow the same progressive course. It is therefore not possible to state with absolute finality that every cancer arising in the site of an old burn was caused by the radiation but the inference is strong that radiation played a part in initiating or precipitating the growth.⁷⁶

Cancers arise with greater frequency in severe than in moderate radiation burns^{76a} and can seldom if ever be shown to result from exposures that do not produce obvious skin damage. Although cancer may appear within a year and a half after irradiation,^{76b} the average incubation time is 5 to 10 years. In order to support the probability that a skin cancer arose as the direct result of irradiation it is necessary to establish a number of facts quite similar to Ewing's criteria of trauma as a cause of tumor.⁷⁷

1. The fact of previous irradiation.
2. Absence of cancer in the same region prior to irradiation.
3. Presence of definite skin damage of a type which could have been caused by the previous irradiation for at least 1 year before the appearance of the cancer.
4. Origin of the cancer within the area of damaged skin.
5. Microscopic or other evidence that the suspected growth is malignant⁷⁸ and is of a type which could have arisen in the skin.

The treatment of radiation cancer is complicated by the fact that the tumors arise in tissues which are already severely damaged, partially devitalized, and deprived of an adequate blood supply. The prognosis (expected outcome) is therefore less favorable than for spontaneous tumors of the same microscopic character and location. Although it may appear

76. Thus, if plaintiff's cancer has already begun at the site of the burn, the requirement of probable causal connection can be satisfied by trustworthy expert testimony which fulfills the criteria Dr. Dunlap lists. It is worth noting that serious burns of the skin from any cause involve some risk of subsequent cancer. See Aldrich, R. H.: *Forensic Aspects of Burns with Special Reference to Appraisal of Terminal Disability* (1943) 29 VA. L. REV. 739; (1943) 117 ANN. OF SURG. 576, an article in the Symposium "Scientific Proof and Relations of Law and Medicine" (1st series, April 1943).

76a. See n. 75 *supra*.

76b. *Id.*

77. EWING, J.: *NEOPLASTIC DISEASES; A TREATISE ON TUMORS* (4th ed., 1940) 108. Philadelphia and London, W. B. Saunders Co.

78. *Malignant*: Virulent, and tending to go from bad to worse. When the word is used as in the present context, it means that the new growth is a form of cancer.

illogical, radiation cancers can often be destroyed successfully by the application of further radiation and this method is frequently employed by competent radiologists. It is preferable, when the size and location of the lesion permit, to excise the tumor surgically, together with the entire region of damaged skin. If the tumor is large or rapidly growing amputation of the part may be necessary.

Surgical treatment of tissues damaged by radiation requires special skill and judgment whether or not cancer is present.⁷⁹ In addition to the risk of poor healing and infection, any cutting or tying of blood vessels supplying the area may further impair an already inadequate blood supply and lead to massive necrosis (death) of the tissues in the region. If the damaged skin is cut away it may be found that the underlying tissues have too poor a blood supply to sustain the growth of skin grafts. A deeper excision must then be carried out or the patient will be left with a raw, ulcerating wound. Wide and deep excision of the entire block of damaged tissue followed by plastic repair and tissue grafts has yielded favorable results in selected cases. Minor surgical interference is dangerous and burns which are not disfiguring, disabling or painful and which do not show malignant change are best treated conservatively by the application of bland salves.

2. Bone and Cartilage

The effect of radiation on bones has not been studied vigorously until the last few years and much remains to be learned concerning the tolerance doses and the character of the damage. The available data have been reviewed by Gates.⁸⁰ Bones are generally considered as radioresistant structures which show little damage even after exposure to large doses. As a broad generalization this is true but the exceptions are important.

The growing bones of infants and children are subject to injury by relatively small doses. The injurious doses have been roughly estimated at 25% and 50%, respectively, of the erythema dose for adults⁸¹ although it is probable that doses several times as large are necessary to produce significant degrees of injury. The damage is manifest as an impairment or cessation of further bone growth, accompanied by only slight changes in

79. Daland, E. M.: *Radiation Damage to Tissue and its Repair* (1941) 72 S. G. & O. 372.

80. Gates, O., *op. cit. supra*, n. 5g, at p. 323.

81. Flaskamp, W.: *Ueber Röntgenshaden und Shaden durch radioactiven Substanzen*, in 12 MEYER, H.: *SONDERBANDE ZUR STRAHLENTHERAPIE* (1930) 147. Berlin, Urban and Schwartzenburg.

the bone already formed. Once the growing portion of a bone has been seriously damaged there is little hope of full recovery and resumption of normal growth.⁸² The late effects are skeletal deformities of a character and severity depending upon the size of the dose, the site of application and the age of the patient at the time of irradiation. Of course only those bones in the path of the rays are affected and the deformities appear as the other bones continue to grow at the normal rate. Fortunately this type of injury is rare since malignant tumors are uncommon in children and there are few other disorders which require heavy irradiation. Most of the reported accidents have followed excessive treatment of hemangiomas (birth marks). The potential danger of overexposing the bones of children's feet in the commercial fluoroscopic devices found in some shoe stores has already been mentioned.

The use of x-rays for diagnostic purposes in children is not dangerous in competent hands. Proper diagnostic procedures involve the application of only a few roentgens and dangerous overexposure can result only from very careless technique or from frequently repeated examinations of the same part.

The mature bones of adults withstand irradiation quite successfully and show damage only after massive exposures. Thus bone damage is seldom seen except as an undesirable side effect of tumor therapy. The bones most readily overexposed are those which lie immediately under the skin, as in the hands, feet, shins and head. Special types of injury are (1) Spontaneous fractures⁸³ of the neck of the femur (upper end of the thigh bone) resulting from heavy irradiation of pelvic tumors,⁸⁴ (2) Painless necrosis and spontaneous fractures of the ribs resulting from heavy treatment for cancer of the breast⁸⁵ and (3) Necrosis and osteomyelitis (bacterial infection of bones) of the jaw resulting from irradiating cancers of the mouth and tongue. In all these conditions the basic damage to bone is the same. Bone is a living

82. Gall, E. A.; Lingley, J. R., and Hilken, J. A.: *Comparative Experimental Studies of 200 Kilovolt and 1000 Kilovolt Roentgen Rays: I. The Biological Effects on the Epiphysis of the Albino Rat* (1940 16 AM. J. PATH. 605.

83. *Spontaneous fracture*: Spontaneous fractures are those which occur as a result of disease in the bone and without mechanical injury sufficient to break a normal bone. A slight mechanical strain such as throwing a ball or stepping off a step may precipitate a spontaneous fracture.

84. Hight, D.: *Spontaneous Fractures of the Femoral Neck Following Roentgen Therapy over the Pelvis* (1941) 23 J. BONE & JOINT SURG. 676.

85. Paul, L. W., and Pohle, E. A.: *RADIATION OSTEITIS OF THE RIBS* (1942) 38 RADIOLOGY 543.

tissue and requires an adequate blood supply for survival. Irradiation damages blood vessels and in some cases may kill living bone cells directly. Other changes occur but these are believed to be the most important. Heavily irradiated bone loses its toughness and becomes chalky, brittle and easily broken. All the bone cells in the region may die (sterile necrosis) but the bone may still retain its shape and function for a time unless it is subjected to mechanical strain or infection. As a rule there is slow irregular resorption⁸⁶ of the dead bone and in favorable cases new living bone grows in to repair the defect. However, repair is poor in this as in other radiation injuries because the surrounding living tissues are damaged.

Radiation damage to the bones of the jaw requires particular comment because of the special risk of infection. The mouth normally harbors great numbers of bacteria and many people have, in addition, active infection in the gums or about the roots of teeth. Bacteria are very likely to gain access to the damaged bone and are able to set up a progressive destructive inflammation in the irradiated tissues which is very difficult to control. In order to avoid this serious complication many radiologists have the teeth of patients extracted and permit the gums to heal before delivering heavy radiation to the jaws or mouth.

A special type of bone injury occurs in persons who have taken radioactive substances into the body. Most of the natural radioactive substances are selectively deposited in bone after injection or ingestion and produce their principal injurious effects on the bone and bone marrow. The nature of the damage and its end results of anemia, crippling bone lesions and occasional osteogenic sarcoma (bone cancer) have been briefly outlined in the previous section on the hazards of the luminous dial industry. It might be mentioned that while internal deposits of radioactive substances are accepted as a cause of osteogenic sarcoma there are very few cases on record of such tumors resulting from the external application of radium or x-rays.⁸⁷

The degree of pain associated with radiation osteitis (bone injury) bears little relationship to the amount of demonstrable bone damage. Radiation necrosis of the ribs even when accompanied by fractures produces no discomfort in the great majority of cases.^{87a} Most of the cases of radia-

86. *Resorption*: Removal by absorption.

87. Wilson, H., and Brunschwig, A.: *Irradiation Sarcoma* (1937) 2 SURGERY 607.

87a. See n. 85 *supra*.

tion necrosis⁸⁸ of the head of the femur⁸⁹ are asymptomatic (free of symptoms) unless a fracture occurs. Injury to the bones of the jaw is sometimes painless but may produce great discomfort particularly if complicated by infection and osteomyelitis. Radiation burns of the hands with severe damage to the underlying bone very commonly cause excruciating pain, so severe and intractable that amputation is sometimes necessary. Radiation osteitis resulting from deposits of radioactive substances in the bones (radium poisoning) is characteristically painful but the amount of pain does not correspond strictly to the amount or principal location of bone damage demonstrable in x-ray photographs. These inconsistencies suggest that pain in radiation osteitis does not arise directly in the affected bone but rather in the periosteum (covering of the bone) and adjacent soft tissues.

Disabilities attributable to radiation osteitis (inflammation of bone following irradiation) are almost all due to pain, fracture or secondary infection.⁹⁰ Bones fractured through a region damaged by radiation heal poorly or not at all with resultant loss or impairment of function of the part. Treatment is generally unsatisfactory but in lesions which are painful and of favorable location and extent, the damaged bones may be removed surgically. Such operations must be radical (extensive) in order to remove neighboring damaged soft tissues and avoid the danger of poor healing and post-operative infection.

Mature cartilage is damaged by large doses of radiation and shows little ability to repair. This is of practical importance since overtreatment of cancers of the ear or nose can result in disfiguring destruction of the supporting cartilages and radiation treatment of cancer of the larynx⁹¹ is complicated by the danger of irreparable injury to cartilage. The normal growth of cartilage in children and the orderly replacement of cartilage by bone can be arrested by doses of the order of one erythema. It is be-

88. *Radiation necrosis*: Localized destruction of tissue due to irradiation.

89. *Head of the femur*: The femur is the long bone which extends from the hip joint to the knee. The upper part of the bone has a rounded, ball-like protuberance, called the head of the femur; it moves in the special bone cavity into which it fits to form the hip joint; this joint, surrounded by strong ligaments, enables the individual to move his femur through a rather extensive range of different motions.

90. *Secondary infection*: Strictly speaking, an infection by a microbe following an infection by a microbe of another kind; the term is oftentimes used more loosely to indicate bacterial infection beginning at the site of a previous injury.

91. *Larynx*: A box-like structure situated at the top of the trachea, or wind-pipe, and below the root of the tongue. It is the organ of voice. It contains nine cartilages and this accounts for the special risk of injury from intensive irradiation.

lieved that radiation injury to cartilage plays an important part in the impairment of normal bone growth.

3. *Stomach and Intestine*

The stomach and intestine are moderately sensitive to damage by x-ray and radium^{91a} but are partially protected from exposure by the overlying tissues of the abdominal wall. Injuries seldom occur except as a complication of tumor therapy and usually involve the intestine rather than the stomach.

Moderately heavy doses cause a temporary increase in the normal muscular contractions of the intestine and impair the secretion of digestive juices and the absorption of food. The earliest and greatest structural changes are seen in the glandular lining or "mucosa" of the tract but the blood vessels, muscles and connective tissue also suffer. The character of the changes is similar to that seen in other tissues. The early reaction is chiefly one of edema, hyperemia⁹² and inflammation of the mucosa.⁹³ Later on circulation is compromised to a certain extent by edema and injury to blood vessels. The mucosal cells show some attempts at repair intermingled with all grades of progressive injury which vary from alterations in the character of the secretions to marked structural abnormalities and cell death. Since the mucosa lining the intestine is in contact with the rich bacterial flora of the intestinal contents, slight mechanical trauma to the mucosa permits bacteria to enter the damaged bowel wall and set up chronic, inflammatory, ulcerative lesions. Irradiated tissues have lowered resistance to infection and decreased powers of repair, thus, ulcers of the intestine like those of the skin follow an indolent course and heal slowly or not at all. Extensive formation of scar tissue in the bowel wall may occur without frank ulceration but is usually found only in association with an ulcer. In either case the lumen (inside) of the intestine may be constricted. Intestinal obstruction may result and bleeding into the intestine is common. At times the ulcer breaks through the intestinal wall forming a fistula (deeply penetrating ulcerated tract) or spilling the intestinal contents into the general abdominal cavity. Ulcerations occur most commonly in the lower end of the large intestine (rectum and sigmoid), not necessarily because this region is more radiosensitive than other portions of the bowel

91a. See n. 5c *supra*.

92. *Hyperemia*: Excess of blood in any part of the body.

93. *Mucosa*: The mucous membrane which lines the intestines.

but because tumors amenable to radiation therapy are more often located in the pelvis than in the upper abdomen.

Early or acute reactions are characterized clinically by diarrhea and abdominal cramps sometimes associated with loss of appetite, nausea or vomiting. Such reactions are relatively mild, seldom last more than two or three weeks and occur in 20 to 30 percent of persons receiving pelvic irradiation.

Late "delayed" or chronic reactions are less frequent but much more serious. They are due to the formation of chronic intestinal ulcers or fibrous and come on as a rule six to twelve months after exposure although they may be delayed for several years. The symptoms develop insidiously with intermittent, progressively severe, cramping abdominal pains and bloody stools. The subsequent clinical course is determined by whether the ulcers heal satisfactorily, cause scarring and obstruction or perforate the bowel.

Radiation injuries of the bowel are treated conservatively by giving a soft diet and sedatives in the hope that spontaneous healing will take place. Intractable pain is a prominent feature of many cases but surgical intervention is usually delayed until the pain demands relief or the progress of other symptoms indicates that spontaneous healing is improbable. Surgical treatment depends upon the extent and location of the lesion and may consist in removal of the involved segment of intestine or short circuiting the flow of intestinal contents to avoid passage through the damaged region (enterostomy or colostomy).

Late radiation reactions in the intestine occur in about 1 to 5 percent of patients receiving abdominal or pelvic radiation therapy.^{93a} The patients receiving the largest doses are not always the ones affected and the ulcers are not always located in the exact portion of bowel subjected to maximum exposure. These apparent inconsistencies are explained by the fact that the ulcers are not pure radiation effects but that secondary factors such as mechanical trauma and infection play a part in determining the occurrence and location of lesions within the region of radiation injury.^{93b}

4. *Blood and Blood Forming Organs*

A change in the number and character of the cells in the circulating blood is among the most delicate indicators of exposure to radiation. Many

93a. See n. 5c *supra*.

93b. *Id.*

professional radiologists show mild abnormalities of the blood, which are usually not associated with any symptoms, but do serve as a warning that protection against radiation has been inadequate. Most patients undergoing heavy radiation therapy show transient changes in the blood picture (number and character of blood cells). The extensive literature on this subject has been recently reviewed and the present discussion will include only the more important features.

The principal early effect of intensive irradiation is a sudden drop in the number of white cells in blood (leukopenia). As a rule recovery is rapid and complete. Radiation therapy as ordinarily employed carries no great hazard of serious or permanent damage to the white cells. However, in patients who have received several courses of radiation therapy to large areas of the body or who were already debilitated, leukopenic or infected, the blood counts should be followed with care during further treatment. If the white (or red) cells fall to dangerously low levels, radiation treatment should be stopped at once. It is not easy to characterize a "dangerous level" since the patient's general condition and past performance in regenerating blood must be taken into account, but some radiologists have decided arbitrarily that they do not care to depress a patient's white count below 3000 cells per cubic millimeter of blood.⁹⁴

The red cells of the blood are more resistant to irradiation than the white cells and seldom show significant depression during ordinary radiation therapy. However, when their number is reduced by heavy or repeated treatments the count may fall progressively for several months and recovery is slow and often incomplete. A falling red blood cell count during radiation therapy is a danger signal indicating that further treatment should be given with great caution.

In addition to the red and white cells the blood contains small free particles known as platelets⁹⁵ which play an important part in the mechanism of blood clotting. There is evidence that moderate doses of radiation cause a rise in the number of platelets and by this and other changes increase

94. Levitt, W. M.: Treatment of Lymphadenoma and Certain Malignant Growths with X-ray Baths, *Lancet* 1: 212, 1940.

95. *Platelets*: The platelets are small bodies normally present in the circulating blood. They have an average diameter about one-third that of a red blood cell, namely, 2.5 microns, and number from 200,000 to 400,000 per cu. mm. of blood. They vary considerably in shape. They are non-nucleated and are commonly stated to be simply fragments of protoplasm derived from the cytoplasm of giant cells of the bone marrow called megakaryocytes.

for a short time the clotting power of the blood. Very heavy irradiation reduces the platelet count and results in a tendency to bleed readily. This condition (secondary thrombocytopenic purpura) is seldom seen except in patients who also show severe depression of the red and white cell counts.

Poorly protected radiologists and their assistants may show similar anemias, leukopenias and low platelet counts but in the blood of some radiologists one or more of the blood elements is found at a higher level than normal. Such states are best explained as the result of excessive compensatory regeneration of blood cells after repeated slight injuries. Excessive multiplication of white blood cells can sometimes take on the properties of a malignant growth and this fatal disorder, known as leukemia,⁹⁶ is occasionally seen in radiologists.⁹⁷ Leukemia also occurs in persons who have never been exposed to x-rays or radium but the incidence among radiological workers is probably a little higher than in the population at large. It is possible to induce leukemia by irradiation in susceptible strains of mice,⁹⁸ and most authorities on the subject believe in spite of the scanty evidence that repeated small exposures in human beings can serve as an exciting or precipitating cause of leukemia.

Radiation damage to the blood does not respond significantly to any known form of medication. At present treatment consists in general supportive measures such as rest, fresh air and good diet coupled with absolute avoidance of further exposure to radiation. Most patients make a slow, complete or partial recovery under this regimen and death from radiation anemia or leukopenia is exceptional. Victims of radium poisoning, of course, can not be removed from further exposure and may suffer progressive blood damage.

5. *Sex Organs and Fertility*

The ovaries⁹⁹ and testicles are highly sensitive to damage by x-ray or radium and sterility is easily produced in both sexes either by a single

96. *Leukemia*: See n. 9, *supra*.

97. References to the 24 reported cases are given in the article cited in n. 5b, *supra*.

98. Furth, J., and Furth, O. B.: *Neoplastic Diseases Produced in Mice by General Irradiation with X-rays* (1936) 28 AM. J. CANCER 54.

99. *Ovary*: The female sexual gland in which the ova are formed, there being one ovary on each side situated in apposition to the end of the fallopian tubes. When the ovum is extruded it usually passes through the fallopian tube to the uterus; fertilization of the ovum by the male element usually takes place in the fallopian tube and in that event, the impregnated ovum will implant itself on the inner wall of the uterus and develop into an embryo.

exposure or by the cumulative effects of repeated small doses. A dose of 500 roentgens of x-ray directed to the ovaries is sufficient to destroy the germ cells and produce permanent sterility in most women although young women may withstand a little more and a few cases are recorded of women becoming pregnant after exposure to several times this dose.¹⁰⁰ Smaller doses produce temporary sterility with return of menstruation and fertility after a lapse of several months or years.

The sterilizing dose for men has never been determined with accuracy but it is probably smaller than the dose for women. The germ cells in the testicle are destroyed but the interstitial cells, which are believed to produce male sex hormone, are little affected. Men sterilized by radiation retain potency as a rule and produce seminal fluid but the fluid no longer contains living sperm.¹⁰¹ The victim's testicles become soft and somewhat smaller but there is little obvious change in his beard, his voice or his general social behavior. In short a man can be effectively sterilized without it being apparent to himself, his wife or his friends. The diagnosis is easily made, however, if repeated microscopic examination of seminal fluid fails to reveal the presence of living sperm.¹⁰²

Women sterilized by radiation suffer greater physiological disturbances than men. The process by which the ovary produces sex hormones is intimately related to the production and discharge of ova (eggs). When the production of ova is terminated by irradiation the sterilized woman suffers an artificial menopause (change of life) similar in most respects to the natural menopause. Menstruation of course ceases, hot flashes (sensations as of waves of heat passing through the body) occur, sexual appetite is usually diminished and severe psychic depression develops in a few cases. It has been claimed, without convincing evidence, that the symptoms of the menopause induced by radiation are more distressing than those which accompany the natural menopause. The symptoms if severe can be re-

100. JACOX, H. W.: *Recovery Following Human Ovarian Irradiation* (1939) 32 RADIOLOGY 538.

101. Hickey, P. M., and Hall, E. W.: *A Report Analyzing the Results of the Questionnaire Sent Out to Radiologist, Under the Direction of the Sex Committee of the National Research Council* (1927) 18 AM. J. ROENTGENOL. 458.

102. A statute authorizing use of X-ray to sterilize mental defectives, whose condition is transmissible by hereditary mechanisms, has been held not to involve an unusual and cruel form of punishment within the meaning of a state constitution: it is a eugenic measure rather than punishment for any crime. *Smith v. Command*, 231 Mich. 409, 204 N. W. 140, 40 A. L. R. 515 (1925).

lieved in part by the administration of female sex hormone but the sterility is not subject to remedy.

Sterilization of women is usually unavoidable in effective radiation therapy of malignant tumors of the pelvis. At other times it is done deliberately as a means of controlling bleeding from the uterus or as a permanent measure of birth control in women whose lives or health might be jeopardized by pregnancy (cases of heart disease, advanced tuberculosis, etc.).¹⁰³ Some sterilizations have been performed at the request of the patient without definite medical indications.^{103a} Unintentional sterilization of patients can be avoided by carefully shielding the region of the ovaries or testicles with a sheet of lead during irradiation of neighboring parts.¹⁰⁴

103. It has been held, and doubtless it is the law everywhere, that sexual sterilization is legal where it is performed for a therapeutic purpose, as for instance, to protect a wife in poor health from contra-indicated risks of pregnancy. Thus, in *Christensen v. Thornby*, 192 Minn. 123, 255 N. W. 620 (1934), the court held it was not against public policy for a surgeon to sterilize a husband in good health as a means of protecting his ailing wife whose health would have been prejudiced by pregnancy.

Many states have enacted statutes authorizing compulsory sterilization of named classes of institutionalized mental defectives, such as feeble minded or insane persons. (Ariz.; Calif.; Del.; Ga.; Idaho; Ind.; Iowa; Kan.; Me.; Mich.; Minn.; Miss.; Mont.; Neb.; N. H.; N. C.; N. D.; Okla.; Ore.; S. C.; S. D.; Utah; Vt.; Va.; Wash.; Wis.) Such a statute is constitutional insofar as it pertains to conditions known to be transmissible by heredity, and if it assures to the person to be sterilized a right to a fair hearing and determination of the merits of his case in accordance with due process of law. *Buck v. Bell*, 274 U. S. 200 (1927).

Such sterilization, by X-ray or vasectomy, is a eugenic measure based on biological considerations and not a punishment for crime and a constitutional provision that "cruel or unusual punishment shall not be inflicted" is not violated by the procedure. "It is clearly apparent . . . that the methods provided by the statute for carrying out its purpose are not unreasonable, cruel, or oppressive, and that the results are beneficial both to the subject and to society." *Smith v. Command*, 231 Mich. 409, 204 N. W. 140, 40 A. L. R. 515 (1925).

103a. *Id.*

104. Juries tend to award large verdicts for injuries which impair sexual powers, and particularly for those which destroy the capacity for procreation. See, in this Symposium series, Bauer, R. S.: *Fundamental Principles of the Law of Damages in Respect to Medico-legal Cases* (1946) 19 TENN. L. REV.

Courts have allowed the woman herself to recover damages against one who has negligently destroyed her reproductive capacity. (*Potts v. Guthrie*, 282 Pa. 200, 127 Atl. 605 (1925); *Normile v. Wheeling Traction Co.*, 57 W. Va. 132, 49 S. E. 1030 (1905). It is difficult, and probably impossible, to make a monetary valuation of such an injury in a scientific manner, as one cannot say how many children might have been born but for the injury; the fact is that the damages awarded seem to involve compensation of mental anguish rather than of a definite determinable loss. Whether one spouse can recover damages for the negligently caused sterilization or emasculation of the other, is a controversial question. See, for more detailed discussion, *Smith, H. W.: Antecedent Grounds of Liability in the Practice of Surgery* (1942) 14 ROCKY MT. L. REV. 233. One question is whether the interest in procreation is included in the husband's common law rights of consortium; another is

Treatment of distant tissues, with the possible exception of the pituitary glands, does not affect the organs of reproduction.

Accidental sterilization is one of the major occupational hazards of male and female radiological workers. Among 377 radiologists circularized by Hickey and Hall^{104a} 37% of the marriages were sterile. Such tragedies can be avoided only by constant and scrupulous attention to the details of protection.

6. *Other Organs and Tissues*

Although any tissue can be damaged by sufficiently large doses of radiation most of the injuries commonly encountered occur in those tissues already discussed. However the occasional injuries to other tissues might be briefly noted. Further information on special tissues can be found in the general reviews previously cited.^{104b}

Eye: There are few data on the effects of radiation on human eyes. It is probable that exposure to about one erythema dose will produce inflammation of the exposed surfaces of the eye (conjunctivitis¹⁰⁵ and keratitis¹⁰⁶) and that larger doses, particularly in children, can cause cataract (opacity of the lens) and damage to the retinal cells (cells at the back of the eye which are sensitive to light).

Brain and nervous tissue: Therapeutic irradiation as ordinarily given has little effect on adult nervous tissue. Very large doses to the head seldom cause serious impairment of the function of the brain but can produce microscopic changes in the nerve cells and fibres. The changes probably result more from blood vessel injury than from direct damage to nervous tissue. The nervous system of the very young child and particularly of

whether courts will hold that a spouse has a primary interest in preservation of the procreative powers of the other. In *Landwehr v. Barbas*, 268 N. Y. 547, 241 App. Div. 769 (1935), the wife sued defendant for negligence resulting in emasculation of her husband and sought to recover damages for destruction of her interest in procreation. The wife's right, if any, would need to be primary, for she had no derivative rights of consortium at common law. In a divided opinion, the court held that the wife could not recover damages, chiefly because they were too remote; the dissenting judge insisted that the wife had a primary interest which was injured by the defendant's negligence and that she should be allowed to recover damages for such a loss.

104a. See n. 101 *supra*.

104b. See n. 5 *supra*.

105. *Conjunctivitis:* Inflammation of the conjunctiva, the delicate membrane that lines the eyelids and covers the eyeballs in front except for the cornea.

106. *Keratitis:* Inflammation of the cornea, the transparent structure forming the anterior (forward) part of the external layer of the eyeball.

the unborn fetus is more easily injured but the tolerance doses are uncertain.

Lungs: The lungs are relatively radioresistant and are seldom affected except during intensive therapy of cancer of the breast. The reaction consists of a complex series of degenerative and reparative changes accompanied by edema and sometimes terminating in slight diffuse fibrosis of the lung. Slight shortness of breath is occasionally noted and it is believed that resistance against infections, such as bronchitis and pneumonia, is decreased. Most of the changes are transitory and if infection does not occur, the structure and function of the lung is not seriously or permanently impaired.

Liver: Heavy irradiation in the region of the liver often results in violent nausea and vomiting and profound generalized depression. The symptoms seldom last more than a day or two and on examination of the liver, both in human beings and experimental animals, little evidence of structural damage can be found.

Spleen and lymph nodes: The spleen and lymph nodes are radiosensitive and are easily damaged by irradiation. However, repair is rapid and adequate and the only effect worth mentioning is a transitory decrease in the number of white cells in the circulating blood.

Pancreas: Significant changes in the structure or function of the pancreas are not to be expected as a result of irradiation.

Kidneys, ureters and bladder: It has been claimed on doubtful evidence that small doses of radiation directed to the kidneys increase the secretion of urine. The kidneys withstand larger doses of radiation quite successfully but usually show some degenerative changes and fibrosis after exposure to 3,000 roentgens or more. The ureters, which lead down from the kidney to the bladder are seldom injured. The bladder is inherently radioresistant yet it is occasionally injured by the large doses used in treating pelvic cancer. Chronic ulcers may be confined to the lining of the bladder but sometimes break through to form open fistulas¹⁰⁷ into the rectum or vagina. Treatment in these cases is seldom successful.

Heart: Massive irradiation produces slight changes in the action of the heart as revealed by electrocardiographic studies but the function of the heart in pumping blood is not perceptibly impaired. Slight fibrosis and damage to the blood vessels supplying the heart muscle have been described

107. *Fistula:* A deep, sinuous ulcer, often leading to an internal hollow organ.

but for all practical purposes the heart is not affected by therapeutic doses of radiation.

Muscle: Very large doses of radiation can produce degeneration and fibrosis of ordinary muscle but the effect is seldom of importance.

CHILDREN OF IRRADIATED PARENTS

The possibility that parents subjected to irradiation might produce abnormal children has been the subject of considerable study. The question is naturally divided into two independent problems: first, will irradiation of the genital organs of either parent before conception of a child so damage the germ cells of the parent that the child will be abnormal and second, will direct irradiation of the pregnant uterus cause injury to the fetus (baby) within?

1. *Children Conceived after Irradiation of Parent*

There is no conclusive evidence that radiation injury to the ovaries or testicles of human beings results in damage to children subsequently conceived although experimental observations on the progeny of irradiated mice, frogs and insects do indicate that occasional abnormalities may occur in the young. In a study by Hickey and Hall^{107a} of the reproductive history of 377 radiologists it was found that the percentage of abnormal children among the 262 born before employment of their parent in radiology was 1.1 percent while of the 365 children born after such employment 1.8% were abnormal. The difference is not striking and the recorded abnormalities include such minor defects as strabismus (cross-eyes), enlarged thymus¹⁰⁸ and astigmatism¹⁰⁹ any of which might easily have occurred independent of irradiation.

107a. See n. 101 *supra*.

108. *Thymus:* A ductless gland-like body situated in the upper part of the thorax, or chest cavity. It reaches its maximum development during the early years of childhood. The thymus begins to decrease in weight during later childhood and around the age of puberty a definite involutionary process commences, resulting in further marked reduction in size, etc. Very little is known at the present time concerning the physiological function of the thymus. Some believe that so-called *status thymico-lymphaticus*, involving enlargement of the thymus, may be a cause of sudden death of infants and young children following some trifling shock or during anesthesia. Recently, however, an investigation carried out by Turnbull and Young for the Medical Research Committee of Great Britain has failed to substantiate this belief. The two investigators concluded that there is . . . "no evidence that so-called *status thymico-lymphaticus* has any existence as a pathological (disease) entity." Best, C. H. and Taylor, N. B.: *THE PHYSIOLOGICAL BASIS OF MEDICAL PRACTICE*, 2d ed., Baltimore, The Williams and Wilkins Co., 1940, p. 1248.

109. *Astigmatism:* A defect of curvature of the refractive surfaces of the eye in which rays of light are not focused to a single point, but form a diffused area on the retina.

Apparently the radiologists investigated by Hickey and Hall were all men, but Naujoks¹¹⁰ studied the reproductive history of 91 women who had formerly been radiological technicians. He found the incidence of sterility to be 24 percent, the incidence of abortions about average and the incidence of abnormalities among the 125 offspring to be 4%. This is somewhat higher than the expected incidence of congenital abnormalities but Naujoks did not consider the difference to be statistically significant. The extensive studies of Murphy¹¹¹ on female patients who conceived after exposure to radiation showed no conclusive evidence of injury to the children. While this question is not finally settled, it can be said that no abnormality or defect appearing in a child either at the time of its birth or in later years has yet been proved to be a direct consequence of irradiation of either parent before conception of the child.

2. Children Irradiated in Utero

Normal children are often born to women who have received heavy pelvic irradiation during pregnancy. However, animal experiment and human experience have both revealed an increased incidence of malformations of the central nervous system, eyes and limbs in the offspring of irradiated pregnant mothers. Injury is most likely to occur if radiation is applied during early pregnancy, particularly before the third month. Death of the fetus and abortion ordinarily follow the exposure of the pregnant human uterus to two or more skin erythema doses of x-rays during the first four months of pregnancy.¹¹² The effects of smaller doses, or of treatment delivered later in the course of pregnancy are unpredictable. The fetus may be killed, may develop normally or may survive with serious developmental abnormalities. Goldstein and Murphy¹¹³ gathered reports of 75 children

110. Naujoks, H.: *Fertilität und Nachkommenschaft früherer Röntgenassistentinnen*. (Ein Beitrag zur Frage der sog. "Keimschädigung".) (1929) 32 STRAHLENTHERAPIE 613.

111. (a) Murphy, D. P.: *Ovarian Irradiation: Its Effect on the Health of Subsequent Children* (1928) 47 S. G. & O. 201.

(b) Murphy, D. P.: *Ovarian Irradiation and the Health of the Subsequent Child. A Review of more than Two Hundred Previously Unreported Pregnancies in Women Subjected to Pelvic Irradiation* (1929) 48 S. G. & O. 766.

(c) Murphy, D. P., and Goldstein, L.: *The Etiology of the Ill Health of Children Born after Maternal Pelvic Irradiation. Part I. Unhealthy Children Born after Preconception Pelvic Irradiation* (1929) 22 AM. J. ROENTGENOL. 207.

112. Mayer, M. D.; Harris, W., and Wimpfeimer, S.: *Therapeutic Abortion by Means of X-ray* (1936) 32 AM. J. OBST. & GYN. 945.

113. Goldstein, L., and Murphy, D. P.: *Etiology of the Ill-Health in Children Born after Maternal Pelvic Irradiation. Part II. Defective Children Born after Post-conception Pelvic Irradiation* (1929) 22 AM. J. ROENTGENOL. 322..

who had been exposed to radiation *in utero* and found that 38, or 50 per cent, showed congenital defects or ill health. In 10 the disorder was not attributable to irradiation and in 8 more the relationship was questionable. However, 20 of the 75 children suffered grave disorders and malformations presumably caused by irradiation. The most common defect (16 cases) was microcephaly, a deformity in which the head and brain are very small and idiocy is usually present. Deformities of the eyes and the limbs were also noted in this and other reports. Congenital abnormalities of similar character occur sporadically and without assignable cause in a small percentage (less than 1%) of children born after uncomplicated pregnancies. The incidence of abnormalities reported by Goldstein and Murphy is probably higher than would be expected in an unselected group of babies irradiated *in utero* since the data were gathered for the most part from published case reports and there is always less incentive to publish cases when no interesting abnormalities result. There are, at present, no dependable data on the frequency with which abnormalities may be expected following different doses of radiation administered at different periods during pregnancy. The amount of radiation absorbed in diagnostic procedures is not ordinarily considered hazardous to the fetus. However, since the tolerance dose of the fetus is not known, unnecessary or repeated diagnostic exposures should be avoided.

Miller, Corscaden and Harrar¹¹⁴ have reviewed the important literature on this subject with considerable clarity. Their conclusions which are in accord with the present opinion of most competent radiologists are as follows:

"It seems reasonable to advise that the use of radium and x-ray during pregnancy for treatment purposes be restricted to very clear and urgent indications, and that the use of diagnostic x-ray examinations be not too frequently repeated during pregnancy." . . .

"It seems advisable to interrupt any pregnancy which has been subjected to therapeutic radiation, for it is generally admitted that serious radiation effects on the offspring will result in a high percentage of cases." . . .¹¹⁵

114. Miller, J. R.; Corscaden, J. A., and Harrar, J. A.: *The Effects of Radiation on the Human Offspring* (1936) 31 AM. J. OBST. & GYN. 518.

115. Injuries to pregnant women raise interesting legal problems involving possible rights of action which might accrue to the woman, to her husband, and to the unborn child.

Rights of action of the pregnant woman. A pregnant woman who is injured through defendant's negligence, may recover damages for mental anguish arising

SUMMARY AND DISCUSSION

Radiation damage to tissues results from a combination of direct injury to the tissue cells and impairment of the blood supply to the region. Recognizable tissue damage first appears several weeks or months after exposure

from her reasonable fears that the child will be born deformed. *Macke v. Sutterer*, 224 Ala. 681, 141 So. 651 (1932); *Davis v. Murray*, 29 Ga. App. 120, 113 S. E. 827 (1922); *Selman v. Cockrell*, 198 So. 785 (La. App. 1940); *Fehely v. Senders*, 135 P. (2d) 283 (Ore. 1943); *Elliott v. Arrowsmith*, 149 Wash. 631, 272 Pac. 32 (1928).

Contra: *Nevala v. City of Ironwood*, 232 Mich. 316, 205 N. W. 93, 50 A. L. R. 1189 (1925). If she suffers a traumatic miscarriage she can recover no damages for death of the child, or for mental anguish caused thereby: *Sullivan v. Old Colony St. Ry.*, 197 Mass. 512, 83 N. E. 1091 (1908); *Tunncliffe v. Bay Cities Consolidated Ry.*, 102 Mich. 624, 61 N. W. 11 (1894); *Malone v. Monongahela Valley Traction Co.*, 140 S. E. 340 (W. Va. 1927); nor can she recover damages for mental anguish caused from beholding traumatic deformities in a living child after it is born: *Prescott v. Robinson*, 74 N. H. 460, 69 Atl. 522 (1908); *Cagnon v. Rhode Island Co.*, 40 R. I. 473, 101 Atl. 104 (1917), L. R. A. 1917 E, 1047.

Under the law of all states, a pregnant woman may recover damages for her own personal injuries, pain and suffering, and medical expenses, resulting from a miscarriage caused by the defendant's culpable physical impact (willful or negligent); if the stimulus was psychic, she may still recover damages according to the view followed by courts in a majority of the States which have passed on the question; courts in a minority of such States, however, hold that no damages can be recovered in cases of simple negligence unless the plaintiff proves that a contemporaneous impact against his body was involved. See *Smith, H. W.: Relation of Emotions to Injury and Disease: Legal Responsibility for Psychic Stimuli* (1944) 30 VA. L. REV. 193.

b. *Rights of the husband*. There are many negligence cases which deny the husband's right to recover damages for loss of the society, enjoyment and prospective services of a child destroyed *en ventre sa mere*. The reason assigned is that such a loss is too remote and speculative to form an element in the recovery of damages. *Tunncliffe v. Bay Cities Ry. Co.*, 102 Mich. 624, 61 N. W. 11 (1894); *Butler v. Manhattan Ry.*, 143 N. Y. 417, 38 N. E. 454 (1894); *Western Union v. Cooper*, 71 Tex. 507, 9 S. W. 598 (1888); *Hawkins v. Front-St. Cable R. R.*, 3 Wash. 592, 28 Pac. 1021 (1892).

The wife can recover damages for impairment of her capacity for sexual intercourse caused by a defendant's negligent injury. In *Golden v. Greene Paper Co.*, 44 R. I. 226, 116 Atl. 579 (1922), the court held that a husband could not recover damages for impairment of his wife's capacity for sexual intercourse, as this did not constitute a part of his rights of consortium. But other cases intimate that a jury may consider this item in assessing the damages recoverable by a husband. *Baldwin v. Kansas City Rys.*, 231 S. W. 280 (Mo. App. 1921); *Selleck v. Janesville*, 104 Wis. 570, 80 N. W. 944 (1899); *Birmingham So. Ry. v. Lintner*, 141 Ala. 420, 38 So. 363 (1904); *Indianapolis and Martinsville Rapid Transit Co. v. Reeder*, 42 Ind. App. 520, 85 N. E. 1042 (1908); and see *Guevin v. Manchester St. Ry.*, 78 N. H. 289, 99 Atl. 298 (1916) and *Tunget v. Cook*, 94 S. W. (2d) 921 (Mo. App. 1936).

c. *Rights of the unborn child*. In the case of *Stemmer v. Kline*, 128 N. J. L. 455, 26 A. (2d) 489 (1942) the question was raised as to whether an unborn child has rights of personality which will enable him, after birth, to sue one who negligently injured him while he was still within his mother's uterus. In that case, the defendant physician in attending plaintiff's mother before his birth, erroneously diagnosed her abdominal protuberance as a tumor and treated the person with X-ray irradiation when she was in fact pregnant. Plaintiff was born an idiot and when he was

and characteristically pursues a chronic, slowly progressive course. The affected tissues show decreased resistance to bacterial infection and impaired ability to heal. The most important specific types of radiation injury can be listed as follows:

1. Dermatitis (skin damage)
2. Tumor induction
3. Bone necrosis
4. Enteritis (damage to stomach or intestine)
5. Blood damage
6. Sterility
7. Fetal injury

Dermatitis is by far the commonest injury and may result from diagnostic, therapeutic or occupational overexposure. Tumors induced by X-ray

5 years of age, an action was brought on his behalf against defendant, alleging that the X-ray therapy applied as a result of the negligent diagnosis of tumor caused injury to plaintiff *in utero*. The doctor contended that no duty of care was owed to defendant at the times involved because he was not then a living person. The intermediate appellate court respected this contention (19 N. J. Misc. 15, 17 A. (2d) 58 (1940)). It held that a physician examining a pregnant mother owes a duty of care to an unborn child, if viable, so that after birth it may recover damages for prenatal injuries caused by the doctor's negligence.

On further appeal, the highest court of New Jersey, by a 9-5 decision, reversed the judgment in the Stemmer case, on the ground that a majority of courts, in jurisdictions where the question has arisen, have denied the existence of any common law duty of care to an unborn child. The cases relied upon, however, were not actually in point, for they involved public carriers which might have no means of discovering the fact of a woman's pregnancy. The physician, on the other hand, is duty-bound to examine the woman and to determine whether her abdominal protuberance is due to pregnancy or to a tumor. The majority opinion in the Stemmer case is ably criticized in (1942) 22 B. U. L. REV. 621. The present writer is convinced that the decision of the court in the Stemmer case is erroneous, for the law of property and the criminal law have recognized rights of personality of the unborn, but viable, child, and the law of torts should do likewise. This conclusion is shared by Professor P. H. Winfield, a leading English authority on the law of torts. See Winfield, *The Unborn Child* (1942) 8 CAM. L. J. 76.

Pilgrim v. Landham, 11 S. E. (2d) 420 (Ga. App. 1940) was a case where pregnancy was erroneously diagnosed as tumor and the plaintiff was subjected to irradiation. The interesting feature of the case is the holding that a roentgenologist is entitled to rely upon the diagnosis established by the general physician who referred the patient for treatment. It is probably true that a roentgenologist is so specialized that he cannot be expected to undertake adequate diagnostic studies of every patient, and may limit his engagement to treating on the basis of a diagnosis established by a referring physician whose competence he has no reason to doubt. Whether or not such a roentgenologist, when asked to irradiate a woman with a protuberant abdomen has a duty to make a preliminary film to test the possibility of pregnancy, when the referral diagnosis is tumor, is not entirely clear. Other courts may well hold that such a duty does exist in view of the ease with which the roentgenologist can make a preliminary diagnostic film and the considerable risk of injury to mother or embryo involved in irradiating a pregnant woman.

and radium are almost exclusively skin cancers although bone cancers may develop in persons poisoned with radium. It is probable that a few cases of leukemia have been initiated by radiation but the origin of other forms of malignant disease can rarely if ever be attributed to irradiation. Bone growth can be impaired by moderate doses but necrosis of mature bone results only from massive exposures. Significant damage to the stomach and intestine also requires large doses and is seldom seen except as a complication of tumor therapy. Changes in the blood are often seen as a result of exposure but are seldom important except in patients who have received heavy treatment over large areas of the body and in poorly protected radiological workers. Sterility is a major occupational hazard of both male and female radiologists but can be avoided by proper observance of protective measures. It has not been proved that a child can be adversely affected by irradiation of either parent before conception of the child but a child exposed to radiation while in its mother's uterus suffers grave danger of serious physical injury.

Numerous industrial, commercial and experimental uses of radiation present a hazard of overexposure but so far most of the actual injuries have arisen from the improper use of X-rays and radium in medical diagnosis and treatment. Well-trained specialists in radiology seldom burn themselves or their patients and a high proportion of the serious injuries result from the use of radiological equipment by physicians, surgeons and dermatologists (skin specialists) who have a limited understanding of the dangers involved. Any licensed physician regardless of his training can employ X-rays and radium in his practice, a situation which has been compared to a general permission to practice medicine with liability only in case of injury. It seems as though some legal restriction might properly be established to limit the use of X-rays and radium to persons familiar with their potentialities for good and evil.