3. Radiation: early warnings; late effects

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Since the discovery of ionising radiation just over 100 years ago, it has been appreciated that injudicious exposure could produce harmful effects, even death. However, the general excitement in the scientific community and the, often inappropriate, publicity which followed these discoveries ensured that the damage to health, particularly in the long term, was not given any prominence. The undoubted medical diagnostic and therapeutic value of X-rays and radioisotopes meant that caution tended to be thrown away and it was several decades before control over exposure of the public and workers was put in place. This control has slowly evolved as more knowledge of the processes of interaction between radiation and biological tissue has accrued, but it has often lagged behind clear evidence of effect. Changes over the last 70 years to recommendations governing radiation exposure have usually been more restrictive; even over the last 20 years we have perceived that the risk is about four to five times larger than hitherto thought. However, the controls have not always managed to adequately balance risk and benefit. To understand and analyse the development of radiation protection it is necessary to go back more than 100 years.

3.1. X-rays

Wilhelm Conrad Roentgen is credited with the discovery of X-rays at the University of Wurtzburg in 1895 but there is reasonable evidence that a number of other physicists, notably Goodspeed in 1890, had produced similar penetrating radiations without appreciating their significance. Roentgen was the first to publish an account of the production of X-rays (Roentgen, 1895) and immediately recognised their value to medical diagnosis — in fact he publicised his work by sending an X-ray of his wife's hand to prominent scientists. There was an immediate worldwide interest in this tool for medical diagnosis, and because of the cavalier approach generally adopted by physicians it was inevitable that X-ray injuries would soon appear. The scientific and lay worlds were captivated by the new phenomenon, which could penetrate human tissues and reveal bony structures. Despite the occasional ominous warning to the contrary (Thompson, 1898), the general consensus was that X-rays, used judiciously, were without adverse effects. Simplistically it was assumed that harm could not result from an agent that could not be appreciated by the senses — ironically, this is the very reason given, nowadays, for the unreasonable fear of radiation.

There were reports of injuries as early as 1896 — for instance, Thomas Edison, Tesla and Grubbe noted eye and skin injuries and the former, particularly, cautioned about excessive exposure to X-rays (Edison, 1896). Unfortunately, this was too late for Edison's assistant, Clarence Dally, who suffered from severe radiodermatitis resulting in the amputation of his arm and his subsequent death in 1904. By the late 1890s there were numerous reports of radiation skin burns and loss of hair (epilation) in the scientific literature bearing testimony to the apparent cavalier attitudes and the size of the doses which were being experienced. One of the more absurd actions was that of the well-known American physicist Elihu Thomson, who purposely exposed the little finger of his left hand to the direct beam of an X-ray tube over a period of several days. The inevitable severe damage to his finger made him caution against overexposure '...or there may be cause for regret when too late' (Thomson, 1896). Ironically, because of the increasing number of reports of radiation injury, some physicians recognised the possible therapeutic value of the rays and the first 'treatment' was reported in 1896 (Stone, 1946) when a woman with advanced carcinoma of the left breast was treated in Chicago. At about this time there was some pressure in the media. John Dennis, a New York journalist, who could possibly be considered the first radiation 'whistle blower', campaigned for controls on radiologists and radiographers by licence issued by the state, and suggested that injury to a patient was a criminal act (Dennis, 1899). It was many decades before this was acted upon.

Despite the reports and cautions of adverse effects, and even the use of X-rays for therapy, a degree of overconfidence existed in the medical fraternity regarding the use of X-rays. The theories were that the effects were not caused by the interactions of the X-rays themselves but by static electricity or individual sensitivity — there was even total denial of the existence of X-ray effects (Scott, 1897).

Perhaps the first and most important person in the role of radiation protection pioneer was a Boston dentist, William Rollins. Rollins, who was a Harvard graduate in dentistry and medicine, was the first to suggest a 'tolerance' dose or exposure for X-rays and also the first to recommend ways of shielding and collimating X-ray tubes. His criterion or standard was to expose a photographic plate outside the tube; if the plate did not fog in 7 minutes the shielding was adequate. During the period 1900-1904 he published more than 200 papers urging physicians to use the minimum possible exposure, and he made many suggestions on how to reduce the exposure of both radiologist and patient (Rollins, 1904). This latter point has only recently been addressed again by the United Kingdom's National Radiological Protection Board (NRPB, which advises the government). Rollins also recognised the potential for the induction of cataract and he carried out some animal experiments that showed, amongst other effects, the possibility of acute (teratological) damage to the foetus. He was the first to warn of the risks in the X-ray of women for the diagnosis of pregnancy (pelvimetry). However, his cautions often went unheeded — his warnings about pelvimetry were only revisited, albeit with reference to late effects, by Alice Stewart, the British epidemiologist, about 40 years later (Stewart *et al.,* 1958). It is noteworthy that her work was also at first rejected by the medical authorities (see below).

It would be reasonable to assume that, once it had been identified that excessive X-ray exposure produced tissue damage, care would be exercised. This was not so — even in 1903, Albers-Schonberg (1903) who produced a set of rules for the use of radiologists in protecting themselves, suggested that the regularly used technique of testing the 'hardness' of the X-ray tube by placing the hand between the tube and fluorescent screen was dangerous. It must be said that, in this period, the absence of an agreed unit of radiation exposure or dose was a problem to those who wanted to establish effective standards of protection — this had to wait until the adoption of the roentgen as the unit of exposure in 1928. However, notwithstanding the absence of units, the first set of published rules of radiation protection was produced by the German Radiological Society in 1913 (Taylor, 1979). Shortly after this, also in 1913, Coolidge invented the hot-cathode, tungsten-target X-ray tube which contributed immeasurably to lower doses to both patients and radiographers (for instance, with early tubes operating at low voltages, exposures of more than an hour were common).

3.2. Radioactivity and radioactive materials

Unfortunately, another hazard became apparent very soon after Roentgen's work because within weeks Henri Becquerel had discovered radioactivity and then, in 1898, Marie and Pierre Curie reported the discovery of radium. The extent of the hazard of radioactivity was no more recognised than that of X-rays and both Becquerel and Pierre Curie suffered skin erythemas from carrying samples of radioactive materials in their pockets. Although it was soon realised that radium could be used therapeutically, for example for killing malignant cells, for some reason the public became besotted with the idea of radium (and radium-emanation, radon) being a general panacea.

The precautionary principle seemed to act even slower in this field because not until about 1920 was it realised that controls were necessary. This was initiated at least partly by the use of radium in luminous paint that was used extensively in the First World War. The radium-activated paint was applied by brush and the painters, mostly young women (in New Jersey and elsewhere), found they could work faster and earn more by tipping their brushes with their lips — in this way they ingested considerable quantities of radium. Very little attention was paid to industrial hygiene and the workers were irradiated internally from the radium they had taken in, externally from accumulations of the paint which contaminated their workplaces and from the inhalation of radon. The hazard of this work was not at first recognised but in 1924 a New York dentist, Theodore Blum, published a paper that identified a new disease which he called 'radium jaw' (sometimes known as 'phossy jaw') which he had seen in his patients who were ex-dial painters. He attributed the condition to the toxicity of phosphorus. However, a local New Jersey pathologist, Harrison Martland, recognised the bone lesions as being caused by radium and in 1925 started a study that unearthed the whole sorry story (Martland and Humphries, 1929). The first bone sarcoma was recorded in this group of women in 1923 and there have been 55 such cancers studied in a population of nearly 3 000 women (Rowland *et al.*, 1983) — altogether about one third have died of various malignancies (including leukaemia and breast cancer). The data derived from the experiences of these women did eventually set the standard for the intake of radioactive material for many years — this was the so-called radium standard. This standard was set at the amount of radium in the body which apparently produced no effect. There was then an assumption of a threshold for the effects but this was in accord with the general attitude in the years up to 1930 of setting a 'tolerance' dose. The radium standard was set at a level of radioactivity of 0.1 microcuries (3.7 kilobecquerels) of radium which would deliver a radiation dose of 150 millisieverts to the bone.

In a somewhat bizarre way, in the 1920s radium was looked upon as a source of health and healing. This cumulated in many potions being sold containing radium, the most famous being Radiothor. Four hundred thousand bottles of this quack nostrum, which was said to cure a range of maladies from stomach ulcers to impotence, were sold between 1925 and 1930. The more dangerous aspects of this were highlighted when a famous US golfer, industrialist and millionaire, Eben Byers, died from radiation-induced disease after consuming about 1 000 bottles over a long period of time (Macklis, 1993). This case did quite a lot to encourage a more restrictive approach to the use of radium, as did the death of Marie Curie in 1934 from (probably) aplastic anaemia (which was at the time attributed to the effects of radium). Nevertheless, such use of radium and radon has lasted to this day in the form of, for instance, 'emantoria' where radon is breathed for (presumed) beneficial purposes, for example in Salzburg.

3.3. Early moves towards control of exposure

During the 1920s the concept of radiation dose was not defined but there were a number of reports aimed at restricting exposure. These often quoted a level which could be 'tolerated'. One of these was a fraction of the skin erythema dose (SED) which was suggested by an American physicist, Arthur Mutscheller (Mutscheller, 1925). His proposal was one hundredth of the SED in a month. This would be very roughly equivalent to an annual dose limit of about 700 millisieverts (the contemporary dose limit for workers is now 20 millisieverts per year). It is noteworthy that during this period the emphasis was on limits driven by a desire to control the immediate effects of radiation. There seemed to be no realisation that cancer would follow after a long lag, or latent, period.

Clearly there was some pressure from within part of the scientific community for control of the use of radiation and with the establishment of the International X-ray and Radium Protection Committee (IXRPC) at the second International Congress of Radiology in 1928 the setting of standards became more regularised. However, comments on the misuse of radiation were often missing. For some reason in the early pontifications of the IXRPC emphasis was placed on leisure activities for radiographers (Desjardins, 1923). For example, 'The cultivation of an outdoor hobby is of special importance to all persons exposed to radiation.' The IXRPC eventually metamorphosed into the International Committee on Radiological Protection (ICRP) but again it was some time before this committee began to recommend dose limits without connotation of a dose threshold. All this was against a background of reports of more than 200 radiologists who had died of what were thought to be radiation-induced malignant diseases (Colwell and Russ, 1934), particularly the pioneering British radiologist Ironside-Bruce in March 1921. As a result of his death there were several press articles commenting on the adequacy of shielding of X-ray tubes which prompted the Roentgen Society ('Editorial', 1921) to state 'the scientific competency of the press is less than its ability to write lurid journalise'.

3.4. The post-war watershed: justification, optimisation, limitation

The essential change in radiation protection philosophy came at a meeting in Canada in 1949 (NBS, 1954) when it was concluded that, 'there may be some degree of risk at any level of exposure' and 'the risk to the individual is not precisely determinable but however small is believed not to be zero'. The additional philosophy from this meeting, which is of great importance, was that 'radiation exposures from whatever sources should be as low as practicable'. This is what is now known as the optimisation principle. The risk *vs.* benefit (justification) principle, which is probably unique to radiation as a pollutant, was also introduced.

The ICRP was set up to do no more than make 'recommendations' which, presumably, could have been accepted or rejected by national governments, but from its inception its role has been criticised. For example, it took no stand about the testing of nuclear weapons in the atmosphere which produced worldwide fallout. In addition it has generally been the work of individuals, rather than the ICRP, which has prevented the misuse of radiation. There are numerous examples of the ill-conceived use of radiation, including:

- The widespread use of Pedascopes for fitting children's shoes. These X-ray fluoroscopy devices were in nearly every shoe store in the 1940s and 1950s and could produce reported dose rates of 1 roentgen per minute. They did no more than keep children amused whilst their parents selected shoes and thus the radiation doses received by children and shop staff were totally unnecessary.
- Children who had ringworm were treated with X-rays to produce epilation but many subsequently developed cancer (see, for example, Ron *et al.*, 1989).
- Mental patients were 'treated' with radium in the 1930s.
- X-rays were used for the removal of unwanted hair in beauty shops in the 1930s and 1940s.

These misuses of radiation were largely uncontrolled because there were, at that time, no specific legal regulations governing radiation safety, only recommendations. In the United Kingdom legal regulation was first encapsulated in the Ionising Radiations Regulations (1961); and later separately for medical radiations (POPUMET, 1988).

Following the Second World War there was a rush to develop both nuclear power and nuclear weapons. The radiation protection community was faced with the problem of setting dose limits that did not appear to restrict the expansion of these industries — politics entered the scene. At first the public were beguiled by the promise of endless cheap nuclear power but demonstrations of nuclear weapons produced a different reaction. Gradually people began to have less and less confidence in, and more suspicion of, the motives of governments, particularly with regard to bland reassurances about the effects of radioactive contamination of the environment. This apprehension was fuelled by the rise of the 'green movement' and was to a certain extent justified — it is only surprising that it took so long to develop. This was maybe because the early uses of radiation had to a large extent been in medicine and the public had a trust of doctors. However, the motives of the nuclear industry were seen as less likely to be for the good of the individual. Even confidence in medical radiology received a jolt in the late 1950s when a well-known public health epidemiologist, Alice Stewart, carried out some studies which linked radiology during pregnancy (pelvimetry) with leukaemia in children (Stewart *et al.*, 1958). This finding was at first controversial and disbelieved but, after being repeated by others, it is now accepted that there is a significant risk of leukaemia from even small radiation doses received by the embryo or foetus. Nowadays it is recommended (RCR, 1993) that no obstetrician should consider the use of X-rays if some other diagnostic tool is available. It has been estimated (Doll, 1989) that about 5 % of all cases of childhood cancer were caused by pelvimetry, which in the United Kingdom was about 75 cases each year and in the United States about 300. In could be claimed that these numbers of leukaemias would have been saved had the work of Stewart *et al.* been acted on earlier. A similar and contemporary story may be unfolding in relation to the childhood leukaemia risk in proximity to overhead power lines in the United States.

Contemporary risk estimates for radiation are probably more quantified and more soundly based than risks from any other environmental pollutant. However, there are problems with even these estimates because they are derived almost exclusively from the health records of the survivors of the atomic bombings in Japan in 1945 i.e. at high dose and dose rate. A conservative linear dose-effect relationship is assumed and it is therefore appreciated that there is a risk at all doses. Exposures to radiation are therefore associated with a certain acceptance of risk. For this reason the ICRP have based their philosophy (ICRP, 1977) around three tenets:

- Justification — all uses of radiation have to be justified so that the detriment is offset by some net benefit.
- Optimisation — all exposures must be kept as low as reasonably achievable, social and economic factors being taken into account.
- Limitation — all exposures must be below the appropriate dose limit.

It is of interest to examine the first and second of these tenets to see what progress has been made in the 100 years of radiation use, using medical radiology as an example.

In medical radiation exposure it is intended that there should be some benefit to the patient. Although this is usually true there are an increasing number of occasions when it is doubtful, for example the use of X-rays as part of health monitoring for job selection, or some screening procedures. The NRPB has estimated (NRPB, 1990) that about 20 % of all X-rays carried out in the United Kingdom are clinically unhelpful. Thus it has been stated in guidance principles given to radiographers that 'there should be a valid clinical indication for all examinations of patients where ionising radiation is used.' This constitutes 'justification' and is a major step forward compared to the radiology of, say, even 40 years ago, particularly as it refers to the patient and not just the radiologist. In addition to this criterion, the dose received by the patient should be optimised, and here progress is not so good. The NRPB has estimated (NRPB, 1990) that the total annual collective dose from medical examinations in the United Kingdom is about 16 000 man-sieverts. It also suggests a number of patient dose reduction methods which should result in a reduction in this collective dose of about 7 500 man-sieverts, i.e. nearly 50 %. It has also been shown, more recently, that the variation in the dose received at different hospitals for the same examination can be more than an order of magnitude (Wall and Hart, 1997). Thus, although the individual radiation dose is now maybe two orders of magnitude lower than 60 years ago, the problem of optimisation of that dose still exists.

3.5. Conclusions

Overall it can be concluded that radiation protection standards have slowly evolved as the perception of radiation effects has developed. However, there have also been some people, maybe ahead of their time, who warned of impending doom. Thus, there have always been periods when changes in limits have lagged some years behind clear evidence of harm to human health. There are now substantial lobbies for changes which include both re-introducing the concept of thresholds and considerations of hormesis (small doses which are thought to do some good) — these have been resisted by the ICRP.

Radiation protection is now firmly established in legislation both in the European Union (by directives) and, internationally, in the Basic Safety Standards of the International Atomic Energy Agency (IAEA). All of these use the recommendations of the ICRP as their basis. In the United Kingdom the most recent legislation which covers workers and members of the public is the Ionising Radiations Regulations of 1999. These are intended to implement EU Directive 96/29 (laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation). This directive will (eventually) be implemented throughout Europe, and similar regulations from the IAEA should apply in other countries. There are now, also, regulations which cover the use of radiation in medicine and the limitation of doses to patients. However, it has been found difficult to ensure that radiation protection legislation is implemented uniformly and there continue to be examples of careless or irresponsible attitudes towards radiation sources and waste which have resulted in horrendous injuries and death, such as the caesium-137 incident at Goiania (Rosenthal *et al.*, 1991).

Historically, less stringent dose limits have also given rise to claims from workers for compensation for cancer allegedly caused by radiation exposure. In this context, the issue of liability for radiation injury has some lessons for other 'long latent period' hazardous agents. In the United Kingdom liability in the nuclear industry was originally state funded (Nuclear Installations Act 1965) but the Radiation Workers Compensation Scheme, which is run jointly by trades unions and the nuclear industry, has been extremely successful in providing an alternative to litigation.

Thus, although we have learnt much about the risks of radiation exposure in the last 100 years (probably more than about any other environmental pollutant) we are still constantly having to react to new knowledge. For instance, the risk rate for radiation-induced cancer was perceived (by ICRP) as four to five times higher in 1990 as compared to 1977. This resulted in changes in dose limits but was a belated response to mounting incontrovertible evidence, a situation which has been a recurring theme in the history of radiation protection, where precaution has sometimes been lacking despite the clear warnings given from the discovery of radiation to the present day. Thus it must be concluded that the precautionary principle suggests that epidemiological databases of long-term effects must be funded and maintained for the future even when an immediate need is not perceived.

Table 3.1. **Radiation: early warnings and actions**

Source: EEA

1896	Injuries from exposure to X-rays noted by Edison, Tesla and Grubbe.
1899	John Dennis, New York journalist, campaigns for licensing of radiologists and warns of harm from X-rays.
1904	Death of Edison's assistant from complications arising from severe X-ray radiodermatitis.
1904	William Rollins, Harvard dentist/doctor, publishes many warnings on X-ray hazards, and recommendations on prevention for radiologists and patients, including pregnant women.
1913	First published rules of voluntary radiological protection by German Radiological Society.
1924	New York dentist, Theodore Blum, identifies 'radium jaw' in radium dial painters: but wrongly attributes this to phosphorous.
1925–29	Harrison Martland, New Jersey pathologist, identifies radium as the cause of the jawbone cancers in the dial painters studied.
1928	Establishment of the International X-ray and Radium Protection Committee: which later became the International Committee on Radiological Protection (ICRP).
1934	Reports by Colwell and Russ, on the death of more than 200 radiologists from radiation-induced cancers.
1949	ICRP concludes that there is no dose threshold for radiation-induced cancer and optimisation of all exposures is crucial.
1958	Alice Stewart reports that 'low dose' X-rays to pregnant women can cause leukaemia in their children. Not generally accepted until the 1970s.
1961	UK publishes regulations covering the use of radioactive substances.
1977	ICRP updates its radiation protection recommendations and links dose limits to risk.
1988	Regulations covering radiation doses to patients produced in the UK
1990–97	NRPB reports 20 % of medical X-rays are probably clinically unhelpful; that 50 % of the collective dose to patients could be avoided; and that individual doses for the same X-ray vary by 100x between hospitals.
1990	ICRP concludes in Publication 60 that the risk of radiation-induced cancer is 4-5 times greater than estimated in 1977 — reduces the occupational dose limit to 20mSv per year.
1996	EU Directive on Ionising Radiations based on ICRP 60 which will be mandatory on member states.

3.6. References

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