Radiation hazards in medicine, industry and education

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Introduction
Ionising radiation is widely used in medicine, industry and education. Most people are familiar with medical applications for diagnosis and treatment of disease. However the public at large is probably not aware just how commonly it is used in industry. Such uses include: the measurement and control of various processes e.g. - liquid levels in bottling and canning plants and the thickness and density of a wide range of materials, the examination of metallic structures for defects, the radiation treatment of plastics to change their properties and the sterilisation of medical products. Educational applications range from demonstrating the basic laws of radiation physics to sophisticated studies of chemical and biological processes using chemical compounds which have been labelled with suitable radioisotopes. Furthermore many pieces of laboratory equipment, for example X-ray diffractometers and X-ray fluorescence analyzers, incorporate a source of radiation.

The safety record of the use of radiation, when compared with many other processes, is generally good. However, serious accidents can and have occurred. While most accidents involve small numbers of people, a few have had widespread consequences. These include accidents where large numbers of patients undergoing radiotherapy received the incorrect dose and where the inadvertent disposal and scrapping of radiation sources led to widespread contamination of persons, property and the environment.

This paper will discuss the hazards associated with particular applications and outline the causative factors which have been identified. These include, equipment faults, simple but serious errors in dose calculations and loss or incorrect disposal of radioactive sources. The lessons that have, or should have been learned, from the past events will also be considered.

The paper will also describe briefly the regulatory system in Ireland for controlling the use of radiation in medicine, industry and education. The description will show how regulations are established within the framework of European Commission Directives on radiation protection. Other initiatives, particularly those emanating from the International Atomic Energy Agency to ensure that all countries have at least basic infrastructures to ensure the safe use of radiation, will also be discussed.

The main hazards associated with the more common applications of ionising radiation may be summarised as follows:

Medical Applications
The use of radiation in medicine is the largest contributor to population dose from man-made sources. A small reduction in the population dose from medical applications would have the same effect as eliminating the dose from, for example, routine discharges of radioactive waste from the nuclear industry. It therefore behoves doctors and paramedical staff who have
responsibility for medical exposures to ensure that doses are kept as low as reasonably achievable. Doses received as a result of medical procedures may be optimised by ensuring that:

- ionising radiation is used only when the need is clinically indicated, for example, if the same diagnostic information can be obtained from an ultrasound scan then ultrasound should be used instead of X-rays.

- equipment including image processing equipment is kept in good condition. This reduces the need for repeat examinations.

- only equipment which meets up-to-date standards of design and performance is used. For example, it has been shown that modern dental X-ray equipment delivers a significantly lower skin dose than older units [Fenton, 1994]. It is for this reason, as well as for reasons associated with safety generally that, from 1st January 1995, the Radiological Protection Institute of Ireland licenses only those dental X-ray units which meet certain minimum standards of design and performance [RPII, 1996].

- carefully keeping and making available X-ray films and the reports thereon. This reduces the need for repeat examinations. Moreover the advent of computerised storage and electronic transfer of images, should in principle reduce the need for repeat examinations, particularly where a patient is referred or voluntarily goes from one hospital to another. However, it will be many years before this facility is available in all but the largest hospitals.

1. **Major causes of incidents/accidents - equipment faults**

The most serious radiation accident to date in Ireland, involved a brand new X-ray unit on which the timer had been inadvertently bypassed, so that as soon as the machine was connected to the mains supply, it started to produce X-rays. While it was not possible to estimate the doses to the dentist and his assistant with any certainty [Malone and Hone, in press], it may have been significant and resulted in both the dentist and his assistant being awarded substantial damages. Timer faults on radiotherapy equipment can obviously have catastrophic implications for the patient and for this reason all radiotherapy equipment must now be fitted with some form of back up timer which terminates the exposure if the main timer fails.

A particular hazard associated with radiotherapy equipment is the selection of the incorrect radiation type/target combination on accelerators which produce both X-ray and electron beams. If an X-ray beam is selected without the X-ray production target in place the patient will be exposed to lethal doses, from the electron beam (due to the inefficiency of the X-ray production process a small fraction only of the electron beam is converted to X-rays in the X-ray target).

In the case of diagnostic equipment, the selection of incorrect target material and/or beam filters will obviously not have the same dramatic consequences. However, the use of underfiltered beams will result in an increased skin dose and in mammography, in particular, the X-ray target material and filter combination must be carefully selected to optimise image quality.
The above are examples of the more obvious faults that may occur. There are of course a whole range of things that can go wrong with medical irradiating apparatus, and in the case of diagnostic applications, with detection and image forming systems, as well. However, a discussion of these potential faults lies outside the scope of this paper.

2. Calibration Errors
In radiotherapy doses to the patient should be within 3% of the prescribed value. Accidents have occurred where large numbers of patients have been significantly over or under exposed due to incorrect calibration of radiotherapy equipment. Errors in calibration include simple arithmetic errors in calculating dose rates and, for example, applying correction factors twice. The investigation of such accidents has led to a call for stringent quality control procedures in radiotherapy.

3. Patient specific incidents/accidents
These include:

- the wrong patient being exposed
- incorrect procedures (e.g. irradiating the wrong part of the body)
- the dose not as prescribed by the doctor
- the patient being pregnant (unknowingly)

For diagnostic applications, while such an incident is clearly highly undesirable, the risk to an individual patient, in terms of radiation effects, is in most cases, insignificant - except perhaps where a pregnant patient undergoes a high dose diagnostic procedure involving exposure to the abdomen.

Obviously the most serious consequence of subjecting the wrong patient to a radiological examination, or the incorrect examination, is that he or she will not receive the appropriate follow up treatment. On the other hand in radiotherapy the consequences of such an incident may be catastrophic. In this regard it might be asked how can such a basic accident happen. The answer is in busy radiotherapy departments - all too easily, particularly if there are linguistic difficulties between patients and staff and/or where patients have little idea of what type of treatment to expect. The potential for accidents of this type underlines the need for quality control in all aspects of radiotherapy practice.

Hazards with radioactive sources
These range from minor spills of radiopharmaceuticals which can usually be cleaned up easily to the loss and, in some cases, breaking up of sealed sources. Due to their small physical size radium and caesium tubes and needles which are used for radiotherapy, are easily lost. While most lost sources have probably ended up buried in municipal refuse dumps where they will not constitute a hazard, they may end up being inadvertently stored close to persons. This can happen, for example, if a patient is inadvertently discharged from hospital with a source, or sources, still in situ. Patients to whom therapeutic doses of unsealed radionuclides have been administered, also constitute a potential hazard. The external radiation dose rate as well as the radioactivity levels in their excreta, will be significant in the first few days following treatment.
The most serious accident involving radiotherapy sources is where a large source used in an external beam machine is inadvertently scrapped. This happened in Mexico and in Brazil. In the case of the Brazilian accident four people received fatal radiation doses and large areas of land and many houses were severely contaminated [IAEA, 1988].

**Industrial Applications**

On site industrial radiography is often carried out in locations which are not readily amenable to the enforcement of good practice and regulatory controls, e.g. on oil rigs, in pipe trenches etc.

Particular hazards include:

- **Source loss.** Although the sources used in industrial radiography are not as large as those involved in the accidents referred to above involving medical external beam equipment, they can still cause fatal doses and/or significant contamination if improperly handled. Source loss is also a risk in the case of gauge sources where plant may be scrapped with the gauge containing the source still attached. An Irish steel making plant inadvertently melted down a gauge source concealed in a consignment of imported scrap [O'Grady et al., 1996]. While the source involved was too small to produce hazardous radiation levels at the plant, it resulted in an expensive clean up operation.

- **Failure to evacuate persons from controlled areas during on-site radiography.** Since it may not be practical to erect physical barriers to prevent the ingress of persons, exclusion must be based on the use of warning notices, lights, tapes and ropes.

In the case of the much higher dose rates used in radiation sterilisation and other industrial radiation procedures, e.g. changing the properties of plastics, exclusion from the controlled area must involve shielded walls and a sophisticated system of interlocks, as the dose rates involved in these procedures will result in a lethal dose in a matter of minutes [IAEA, 1990(a)]. Fatal doses have been received as a result of operation of such plants, as a result of:

- intentionally bypassing the interlock system (the operators were unaware of the hazards)

- believing the source to be "off" or in the safe position when it was not

- interlock failure.

Responsible manufacturers of sterilisers continually review the safety systems on their equipment. For example, for sources that are stored in water there is now a requirement to place a detector at the bottom of the pool to verify that the source has fully returned to its shielded position rather than relying on a detector on the source lowering mechanism.

Other hazards associated with industrial applications include:

- sources getting stuck in guide tubes. This can happen as a result of a vehicle or other heavy object squashing the tube in which an industrial radiography source
travels from its shielded container to the exposing position.

- shutters sticking - this may happen on measurement gauges and is usually the result of corrosion from lack of maintenance.

- gauges becoming detached from machinery and being inadvertently disposed of.

- radiation warning notices becoming illegible or their significance not being understood. Where gauges are used in dirty environments the radiation warning symbol may become illegible. Likewise it is important that the trefoil radiation warning symbol be accompanied by a warning notice in a language which is understood by those whom it concerns.

- inadequate training. Industrial radiography is often carried out by small workshops/factories which do not have any formal training system for their radiographers. Much work remains to be done at, for example, European Union level on formulating and promulgating training programmes for industrial radiographers. Also general mechanics may attempt to repair equipment containing sources without them being aware of the hazards involved.

Teaching and Research
Potential accidents include:

- Source loss. Fortunately sources used in teaching are relatively small compared with those used in the applications referred to above. However, for example, a student may remove a source from a laboratory and bring it home as a prank.

- Contamination of workers. Serious contamination incidents are rare due to the small radioactive content of the sources usually used in research. However, serious internal contamination may occur in iodination procedures and in handling certain biologically active labelled compounds e.g. thymidine which is incorporated into DNA, if proper procedures are not followed.

- Inadequate training and/or supervision. Research students often use ionising radiation for a small part only of their overall research programme. Under these circumstances it is often hard to convince both them and their supervisors of the need for training. Also elderly, and sometimes not so elderly university professors see the need for training and care as interfering unreasonably with their research!

National and international initiatives to minimise radiation hazards
All developed countries have a system of regulatory control in place, to minimise the hazards associated with all peaceful applications of ionising radiation.

In Ireland all activities, except those involving very small and essentially innocuous sources, require a licence from the RPII (SI No 151) [Ireland, 1993]. The RPII will issue a licence only if satisfied that: 
- the application is justified

- the source of radiation and the facility in which it will be used and/or stored meet the appropriate standards of design and performance

- administrative and organisational arrangements for radiation protection are in place. These include the appointment of a Radiological Protection Officer

- the operators are trained.

The RPII carries out inspections to check compliance with licence conditions and regulations pertaining to the use of ionising radiation. Penalties for non compliance include withdrawal of licence and prosecution.

There are also international agreements on the transport by air, land and sea of radioactive sources. These are all based on regulations from the IAEA [IAEA, 1990(b)]. The European Union has produced Directives which must be enforced through national legislation in Member States on, for example, the protection of the public and radiation workers, the protection of the patient and the movement of radioactive waste [EU, 1980, 1984, 1992].

The International Atomic Energy Agency [IAEA, 1994] has produced a book of Basic Safety Standards (BSS) to reflect the latest recommendations of the International Commission on Radiological Protection [ICRP, 1991]. The IAEA remain concerned however that more than 50 countries worldwide have been identified as having an inadequate radiation protection infrastructure. To remedy this situation it has developed a Model Action Plan. This plan is designed to ensure that every country has the infrastructure to implement the requirements of the BSS including:

- a legal framework

- enforcement mechanisms i.e. - notification, registration, licensing and inspection procedures

- technical base e.g. personal and environmental monitoring capabilities

- emergency plan.

It is clear that only by having an adequate radiation protection infrastructure will the risk of incidents and accidents as discussed in this paper be minimised and the potential benefits of ionising radiation fully realised.
References


