The Gold Standard for Radiation Effects on People: Scientific Value and Ethical Obligations

Scientific Secretary, International Commission on Radiological Protection Christopher H. Clement

●Overture:Discovery of X Rays to the Second World War (1895–1939)

Just months after the discovery of X rays in November 1895 (Röntgen 1895), radiation damage to the skin was already being observed in early experimental investigators, including erythema, dermatitis, and ulceration (Grubbé 1933) (Drury 1896) (Leppin 1896). Nonetheless, X rays, with their ability to see inside the human body, were used almost immediately in the medical field, including in military field hospitals as early as 1897 (Churchill, 1898). Therapeutic uses were also tested as early as 1896 (Belot 1905). With Curie's discovery of radium in 1898 (Curie 1898) the use of radiation in medicine continued to increase, as did reports of radiation induced damage in practitioners and patients.

On December 12, 1896, just one year after the discovery of X rays, the first radiological protection recommendations were published in the Western Electrician by Wolfram Fuchs (Fuchs, 1896). He reported having "applied the X-ray to all parts of the body" in 1,400 cases over nine months, and "but four instances of the slow healing burns which have lately attracted considerable attention through the columns of the press." Fuchs noted that "the injury may be regarded as slight in comparison with the benefits resulting from this wonderful discovery", adding, in the next sentence: "however, it is desirable, of course, to prevent the inconvenience and pain of these 'sunburns'".

In 1925, the first International Congress of Radiology (ICR) was held in London. Here, the International X-ray Unit Committee, now the International Commission on Radiation Units and Measurements, was formed. Discussions were also held regarding creation of an international radiological protection committee. This occurred at the second ICR in Stockholm in 1928, when the International X-ray and Radium Protection Committee (IXRPC) was created.

Arising from the 1928, ICR were the first "International Recommendations for X-Ray and Radium Protection" (ICR 1929). The focus of these recommendations was on the protection of "X-ray and radium workers" in medical facilities, and the first sentence declared that "The

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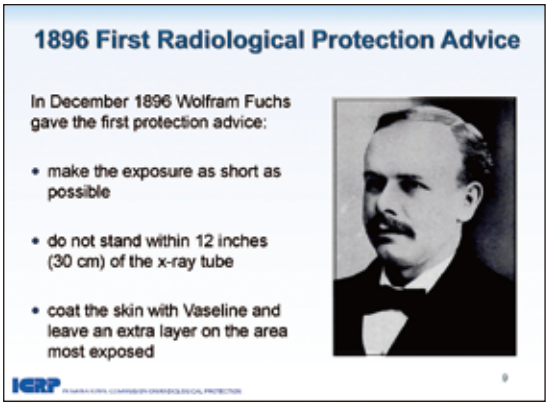

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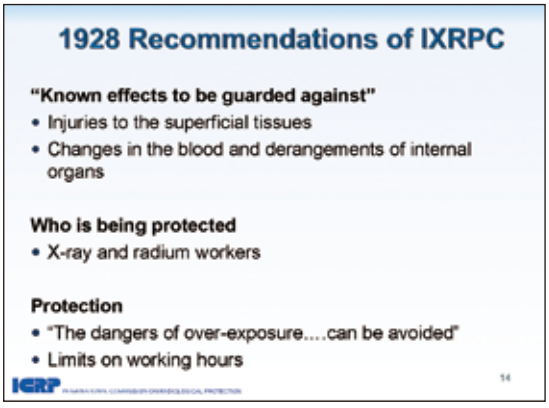

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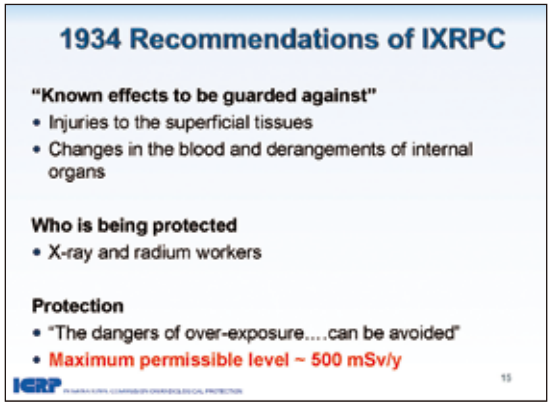
dangers of over-exposure to X-rays and radium can be avoided by the provision of adequate protection and suitable working conditions." The dangers were considered to be "injuries to the superficial tissues" and "derangements of internal organs and changes in the blood". A key method of protection was limitation of working hours, as well as advising operators to stay "as remote as practicable from the X-ray tube", and using shielding around the x-ray tube.

The IXRPC met next during the ICRs held in Paris in 1931, and then in Zurich in 1934. No new recommendations were produced in 1931. In 1934 the main addition was to suggest a level at which "a person in normal health can tolerate exposure to X rays". In modern units this would be similar to an annual dose of about 500 mSv.

The IXRPC met again in Chicago at the 1937 ICR, although there were no great advances in the radiological protection recommendations at that time. They did not meet again before the Second World War.



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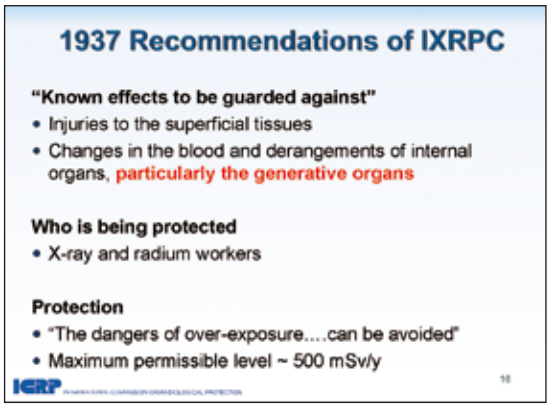

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●Interregnum: World War II (1939–1945))

The Second World War changed many things. Tens of millions of people died. Many peacetime endeavours in the axis and allied countries were interrupted with all focus on the war effort. Two seminal events occurred during the final stage of the war: the atomic bombings of Hiroshima and Nagasaki. To this day, these remain the only uses of atomic bombs in warfare.

On August 6, 1945, the atomic bomb "Little Boy" was dropped on Hiroshima. Just three days later, on August 9, 1945, the atomic bomb "Fat Man" was dropped on Nagasaki. Tens of thousands were killed immediately, and tens of thousands more died in the months that followed. However, many exposed to the radiation from the atomic bombs survived. The number of casualties was not greater than those from other major urban bombing campaigns, but these were caused by two single bombs unlike any that had been seen before. This massive destructive power, and the lingering concerns about those who had been exposed to the bombs left an indelible scar on the human psyche.

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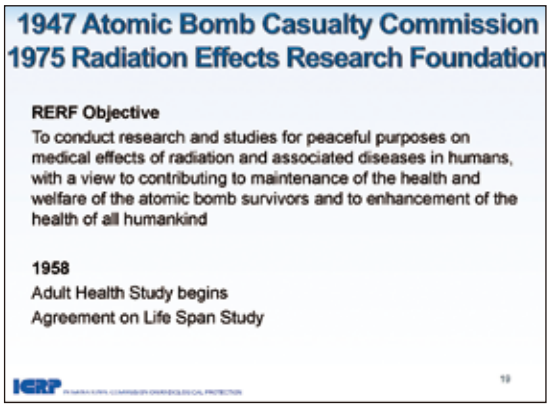

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●Metamorphosis:Increasing Knowledge and Evolving Protection (1946–1990)

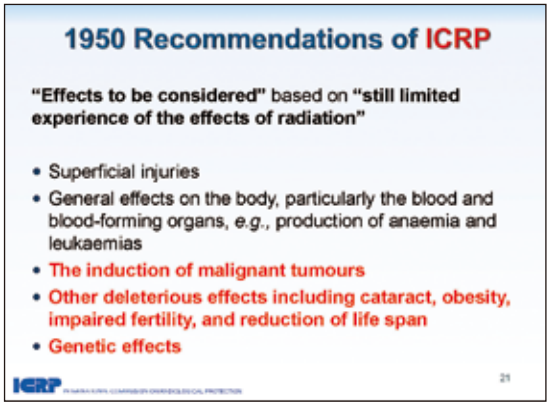
Immediately after the war, in September 1945, Japanese and American scientists established a Joint Commission to investigate medical effects of the atomic bombing. Following this, in March 1947, the Atomic Bomb Casualty Commission(ABCC) was formed to undertake a long range study of the biological and medical effects of the atomic bombs.

In April 1975, the ABCC was succeeded by the Radiation Effects Research Foundation (RERF). The mission of RERF is to conduct research and studies, for peaceful purposes, on the medical effects of radiation

on man and on diseases which may be affected by radiation with a view to contributing to the maintenance of the health and welfare of atomic bomb survivors and to the enhancement of the health of all mankind. Over the years, the ABCC and RERF have undertaken extensive and valuable studies of atomic bomb survivors, the results of which are the gold standard in understanding the effects of radiation on humans.

In the years after the war, aided considerably by the work of the ABCC and later RERF, a major shift in understanding the effects of radiation occurred. It was becoming clear that there were long-term effects well beyond the immediate "injuries to the superficial tissues" and "derangements of internal organs and changes in the blood" seen at high doses. Relatively lower doses of radiation could, in the long term, also lead to cancer and (it was thought at the time) genetic effects.

Meanwhile, international radiological protection community also re-emerged after the war. The first International Congress of Radiology since 1937 was held in London in 1950. There, the IXRPC was renamed as the International Commission on Radiological Protection (ICRP).



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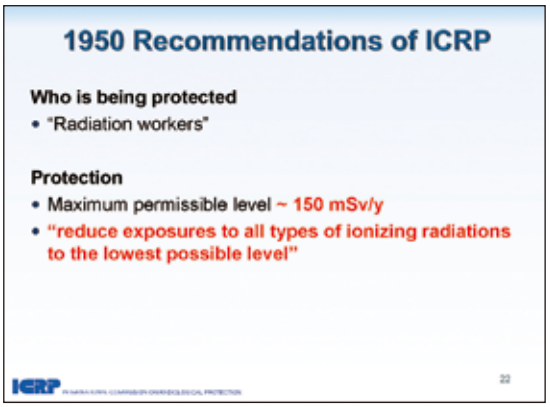

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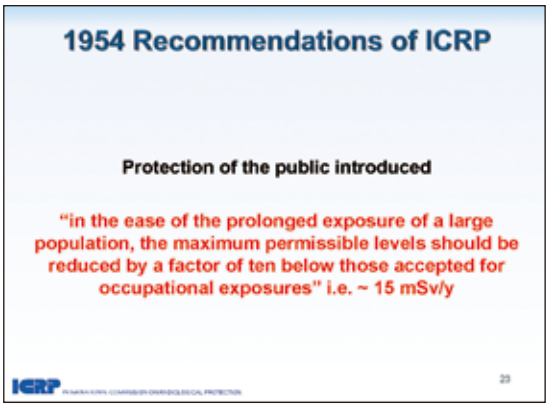
1950 Recommendations of ICRP (ICRP, 1951) included an expanded list of effects of radiation exposure, based on "still limited experience":

(1) Superficial injuries.
(2) General effects on the body, particularly the blood and blood-forming organs, e.g. production of anaemia and leukaemias.
(3) The induction of malignant tumours.
(4) Other deleterious effects including cataract, obesity, impaired fertility, and reduction of life span.
(5) Genetic effects.



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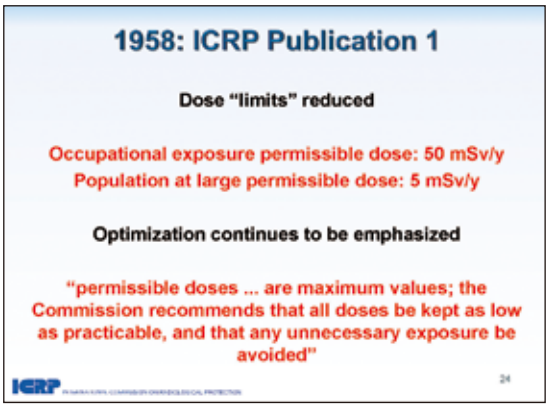
Now, it was not just about skin reactions and ill-defined "derangements". The picture had become much more complicated with the introduction of cancer, genetic effects, and other effects. This complication went far beyond just a longer list of potential effects. It was not realized that potentially harmful effects of radiation exposure could not be completely "avoided by the provision of adequate protection". It seemed that the newly discovered effects, which took a comparatively long time to manifest, could even occur at relatively low doses.



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This lead to recommendations to "reduce exposures to all types of ionizing radiations to the lowest possible level", and also the recommendation of a reduced maximum permissible level of exposure roughly equivalent to 150 mSv/y in modern units.

Public concern about radiation risks began to grow in the mid-1950s. Not only was the memory of the atomic bombs that dropped over Hiroshima and Nagasaki still fresh, but extensive nuclear weapons testing was being conducted in the wake of the Second World War, resulting in widespread of radioactive

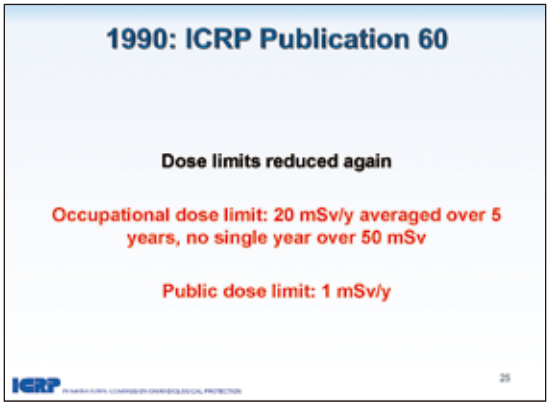
contamination. The incident of the Lucky Dragon (Lapp, 1958) (Schreiber, 2012) also influenced public opinion significantly in Japan and world-wide. The 23-man crew of the Daigo Fukuryū Maru (Lucky Dragon 5), a Japanese fishing boat, was caught in the fallout of US nuclear weapons test "Castle Bravo" at Bikini Atoll on March 1, 1954. The vessel was far enough away to avoid any effects of the blast, which was 1000 times greater than the bomb dropped on Hiroshima less than a decade before. However, the crew was exposed to fallout. Although they did not know the consequences at the time, some symptoms began to show during the two-week voyage back to Tokyo. Upon arrival in port, the ship, crew, and catch were found to be radioactively contaminated. The crew were treated for acute radiation syndrome, and one died in September of the same year.

The Lucky Dragon and their not-so-lucky crew were not alone. The Japanese Ministry of Health and Welfare reported that that 856 Japanese fishing vessels and nearly 20 000 crew members had been exposed to radiation from the Castle Bravo test. The price of tuna dropped, and 75 tons caught during the remainder of the year were found unfit for consumption.

Protecting the public from radiation exposures was also high on the list of concerns for ICRP during this period. Not only were weapons tests being carried out, but nuclear power and the use of radioactive sources in many fields were on the rise.

In this atmosphere, the 1954 Recommendations of ICRP (ICRP, 1955) marked another important change: the explicit introduction of protection of the public. Until this time protection advice had been aimed at "occupational workers". Now, with just a single sentence, this was expanded: "In the case of the prolonged exposure of a large population, the maximum permissible levels should be reduced by a factor often below those accepted for occupational exposures" i.e. about 15 mSv/y in modern units.

Building on this, and also responding to new information on radiation effects, the 1958 Recommendations of ICRP (ICRP, 1959) expanded considerably on its recommendations for protection beyond occupational exposure. Explicit mention was made of "members of the public living in the neighbourhood of controlled areas", "the population at large", and "medical exposure".



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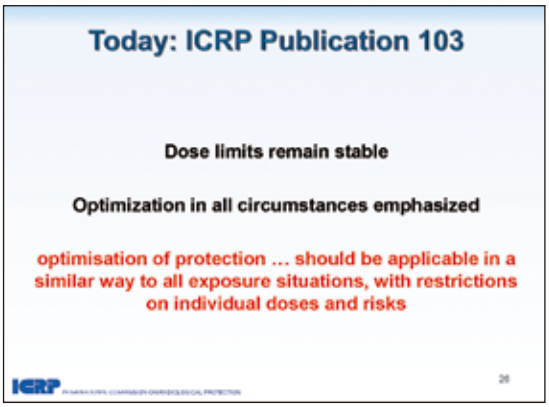

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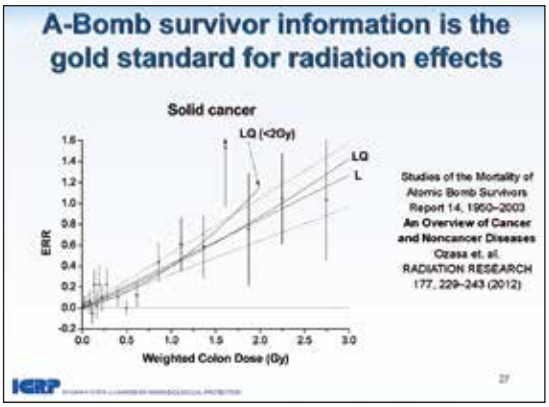

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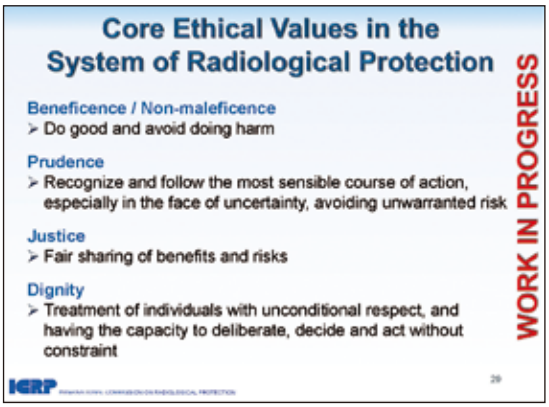

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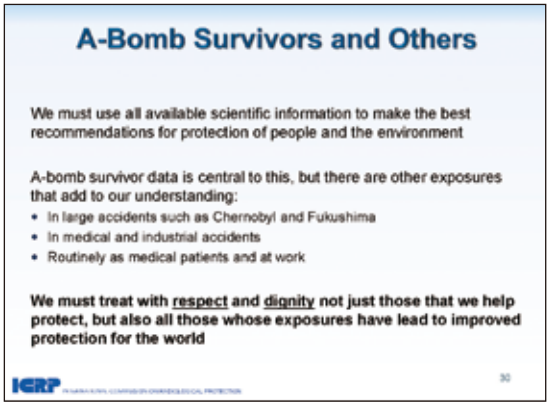
In addition, 1958 saw an important reduction in dose limits, to 50 mSv/y for occupational exposures, and 5 mSv/y for the population at large, with the caution that "permissible doses ... are maximum values; the Commission recommends that all doses be kept as low as practicable, and that any unnecessary exposure be avoided".

There were considerable additional developments over decades that followed, both in terms of the knowledge of radiation effects, and the sophistication of the system of radiological protection. The 1977 Recommendations (ICRP, 1977) introduced the basics of the system of protection that is still used today. The 1990 Recommendations (ICRP, 1991) set the dose limits that are now used: 20 mSv/y averaged over 5 years and no single year over 50 mSv for occupational exposure; and, 1 mSv/y for public exposure. Only the recommended occupational dose limit for the lens of the eye has changed since then (ICRP, 2012).



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The work of RERF continues to be the gold standard in understanding the effects of radiation on humans. Their work continues, following the remaining population of atomic bomb survivors, and using more and more sophisticated methods to analyse the results.

Cancer remains the main long-term effect of concern related to radiation exposure. Despite concerns raised in the 1950s primarily due to some animal studies, direct evidence of genetic effects in humans has not been observed. However, new evidence, from the atomic bomb survivor studies and others, is pointing towards the potential for cardiovascular and cerebrovascular diseases to be important even at low doses and dose rates. More work is needed in this area to clarify the situation.

To this day, ICRP continues to be the leading international organization with respect to the development and maintenance of the system of radiological protection. ICRP has published nearly 150 reports on all aspects of protection from ionizing radiation since 1977 in its dedicated journal, The Annals of the ICRP. Its recommendations form the basis of radiological protection standards, legislation, guidance, and practice world-wide.

In addition to closely following scientific developments, in recent years, ICRP has also put more emphasis on clarifying the ethical basis of radiological protection. Today, ICRP Task Group 94 is charged with consolidating the ethical basis of the recommendations of ICRP to improve the understanding of the system, and to provide a basis for communication on radiation risk and its perception.

This effort has led to some preliminary results, using a core set of ethical values to describe the ethical basis of the system:

•Beneficence / Non-maleficence: Do good and avoid doing harm;

•Prudence: Recognize and follow the most sensible course of action, especially in the face of uncertainty, avoiding unwarranted risk;

•Justice: Fair sharing of benefits and risks; and,

•Dignity: Treatment of individuals with unconditional respect, and having the capacity to deliberate, decide, and act without constraint.

This early result has been developed in collaboration with a wide variety of people including radiological protection experts, ethicists, and other individuals with a direct interest in the ethics of radiological protection such as some residents of Fukushima. The work will be refined further in the coming year or two through broader consultations.

However, the concept of dignity in radiological protection could, and perhaps should, be extended not only to those being protected, but also to those whose experiences have contributed to the system of protection.

We cannot forget the people behind the numbers: those whose exposures have helped progress the science of radiation effects. The survivors of the bombings in Hiroshima and Nagasaki deserve our respect and gratitude, and to be treated with dignity. This is also true for others whose exposures have contributed to the sum of human knowledge: those exposed due to accidents such as Chernobyl and Fukushima, and those

routinely exposed as medical patients and at work.

Out of respect, and for the overall benefit of society, scientists and radiological protection professionals have a duty to make the best use of this information to contribute to the protection of people from detrimental effects of radiation exposure world-wide. Similarly, there is a duty to treat those effected with dignity.

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