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IONISING RADIATIONS, RADIOACTIVE MATERIALS AND THE FIRE SERVICES

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1. INTRODUCTION

It is an unfortunate fact that the average person has little understanding of ionising radiations or radioactive materials. They have become emotive issues and are often treated with suspicion. When they are featured in an item in the news media needless anxiety may be caused and the uninformed may be forgiven for concluding that:

- they are new phenomena which have only recently been discovered,
- little is known about them, and,
- they are always extremely hazardous, even when closely controlled or present in small amounts.

In fact:

- ionising radiations have been closely studied, and well understood, for eighty years,
- radioactivity is a natural phenomenon which was first discovered towards the end of the last century,
- throughout the whole of history we have always been subjected to a natural background of ionising radiation from our surroundings,
- small amounts of radioactive materials are present naturally in air, water, food, soil, building materials and our own bodies, and,
- much more is known about ionising radiations, and radioactive materials than is known, for example, about many of the wide variety of chemical compounds in use throughout the world.

All matter is made up of atoms of the various elements and/or molecules of their compounds. The vast majority of atoms are stable but some are unstable and undergo spontaneous transformation into more stable atoms. These unstable atoms are radioactive and this transformation is the radioactive decay or disintegration process which is usually accompanied by the emission of charged particles or gamma rays. The transformation rate, or decay rate, of a given radioactive species is characterised by its radioactive half life; this is the time required for one half of the radioactive atoms in a given sample to disintegrate. Measured half lives range from a fraction of a second to millions of years.

After the discovery of ionising radiations and radioactive materials their potential for harm, if misused, was quickly realised and recommendations for their safe use were soon formulated. An international body, the International Commission on Radiological Protection (ICRP) (1), publishes such recommendations and these are incorporated into national and international codes of practice and legislation (2,3,4,5).

Following the discovery of naturally occurring radioactive materials (e.g. uranium, thorium, radium), research workers developed some artificially produced radioisotopes. The development of the nuclear reactor in the early 1940s made available a much wider range of man-made radioisotopes in increasing amounts. These find ever-increasing applications in many fields of human endeavour.

The ionising radiations emitted from radioactive atoms, or produced by certain devices include:

- alpha particles,
- beta particles,
- gamma rays,
- X-rays.

Neutrons, which ionise indirectly, are produced in certain nuclear reactions including fission (e.g. of uranium).

None of these radiations can be detected by any of the human senses. They can be detected and measured only by means of special ionising radiation detection devices including geiger tubes, ionisation chambers, scintillation detectors, film badges and thermoluminescent dosemeters.

In Australia, permissible levels of exposure of person to ionising radiation and radioactive materials are prescribed in relevant State legislation (3,4). For adults exposed to ionising radiation in the course of their employment the permissible exposure for whole body radiation is 50 millisievert (5 rem) per annum. Individual members of the public are not allowed to receive more than 5 millisievert (0.5 rem) per annum whole body radiation. These permissible levels are not "target" figures in the sense that a person's exposure should be just within these prescribed limits; because exposure to ionising radiation is potentially harmful, every attempt must be made to ensure that such exposure is kept to the lowest practicable level. However, excessive exposure to ionising radiations and radioactive materials may cause harm. Depending on the circumstances such exposures could lead to radiation burns, radiation sickness or eventually cancer. Ionising radiations and radioactive materials can be used safely, provided that proper precautions and controls are used.

Exposure to ionising radiation may be of two forms:

- external radiation exposure - when the source of radiation is external to the body, e.g. when a person is exposed to radiation from an X-ray machine or to the radiation from an encapsulated gamma emitting source, and,
- internal radiation exposure - when unsealed radioactive materials (e.g. powders, gases) are taken into the body by a mechanism such as inhalation, ingestion or absorption through a wound or the intact skin.

2. PROTECTION AGAINST IONISING RADIATION HAZARDS

The safety precautions used when working with ionising radiations and radioactive materials are designed to minimise the harmful effects by ensuring that:

- exposure to ionising radiation is kept below the permissible levels, and
- radioactive materials are prevented from entering the body.

2.1 Protection against external radiation hazards

When an external radiation hazard is involved, three factors which may be invoked, either singly or together, to protect persons are:

- time - i.e. minimise the time spent in a field of ionising radiation;
- distance - i.e. maximise the distance between a person and a source of ionising radiation. (For a "point" source which emits gamma radiation the intensity of radiation decreases inversely as the distance from the source; this is the so-called inverse square law); and
- shielding - i.e. interpose adequate amounts of appropriate shielding material between a source of ionising radiations and persons in its vicinity. (Alpha radiation does not constitute an external radiation hazard. For beta radiation, only small thicknesses of low density shielding material e.g. aluminium or plastics are required; X and gamma radiation require larger thicknesses of denser materials such as lead or steel; neutrons require larger thicknesses of materials such as concrete, paraffin wax or other materials containing a high percentage of hydrogen atoms).

Appendix A gives brief details of some gamma emitting radioisotopes and shielding materials suitable for use with them.

2.1 Protection against internal radiation hazards

Protection against internal radiation hazards is achieved by:

- ensuring unsealed radioactive materials are properly contained,
- using appropriate instruments to ensure that no radioactive material has escaped from its containment,
- promptly cleaning up any radioactive spillages which may occur, while appropriately protecting the persons engaged in the cleanup.

3. THE INTERNATIONAL SYMBOL DENOTING THE PRESENCE OF IONISING RADIATIONS

Figure 1 shows the internationally agreed symbol used to denote the actual or potential presence of ionising radiation and to identify objects, devices, materials or combinations of materials which emit ionising radiation (6). It is known as the "trefoil" symbol, and is coloured black, often on a yellow background. Such a symbol is found on transport packages containing radioactive materials and at the entrance to areas where ionising radiations and/or radioactive materials are in use. It is also displayed at the entrance to any area where radioactive materials are stored and where there are devices or machines which generate ionising radiation.

4. RADIATION AND RADIOACTIVE CONTAMINATION

It is important to understand and distinguish bwtween, the terms "radiation" and "radioactive contamination".

Radiation refers to the actual ionising radiation given off by a radioactive source or a device which produces ionising radiation (e.g. an X-ray machine). A person who is exposed to external X-radiation from an

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X-ray machine, or gamma radiation from a gamma-emitting radioactive source, is irradiated but does not, in consequence become contaminated or radioactive.

Radioactive contamination may be defined as radioactive material which is unconfined or is in an undesired location. Examples are radioactive material (e.g. powder or liquid) spilled on a bench top, the floor or a person's hand or radioactive material dispersed into the air (airborne contamination). Radioactive contamination always has some ionising radiation associated with it; an external radiation hazard may arise if the contamination is present in sufficient quantity and if it emits penetrating radiation.

5. USES OF IONISING RADIATIONS AND RADIOACTIVE MATERIALS

Ionising radiations and radioactive materials find a diversity of uses in such fields as research, the physical sciences, agriculture, industry, hydrology and medicine (7).

In Australia, legislation in the various States requires that persons using, selling or possessing more than certain defined quantities of radioactive materials be licensed (3,4).

A few examples follow which illustrate the wide variety of applications of ionising radiations and radioactive materials.

5.1 Uses in industry

Industrial radiography utilises X-ray machines or sealed gamma emitting radioactive sources (e.g. ^{60}Co, ^{192}Ir, ^{137}Cs) for examining welds, castings, pipes etc. to detect cracks, porosity, faulty welds, blowholes and other defects.

Thicknesses, density and level gauges used in industrial production and manufacturing processes make use of the fact that ionising radiation is reduced in intensity (or attenuated) when it passes through matter.

Radioisotopes are used as tracers in industrial blending and mixing processes and to detect leaks from vessels or pipelines or manufactured items required to be leakproof.

Studies of wear in machinery are aided by using radioisotope tracer methods; wear processes of this type are essentially slow but the high sensitivity of these tracer techniques permits quantitative assessment of wear during tests of very short duration. Applications have included studies of wear of piston rings in engines, wear of wire-drawing dies, wear of lathe tool cutting tips and lubrication studies.

In the area of fire prevention field_radioactive sources have been used in ionisation chamber smoke detectors (8); the most commonly used radioisotope being americium-241. A level gauge containing a radioactive source can be used for checking the contents of CO_2 fire extinguishers.

5.2 Uses in hydrology

In the field of hydrology, radioisotopes have been used to trace the flow of silt and sediment in harbours, rivers, and estuaries, often using sand which has been labelled with a radioisotope such as gold-198.

Studies of underground water in aquifers, using appropriate radioisotopes enable rates and direction of water flow to be established.

The adequacy of the dispersal of treated sewage to natural waters (e.g. the sea), or the movement of factory effluents in tidal streams have been studied using radioisotopes.

5.3 Uses in medicine

X-rays have been used for many years in medicine, for both diagnostic and therapeutic applications.

Sealed radioactive sources (e.g. cobalt-60) are in widespread use in hospitals for therapeutic treatment of carcinomas of various types. Strontium-90 sources have been found useful for treating certain diseases of the eye.

Within recent years a new medical speciality, known as nuclear medicine, has developed (9) and plays an important role in the diagnosis of diseases by using radioisotopes. When certain biologically active compounds are injected into the blood stream, they concentrate in a particular organ of the body, e.g. liver, kidneys, brain, lungs, heart, bone etc., depending on the physical and chemical form of the compound. If such a compound is labelled with a radioisotope then the radiation emitted when it lodges in the organ may be used, in conjunction with an appropriate instrument (usually a gamma ray camera), to photograph the organ and enable a diagnosis to be made about its condition and function or the presence of tumours. Most of such radiopharmaceutical products involve radioisotopes with very short half lives such that their radioactivity will decay to negligible proportions after several hours (e.g. technetium 99m with a half life of 6 hours).

Major Australian hospitals generally have nuclear medicine departments.

6. TRANSPORT OF RADIOACTIVE MATERIALS

Many dangerous goods are consigned annually by all modes of transport, and radioactive materials are designated as Class 7 Dangerous Goods. There are a number of international regulations for the safe transport of radioactive materials.

Air transport of radioactive materials within and from Australia is covered by Part 33 of the Air Navigation Orders, made under Regulation 120 of the Commonwealth Navigation Regulations. This states that "an aircraft shall carry dangerous goods only in accordance with the International Air Transport Association (IATA) Regulations" (10). Part 2 of the IATA Regulations refers to the carriage of radioactive materials by aircraft and is based on the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Materials (11,12).

Each Australian State refers to the transport of radioactive materials in the Regulations made under its Radioactive Substances Act, or equivalent (3,4).

Radioactive materials represent a few percent of the shipments of dangerous goods throughout the world; several million packages of radioactive materials are transported annually throughout the world using various transport modes. In Australia several tens of thousands of shipments of radioactive materials are made annually. Figure 2 from the latest Annual Report of the Australian Atomic Energy Commission (AAEC) (1979-1980) (13) indicates how the annual sales value of radioisotopes manufactured by the AAEC continues to increase annually. Figure 3 indicates the supply of radioisotopes by the AAEC for the period 1 April 1980 to 28 March 1981.

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7. REGULATIONS FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIALS

These regulations, from whatever source (e.g. IATA, IAEA etc.), are designed to ensure safety when radioactive materials are transported, and to reduce the hazards, both to workers in the transport industry and to the general public, to acceptably low levels. Such safety is achieved by ensuring that packaging is designed so that:

- radioactive and fissile materials are adequately contained,
- ionising radiations emitted from the packages are at an acceptably low level,
- radioactive contamination on packages is non-existent, or within acceptable limits,
- heat generated by radioactive material within the package is dissipated adequately, and
- for fissile materials, there is no likelihood of criticality developing.

7.1 Containment

Packaging (14,15) for radioactive materials must be designed to minimise the possibility of the release of the contents.

There are five main types of packaging:

- Type A
- Type B
- Low specific activity
- Low level solid
- Exempt

7.1.1 Type A packaging

The design of Type A packaging is such that it will withstand the rigours of handling during transport, and tests are designated to ensure this. A severe accident may involve the release of a fraction of the contents of this type of packaging, so limits on the contents are prescribed. Adherence to these limits will ensure that if such an accident occurs, the resultant release of radioactive contamination and external radiation are not unduly hazardous. Type A packaging is required to undergo tests involving:

- water spray
- free drop
- compression, and
- penetration.

7.1.2 Type B packaging

If large amounts of radioactive materials are to be transported, then Type B packaging is required. Such packaging is designed to withstand a major accident consisting of a very severe impact immediately followed by an intense fire; it must be capable of withstanding the tests prescribed for Type A packaging and other more severe tests for:

- impact (a 9 metre drop equivalent to a striking velocity of 48 km/h)
- thermal exposure (800°C for 30 minutes)

- integrity of containment and shielding.

Type B packaging is subdivided into two groups:

- Type B(U)
- Type B(M)

depending on whether or not the design warrants approval by the competent authorities of all countries through which it is to be transported. Type B(U) packaging fulfils all of a series of design requirements, and requires only unilateral approval by the competent authority of the country where it is designed. Type B(M) packaging does not meet all of these requirements, and requires multilateral approval by the competent authorities of all countries through which it is to be transported.

7.1.3 Low specific activity materials

In this category the materials being transported have such low specific activities that they may be regarded as inherently safe, or their physical form is such that they cannot be readily dispersed. They include radioactive ores of uranium and thorium and their concentrates.

7.1.4 Low level solid radioactive materials

This category is an extension of the low specific activity category and includes solids, such as consolidated wastes and activated materials where the activity remains uniformly distributed in a solid compact binding agent. The activity is (and remains) insoluble, and, when averaged throughout the radioactive material, does not exceed certain prescribed values. etc.

7.1.5 Exempt items

Exempt items include radioactive materials in limited quantities, instruments and other manufactured articles containing natural/depleted uranium or natural thorium, and empty packages which have previously contained radioactive material, provided that external radiation and activity content are within certain limits.

7.2 Permissible Levels of External Radiation

Packages containing radioactive materials are divided into three categories based on the external radiation levels at the surface of the package and at a distance of one metre from the surface. The number representing the maximum external radiation dose rate, in millirem per hour at a distance of one metre from the surface of a package, is called the transport index.

Packages are required to incorporate additional shielding to reduce external radiation levels to prescribed values. These acceptable levels are based on considerations of radiation exposure of persons and of radiation sensitive materials e.g. photographic emulsions.

The three categories are:

Category I	- White :	Maximum radiation level at surface 0.5 millirem/hour (5 microsievert/hour)
Category II	- Yellow:	Maximum radiation level at surface 50 millirem/hour (500 microsievert/hour) Transport index does not exceed 1.0.

Category III - Yellow: Maximum radiation level at surface
200 millirem/hour (2 millisievert/hour).
Transport index does not exceed 10.

7.3 Permissible Levels of Radioactive Contamination

The removable radioactive contamination on any external surface of a package must be kept as low as practicable, and in no case should it exceed the levels shown in the following table:

Containment	Maximum Permissible Level *
Beta or gamma emitters	10^{-4} µCi cm^{-2} (3.7 Bq cm^{-2})
Alpha emitters	10^{-5} µCi cm^{-2} (0.37 Bq cm^{-2})

* These levels are permissible when averaged over any 300 cm^2 of the surface.

7.4 Labelling of Packages Containing Radioactive Materials

Under the regulations for the carriage of radioactive materials, the shipper is required to complete and attach the appropriate labels to opposite sides of each package containing such materials.

Each label is required to state:

- the contents of the package,
- the activity of the contents, and
- the transport index (Categories II and III Yellow).

7.5 Heat Dissipation

Packages containing large amounts of radioactive materials require a means of dissipating the heat generated by the contents e.g. by external fins or, in extreme cases, by forced ventilation.

7.6 Criticality Control

Fissile materials (e.g. ^{235}U, ^{239}Pu) must be so packed and transported that criticality (an unwanted neutron chain reaction) cannot credibly be reached under any foreseeable circumstances during transport. This is normally achieved by the use of special packaging (which incorporates features not required in packaging for non-fissile radioactive material) and, where necessary, by a limitation on the number of packages which may be transported or stored together.

Contingencies which need to be considered for fissile materials include:

- water leaking into or out of packages,
- loss of efficiency of built-in absorbers or moderators,
- rearrangement of package contents into an array which will enhance the possibility of criticality,
- reduction of spacing between packages or their contents,
- immersion of packages in water or snow, and
- effects of temperature changes on the reactivity of package contents.

Packages of fissile materials are generally classified as:

- Fissile Class I

  Packages which are nuclearly safe in any number and in any arrangement under all foreseeable circumstances of transport.

- Fissile Class II

  Packages which, in limited number, are nuclearly safe in any arrangement under all foreseeable circumstances of transport.

- Fissile Class III

  Packages which are nuclearly safe under all foreseeable circumstances of transport by reason of special precautions, or special administrative or operational controls imposed upon the transport of the consignment.

8. ACCIDENT EXPERIENCE DURING TRANSPORT OF RADIOACTIVE MATERIALS

The literature contains a wealth of information concerning experiences in the movement of radioactive materials by all modes of transport throughout the world (16,17,18). Considering the number of consignments of such materials, the accident record has been remarkably good, confirming the adequacy of the packaging standard demanded.

In 1971 the US Department of Transportation instituted a centralised, standardised system to accumulate uniform data on incidents involving transport of all hazardous materials. As from 1 January 1971 a regulatory requirement (19) became effective, whereby carriers of hazardous materials became responsible for reporting such transport incidents. In particular a carrier is required to submit a detailed written report within 15 days of discovery of any incident occurring during transportation (including loading, unloading or temporary storage) which leads to an unintentional release of hazardous materials (including radioactive materials). One of the criteria for incident reporting is 'suspected radioactive contamination'. In the period 1971-1975 more than 32,000 Hazardous Materials Reports were submitted. Of these only 144 (0.45%) involved the radioactive materials category; of those 144, only 36 actually involved some loss of contents (20). In no case in the USA, has a Type B package released radioactivity to the environment as a result of an accident (21,22). Two cases have occurred where some radioactive material has escaped from Type B packages, but this has been caused by faulty packaging procedures. Improved quality assurance should prevent further incidents of this type.

Accidents during air transport of radioactive materials have generally involved Type A or Exempt packages; in most cases, the package has been dropped onto the ground during aircraft loading or unloading operations, or before aircraft loading. Crushing by the handling vehicle (e.g. a cargo handling train in transit between the cargo terminal and the aircraft) has often been the cause, and seldom has an aircraft been involved. Between January 1979 and May 1980 there were fifteen minor incidents of this type at Sydney (Kingsford-Smith) Airport. Most of them involved Type A packages which were dropped and crushed by vehicles. In only two of these incidents was there any release of radioactive materials; both incidents involved Exempt packages and in each case contamination was very minor (23). There are no recorded accidents where road transportation of radioactive materials in Australia has given rise to any radiation safety problems. On 4 December 1980, a vehicle carrying radioactive sources (americium-241 and caesium-137) and other goods was involved in an accident near Laurieton, New South Wales. The news media carried stories indicating that a number of persons suffered "radiation sickness" after this accident. The facts are that:

- the radioactive sources were not released from their containment,
- the radiation dose-rate levels from such sources permitted by the regulations for safe transport of radioactive materials are so low that persons staying in the vicinity of the sources for several hours could not possibly have received sufficient external radiation for "radiation sickness" to be possible, and,
- blood tests on two policemen who were apparently in the vicinity of the sources for the longest period of time showed no evidence of significant radiation exposure.

9. THE FIRE FIGHTER AND THE RADIATION/RADIOACTIVE ENVIRONMENT

9.1 Available Literature

The literature contains relatively few readily available documents which give guidance to firefighters faced with a situation which also involves ionising radiation/radioactive materials.

In 1958, in the UK a technical bulletin (24) was issued under the authority of the Home Office (Fire Service Department) and the Scottish Home Department which gave some guidance on fire-fighting hazards of radioactive materials.

The New Zealand Fire Service Council in 1958 also issued a bulletin (25) discussing hazards of radioactive materials to fire service personnel.

In 1961 the US Department of Health, Education and Welfare and the US Atomic Energy Commission (USAEC) issued two manuals (26) relating to peacetime radiation hazards in the fire service. One was an orientation unit-instructor's guide and the other an orientation unit-student manual. Around 1960 the USAEC also produced manuals (27) entitled "Living with Radiation". Part I dealt with some fundamentals of atomic physics and radiation problems, and Part 2 extended the discussion of those fundamentals into the areas of fires and other emergency situations.

The 1973 Year Book of the UK National Association of Fire Officers carried an eight page article (28) on radioactive materials, ionising radiations and fire fighting.

More recently (1980) Lawrence E. Whitman in his 265 page book "Fire Safety in the Atomic Age" (29) gave a fairly simplified view of radiation matters as they affect the fire fighter. The treatment in the book is not rigorous and, in some places in the text, errors are evident.

Obviously literature of the nuclear energy industry contains other items relating to fires and fire fighting in that industry. These are often issued as reports on specific aspects by individual establishments in that industry.

9.2 What are the Fire Fighting Problems?

The fire characteristics of a given material will be the same whether it is radioactive or non-radioactive. Thus a radioactive material will follow the same course in a fire as would non-radioactive material of the same physical and chemical composition. Obviously, the presence of radioactive materials in a fire complicates the fire fighting situation because of the additional hazards that may arise from external radiation and radioactive contamination. The extent to which such hazards will be significant depends on the type and amount of radioactive materials involved.

Radiation-producing devices, such as X-ray machines and accelerators, will not pose a radiation hazard in a fire situation as they can be switched off, thus stopping emission of ionising radiation.

When not in use, sealed radioactive sources which emit penetrating radiation (e.g. gamma radiation) are shielded so that the radiation dose rate in their immediate vicinity is low (e.g. 25 microsievert /hour (2.5 millirem/hour) thus eliminating significant radiation hazard. If such a source was in an operating position (i.e. exposed and unshielded) when a fire occurred, and it was not returned to its shielding, then the extent of the external radiation hazard would depend on the source strength and the energy of its radiation. Shields for such sources may be made of lead (sometimes with an outer steel case). The intensity and duration of the fire would determine whether the lead shield (which melts at 327°C) maintained its integrity.

Unsealed radioactive materials involved in a fire situation may be dispersed in the heat and updraft of the fire and create a contamination problem. The extent of this problem would depend on the intensity of the fire, the amount and type of unsealed radioactive material involved and the extent of its dispersion.

The staff of establishments where significant amounts of radioactive materials, or large sealed sources which emit penetrating radiation, are used, generally include persons who have a knowledge of radiation protection and who have access to appropriate radiation and contamination measuring instruments. Examples of such establishments are atomic energy establishments, large hospitals, universities and some industrial premises.

The hazards which the presence of ionising radiation and radioactive materials may pose to the fire fighter must, of course, be placed in perspective and considered in relation to the other hazards commonly encountered, such as fire, explosion and toxic fumes. In any fire situation currently envisaged in Australia these more common hazards are unlikely to be overshadowed by the radiation or radioactive hazards.

In a fire where ionising radiation/radioactive materials may be present someone should be available who is knowledgeable in radiation protection matters and who can make appropriate measurements and give the necessary guidance to fire fighters. Such guidance should include:

- limitation on time permitted in any areas where there are significantly high radiation dose rates,
- measures to be taken to provide adequate contamination control and to minimise contamination of fire fighting personnel and equipment, and to prevent unnecessary spread of radioactive contamination;
- checking for contamination of fire fighting personnel and equipment, and subsequent decontamination after cessation of fire fighting and salvage operations.

The normal clothing worn by fire fighters will give adequate protection against any beta radiation which may be present. Protection against inhalation of airborne radioactive material will be provided by the self-contained breathing apparatus worn by fire fighters for protection against smoke and toxic fumes.

Fires could occur in accidents when radioactive materials are being transported. However, as mentioned, Type B packages are very unlikely to release their radioactive contents in such an accident situation (such packages must be demonstrated to maintain their integrity for 30 minutes at a temperature of 800°C). Type A packages involved in a fire during transport could release their contents; however, the amount of radioactive material contained in such packages is limited and the consequences of a fire during transportation are unlikely to be unduly hazardous. In an aircraft crash and fire, the effects of the release of radioactive materials from Type A packages must be placed in perspective and considered in relation to the other injurious effects possibly affecting persons involved in such an accident. These include major burns, physical injury and toxic effects arising from combustion of plastics used in the electrical wiring, seats etc of the aircraft. Similarly, if a fire affects a road vehicle which is transporting radioactive materials, then Type B packages can be expected to maintain their integrity but Type A packages may be affected. In such a fire, fire fighters should attack the fire from upwind, wear breathing protection and call for advice from a person knowledgeable in radiation protection.

What hazards may be posed to fire fighters by the"protective devices" containing radioactive materials installed in some buildings? These include ionisation chamber smoke detectors (ICSD) and gaseous tritium light devices (GTLD). Modern ICSDs contain americium-241 with activities up to about 3.7 megabecquerels (100 microcuries) when used in industrial, commercial and public buildings, and up to about 37 kilobecquerels (1 microcurie) when used in private homes. GTLDs which are used in a variety of "Exit" signs, contain tritium with activities up to several tens of gigabecquerels (several curies). Neither ICSDs nor GTLDs of the above types can cause any external radiation hazard because americium-241 emits alpha particles and only a small amount of very low energy gamma radiation; tritium only emits beta radiation of very low energy.

In the metal foil sources used in ICSDs the radioisotope is sandwiched between two thin layers of non-radioactive metal. Tests carried out by the National Radiological Protection Board (NRPB) in the UK (8,30) showed that, in general, at temperatures up to 600°C no radioactivity from an ICSD became airborne in a one hour test. At higher temperatures, negligible amounts of radioactivity became airborne from well-designed sources. The NRPB concludes that, if an ICSD is involved in a fire situation, a fireman not wearing breathing apparatus is likely to inhale only a very small amount of the americium in the device; this amount has been estimated (8) to be a small fraction of the maximum permissible annual intake for americium-241. The National Health and Medical Research Council (NHMRC) of Australia has recommended (31) that the radioisotope used in single station (i.e. domestic) ICSDs should be americium-241, the nominal activity of which should not exceed 37 kilobecquerels (1 microcurie); if a radioisotope other than americium-241 is used the quantity shall be such that the risk due to radiation exposure shall not be greater than that from the use of one microcurie of americium-241. The Australian Radiation Laboratory has published an information bulletin (32) on domestic smoke detectors.

Gaseous tritium light sources in GTLDs are fabricated in the form of sealed glass containers, internally coated with a phosphor and filled with tritium gas. The glass containers are generally made of borosilicate glass which is resistant to thermal shocks and has a transformation temperature of about 350°C. Even at this temperature, borosilicate glass contains tritium very well,requiring temperatures of 700 to 800°C to liberate it (33). If a GLTD is broken in a fire situation, intense heat would convert its tritium gas into tritiated water vapour. In the case of a normal fire where a GTLD is broken and, where products of combustion are carried to atmosphere by fire updraught the resultant tritiated water vapour probably would be quickly carried upwards and dispersed. The extent of possible internal radiation hazards would depend upon the rate and degree of dispersion and whether or not fire fighters were wearing self-contained breathing apparatus. In the case of a fire contained within a room or building with little release of combustion products to outside atmosphere, the breakage of a GTLD would probably cause a greater potential internal radiation hazard. In such a case, wearing of self-contained breathing apparatus by fire fighters entering the room or building would be essential.

10. CONCLUSION

Ionising radiations and radioactive materials can be harmful if not used safely. Extensive experience over a number of decades has shown that they can be used safely in a wide variety of applications, provided a number of commonsense precautions are implemented.

Transport of radioactive materials is commonplace throughout the world and regulations designed to ensure safety in such transport have resulted in an excellent safety record.

The fire fighter must recognise ionising radiations and radioactive materials as additional potential hazards to be placed in perspective with those others he accepts in the course of his work. Where radioactive materials are present in a fire situation, it is sensible to have a person present with knowledge of radiation protection to advise on the nature and extent of the radiological hazards. Pre-planning for fire situations in buildings where radioactive materials are known to be present is very desirable. An Australian Standard (34) recommends that Station Officers of the local fire brigade be appraised of the hazards and the need to take particular care in areas marked with ionising radiation warning signs.

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Basic ionizing radiation symbol

SHAPE AND PROPORTIONS OF SYMBOL

The basic symbol for signifying ionizing radiation or radioactive materials shall be designed and proportioned as illustrated in the figure.

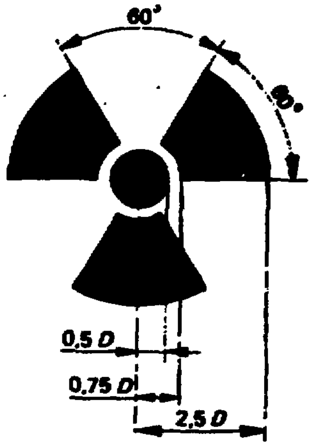

FIGURE 1

(From reference 6)

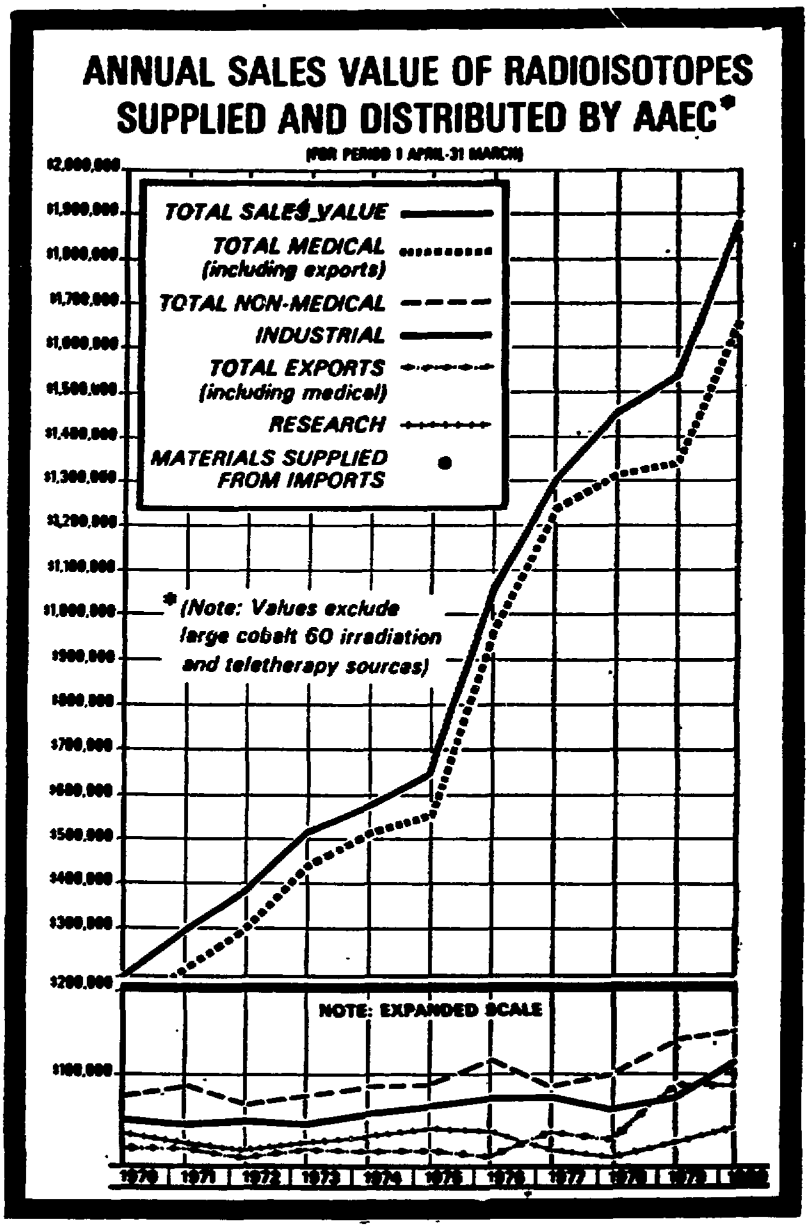
ANNUAL SALES VALUE OF RADIOISOTOPES SUPPLIED AND DISTRIBUTED BY AAEC*
(FOR PERIOD 1 APRIL-31 MARCH)
$2,000,000
$1,900,000
$1,800,000
$1,700,000
$1,600,000
$1,500,000
$1,400,000
$1,300,000
$1,200,000
$1,100,000
$1,000,000
$900,000
$800,000
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
TOTAL SALES VALUE
TOTAL MEDICAL (including exports)
TOTAL NON-MEDICAL
INDUSTRIAL
TOTAL EXPORTS (including medical)
RESEARCH
MATERIALS SUPPLIED FROM IMPORTS ●
* (Note: Values exclude large cobalt 60 irradiation and teletherapy sources)
NOTE: EXPANDED SCALE
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980

FIGURE 2

VALUE OF RADIOISOTOPES SUPPLIED AND DISTRIBUTED BY THE AAEC

(For the period 29 March 1979 to 28 March 1980)

Use and Type	Deliveries	Items	Activity	Value $A
WITHIN AUSTRALIA				
Industrial				
Radiography sources	217	217	233 TBq	63,600
Sealed sources	60	262	130 GBq	12,300
Service on Industrial Units	57	322	—	7,400
Miscellaneous solutions etc	29	37	9 TBq	13,600
γ-irradiations for industry	205	2,160	—	8,200
Total for Industrial Use	568	2,998		105,100
Research				
Cobalt 60 sources	2	2	8 TBq	500
Miscellaneous solutions etc	626	2,714	1 TBq	37,200
Neutron irradiations	84	194	—	4,400
γ-irradiations and sterilisations	127	367	—	1,300
Total for Research	839	3,277		43,400
Medical				
Implant sources	62	1,900	214 GBq	7,700
Miscellaneous solutions etc	597	1,360	165 GBq	16,600
Lyophilised products	578	11,721	—	22,800
Iodine 131 products	3,539	6,769	3 TBq	100,700
Technetium 99m solutions	28,161	35,088	102 TBq	925,700
Technetium 99m generators	939	939	21 TBq	238,700
Cobalt therapy sources	2	2	398 TBq	27,500
*Materials supplied from imports	1,746	6,223	626 GBq	267,800
Total for Medical Use	35,624	64,002		1,607,500
EXPORT				
Radiography sources	59	61	63 TBq	19,700
Cobalt 60 therapy sources	3	3	527 TBq	46,000
Technetium 99m generators	239	239	4 TBq	51,400
Miscellaneous solutions etc	156	299	2 TBq	23,000
Total for Export Users	457	602		140,100
TOTAL FOR ALL CATEGORIES	37,488	70,879		1,896,100

* This category does not include material imported due to extended HIFAR shutdown.

Note: 1 Bq (becquerel) = 2.7×10^{-11} Ci (curie) (rounded).

FIGURE 3

APPENDIX A

SOME GAMMA EMITTING RADIOISOTOPES AND SUITABLE SHIELDING MATERIALS

Radioisotope	Half-life	Dose rate at 1m from 1 curie (R/h) (Note 1)	Half value Lead (cm)	Layer (Note 2) Concrete (cm)
Sodium-24	15.0 h	1.84	1.7	8.1
Cobalt-60	5.26 y	1.32	1.2	6.6
Iridium-192	74.4 d	0.48	0.6	4.3
Gold-198	2.7 d	0.23	0.8	4.1
Radium-226	1620 y	0.825	1.3	7.1

Notes

1. Strictly this is exposure rate when expressed in roentgens per hour.
2. The half value layer is the thickness of material required to reduce the intensity of the radiation to one half of its incident value.

GLOSSARY

The following definitions are provided for the reader not familiar with some nuclear and other terms used in this paper.

ACTIVITY (of a substance)
The number of disintegrations per unit time taking place in a radioactive material.

ALPHA PARTICLE
A positively-charged particle from the nucleus of an atom emitted during radioactive decay. Consists of 2 protons and 2 neutrons (a helium 4 nucleus). Although alpha particles are normally highly energetic they travel only a few centimetres in air and, in fact, are stopped by a sheet of paper or the outer layer of dead skin. Hence, alpha particles are generally not an external radiation hazard to living matter; however, they may cause internal damage in the body, if taken in with the food and water we consume or the air we breathe.

ATOM
A particle of matter which cannot be broken up by chemical means. Atoms have a nucleus consisting of positively charged protons and uncharged neutrons of the same mass. The positive charges of the protons are balanced by a number of negatively-charged electrons in motion around the nucleus.

BACKGROUND RADIATION
The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements.

BETA PARTICLE
A particle emitted from an atom during radioactive decay. Beta particles are essentially electrons with either negative or positive electric charge. Although beta particles are generally much less energetic than alpha particles they are much more penetrating because they have a much smaller mass than the alpha particle. High energy beta particles may travel many metres in air and are able to penetrate human skin; low energy betas are unable to penetrate the skin. Beta rays in general are easily shielded by a small thickness of light material, e.g. aluminium or plastic sheeting.

CHAIN REACTION
A process in which one nuclear transformation sets up conditions which permit a similar nuclear transformation to take place in another atom. Thus, when fission occurs in uranium atoms, neutrons are released which in turn produce fission in neighbouring uranium atoms.

DECAY (e.g. radioactive decay)
The radioactive disintegration of an atomic nucleus resulting in the release of alpha, or beta particles or gamma radiation.

ELEMENT
A chemical substance that cannot be divided into simpler substances by chemical means; atomic species with the same number of protons.

FISSILE MATERIAL
Any material capable of undergoing fission by thermal (or slow) neutrons. For example uranium-235 and plutonium-239.

FISSION
The division of a heavy nucleus into two (or, rarely, more) parts with masses of equal order of magnitude usually accompanied by the emission of neutrons, gamma radiation, and, rarely, small charged nuclear fragments.

GAMMA RADIATION
Gamma radiation is electromagnetic radiation and is of the same physical nature as light, X-rays, radio waves, etc. However, gamma radiation is highly penetrating (more powerful than X-rays) and depending on its energy may require a considerable thickness of lead or concrete to absorb it completely, for example, tens of centimetres of lead or metres of concrete. Gamma radiation may cause ionisation in living matter and hence constitutes a biological hazard.

HALF LIFE (radioactive)
For a single radioactive decay process, the time required for the activity to decrease to half its value by that process.

IONISING RADIATION
Radiation (including alpha particles) capable of causing ionisation of the matter through which it passes and hence damage to living tissue.

IONISATION
Any process by which an atom, molecule, or ion gains or loses electrons.

ISOTOPE
Atoms of an element having the same number of protons but different numbers of neutrons in the nuclei. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.

NEUTRON
An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen. Neutrons are the links in a chain reaction in a nuclear reactor.

NUCLEAR REACTOR
A structure in which a fission chain reaction can be maintained and controlled. It usually contains fuel, coolant, moderator, control absorbers and safety devices and is most often surrounded by a concrete biological shield to absorb neutron and gamma ray emission.

RADIOACTIVITY
The property of certain nuclides of spontaneously emitting particles or gamma radiation or of emitting X-radiation following orbital electron capture or of undergoing spontaneous fission.

RADIOISOTOPE
An isotope which is radioactive. Most natural isotopes lighter than lead-208 are not radioactive.

TRITIUM
The isotope of hydrogen of mass 3. It is very rare, naturally radioactive, but can be made by neutron absorption in lithium and in deuterium or heavy water, and is present in fall-out.

URANIUM
A radioactive element with two isotopes which are fissile (uranium-235 and uranium-233) and two which are fertile (uranium-238 and uranium-234). Uranium is the basic raw material of nuclear energy.