The daily dice with death.

The perils workers face from nuclear technology

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etui.

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Introduction

Ionising radiation and its medical and industrial applications were discovered just over a century ago. The finding that it is carcinogenic, mutagenic and toxic for reproduction has not stopped it coming into widespread use in many industry sectors, nor being used for military purposes and the manufacture of massively destructive nuclear weapons.

The 20th century is littered with nuclear disasters, most notably the atom bombs dropped on Hiroshima and Nagasaki, and the explosion of a nuclear reactor at Chernobyl. But there is also the silent disaster that affected those who worked in daily contact with ionising radiation often unaware of the risks they were running. How many died before their time? Individual monuments commemorate the odd few hundred. But many, many more have likely borne the risks and burden of disease from the use of ionising radiation.

The devastating consequences of the Fukushima nuclear accident in the wake of the earthquake and tsunami that struck north-eastern Japan on 11 March 2011 are a salutary reminder that the risks of nuclear power are not a thing of the past. It is an event whose influence will be felt on the nascent resurgence of nuclear power as the management of existing nuclear weapon stockpiles is still beset by risks, as new threats emerge, like the acquisition of nuclear capability by states ostracised by the international community or “dirty bombs” by terrorist groups. The peaceful use of sources of radiation outside the field of nuclear energy continues to make quiet progress in many areas and is no longer the exclusive preserve of a small club of countries. Growing numbers of workers are and will be confronted with ionising radiation in industrial, medical and military activities, and more obviously, in nuclear power plants. As more account starts to be taken of exposure to natural radiation sources, the list of areas affected by potential exposure to radon, a radioactive gas that occurs as the decay product of natural uranium, lengthens.

A 2010 report by a United Nations agency estimated that approximately 23 million workers were exposed to ionising radiation in the world. About 13 million of these work in jobs that expose them to natural sources of ionising radiation and about 10 million to radiation sources from human activities. Only 7.4 million of these workers have their exposure levels regularly checked.

The relative risk-benefit balance of using nuclear sources, particularly for medical or energy purposes, has so far been judged politically and socially acceptable. This has obviously not made for a proper assessment of the dangers of the peaceful use of ionising radiation. And yet the risks are very real, as is evidenced by the recommended exposure limits that have been revised steadily downwards since they were first set. Initially calculated in terms of visible short-term risks, the dose limits were subsequently adjusted in light of the results from the follow-up of thousands of Japanese citizens exposed to the atomic blasts of World War II. Recent epidemiological studies focus more on the effects of “low dose” exposure. They suggest that the long-term effects of low but continuing lifelong exposure to ionising radiation may well have been underestimated. This is good reason for sticking rigidly to the ALARA principle which requires human exposure to ionising radiation to be as low as reasonably achievable.

The health effects of low dose radiation – that affecting the vast majority of exposed workers – are still hotly disputed. They can only be addressed through a highly rigorous safety culture that not all may be willing to implement, and an acknowledgement that while ionising radiation has and does drive progress, it is still inherently a cause of occupational accidents and diseases. It is an insidious danger for most workers who feel no short- or medium-term effects, but whose lives may be prematurely blighted by thyroid cancer, lung cancer or leukaemia.

This publication briefly reviews the use of ionising radiation. As a new EU directive on basic nuclear safety standards is under discussion, it is particularly important to understand the workings of the rule-making bodies, learn the lessons of accidents in the distant and recent past, and gain a better knowledge of the exposed workers and sectors. In a global economy, it is also important to understand that the risks of ionising radiation do not stop at plant perimeters or country borders, and that there is no safe harbour from their dangers.

The need to put into layman’s terms scientific concepts that have become increasingly elaborate over time, and the wide field covered by this publication, has inevitably meant simplifying otherwise complex concepts. Similarly, so that the narrative does not get bogged down to no avail by piled-up repetitive data, we have focused principally on long-standing nuclear technology countries like Belgium, France and the United Kingdom in Europe, and the United States, the former Soviet Union and Japan in the wider world.

Chapter 1

Fascination, destruction, regulation

Ionising radiation derives its name from its ability to liberate electrons from an atom, producing ions. Some electrical equipment artificially emits ionising radiation - X-rays are a case in point. Ionising radiation is also part of the natural decay chain of chemical elements like uranium. These two sources of ionising radiation were discovered almost simultaneously.

1.1. From the discovery of X-rays to Hiroshima

In November 1895 the German physicist Wilhelm Conrad Röntgen discovered hitherto unknown and invisible rays that had the ability to penetrate through many materials. He called them “X-rays” using the mathematical term “X” to denote something unknown. He was quick to see their value for medical diagnosis from taking an “X-ray photograph” of his wife’s hand which rapidly achieved worldwide renown. Röntgen did not file a patent, which encouraged the uptake of his discovery.

The process, which enabled the human body to be penetrated to reveal the skeleton, received immediate acclaim from doctors and physicists. But the indiscriminate use of X-rays soon produced side-effects, in particular the skin reaction known as radiation dermatitis. It was a bitter lesson learned by many physicists, like Thomas Edison’s assistant, Clarence Dally, who despite the amputation of his arm, died in 1904. An American doctor, Emil Herman Grubbe, working in Chicago was among the first to think of turning this toxic effect into a therapeutic treatment. He administered X-ray treatment to a woman with carcinoma of the breast, protecting the healthy tissue with a lead shield. Radiotherapy and radiation protection were born together but were not destined to develop apace as the appetite for the former would often result in neglect of the latter.

Some months after Röntgen's discovery, French physicist Henri Becquerel observed that rays emitted by uranium salts had similar penetrating power to X-rays. Shortly after, another French scientist, Marie Curie, brought evidence that the rays emitted by uranium salts were ionising and demonstrated that thorium compounds had the same properties. It was Marie Curie who would give the name "radioactivity" to the emission by different chemical elements of radiations similar to those of uranium.

In 1898, Marie Curie and her husband Pierre discovered polonium, then radium. They soon observed that exposure to radium caused skin burns similar to those observed with X-ray machines. Radium nevertheless gained rapidly in popularity, being seen as a cure-all for health problems as varied as cancer, stomach ulcers and impotence. Marie Curie died of radium-induced leukaemia in 1934.

The *Radium Girls*

In 1915, physicist Sabin von Sochocky developed a phosphorescent paint whose ingredients were zinc sulphide plus a tiny amount of radium. He founded a New Jersey-based company - the Radium Luminous Materials Corporation – to manufacture watches and clocks with luminescent dials. The products were very quickly taken up by the American military during the First World War, and then by ordinary families. The firm mainly employed young women workers who were glad to be contributing to the war effort. They were soon to be disabused. In the early 1920s, several died while others developed bleeding gums, necrosis and porosity of the jaw or lost their teeth. It was a dentist, Theodore Blum, who discovered the occupational origin of these disorders: the women painting radium dials were pointing the paintbrushes with their lips to keep them sharp. In so doing, they were swallowing small fragments of paint with their saliva. The first case of bone cancer was diagnosed in 1923; scores more would follow.

Faced with a flood of complaints from its women workers, the company pressured doctors and dentists not to disclose their medical records, and pursued a diversionary strategy, accusing the women of actually suffering from syphilis. Five of the women, soon to be dubbed the Radium Girls, held firm and sued. In 1928, a year after the firm shut down, they were awarded compensation of US$10 000 apiece (about $100 000 at today's rates). It was a landmark case, setting the precedent for American workers' right to bring a personal claim for damages against their employer for a work-related injury. In the year of the judgment, the inventor of the luminescent paint died of aplastic anaemia, a victim of his own invention.

Radium paints gained widespread popularity, being used in the production of dials for military equipment dashboards (tanks, boats, planes), but also in more general public applications like switches, watches, compasses, house and theatre seat numbering.

A 1983 review in the United States reported a third of cancer deaths (leukaemia, bone and breast* cancer) among 3000 dial painters.

* The breast cancers reported were attributable not to ingested radium but rather to continued exposure to external radiation from the gamma rays emitted by the radium in the paint pot situated twenty centimetres away from the workers' chests.

Two years later, the German Röntgen Society erected a "Martyrs Memorial" in Hamburg to honour the pioneers of X-rays and radium. Marie Curie's name is among the list of 360 doctors, physicists, chemists, technicians, laboratory technicians, etc., now engraved on the monument. But these are not the only occupations that have fallen victim to radium as the history of the hapless Radium Girls, the American women workers exposed to radium (see box). Despite her own illness and the Radium Girls' beseeching her to focus her research on treatments for the bone cancer they were suffering from, Marie Curie would never acknowledge the risks associated with the development of the technology she instigated. Yet the scientific community had known about cancers caused by ionising radiation since the early 20th century.

The earliest cases of X-ray-induced skin cancer on doctors' and technicians' hands were observed in 1902. Between 1900 and 1920, the deaths of more than 100 radiologists as a result of work-related exposure would be reported. At that time neither exposures nor received doses were measured, so there was no concept of either a threshold or a non-exceedable limit. Despite the observed deaths and diseases, an awareness of the need to limit and control exposure to ionising radiation was slow to win out over the enormous enthusiasm for the new technique.

And yet the dangers of X-rays had been officially acknowledged by German and British scientific societies in 1913 and 1915, respectively. A series of scientific reports in the 1920s urged that exposure be limited. At that time, scientists were speaking in terms of "tolerable" doses. In 1925, an American physicist suggested setting that dose as a fraction of the dose apt to cause a skin rash (redness of the skin caused by congestion of the capillaries) - what he called the Skin Erythema Dose (SED). He set the tolerable dose at one hundredth of the SED per month, equivalent to about 35 times the current annual standard for workers (Lambert 2001)[1].

This maximum permissible limit was set at the time by reference to the visible short term (a few weeks) damage done by ionising radiation. The idea of a malignant tumour developing after a latency period had not yet emerged.

It was not until the second International Congress of Radiology in 1928 that a real unit of measurement of radiation - the roentgen – would be adopted. The roentgen measures electrical charge, i.e., the quantity of electricity that the radiation will produce in air (this unit has now fallen into disuse). That same year saw the founding of the International X-ray and Radium Protection Committee (IXRPC), later to become the International Commission on Radiological Protection (ICRP), the name by which it is still known today. Its first general recommendations concerned protection for medical workers by limiting working hours with medical imaging sources.

In 1934, a panel of US experts, representing X-ray equipment manufacturers came up with the concept of a *tolerance dose* of radiation which it suggested be set at 0.1 roentgen per day for whole body exposure. The following year, the International X-ray and Radium Protection Committee took up the idea of a tolerance dose threshold below which the level of irradiation was assumed not to cause damage to the "average individual". This belief predominated until the early 1940s, when a number of scientists began to reject the idea of a harmless level of exposure.

In the 1930s, science began to unlock the mysteries of radioactive elements. The physicists Niels Bohr and Ernest Rutherford discovered that the atoms that make up matter consist of a nucleus composed of protons and neutrons surrounded by electrons. Some nuclei are unstable and decay spontaneously, emitting different types of radiation – this is the origin of natural radioactivity. In 1933, husband and wife physicists Frédéric and Irène Joliot-Curie found that a natural stable element if bombarded with alpha particles could be transformed into an artificial and unstable (radioactive) element, thereby discovering artificial radioactivity. In Rome, fellow physicist Enrico Fermi experimentally bombarded all known chemical elements with neutrons to create new radioactive elements.

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[1] The skin dose is 500 mSv/year, set in 1970.

Her critical analysis of Enrico Fermi's work led the German scientist Ida Noddack to suggest for the first time in 1934 that an atomic nucleus which has absorbed a neutron may undergo nuclear fission. Her findings, however, were largely dismissed in Italy and Germany alike. And yet four years later, other German physicists - Otto Hahn, Lise Meitner and Fritz Strassmann – reached the same conclusion: a uranium atom, when bombarded by neutrons, splits in two, releasing neutrons and emitting considerable energy, called "nuclear energy". The released neutrons may in turn collide with other uranium atoms, creating a chain reaction.

Lack of interest by the Nazi and Fascist regimes in their scientists' discoveries probably stopped Hitler and Mussolini getting the atom bomb in time to use it. In the late 1930s, various scientists and Nobel Prize winners fled Italy and Germany for the United States. Some were persuaded that the energy released by nuclear fission could be used by Germany to manufacture bombs. Via Albert Einstein, they urged the US authorities to seize the initiative and launch a vast nuclear research project codenamed the Manhattan Project. It was this programme that would enable America aided by Britain and Canada to develop the two atomic bombs that would be dropped on Japan (see box).

Hiroshima and Nagasaki, a world plunged into a nuclear firestorm

The first atomic bomb, *Little Boy*, dropped on central Hiroshima at the start of the working day on 6 August 1945 contained a mass of highly enriched uranium-235 that would generate energy equivalent to the explosion of 16 000 tonnes of TNT. *Fat Man*, the bomb dropped on Nagasaki on 9 August, used plutonium 239 and released the even-greater energy equivalent of approximately 21 000 tonnes of TNT. Despite being more powerful, it created fewer casualties due to geographical conditions that spared some of Nagasaki's inhabitants.

In Hiroshima, the intense heat release, fires, blast and ionising radiation left 140 000 dead and 80 000 injured from a population of about 360 000 people. Nagasaki's 250 000 inhabitants suffered an estimated 70 000 dead and 80 000 injured. Various senior US officials, including former Defence Secretary Robert McNamara, have testified that had the US not been victorious, the bombings would have constituted war crimes. Almost all the victims were civilians. Of the 300 000 survivors, 280 000 were exposed to radiation revealed a Japanese census conducted in 1950.

In January 2010, the American journalist Charles Pellegrino chronicled testimonies of explosion survivors in *The Last Train from Hiroshima*, (Pellegrino 2010). One of them, Tsutomu Yamaguchi, said that the only people who should be allowed to run a country possessing nuclear weapons were breastfeeding mothers.

The commemoration ceremony of the 65th anniversary of the nuclear attack on Hiroshima held on 6 August 2010 was attended for the first time by a representative of the United States, Ambassador John Roos, and UN Secretary General Ban Ki-moon. There have been calls in Japan for the United States to apologise for the atomic bombings, as yet to no avail. Within weeks of the ceremony of remembrance, the United States carried out new so-called "sub-critical" (because causing no chain reaction) underground tests in their Nevada experimental centre. The mayors of Hiroshima and Nagasaki greeted them with indignation and regret, judging them to be against the desire for a world without nuclear weapons voiced by President Obama in his Nobel Peace Prize acceptance speech.

In October 2011, US nuclear experts completed the disassembly of the most powerful bomb in the US nuclear arsenal – the B53 – which had an energy yield of 9 million tonnes of TNT, 500 times the power of the Hiroshima bomb.

Nuclear weapons research let the genie of radiation and radioactivity permanently out of the scientific and medical bottle to inhabit the military arena. The innocence of the atomic dawn was to be permanently lost with the Hiroshima and Nagasaki bombings. The political conditions of the 1930s, when the major discoveries on atomic energy were made, fostered a culture of secrecy within the scientific community about nuclear technology which is still in evidence today.

In the immediate aftermath of the Second World War, nuclear energy came to represent the power of destruction. In the US in particular, a group of politicians, journalists, scientists and industrialists would try to re-brand it by giving a positive image to "atomic energy" as it then became known. These atomic energy advocates propounded the idea that the benefits of the peaceful applications of nuclear power could be equal to its destructive potential. That would be some years away, as the dawn of the Cold War saw the priorities go first to harnessing nuclear technology to military ends.

1.2. Nuclear testing and the creation of regulatory bodies

The Atomic Energy Act passed by the US Congress in 1946 reflects the state of tensions with the Soviet Union. The Act created a virtual government monopoly on nuclear energy by disallowing its use for commercial applications. It focused on the military aspects of nuclear energy, and the need for secrecy in new weapons research. It established the United States Atomic Energy Commission (AEC) to manage national nuclear energy programmes.

Meanwhile, a committee of US experts, the National Committee on Radiation Protection (NCRP), a member of the International Commission on Radiological Protection (ICRP), abandoned the old *tolerance dose* concept in favour of the *maximum permissible dose,* defined according to the state of the art of the time as a dose that is "not expected to cause appreciable bodily injury to a person at any time during his lifetime" (USNRC 2010). The probability of such harm occurring below the permissible limits was not ruled out, but was deemed to be low enough for the risk to be considered acceptable by the average person. In 1948, the NCRP experts in agreement with the International X-ray and Radium Protection Committee[2], suggested reducing the whole body exposure standard to 0.3 roentgen (R) for a six day working week, or 15 R/year - half the 1934 level.

In 1949, the Soviet Union carried out its first nuclear test, followed by the United Kingdom in 1952. This nuclear arms race was to cause long-concealed or downplayed disasters in both countries (see box, p. 12). The US lost its monopoly on nuclear technology and mounting Cold War tensions finally extinguished the hope of a nuclear arms-free world.

In December 1953, within months of Joseph Stalin's demise, President Eisenhower unveiled to the UN General Assembly the Atoms for Peace programme, marking a dramatic shift in US policy. The centrepiece of Eisenhower's speech was the proposed creation of an international agency to promote the controlled peaceful use of nuclear energy and to ensure that it was not used for military purposes. Hitherto, not only had no other nation - not even in Europe - evinced an interest in international control but several countries were actually keener on getting "the bomb" quickly than on preventing nuclear proliferation.

In December 1955 the UN General Assembly set up the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear). The Commission, which comprises only 21 of the UN's member countries, has issued fewer than 20 reports since its

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[2] Renamed the International Commission on Radiological Protection (ICRP) in 1950.

Kremlin cover-up versus UK whitewash

The Soviet Union embarked in total secrecy on the construction of large-scale reactors to produce weapons-grade plutonium in the southern Urals in 1947. Ten years later, on 29 September 1957, the heating-up of nitrates and acetates at the bottom of a tank of highly radioactive waste caused a violent explosion in the then-secret Mayak nuclear complex. The explosion, caused by a failure in the tank cooling system, seriously contaminated the entire region. Over the following months, 11 000 people were permanently evacuated and several hundred sq. kms of land were left unusable. The nearby Techa River, already heavily contaminated since the early 1950s by radioactive discharges from the military complex (Degteva 2012), was further polluted by the radioactive effluent released by the accident. Some 28 000 people in villages bordering the river were exposed. The massive discharges of the 1950s and the Mayak disaster seven years later were covered up by the Soviet authorities until the refugee Soviet biologist Zhores Medvedev living in London blew the whistle*. The Chairman of the United Kingdom Atomic Energy Authority (UKAEA) dismissed Medvedev's account as pure science fiction. And yet it was Medvedev's comprehensive review of a wide body of scientific literature on strontium-90 radioactive contamination of places whose names were undisclosed by their authors that enabled what happened at the Soviet nuclear facility in autumn 1957 to be pieced together.

The UK authorities' dismissive attitude towards the Russian dissident's disclosures comes as no surprise given the major accident which occurred in the United Kingdom's own race for the A-bomb. On 9 October 1957, just days after the secret Mayak accident, fire broke out in one of the natural-uranium reactors (Pile 1) of the Windscale plant (location called now Sellafield, in northwest England) built by the UK after World War Two as part of the British atomic bomb project. The fire lasted several days, during which it was estimated that 150 of the 1 500 fuel rods burned. With no secondary containment, radioactive iodine leaked into the atmosphere along with polonium and small amounts of plutonium. Fortunately, recently-fitted filters helped contain the release of radionuclides from the fuel. As a result of these leaks, the authorities decided to ban consumption of particular foods like milk, two million litres of which were dumped into the Irish Sea.

The UK authorities fended off queries about the incident with bland platitudes and the Official Secrets Act. The government of the day led by PM Harold Macmillan was in the midst of sensitive discussions with the US on the resumption of nuclear arms cooperation. In January 1958, the United Kingdom Atomic Energy Authority published a report which concluded that there had been "no immediate damage to health of any of the public or of the workers at Windscale", and it was most unlikely that any harmful effects would develop. The consequences of the accident remained shrouded in secrecy for decades afterwards. A 2007 report, 50 years after the event, estimated that pollution was higher than admitted at the time, and that the radioactive cloud may have caused 240 additional cases of cancer compared to the expected rate in the general population. The Windscale site – now renamed Sellafield – hosts several nuclear facilities (nuclear reactors and fuel reprocessing plants) operated by the BNG group.

* The Soviet authorities continued to deny the disaster up to the late 1980s. With Mikhail Gorbachev's ascendancy to power, *glasnost* and the Chernobyl accident, Russian scientists began to lift the veil of secrecy. At an extraordinary IAEA meeting in Vienna in 1989, Russian physicists gave details of the 1957 explosion and the pollution of the Techa river (Vilanova 2007).

inception, but they speak to the advance of knowledge about ionising radiation. They are authoritative and shape the policy of international agencies like the International Labour Organisation (ILO), the World Health Organisation (WHO) and the International Atomic Energy Agency (IAEA).

The **IAEA**, created in October 1956, stands as the other big international player in nuclear matters. The main objectives set for it were:
— to promote the applications of nuclear science in medicine, agriculture and energy;

- to establish internationally accepted standards of nuclear safety, in particular for the safe transport of nuclear materials;
- to promote the exchange of scientific information and training for personnel required to work in nuclear facilities;
- to establish a sort of bank of nuclear materials;
- to acquire a staff of specialists and inspectors responsible for enforcing nuclear safety.

The IAEA granted consultative status to 19 non-governmental organisations, including the International Confederation of Free Trade Unions and World Confederation of Labour, both of which proclaimed an interest in protecting workers against radiation exposure.

In March 1957, the six founding countries of the European Union (Germany, Belgium, France, Italy, Luxembourg and the Netherlands) signed two treaties in Rome, one establishing the European Economic Community, the other the European Atomic Energy Community or Euratom. The fundamental principle of Euratom is “to create the conditions necessary for the development of a powerful nuclear industry which will provide extensive energy resources, lead to the modernisation of technical processes and contribute, through its many other applications, to the prosperity of their peoples”. The Treaty establishes a system of controls designed to make certain that civil nuclear materials are not diverted to other (particularly military) purposes. A staff of 300 inspectors was set up for this purpose with powers to inspect Member States’ nuclear facilities, make findings and take samples. The treaty also provides for proposed harmonised standards for radiation protection (see Chapter 3).

By the late 1950s, the international, American and European institutions in charge of promoting and controlling nuclear energy were therefore in place. The IAEA had difficult beginnings. Headquartered in Vienna, a city still partly in ruins, the agency was suspected of harbouring several secret service agents. From time to time, the Cold War raged more violently in the IAEA Board than in the UN itself.

For a number of years, the IAEA’s focus was to be polarised on the growing controversy around the fallout from atomic testing and non-proliferation of nuclear weapons. The nuclear tests carried out by the United States, France, the United Kingdom and the Soviet Union were generating fine radioactive fallout dust which dispersed into the atmosphere, often settling far from the testing sites in populated areas. A number of scientists gave public expression to their fears. Radioactive fallout became a focus of discussion in the press and in politics. Public opinion was alerted to the potential risks of low-dose radiation and scientists’ lack of knowledge about its health effects.

A chart produced by the Mol Nuclear Power Centre in Belgium confirmed a rise in the radioactivity of atmospheric air contaminated by radioactive fallout and, with an approximately two-year lag, the increased body burden of caesium-137 in the population, as human contamination occurs progressively through air, water and food chain. Human contamination peaked in the mid-1960s. Two years after the Chernobyl disaster, the Mol Nuclear Centre also observed elevated caesium 137 contamination of humans.

In response to public concerns, the US NCRP and the ICRP embarked in the late 1950s on an overhaul of their standards, lowering the permissible exposure levels but insisting that insufficient evidence existed of the risk posed by previously recommended exposure levels. The rad - equivalent to 1/100th of a joule per kilogram of matter - became the dose unit, and the new exposure standards were expressed in rem (rad equivalent man), a unit of measurement that assesses the potential effects of doses of radiation on humans. The mean exposure limit dose over a period of one year was set at 5 rem for workers, and 0.5 rem for the general population, which is 2.5 and 5 times the maximum doses, respectively, in the

European Union today (see 3.3). These new standards were incorporated into United States law in January 1961, where they remained unchanged for many years thereafter as the US authorities showed no willingness to follow changing ICRP recommendations.

Nuclear fallouts

Atmospheric nuclear tests conducted from 1945 to 1980 were the most significant source of environmental exposure to human-generated ionising radiation for the world's population. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear), 543 atmospheric tests were carried out over this period - 219 by the Soviet Union, 197 by the United States, 45 by France, 22 by China and 21 by the United Kingdom – at a wide range of locations (mountains, towers, barges, aircraft, balloons, etc.) for a total yield of 440 megatonnes. The 25 tests with a yield greater than four megatonnes each accounted for about 66% of the total yield: 1 Chinese test in 1976, 11 US tests between 1954 and 1956 in the Pacific Ocean, 13 Soviet tests between 1961 and 1962 in Novaya Zemlya (Russian archipelago in the Arctic Ocean). The Soviet Union holds the record for yield with a 50 megatonne explosion - 2380 times the yield of the Nagasaki bomb.

The radioactive dust and debris produced by the explosions – an estimated volume of about 160 000 tonnes – was deposited up to several thousand kilometres from the testing sites. Radioactive dust released by these tests mostly contaminated the northern hemisphere where virtually all the testing took place. The radioactive material dispersed included the highly persistent radioactive elements caesium-137 and strontium-90. Radioactivity from the nuclear tests was at its height in 1963, but is still measurable. Caesium-137 levels had only halved by 2000.

Fierce controversy surrounds the question of whether there has been an increase in cancers worldwide as a result of nuclear testing. An increase in cancers was observed around the Semipalatinsk testing site in north-eastern Kazakhstan where the Soviet Union carried out 118 atmospheric tests (including 26 above-ground tests): firstly, leukaemia in children, followed later by solid cancers (breast, thyroid, lung, digestive system, etc.). In the US, payments of sickness compensation to Nevada nuclear test veterans were followed from the early 1990s by payouts for the health impacts (notably the occurrence of certain cancers) suffered by affected civilian populations. The health impacts on civilians and soldiers at France's nuclear test sites in the Sahara and in Polynesia are now beginning to be studied. Legislation introduced in 2010 provides compensation for civilian and military victims of French nuclear testing under certain conditions (see Annex 3). No specific regulations have been passed in the UK to compensate British servicemen affected by testing in the Australian desert. Australia, meanwhile, has had a bill going through since 2010 on compensation for Australian service personnel, but not residents.

1.3. Nuclear energy: development and dispute

The US Congress passed the Atomic Energy Act in August 1954 as part of the Atoms for Peace programme, putting an end to the government monopoly and making the development of a private, commercial nuclear industry a national priority. The US Atomic Energy Commission (AEC) was tasked with encouraging the use and regulating the safety of nuclear power. This was an ambiguous role which later brought the AEC in for much criticism, not least for the military oversight exercised over the early development of civil nuclear technology.

As part of the Atoms for Peace programme, the US military developed a programme for studying food irradiation and its health consequences aimed at tackling world hunger by protecting crops against pests and germination. This programme would later be taken over by a joint committee of the IAEA, the UN Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO), later joined by Euratom. There was also military involvement in the development of civil nuclear energy: the first nuclear power reactor developed by Westinghouse would be trialled in US Navy submarines (Eggermont 2011).

The early 1960s would see a groundswell of public opposition in America to the dumping of low-level radioactive waste at sea, permitted under certain conditions by the AEC, and the construction of nuclear power plants in New York and at Bodega Bay in California. Despite public antagonism to nuclear power, the 1960s witnessed a building boom in nuclear power stations. But mounting domestic opposition and criticism of the AEC itself would eventually prevail. Reputable scientists including John Gofman and Arthur Tamplin, working in an AEC-funded research laboratory, stepped into the debate to denounce the general population standard. They calculated that exposure of the entire US population would result in tens of thousands of additional cancers a year. They issued a blunt criticism of the AEC's underlying philosophy: "The AEC is stating that there is a risk and their hope that the benefits outweigh the number of deaths (...) This is legalised murder, the only question is how many murders?" (USNRC 2010).

In 1974, Congress dissolved the AEC and created the US Nuclear Regulatory Commission (NRC) with a function now limited to safety and protection of public health. After the accident at the Three Mile Island nuclear plant (Pennsylvania) on 28 March 1979, the NRC decided to follow the ICRP recommendations and cut the annual general population exposure limit to ionising radiation from human activities to one-fifth, setting it at 0.1 rem or 1 millisievert per year (see box) - the same limit adopted by the Euratom Directive on the protection of the health of workers and the general public against the dangers arising from ionising radiation (Council 1996).

The steps to achieving radiation protection

1. The United Nations Scientific Committee for the Effects of Atomic Radiation (Unscear) coordinates the substantive discussions on the analysis of the risks from the use of ionising radiation. Expert committees also take part in the discussions: for the United States, the Committee on the Biological Effects of Ionising Radiation (BEIR), and for the European Union, the group of experts established by Article 31 of the Euratom Treaty.
2. The International Commission on Radiological Protection (ICRP) turns advances in science into recommendations on dose levels and practices for optimising prevention and minimising risks.
3. The International Atomic Energy Agency (IAEA), globally and Euratom for the EU formulate basic rules for radiation protection and are responsible for monitoring observance of the rules laid down (see Chapter 3). National agencies in each European country are responsible for monitoring and control of nuclear activity.

Opposition to nuclear power in Europe began to take shape in the mid-1970s. After the Three Mile Island accident in 1979, the criticism extended to the entire nuclear fuel cycle. It gained in strength after the 1986 Chernobyl disaster. In 1997, MEPs backed the creation of the European Committee on Radiation Risk (ECRR)[3] as a counterweight to the policy-shaping influence of international organisations like Unscear and the ICRP. In 2003, the ECRR published an alternative method for assessing the risks of exposure to ionising radiation by re-weighting the biological, epidemiological and environmental factors.

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[3] The ECRR was established in 1997 as a result of a resolution adopted at a conference organised by the Greens in the European Parliament in Brussels. Its first Chair was the renowned scientist Alice Stewart who first highlighted the risks of foetal damage caused by x-rays of pregnant women.

This challenge to official models of radiation risk assessment took place as the precautionary approach was being introduced and would compel international organisations to engage with discussion.

1.4. The ICRP, keeping the nuclear faith but forced to move on

The International Commission on Radiological Protection (ICRP) is a not-for-profit organisation headquartered in the United Kingdom, but with a scientific secretariat currently based in Ottawa (Canada). It was founded in 1928 by the International Society of Radiology under the name International X-ray and Radium Protection Committee (IXRPC). The ICRP is supported by a number of international organisations and many governments. It is funded from donations. Some of its funding comes from copyright royalties on sales of its publications, and from contracts. The ICRP is an advisory body, producing "recommendations" on the principles of radiation protection and drafting guidance for practical radiation protection in the various applications of ionising radiation. It has no regulatory remit; that is the purview of national and international organisations and governments. It revises its basic standards at regular, approximately 15-year, intervals.

The medical community's idea in founding this organisation was to have an advisory body on radiation protection because the health sector was where most ionising radiation exposure could occur at the time. After the war, the ICRP acquired other objectives, including assessing the risks of military use of nuclear energy. Lauriston Taylor, who presided over the ICRP's development and headed it from 1953 to 1969, also founded the US NCRP in 1946 and chaired it for several decades. This earned the ICRP the criticism of being influenced by the military nuclear lobby.

1.4.1. The linear no-threshold (LNT) dose-effect relationship model

Prior to the 1960s, ICRP recommendations were based on maximum permissible doses. As a result, the only requirement for operators using ionising radiation was to ensure that people were not exposed above the limits set by regulators. They were not asked to minimise exposure. Pressure from scientists, including Nobel laureates Bertrand Russell and Joseph Rotblat, forced the ICRP to consider the effects of low-dose but diffuse contamination. In 1966, it officially acknowledged for the first time the linear no-threshold model. In so doing, the ICRP admitted that there was no known dose threshold below which ionising radiation had no harmful biological effects. It was also an acknowledgement that low dose radiation produces a cancer risk that albeit low is directly proportional to the dose.

The development of the LNT model prompted the ICRP to make the quest to reduce exposure a central aim of radiation protection and to define the ALARA principle.

1.4.2. The ALARA principle

The acronym ALARA stands for *As Low As Reasonably Achievable*. In 1959, the ICRP wrote: "The most conservative approach would be to assume that there is no threshold and no recovery (from harmful effects), in which case even low accumulated doses would induce leukaemia in some susceptible individuals, and the incidence might be proportional to the accumulated dose", leading it to conclude that," (...) the Commission recommends that all doses be kept as low as practicable and that any unnecessary exposure be avoided" (ICRP 1959). If there is no threshold, and hence no safe dose however small, and these doses may accumulate, then population exposure – be it environmental or occupational - to ionising radiation must be reduced to the lowest level.

The ICRP devised an "as low as is readily achievable" assumption in 1965, but in 1977 decided to refine the formula to recommend that individual and collective doses be kept "as low as is reasonably achievable, economic and social considerations being taken into account" (ICRP 1977). This form of words has remained unchanged. It reflects a utilitarian calculation which conveys the ICRP's intent to balance out the economic and social cost of dose reduction rather than dose reduction as an end in and of itself regardless of the cost. ALARA allows the risk to be run if it is reasonable, acceptable. But what exactly is "acceptable"?

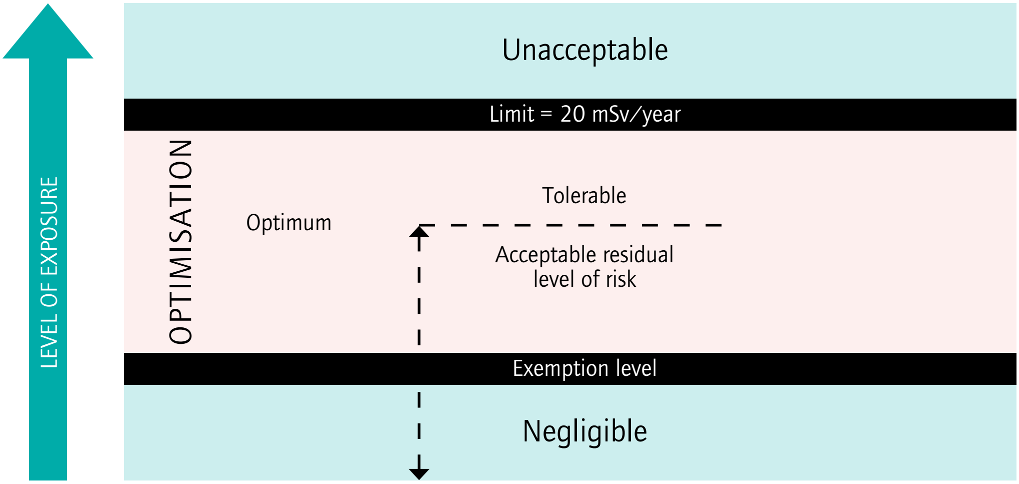
The acceptability of a risk varies with the interests involved for different population categories (general public versus workers, for example). It changes over time as a value judgment based on the perception of the risk. "An insignificant or negligible risk is not necessarily acceptable. An acceptable risk is not necessarily negligible. To decide what is acceptable involves value judgements and qualifications, for example: acceptable to whom?" as former Unscear Chairman Bo Lindell wrote in 1988 (Lindell 2008).

To that extent, ALARA is not just a utilitarian concept, but a means of getting away from a purely economic cost-benefit calculation which unable to resolve two basic problems: acceptance of the risk by those exposed, and their involvement in a collective safety strategy (Eggermont 2008).

1.4.3. The justification and optimisation principles

Having adopted the ALARA principle, the ICRP gradually developed instruments to implement it with. In 1977 it introduced into its recommendations, along with a system of dose limitation, the principles of justification and optimisation.

Figure 1 ALARA and acceptability



Source: CEPN

Justification means that any proposed activity that may cause exposure to ionising radiation must yield a sufficient benefit to justify the risks incurred. This principle deals with acceptance of the risk by the persons exposed.

Optimisation means that the risk must be reduced to the lowest level possible. This addresses the demand for greater safety (see Chapter 2).

The ALARA concept came before the precautionary principle. As currently defined by the EU, the precautionary principle requires authorities and the public to take the hypothetical risk into account and adopt preventive measures without waiting for scientific certainty. Some radiation protection experts believe that ALARA goes further than the precautionary principle by steering action in the direction it should take.

In order to develop and spread the culture of ALARA, the European Commission in 1996 funded the creation of the European ALARA Network initiated by a French association, the Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN), and a British governmental organisation the National Radiological Protection Board (NRPB). The network is now a not-for-profit organisation in its own right with aims that have gone beyond improving working conditions in the nuclear industry to include other areas like the medical and building materials sectors[4].

Key points

Discovered almost simultaneously in the late 19th century, X-rays and radioactivity were to develop at a dizzying pace leading very early on to medical and industrial applications. Dazzled by this veritable scientific revolution, doctors and researchers followed Marie Curie in long refusing to acknowledge that X-rays, and more generally radioactivity, had not only benefits but also health-damaging consequences. The military use of scientific knowledge about ionising radiation, which resulted in the bombing of civilian populations in Hiroshima and Nagasaki, sounded the death-knell for this age of heedless innocence. But the new circumstances of the Cold War brought a rapid resumption in the deployment of nuclear weapons of huge destructive potential.

A new impetus in developments for civil purposes was slower in coming but would be taken up on a large scale worldwide, driven by the huge energy demands of the three post-war boom decades. The health risks stemming from the expansion of nuclear power would be discussed only in the hushed surroundings of specialised international institutions. Challenges to nuclear technology, especially after the Three Mile Island accident and Chernobyl disaster, did nothing to curb the use of ionising radiation. But it did compel the institutions responsible for radiation protection to progress towards giving more consideration to the risks of using it. The incident at Japan's Fukushima nuclear power plant following the tsunami in March 2011 will surely lead to a revisiting of current thinking on nuclear risk evaluation and control.

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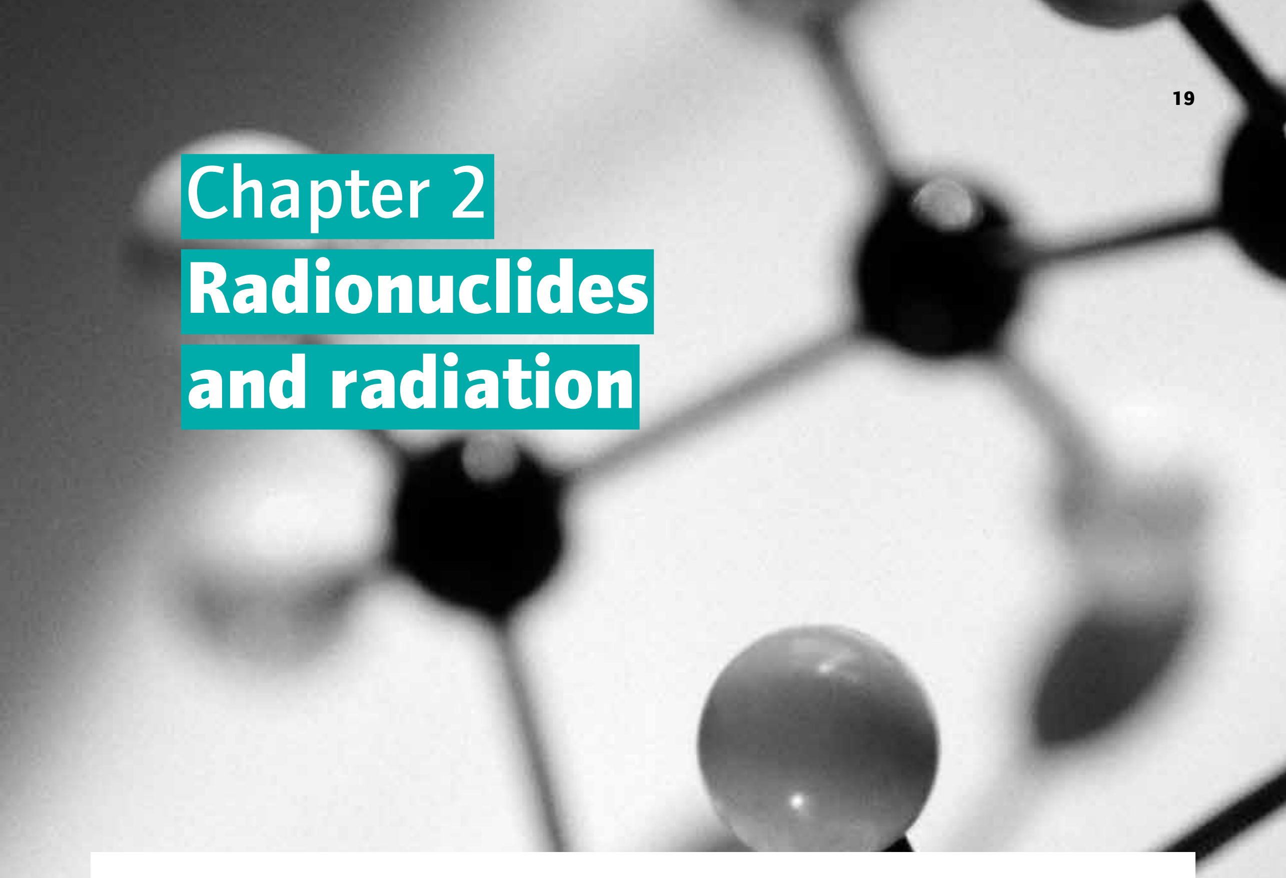
[4] More details on www. eu-alara.net.



Chapter 2

Radionuclides and radiation

To have a credible say in the debate on the regulatory and health issues of the industrial applications of ionising radiation depends on having a clear understanding of the broad general theory behind the technologies involved. And that means looking at a few basic concepts of nuclear physics.

2.1. Measuring the effects of ionising radiation

Everything is made up of atoms. An atom consists of a central nucleus surrounded by electrons. The nucleus is formed of two types of particle: protons and neutrons. Atoms are electrically neutral: there are as many electrons (negatively charged) as protons (positively charged) in the nucleus. Some nuclei are unstable and decay spontaneously, emitting particles in a stream of energy-bearing radiation. Chemical elements in which the nucleus decays spontaneously are described as radioactive. They are called radioelements (used only for naturally occurring radioactive elements) or radionuclides (both artificial and natural radioactive isotopes).

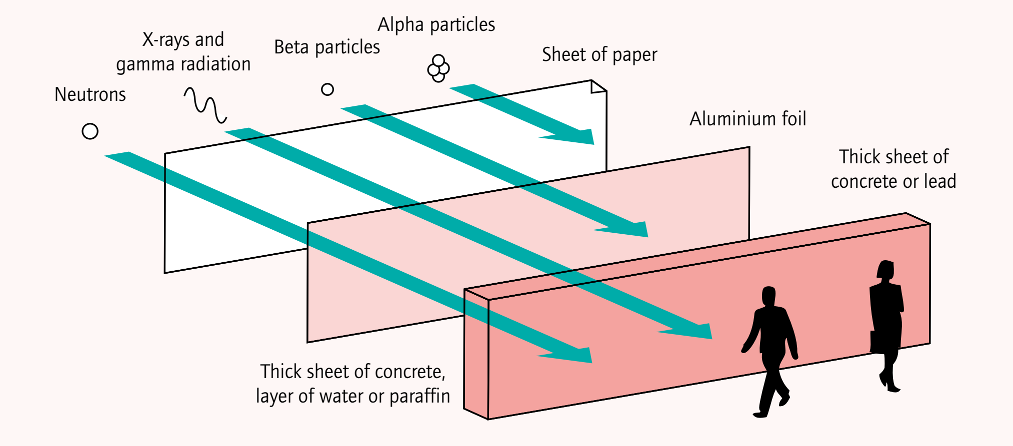
Atoms are uniquely identified by an atomic number (corresponding to the number of protons found in the nucleus) and a mass number (the total number of neutrons and protons in the nucleus). Atoms with the same atomic number but a different mass number are called isotopes. So, natural uranium has three isotopes all of which are radioactive: uranium-238, uranium-235 and uranium-234. Some natural chemical elements like carbon, sodium and potassium include a radioactive isotope (carbon-14, sodium-22 and potassium-40) in addition to their stable isotopes.

Radionuclides can be produced artificially (over 3 000 are known) either by irradiating natural elements with beams of electromagnetic radiation or particles, or by fission of uranium-235, plutonium-239 or curium-244, for example. Radionuclides can also be created when stable elements are bombarded by cosmic rays originating in outer space and the sun. Tritium, beryllium-7, carbon-14 and sodium-22 are examples of this.

The forms of electrically charged radiation - alpha and beta radiation – are said to be directly ionising because they knock electrons out of the matter through which they pass. They do not travel very far and are easily stopped by a thin sheet of paper (alpha particles) or a few millimetres of metal (the more strongly ionising beta particles). The former pass through the outermost layers of the skin, the latter penetrate living tissue to depths of millimetres. Alpha- or beta-emitting radionuclides that enter the body by being inhaled or swallowed transfer all their energy to the organ or tissue in which they are deposited.

Electrically uncharged radiation may be particle radiation, such as neutrons, or electromagnetic X-rays and gamma radiation emitted during radioactive decay or produced by electrical radiation generators[5]. These are known as "indirectly ionising" because in interacting with matter they transfer all or part of their energy to charged particles that they set in motion. They are highly penetrating and can pass through the human body. Protective shields comprised of layers of concrete, lead glass, steel or lead are used to stop X-rays and gamma radiation, and paraffin or boron shields for neutrons. The thickness of shielding required is determined in particular by the energy of the radiation, and the type of shield.

Figure 2 The types of ionising radiation and their penetrating power



Source: www.developpement-durable.gouv.fr

Exposure to radiation is external where it originates from a source outside the body. The level of radiation is then relative to the body penetrating ability of the radiation emitted by the source. This concerns X-rays, beta, gamma and neutron radiation. Exposure is internal where radioactive elements have penetrated the body by being inhaled or swallowed, e.g., as gases or aerosols. Alpha radiation is not generally dangerous to life through external exposure, but is very dangerous through internal exposure (when, for the same received dose, it is 20 times more damaging than beta or gamma radiation).

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5. For historical reasons, the photons of ionising radiation (which are electromagnetic in nature) emitted by an excited nucleus are called gamma rays and those emitted by electrical devices are called X-rays (in honour of Roentgen).

Work-related exposures are often external, but some workers may run the risk of internal exposure by absorption of radioactive particles, as in the case of exposure to radon (see box p. 23). The exposure received depends on the type of radiation, the distance from the source, the duration of the exposure and the effectiveness of protection.

The main units in the field of radioactivity are: the becquerel (Bq) for the intensity of the radioactive source itself; the gray (Gy) for the energy imparted by the radiation emitted by the radioactive source; and the sievert (Sv) for the effects that may result from exposure to that radiation. These units are internationally recognised and replace the older units known as curie, rad, and rem, respectively (see box below).

The main units of measurement used in radiation protection

The units used in radiation protection refer to standard measurable quantities like time, mass or energy, but also to concepts that result in units that are not directly measurable like the "effective dose" which is an indicator of the potential risk of developing disease, in particular cancer.

The becquerel (Bq) is used to measure the activity of a radioactive source. When a radioactive atom decays, it emits ionising radiation. The activity is the number of spontaneous nuclear disintegrations (or decays) occurring in a given amount of material in a given period of time. One becquerel is equal to one disintegration (or decay) per second. The becquerel is used to describe the activity of a source, but also an activity per unit of volume (Bq per cubic metre), surface area (Bq per square metre), or mass (Bq per litre or per kilogram depending on the type of contamination, air or water, surface, matter). The becquerel replaced the curie (Ci) which was defined as the activity of one gram of radium or 37 billion disintegrations per second. One curie is therefore equivalent to 37 billion becquerels.

The gray (Gy) is the unit of measurement of absorbed dose. Any substance or person exposed to a radioactive source absorbs some of the energy associated with that radiation. The gray corresponds to an amount of energy equal to one joule absorbed per unit mass of one kilogram. One gray (Gy) is equal to 1 joule/kilogram (J/kg). When expressing a dose in grays, it is necessary to specify the medium in which the energy is transferred (air, human tissue, iron, etc.). The unit of grays per hour (Gy/h) measures the absorbed dose rate per unit of time. The gray replaced the rad. A rad is equal to 1/100th joule per kg, so 1 gray equals 100 rads.

The sievert (Sv) is the unit of equivalent radiation dose, i.e., the absorbed dose (gray) multiplied by a radiation weighting factor (wR), because radioactive materials, electrical generators and nuclear reactors produce different types of radiation (alpha, beta, gamma or X) which at the same absorbed dose produce at the microscopic level different biological effects. Depending on the type of radiation, this gives the equivalent dose for the organ or tissue exposed for that type of radiation. The sievert is also used to measure the effective dose, defined as the sum of equivalent doses of the principal organs of the human body. Each major organ is assigned a different weighting factor – *the tissue weighting factor* (wT). – designed to factor in the likelihood of developing an ionising radiation-induced fatal cancer (and the average reduction in lifespan associated with that cancer). The effective dose is the estimated whole body dose. It is not a measurable physical quantity, but the product of a calculation. For radiation protection purposes, the effective dose is the one mainly used to set dose limits and assess the risks to an individual's health. There are also specific dose limits for particular organs. The sievert replaces the rem; one sievert (Sv) is equal to 100 rems. The weighting factors wR and wT are defined by ICRP committees. The sievert is the unit used to measure exposures received by the general population, workers or patients. Such exposures are normally of the order of a few millisieverts (mSv).

2.2. The biological and health effects

2.2.1. Exposures

The sources of exposure to ionising radiation may be natural, man-made (industrial or medical) or environmental (from nuclear testing, liquid and gaseous discharges from nuclear facilities, etc.).

The sources of exposure to naturally occurring radiation are cosmic or terrestrial. The sun, in which both nuclear fusion and fission processes take place, emits very high energy, highly penetrating radiation that interacts with the layers of air of different thicknesses that surround the earth. The primary radiation emitted by the sun and the secondary radiation which results when the high energy particles collide with the atoms in the atmosphere (oxygen and nitrogen) is one of the two components of cosmic radiation. The other component originates from outer space and comes from exploding stars that have reached the end of their life. The flux of incoming cosmic ray particles varies with altitude (doubling approximately every 1500 metres) and latitude (it is higher at the poles, where the air layer is thinnest, than at the equator).

Terrestrial radiation comes from very long-lived radionuclides, particularly emitted by uranium, thorium and potassium radionuclides present in the Earth's crust since it was formed about 4.5 billion years ago, and in some building materials.

Exposure from terrestrial sources may be external, such as gamma radiation emitted by the decay of radionuclides in the Earth's crust (mainly potassium-40). Its intensity varies according to region: it is higher in granitic regions like the Massif Central in France. World regions with the highest levels of natural radiation include Kerala in India, Guangdong in China, Ramsar in Iran, and southern Tuscany and the Swiss Alps in Europe (Unscear 2000).

There can also be internal exposure from terrestrial sources through the absorption of trace amounts of radionuclides in food (carbon-14 and potassium-40) or water, although the main source is inhalation of radon or thoron, the radioactive gases produced by the decay of uranium and thorium, respectively (see box p. 23). In Europe, the radon risk is particularly prevalent in the Belgian Ardennes, the Czech Republic, Sweden and Finland.

According to the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear), the world population is exposed to an average dose due to natural radiation of 2.4 mSv per year (mSv/year). It may vary from 1 to 10 mSv/year, and sometimes more, depending on where the individual lives. An estimated 65% of people experience a level of exposure to natural radiation of between 1 and 3 mSv/year, 25% have an exposure level below 1 mSv/year, and 10% a level of exposure in excess of 3 mSv/year. More than half of natural radiation is due to radon.

Exposure to artificial radiation due to human activities is added to natural radiation. Until recently, it was thought that the average radiation dose experienced by the entire world population consisted for about 82% of natural radiation and 18% of radiation due to human activities. This would represent an additional average radiation dose of 0.6 mSv/year for the entire world population, mostly due to medical procedures.

In 2000, Unscear estimated that average per capita exposure to ionising radiation for medical radiology purposes was about 1 mSv/year in developed countries compared to 0.02 mSv/year in the poorest countries.

More recent figures suggest that the average individual radiation dose received by the US population has risen sharply from the growing use of CT scans and nuclear medicine. In 2006, medical exposure to ionising radiation in the US was estimated equal to the exposure level from natural sources - 3 mSv. The average individual dose experienced by an inhabitant of the United States will therefore have almost doubled in nearly 25 years, from 3.6 to 6.2 mSv.

An increased exposure to ionising radiation of medical origin is also to be seen in other industrialised countries. In Belgium, medical radiation is fast approaching the level of natural radiation. In 2006, average total exposure was estimated at 4.6 mSv - 2.5 mSv from natural radiation and 2 mSv of medical origin (Vanmarcke 2010).

Unscear's 2008 report confirmed the increase in the average annual dose of medical radiation from 0.35 mSv in 1988 to 0.62 mSv per person in 2008 in the world. The average dose is 1.91 mSv for developed country populations versus 0.03 mSv for developing country populations. The annual number of radiological examinations rose over the period from 280 to 488 per 1 000 of population. The 24% of the world's population who live in developed countries received two-thirds of the examinations carried out, or 1 332 examinations per 1 000 persons. Worldwide, radiological examinations account for 21% of total public exposure to ionising radiation (Unscear 2008).

These averages reflect nothing of the past or ongoing ionising radiation exposure of people living in the Chernobyl region or former nuclear testing areas, patients undergoing radiotherapy, uranium miners or some nuclear reactor workers.

Radon, a radioactive gas to be taken seriously

Uranium is found in varying, mostly very small, amounts everywhere under the earth. A normal rock formation will contain an average three grams of uranium per tonne. Most uranium deposits are found in granite, shale and phosphatic chalk. It is a radioactive element that has constantly transmuted since the planet was formed. Radon is a radioactive gas occurring as the decay product of uranium. Radon itself transmutes. Its decay product – radon-222 – has a half-life long enough (about 4 days) for it to migrate into the open air via fractures, fissures and clefts, watercourses, through porous rocks and soil. Radon decay products gives rise to very fine solid radioactive particles small enough to be inhaled. These are deposited in the lungs where they continue to decay, delivering high energy alpha particles that irradiate the cells that form the bronchi.

Radon was classified as carcinogenic by the International Agency for Research on Cancer (IARC) in 1987. Radon is naturally present in the air of uranium mines, but some buildings and some poorly ventilated houses can be radon traps. Radon is one of the eight carcinogens most frequently encountered in the workplace. Miners are particularly at risk, but they are not alone. According to the Carex (Carcinogen Exposure) database, 2.7 million workers in the EU-15 were exposed to radon between 1990 and 1993. In a report published in 2010, the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear) estimated that 13 million workers worldwide are occupationally exposed to natural sources of radiation, mostly in mines.

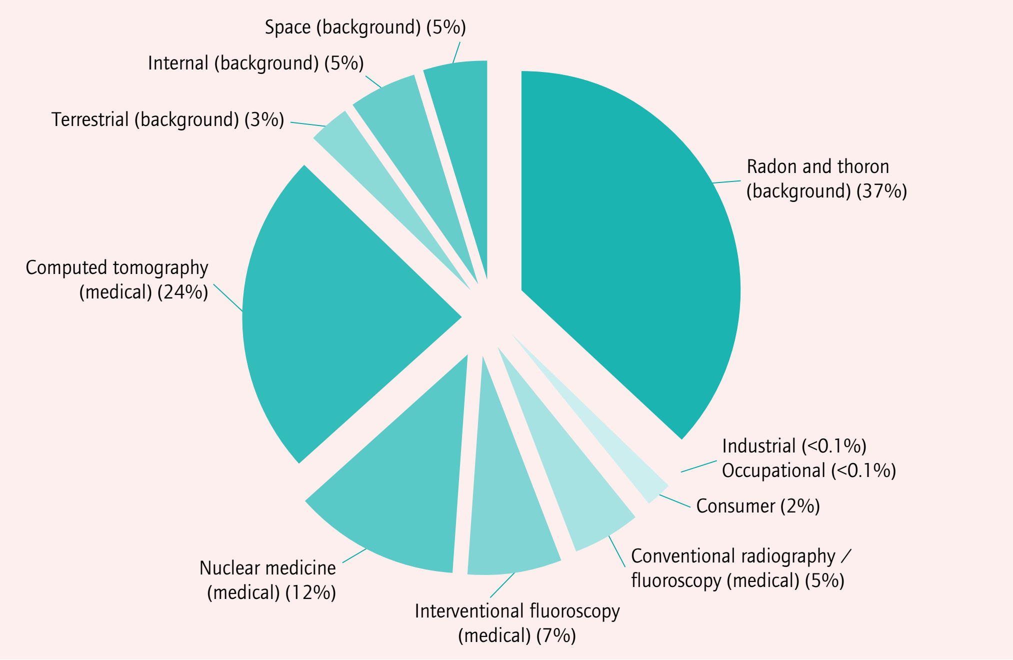
The World Health Organisation (WHO) recommends a reference level for radon of 100 Bq/m^3 which should not in any case exceed 300 Bq/m^3. The WHO estimates that the risk of lung cancer increases by 16% for each additional 100 Bq/m^3. The ICRP now considers that a radon contamination of the order of 300 Bq/m^3 corresponds to an annual dose received of 10 mSv. The ICRP's conversion factor has been questioned by some experts, and the dose actually received could be higher.

Exposure to radon in Europe accounts for about 9% of deaths from lung cancer and about 2% of all cancer deaths. Radon is estimated to be the leading cause of lung cancer among non-smokers and to increase the risk in smokers. A Danish study published in 2008, suggests that children's exposure to radon in the home increases their risk of developing leukaemia (Raaschou-Nielsen 2008). The European Union is likely to review its standards. In early 2011, it was still recommending that action be taken at levels above 400 Bq/m^3 for existing houses and 200 Bq/m^3 for new homes. The proposal for a new Directive published in October 2011 proposes lowering the standard for existing homes to 300 Bq/m^3.

The additional exposure of members of the public from non-medical human activities is subject to an internationally recognised limit of 1 mSv/year – about the same as the global average for natural background ionising radiation. The annual occupational exposure limit - also recognised internationally - is twenty times higher (20 mSv/year). Some workers are at or even above this limit, but the average level of radiation exposure at work is broadly comparable to that of exposure to natural radiation and the average patient medical exposure.

One person may accumulate radiation exposure from different sources (natural, medical, work), and greater account should be taken of this in the medical supervision of workers.

Figure 3 Distribution of sources of exposure of the population of the United States



Source: *Ionizing radiation exposure of the population of the United States*, National Council on Radiation Protection Report No. 160, Bethesda, 2009

2.2.2. The effects of ionising radiation

The energy transfer that occurs in the body of a living being exposed to ionising radiation affects the cells of the exposed tissues and organs, changing their properties and altering their DNA[6]. The DNA lesions are mainly breaks of a single or both strands. In the case of double-strand breaks, the DNA repair system may not work properly and erroneous rejoining of broken ends may occur. These misrepairs may prevent or modify cell reproduction, or result in cell death. Cell death depends on the type of exposure (internal or external), the

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6. More recent research and observations suggest that irradiation has not just effects on irradiated cells, but also on non-irradiated cells. These are known as non-targeted effects (see 2.3.).

type of radiation, the exposure dose rate, and the type of cells damaged (some, like bone marrow cells, being more radiosensitive). A damaged cell may not die, but survive and reproduce an abnormal cell.

The effects of ionising radiation on the human body are divided into two categories: short-term or "deterministic" effects, which inevitably occur in all exposed individuals when the radiation dose exceeds a certain threshold level, e.g., radiation burns; and long term "random" or "stochastic" effects, appearing only in some people, in the form of cancers and genetic defects.

Deterministic effects

Deterministic effects depend on the magnitude of the radiation dose. Where the exposure is to X and gamma rays, they appear from a radiation dose of 0.15 grays (Gy). The most sensitive organs are the reproductive organs, blood cells (spleen, bone marrow, etc.), the lens of the eye, and the skin. In the case of whole-body irradiation, the prognosis depends on the degree of damage to the bone marrow, gastrointestinal tract and lungs. From an effective dose of 4.5 Gy, and without prompt medical treatment, half of those exposed will die. Between 6 and 8 Gy, there will be no survivors.

Deterministic effects like vomiting or raised temperature are clinically observable in the hours or days after exposure only if the dose high enough to cause them was received in a relatively short period of time.

Table 1 Deterministic effects described for exposure to gamma or X-rays

Deterministic effects identified	Radiation dose
Temporary male infertility	from 0.15 Gy
Temporary decrease of leukocytes (white blood cell family)	from 0.2 to 1 Gy
Nausea, asthenia (weakness) Change in the blood count and differential Immunosuppressive effect (risk of infections) (Under medical supervision, there is a rapid return to normal.)	from 1 to 2 Gy
Risk of female infertility	from 2.5 Gy
Permanent male infertility	from 3.5 to 6 Gy
Aplasia (non-development or lack of development of a tissue or organ) (Without treatment, at least half of exposed persons will die and there is a risk of after-effects.)	from 4.5 Gy
Vision damage (potential occurrence of cataract from 1 to 10 years after irradiation)	from 5 Gy *
Gastrointestinal tract injury	6 Gy
Lung damage	8 Gy
Coma, brain death Fatal	beyond 10 Gy

* This table does not yet reflect the new estimates for the increased risk of cataracts that may arise from 0.7 Gy.
Source: INRS, taken from the special "Rayonnements ionisants" (Ionising radiation) report on the website http://www.inrs.fr

Random or stochastic effects

Here, it is not the onset of effects, but the probability of their occurrence, that is proportional to dose.

— Solid cancers and leukaemia

Assessing the risk of developing an ionising radiation-induced fatal cancer according to the radiation doses received is done chiefly by reference to the results of the Life Span Study which has been following-up the health of the Hiroshima and Nagasaki atomic bomb survivors since 1950 (see box p. 29). The study has identified a statistically significant cancer risk for the following organs: erythrocyte (red blood cell) producing bone marrow (first lesion identified), oral cavity, colon, stomach, liver, oesophagus, ovary, skin, lungs, breast, nervous system, thyroid and bladder.

Studies on groups of workers exposed to ionising radiation have also revealed excess cancers for certain sites. Excess cases of leukaemia have been found among radiologists and breast cancers among female X-ray technicians, especially among those who had worked before the 1950s (Mohan 2002).

Voluntarily - in the case of medical treatment - or accidentally ingested radium (see box p. 8) have caused excess bone cancers in proportion to the dose received.

Studies which sought to analyze the effects of internal exposure due to contamination with radionuclides like radon (uranium miners), plutonium (the Mayak site in Russia) or radioactive iodine (Chernobyl) found an increased incidence of lung cancer, leukaemia and thyroid cancers.

It is now scientifically accepted that radiation can cause fatal cancers in almost any human tissue or organ, although in some sites more commonly than others.

Unscear’s 2006 report estimated the lifetime risk of death from all solid cancers together (other than leukaemia) following an acute dose of 1 Sv (= 1000 mSv) as being from 4.3 to 7.2%, and for leukaemia 0.6 to 1%. These figures vary with different populations and risk models, particularly for solid cancers. The risk is two to three times higher for those exposed as children[7].

Among the atomic bombing survivors, statistically significant excess risks for leukaemia are seen at exposures from 100 mSv. For solid cancers, there was a significantly increased risk above 50 mSv and a significant increase in the incidence of these cancers above 200 to 500 mSv (Unscear 2000). Unscear nevertheless recognises that the excess risk of all solid cancers together increases in a linear dose-effect relationship, even for doses in the 0 - 150 mSv range (Unscear 2006).

— Genetic disorders

The Life Span Study found no evidence of an increased incidence of genetic abnormalities among Hiroshima and Nagasaki survivors or their offspring, which does not mean that the risk is zero.

Excess leukaemia was found in cohorts of children living nearby Sellafield (UK) in the vicinity of the Seascale reprocessing plant. Five cases of leukaemia were identified in people under the age of 25 between 1955 and 1984 when less than one was expected. A highly controversial study published in the early 1990s attributed this excess to the fathers’ pre-conception exposure to radiation at doses equal to or greater than 10 mSv (100 mSv cumulative dose) (Gardner 1990). More recent data points to a significant excess of leukaemia cases among children under the age of 15 in a 25 km radius around Sellafield.

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[7] One radiation-associated cancer of particular importance in children is cancer of the thyroid gland. There is strong evidence that the risk of thyroid cancer decreases with increasing age at exposure, so that the risk in children under 15 years of age is substantially higher than in adults (UNSCEAR 2000).

Some epidemiologists have also speculated that a viral infection might be responsible, originating in the population mixing from the influx of people required to build and operate the nuclear plant, but the infectious agent(s) possibly involved have not been identified. The excess of leukaemia in the vicinity of Seascale remains so far unexplained, as do the excess childhood leukaemias observed in the vicinity of nuclear facilities in Germany, especially the Elbmarsch nuclear power plant (Spix, 2008, Hoffmann 2007). A French study, published in early 2012 also found evidence of a significant excess incidence of acute leukaemia in children living within a 5 km radius around nuclear power plants for the period 2002-2007, but does not speculate on the causes of this increase (Sermage-Faure 2012).

Based on their risk indicators, Unscear and the ICRP believe that there is still no direct evidence that parental exposure to ionising radiation results in an excess of hereditary diseases in their offspring. Also, the ICRP's draft recommendations consider the genetic disorder risk only for two generations based on a theoretical estimate derived from human genetics theory and the results of animal experimentation.

Prenatal toxicity

The embryo and foetus are highly susceptible to ionising radiation exposure. Maternal radiation exposure in the first three weeks post-conception may cause miscarriage, and during the embryogenesis and organogenesis stages - i.e., in the first two months of pregnancy – may result in birth defects. The effects of in utero exposure of the foetus may include small head size and mental retardation and even possibly childhood cancers, including leukaemia. A 1956 study by English epidemiologist Alice Stewart suggested a link between X-rays performed on pregnant women and the occurrence of cancer and increased risk of leukaemia in their children. These results have been challenged, not least on the grounds that no such effects have been clearly observed in the population of atomic bomb survivors.

The data of the study of over 15 000 cases of children with cancer identified in the Oxford region from 1955 to 1981 suggested that in utero exposure to radiation of about 10 to 20 milligrays (similar to the average doses received from X-ray examinations in the 1950s) increased the incidence of leukaemia in the first 15 years of life by 40% (Unscear 2000).

A 2011 study by UK researchers of children born between 1976 and 1996 established an increased but statistically non-significant risk of cancer and leukaemia in children of mothers exposed to diagnostic radiation or CT scans during pregnancy. The study found an increased risk of lymphoma in children exposed to X-rays during the first 100 days of life. Although the results need to be replicated, the authors suggest the need for cautious use of diagnostic radiation imaging procedures on mothers during pregnancy and in children at very young ages (Rajaraman 2011).

Unscear assesses the risk of developing cancer before the age of 15 as a result of prenatal exposure to ionising radiation at about 5% per Sv. The ICRP argues that it is "prudent to assume that lifetime (solid) cancer risk following in utero exposure will be similar to that following irradiation in early childhood, i.e., at most, a few times that of the population as a whole" (ICRP 2007).

Cardiovascular diseases

The Life Span Study follow-up studies of the atomic bomb survivors evidenced a statistically significant radiation-induced mortality increase for non-cancer diseases from the 1990s. The 2006 Unscear report states that significant excess risks are mostly seen for diseases of the cardiovascular system. The increase was evident at doses of less than 2 Gy.

Long before these data were published, radiotherapists had observed vascular problems in some of their patients undergoing head and neck radiotherapy. Cardiac disorders had also been observed following radiotherapy for cancer of the lymph nodes (Hodgkin's lymphoma). The increase in cardiovascular disease risks among people receiving chest radiotherapy were attributed to very high doses - of up to 30-35 Gy cumulative doses - received by the heart (Metz-Flamant 2009, European Commission 2009).

The increased incidence of cardiovascular disease observed among the atomic bomb survivors has stimulated research. But oncologists and radiotherapists only grasped the full extent of the problem after the publication of two major studies pointing to an increased risk of heart attacks and cardiovascular diseases among women receiving radiotherapy after breast cancer surgery. Particularly troubling was that, whereas the risk of recurrence of breast cancer was the same after left- or right-sided cancer, the risk of death from heart disease was higher by 44% in those women who had cancer of the left breast than in those women who had cancer of the right breast. This increase was attributed to the higher radiation dose to the heart in patients with left-sided breast cancer (European Commission 2009).

The risk of cardiovascular disease after radiotherapy varies with age at exposure and may persist for decades.

Radiotherapy has also been used to treat non-cancerous conditions like gastric ulcers. In such patients, an increased cardiovascular mortality has been observed for doses of the order of 2 to 4 Gy received by the heart.

Data on workers at Russia’s Mayak site suggest that radiation-induced diseases of the circulatory system may occur as a result of chronic (not just acute) exposures and from cumulative doses of about 500 mSv.

The health impact of even a slight increase in cardiovascular diseases after low-dose radiation exposures may be significant given the frequency of these disorders. The Euratom Treaty Article 31 Group of Experts considers this to be an issue not just for radiotherapy but radiation protection in general.

Cataracts

The lens of the eye is sensitive to ionising radiation. The development of cataracts is considered the main complication for the eye after exposure to radiation. A cataract is a clouding of the lens resulting in a varying degree of impaired vision. The dose threshold at which a radiation cataract arises is uncertain. In 1990, the ICRP considered that the level of exposure at which a detectable lens change arises was approximately 2 Gy for a single exposure, and 5 Gy for a cumulative dose through fractionated exposure. This claim was deduced from the study of atomic bomb survivors in whom the onset of cataract was observed only at exposures above 1.5 Gy.

However, the most recent analyses suggest – and a 2008 major US study confirms (Chodick 2008) - that the lens is more radiosensitive than previously thought. This study, which followed-up a cohort of 35 705 radiographers, found that the lowest cumulative cataractogenic dose is approximately 2 Gy (and not 5 Gy as previously thought), and that the excess risk increased with duration of exposure with no apparent threshold dose. Cataracts can occur many years after exposure, the latency period being dose-related.

Other subsequent studies have further reduced the threshold dose. According to a summary by the Euratom Treaty Article 31 Group of Experts, the dose threshold at which there is an increased risk of cataract development could be around 0.5 Gy. The annual dose limit of 0.15 Gy currently recommended for the lens of the eye would result in a cumulative dose of 3 Gy after 20 years - six times the dose sufficient to cause an increase in the number of cataracts (GoE meeting report).

The atomic bomb survivors, involuntary guinea pigs

The health of the Hiroshima and Nagasaki atomic bomb survivors has been followed-up since 1950 in a clinical cohort study - the Life Span Study - by a Japanese-American Foundation established under an agreement between the two countries' governments (the Radiation Effects Research Foundation - RERF). This research programme has had and continues to have a big influence on the assessment of especially low-dose ionising radiation risks and the setting of global standards on ionising radiation exposure.

The radiation dose received by each of the 86 572 survivors enrolled in the study was estimated based on their location relative to the hypocentres at the time of the bombings. Approximately 65% received doses of less than 100 mSv.

A 2003 publication reviewed mortality causes from 1950 to 1997. During that period, there were 9,335 deaths from solid cancers (other than leukaemia), of which 440 (5%) were attributed to the radiation exposure. While the radiation-related cancer risk increased throughout the study period, the most recent findings indicate that it has peaked and is declining with attained age. The risk is highest for those exposed as children.

Leukaemia was the most common radiation-related cancer experienced by the Hiroshima and Nagasaki survivors. During the period 1950-1990, 176 leukaemia deaths were observed in the group who received doses higher than 5 mSv, 89 (51%) of which were attributed to radiation from the atomic blast. The importance of risk is dependent on the dose received, which itself depends on the distance from the epicentre of the explosion. The leukaemia risk was found to be highest for those exposed as children. It was at its most elevated in the first ten years of follow-up, declining thereafter with increasing attained age.

31881 deaths from non-cancer diseases were recorded among the survivors from 1950 to 1997, of which 250 deaths (0.8%) were attributed to radiation from the atomic blasts. The time-dependent dose-response link for non-cancer mortality is increasing. The risk is significantly higher for heart disease, digestive diseases and respiratory diseases. An estimate published in January 2010 confirms the higher risk of cardiovascular disease even at doses below 1 Gy. There is also a higher incidence of cataracts and thyroid nodules among the atomic bomb survivors.

The review to the end of 1997 found that 779 deaths were attributed to radiation exposure, of which 440 were from solid cancers, 89 from leukaemia, and 250 from non-cancer diseases.

While this may pale beside the enormity of the atomic explosions, it must be borne in mind that the study covers only a portion of the 280 000 survivors considered as radiation-exposed. Those in worst health may already have died from radiation effects between the explosion (August 1945) and the start of the epidemiological study (October 1950). Furthermore, a study of mortality alone effectively discounts treated cancer survivors.

2.3. New concerns: non-targeted and delayed effects

The term "non-targeted effects" encompasses effects of apparently differing mechanisms whose shared characteristic is that they are not a direct consequence of radiation. These effects are the focus of growing scientific interest, but no firm conclusions can yet be drawn. Current knowledge about these effects is derived mainly from laboratory or animal experimentation results, along with observation of radiation accident casualties and radiotherapy patients. They challenge the prevailing dogma that the harmful effects of radiation were a consequence of the irradiated cells alone or, in the case of hereditary effects, cells derived directly from the irradiated cells. The main non-targeted effects observed are of different types.

2.3.1. Genomic instability

Genomic instability is an all-embracing term that describes the increased rate of acquisition of alterations in the genome[8], i.e., induced by causes external to the organism. Instability is measured as chromosomal alterations, micronucleus formation, gene mutation, etc. There is evidence that genomic instability may play a role in the development of cancers, and that persistent instability might strongly influence the development of leukaemia in humans. Radiation-induced genomic instability is observed in cells long after irradiation. It is present in non-irradiated cells derived from exposed cells sometimes several generations after irradiation.

2.3.2. Bystander effects and abscopal effects

The bystander effect is defined as “the ability of cells affected by an agent to convey manifestations of damage to other cells not directly targeted by the agent or not necessarily susceptible to it per se” (Unscear 2006). This means that radiation-induced damage may manifest in cells that were non-irradiated or not derived from irradiated cells, but are the result of a signal generated by an irradiated cell.

In 2008, Italian researchers brought proof of this when they found DNA damage in the non-irradiated brain cells of mice through a bystander effect with neighbouring irradiated cells. The researchers believe their findings call for a reassessment of the induced effects of ionising radiation (Mancuso 2008).

Furthermore, what are known as abscopal effects have also been observed in animals and humans. Abscopal effects are a tissue response to irradiation in tissues definitively separate from the region exposed to radiation.

Other non-targeted effects observed include clastogenic (chromosome-breakage) factors experimentally demonstrated by findings that plasma from irradiated animals and humans can contain factors capable of inducing deleterious effects in non-irradiated cells. Hereditary effects are the effects observed in the offspring of parents exposed to radiation prior to conception. This, mentioned earlier, remains a controversial issue. However, such effects are well documented for certain animal species, and were found in a study on the fallouts of the Chernobyl accident.

While research into the non-targeted and delayed effects of ionising radiation is in its very earliest stages, in the event that proof is brought that these are frequent effects, associated with all types of ionising radiation, and manifesting at low-dose exposures, it will have to be acknowledged that the assumptions currently underlying the founding principles of radiation protection are minimising the risks.

2.4. The controversy over low-dose effects

Conventionally, low doses are doses less than 100 mSv, and very low doses are those less than 10 mSv. Non-occupational and occupational exposures tend to be continuous or occasional low or very low dose exposures.

A conflation of many factors makes it hard to assess the low-dose effects generated by human activities. One is the existence of natural radiation at average doses of between 1 and

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[8] The genome is the set of genes carried by the chromosomes of a species.

10 mSv/year. No health effect has so far been attributed to radiation from high naturally-occurring radioactivity. Also, ionising radiation-induced cancers are not clinically distinguishable from other cancers.

Unscear and the ICRP have long contended that radiation protection risk management should be based on a linear no-threshold (LNT) dose-effect assumption that any exposure may generate a risk. Their model is based on the assumption that the risk remains present at low doses but decreases proportionally with the dose. The ICRP evaluates the long term low-dose effects - notably the cancer risk - by linearly extrapolating the high-dose effects. In this scenario, halving the dose halves the effects.

The concept and application of the LNT dose-effect relationship are the focus of ongoing debate. The European Committee on Radiation Risk (ECRR) endorses the principle of the LNT dose-effect relationship but challenges the ICRP's proportional risk reduction assumption as underestimating the low dose risk. The ECRR believes that the "ICRP model" fails to explain or predict the real increases in ill-health for many groups exposed to low dose ionising radiation (Busby 2004). The ECRR points out that the incidence of cancers observed in many studies is higher than it should have been according to the ICRP's theoretical risk calculations. This mismatch leads the ECRR to consider that low dose exposures elicit specific mechanisms of action that induce more, and more varied effects, than those observed at high doses. A cell damaged by a low dose may be more harmful to the human organism than a cell killed by a higher dose.

Changing dose limits over the 20th century

- 1928: approximately 1000 mSv/year
- 1934: approximately 200 mSv/year
- 1951: approximately 150 mSv/year (3 mSv per week)
- 1956: 50 mSv/year for potentially exposed workers, 5 mSv/year for the public, including other workers
- 1977: 50 mSv and 5 mSv/year confirmed
- 1990: 20 mSv/year averaged over 5 years for potentially exposed workers, 1 mSv/year for the public, including other workers

The ECRR concludes from this that the annual exposure limit to ionising radiation from human activities should be reduced to 0.1 mSv for the general population (from 1 mSv at present) and to 5 mSv for workers.

In contrast to the ECRR's thinking, French scientific opinion – especially that of the National Academy of Medicine and the Academy of Sciences – finds no basis for the low-dose cancer risk. Proponents of this view argue a hormesis effect, which they define as "the effect of a physical or chemical agent which elicits one effect at high doses and an opposite effect at low doses. This is the case for many agents which are toxic at high doses but have a beneficial protective effect at low doses". For these scientists, the ICRP's linear no threshold dose-effect relationship principle is not appropriate for estimating the cancer risk of low doses below 100 mSv, and even less so for very low doses below 10 mSv. They argue that applying it could even be harmful, especially in medicine where it would mean foregoing examinations "that could provide patients with useful information" (Tubiana 2005).

This discussion is anything but a purely academic spat. Exposure to ionising radiation is particularly critical in medicine. In the early 2000s, X-ray examinations exposed patients to radiation of the order of 0.1 to 5 mSv, but up to 20 mSv and beyond for some examinations. And the medical sector is that in which the proportion of workers potentially exposed is greatest and where dose exceedances are most common (see Chapter 5).

In 2006, the U.S. National Academy of Sciences took stock of the low-dose response and reviewed the available data (Biological Effects of Ionising Radiation - BEIR - 2006). It upheld the LNT model and judged that there was no reason to believe that low doses yielded a relatively lower or higher risk compared to high dose rates. The risk, albeit small at low doses, is dose-dependent. According to the model developed by the U.S. Academy of Sciences, exposure to a single 100 mSv dose would induce a lifetime cancer risk in one person in 100, and an exposure of 10 mSv in one person in 1000. This is unlikely to be the final word on this.

2.4.1. There is a confirmed risk at low doses

The International Agency for Research on Cancer (IARC) has done a mortality study of workers occupationally exposed to ionising radiation in 15 countries[9]. The study aimed to clarify the risks of protracted low-dose exposures to radiation. Two reports were published on the IARC study, one on cancers, the other on non-cancer diseases.

The study on cancers included data on 407,391 workers (Cardis 2005). The overall average cumulative recorded dose over a working life was 19 mSv/year: 90% of workers received cumulative doses of less than 50 mSv/year (the previous annual occupational limit), 5% cumulative doses of around 100 mSv/year, and 0.1% cumulative doses of greater than 500 mSv/year.

The analysis of results showed a significantly increased risk of all cancers, including leukaemia, relative to an unexposed population. The increased risk found is greater than that estimated for this dose level by extrapolation from the Life Span Study findings: six times more for solid cancers and nearly three times more for leukaemias (RERF).

The researchers calculated that 1-2% of deaths from cancer (including leukaemia) among workers in the study cohort could be attributed to exposure to ionising radiation. On the basis of their estimates, they suggested that a cumulative dose of 100 mSv/year would lead to a 9.7% increase in mortality from all cancers excluding leukaemia, and 19% in mortality from leukaemia (excluding chronic lymphocytic leukaemia).

These estimates are markedly higher than those of the Unscear 2006 report which estimated that acute exposure to 1000 mSv/year corresponded to an excess lifetime risk of dying from a solid cancer (excluding leukaemia) of between 4.3 and 7.2%, and from leukaemia of between 0.6 and 1%.

Yet however disturbing the findings of the IARC cancer study may be, they surely underestimate the reality. The study cohort for France, for example, did not include temporary agency workers or employees of outside contractors performing maintenance operations in the immediate vicinity of nuclear reactors (ETUI 2006).

The component of the study on non-cancer diseases included data on 275,312 workers with an average occupational lifetime exposure of 21 mSv/year (Cardis 2007). A very slight increased risk of deaths in the exposed population relative to an unexposed population was found. The highest increased risk was observed for respiratory and digestive system diseases. However, the researchers were unable to establish a risk-exposure scale.

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[9] The study collected information only on workers who wore a personal dosimeter and had worked for at least one year in nuclear power plants, reactor/weapons research, nuclear waste processing, production of nuclear fuel, isotopes or weapons in the following countries: Australia, Belgium, Canada, Korea, Finland, France, Hungary, Japan, Lithuania, Slovakia, Spain, Sweden, Switzerland, the United Kingdom and the United States.

2.4.2. The ICRP confirms the LNT dose-effect relationship assumption

In 2007, the ICRP approved its draft new recommendations on the protection of humans and the environment from ionising radiation, bringing to an end nine years' work (ICRP 2007). It maintained the LNT dose-effect relationship assumption, estimating that there was no threshold below which the risk would be zero since for random or stochastic effects, it is impossible to clearly distinguish between a safe dose and a dangerous dose. In the ICRP's view, the LNT dose-effect relationship assumption optimises radiation protection by minimising risk taking, maximising the margin of safety, and ensuring a better assessment of total individual exposure by taking all exposures into account regardless of dose.

The ICRP elaborated this assumption into a coherent philosophy: the use of nuclear power is allowed only if justified and authorised and if protection is optimised, which means at least keeping to the permissible dose limits. In so doing, the ICRP is arguably keeping faith with the ALARA ("as low as reasonably achievable") principle which it helped to develop in the 1970s.

The three key principles of radioprotection derived from the ALARA principle are retained:
— the principle of justification (of a practice): any decision that alters the radiation exposure situation should do more good than harm[10] ;
— the principle of optimisation of protection: the likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors;
— the principle of application of dose limits: the total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission.

The ICRP recognises three types of exposure situations (which replace the previous categorisation into practices and interventions). These three categories are intended to cover the entire range of exposure situations:
— planned exposure situations, which are situations involving the planned introduction and operation of sources (this type of exposure situation includes situations that were previously categorised as practices);
— emergency exposure situations, which are unexpected situations such as those that may occur during the operation of a planned situation, requiring urgent attention;
— existing exposure situations, which are exposure situations that already exist when a decision on control has to be taken, such as those caused by natural background radiation (ICRP Publication 103, 2007)[11].

The principles of justification and optimisation apply in all three exposure situations, whereas the principle of application of dose limits applies only for doses expected to be incurred with certainty as a result of planned exposure situations.

The ICRP distinguishes three categories of exposure: occupational exposures, medical exposures of patients and public exposures (i.e., exposures other than the first two including workers not occupationally exposed).

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[10] This means that an activity incurring exposure to ionising radiation should be introduced only if the benefits from it to the exposed individuals or to society outweigh the harm. Justification might, for example, result from comparing the benefits and disbenefits of an industrial or medical practice that uses radiation with another that does not.

[11] This is a new categorisation that might raise interpretation issues. For example, are exposures from the radioactive discharges of a previous industrial activity to be regarded as an existing exposure situation?

2.5. Criticism of the ICRP exposure limits

The ICRP's proposed values for optimising radiation protection apply to a nominal individual's exposure to a given source. They are called dose constraints for planned situations (predicted exposure situations such as an X-ray examination or work in a risk area, etc.), and reference levels for other situations (emergency and existing exposure situations). The dose constraint is a prospective restriction on the planned upper dose that should be received as part of the optimisation of protection from a given source. If the constraint dose is exceeded, the validity of the precautions taken must be queried. In emergency or existing exposure situations, the reference levels represent the dose above which it is judged to be inappropriate to plan to allow exposures to occur.

In publication 103, the ICRP redefined the bounds of individual doses as maximum acceptable doses in planned exposure situations. The recommended exposure limit for workers is 20 mSv/year over five years (i.e., 100 mSv over five years), not to exceed 50 mSv in a single year. For public exposure, the ICRP considered that the limit of 1 mSv should be retained.

It should be noted that these reference levels correspond to the evaluation of a whole body dose produced by calculating the doses received by various organs and applying a weighting factor (see box p. 21). For workers, the annual dose limit to hands, feet and skin is 500 mSv. It is 150 mSv for the lens of the eye. These limits do not apply to medical exposures of patients.

Dr Patrick Smeesters, member of the Group of Experts established according to Article 31 of the Euratom Treaty and chairman of the working party on Research Implications on Health Safety Standards (RIHSS) found the recent ICRP recommendations to be wanting on several points. He felt that the ICRP had not taken account of information gained during the last decade which should have resulted in more consideration being given to certain risks, including: radiation-induced cataracts and diseases of the circulatory system; in utero exposure; the dose-effective dose relationship; exposure to indoor radon; the greater susceptibility of children than adults, and women than men; uncertainty about long-term genetic risks (Smeesters 2009).

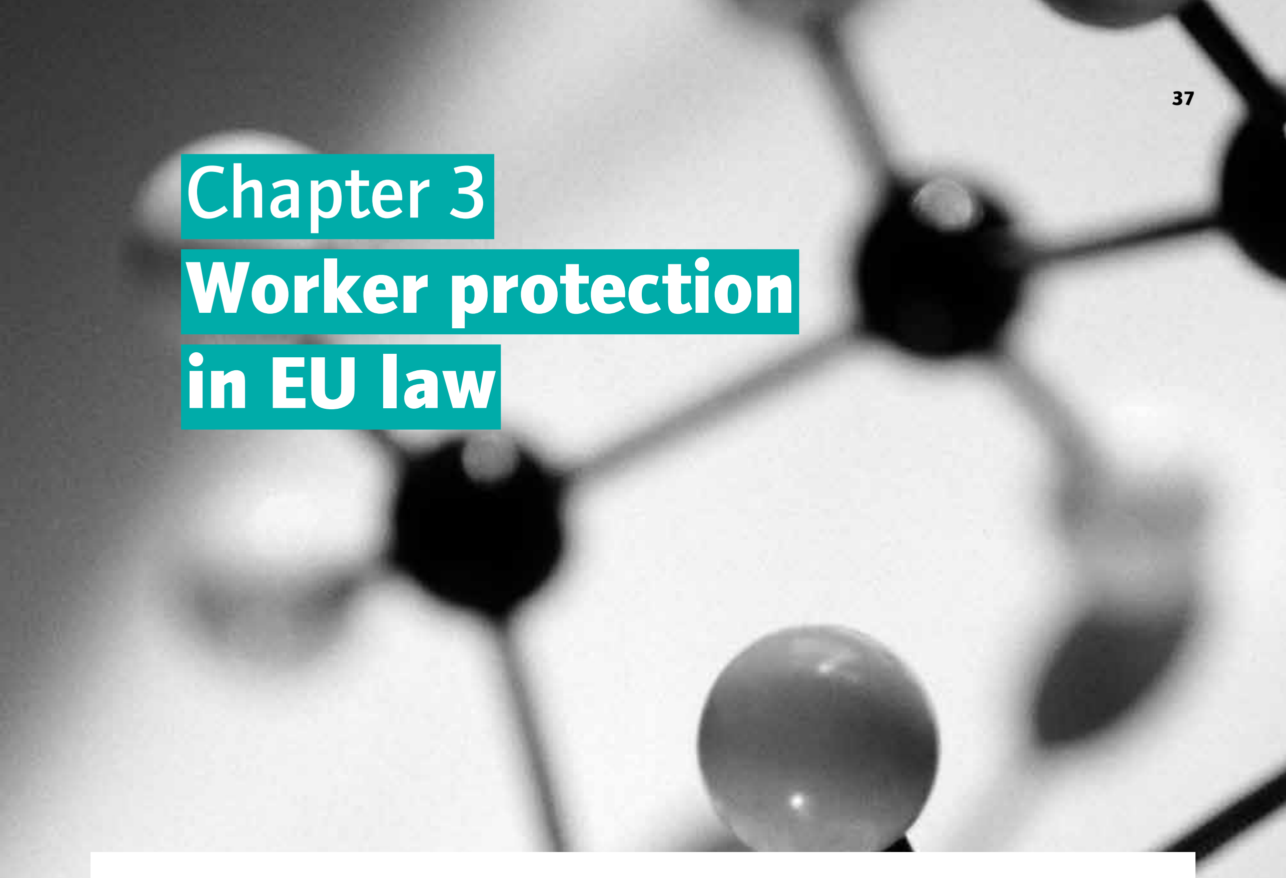
Then, too, there is an inconsistency in the ICRP recommendations: the standards for the protection of workers exposed to natural ionising radiation - such as phosphate industry workers - are less stringent than those applied to workers exposed to artificial ionising radiation. The radon reference level of 1000 Bq/m3 established by the ICRP for the workplace corresponds to an exposure of about 10 mSv/year, which is well above the limit of 6 mSv used to define a Category A worker who benefits from strengthened surveillance measures (Janssens 2010).

The ICRP's new recommendations are tilting towards an acknowledgement of the requirement for higher environmental protection by questioning the premise that "the standards of environmental control needed to protect the general public would ensure that other species are not placed at risk". Prior to 2000, the ICRP considered animals and plants as mere carriers of radioactive contamination towards humans and not as living species to be protected.

These recent developments notwithstanding, some experts find the ICRP's environmental approach to be still highly human-centred and not tied into a global ecosystem approach. They argue that accepting that environmental protection requires specific radiation protection standards effectively throws into question the methodology used by the ICRP to set all radiation protection standards. These experts contend that the ICRP has not yet taken up an approach based on the precautionary principle correlating with recent scientific data (Smeesters 2009).

Key points

Scientists now accept that exposure to ionising radiation induces cancer and non-cancer diseases and toxic effects to the embryo and foetus. It may also be the source of inherited genetic defects. The risk of these diseases occurring is dose-related and increases proportionally to the dose. International scientific organisations specialised in radiation protection accept that no threshold can be set below which exposure to ionising radiation would be entirely without risk to human health. The health consequences of exposure to so-called low doses (less than 100 mSv/year) remain the focus of acrimonious debate among experts. A study by the WHO agency, the International Agency for Research on Cancer, tends to confirm low-dose effects on the health of exposed workers, especially in terms of cancer risks.



Chapter 3

Worker protection in EU law

Many millions of workers across the European Union are exposed to high levels of radon, a naturally occurring radioactive gas. Hundreds of thousands, mainly in the medical sector, manufacturing and nuclear power industries, are exposed to artificial sources of ionising radiation. The EU is the world region where civil nuclear power is most widespread: in early 2011, 143 nuclear facilities were operating in 14 Member States.

The safety of nuclear power plants and the protection of the public and workers against the hazards of ionising radiation are provided for by a set of Directives based on a founding Treaty, the 1957 Euratom Treaty. European directives are drawn up in accordance with the conventions and agreements adopted within the International Atomic Energy Agency (IAEA) and based on recommendations and opinions issued by the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear) and the World Health Organisation (WHO).

Over the years, the Directives have piled up and the European legal framework applicable to radiation protection has grown highly complex. A proposal for a directive consolidating the existing laws and taking into account the ICRP's 2007 recommendations was published by the European Commission on 29 September 2011.

3.1. The Euratom Treaty and the basic radiation protection standards

After the European Coal and Steel Community (ECSC) was established in July 1952, the six ECSC member states (Belgium, France, Luxembourg, Italy, the Netherlands and the Federal Republic of Germany) resolved to set about creating a European common market. In March 1957, they signed two treaties in Rome, known as the Rome Treaties. One established the European Economic Community (EEC), now the European Union, while the other created a European Atomic Energy Community, known as Euratom. Both treaties came into force on 1 January 1958.

The essential aim of the Euratom Treaty was "to create the conditions necessary for the development of a powerful nuclear industry which will provide extensive energy resources, lead to the modernisation of technical processes and contribute, through its many other applications, to the prosperity of their peoples". The signatories nevertheless proclaimed themselves "anxious to create the conditions of safety necessary to eliminate hazards to the life and health of the public". To achieve this task, the Commission is mandated to "establish uniform safety standards to protect the health of workers and of the general public and ensure that they are applied". Two of the articles in Chapter 3 of the Treaty on health protection are particularly important.

Article 30 provides that the European Community shall lay down "basic standards for the protection of the health of workers and the general public against the hazards from ionising radiations", defining "basic standards" as: "maximum permissible doses compatible with adequate safety; maximum permissible levels of exposure and contamination; the fundamental principles governing the health surveillance of workers".

Article 31 lays down that the basic standards shall be worked out by the Commission after it has obtained the opinion of a group of persons appointed by the Scientific and Technical Committee set up by the European Commission (Article 134 of the Euratom Treaty) from among scientific experts in the Member States, commonly known as the "Article 31 Group of Experts". The Article 31 experts are independent. They represent neither the Member States – even though appointed and replaced by them - nor specific organisations. Their priority must be the protection of public health through the development of the highest possible standards of radiation protection. The experts may express opinions on political, economic and financial aspects of radiation protection, but the guiding principle must always be health and safety. Guidance is given to their work by a Code of Ethics (Euratom 2007). Generally-speaking, new laws and regulations are drafted jointly by the Commission staff and the experts.

The basic standards as defined are then submitted by the Commission for the opinion of the Economic and Social Committee (EESC). The members of the EESC are drawn from Europe's socio-occupational interest groups. They are organised into three groups: the Employers Group, the Employees Group, and the Various Interests Group representing various social, occupational, economic and cultural organisations. The Employees Group comprises representatives of over 80 trade unions, most of which are members of the European Trade Union Confederation (ETUC). The EESC is therefore the only forum for workers to have their say on the basic standards of radiation protection.

The Euratom Treaty has remained more or less unchanged since 1957 and is still in force. A body of directives, regulations, decisions and recommendations has been developed and adopted under it. It is a legal instrument for Member States of the European Union, who have an obligation to carry the directives over into national law. The directives set a legal duty, not just an objective. This means that national authorities are free to determine what they consider the most appropriate legal form and means to be used to achieve the Directive's objectives. A Member State whose legislation fails to comply with the Directive's objectives may be taken to the Court of Justice of the European Union by the European Commission for "incorrect or inadequate transposition".

3.2. The international context to the development of European standards

The directives laid down under the Euratom Treaty are set within a wider international context. In Chapter 2, we considered the roles of the UN Scientific Committee on the Effects of Atomic Radiation (Unscear) and the International Commission on Radiological Protection (ICRP) which create the scientific framework of reference for radiation protection. Unscear puts forward estimates of the radiation-induced risk (dose-dependent probability of death, relationship of average radon contamination and annual effective dose, etc.) which are generally[12] taken into account by the ICRP to derive the individual dose limits for workers and the general public.

It then falls to the international and national institutions to give effect to the scientific advances through standards and recommendations and, in the case of the EU, directives. EU bodies work regularly together with various international organisations, such as the International Labour Organisation (ILO), the World Health Organisation (WHO), and the International Nuclear Energy Agency (IAEA), on drawing up - often jointly - texts to put to their Member States and for consultation to the International Radiation Protection Association (IRPA) which links together the professional radiation protection associations.

The Treaty of 26 October 1956 on the Statute of the IAEA tasks the agency in particular with establishing or adopting standards of safety for protecting life and property from the dangers of ionising radiation. The IAEA basic standards reflect an international consensus and are published in a document entitled *International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources.* They set out the basic requirements for nuclear protection and safety. They are not really binding on States and are not intended to replace the provisions of national laws, regulations or standards. They are intended to provide practical guidance to authorities, employers and workers as well as specialised radiation protection services. The basic standards are not intended to be applied as such in all countries and all regions of the world. Being very general, they often need to be adapted to specific uses and risks (Gonzalvez 1994).

The first IAEA standards date from 1962 and have been repeatedly revised. The version of 12 September 1994 was adopted following the publication of new ICRP recommendations in 1990 after the review of the findings of the studies on the atomic bomb survivors and the accidents at Three Mile Island in 1979 and Chernobyl in 1986.

Following the issuing of ICRP Publication 103 in 2007, a further revision of the standards was undertaken by IAEA officials. As at the end of 2011, this revision was pending approval by the international institutions that are cosponsors of the review.

While the EU works closely with international institutions, the Euratom Directive on basic standards has more ambitious aims. The Euratom basic standards are to be uniform throughout the EU and binding on Member States.

The first European Directive on Basic Safety Standards for Radiation Protection dates from 1959. It has been regularly updated, and was completely recast in 1980[13] to incorporate the new radiation protection standards proposed by the ICRP in 1977. It was to be expanded in 1984 and 1990. However, work quickly recommenced to culminate in the publication of a new directive on 13 May 1996 which was still in force in 2012[14].

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[12] The Unscear and ICRP dose assessments for the effective dose received from radon inhalation differed, but have been closer since the new ICRP estimate (November 2009).

[13] Council Directive 80/836/Euratom of 15 July 1980 amending the Directives laying down the basic safety standards for the health protection of the general public and workers against the dangers of ionising radiation.

[14] Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation.

3.3. The EU directives in force in 2011

At the start of 2012, the body of EU radiation protection law comprised no fewer than a dozen directives. The keystone is Directive 96/29 Euratom of 13 May 1996 which sets the basic standards for protecting the general public and workers against the dangers of ionising radiation. Three other directives are closely linked to it: the Protection of Outside Workers (Directive 90/641/Euratom), the Public Information (Directive 89/618/Euratom) and the Control of High-Activity Sealed Radioactive Sources and Orphan Sources (Directive 2003/122/Euratom).

The health protection of individuals against the dangers of ionising radiation in relation to medical exposure has been dealt with by a specific directive since 1984 (Directive 97/43/Euratom).

Other EU rules and regulations are general policy documents or address specific aspects like exposure to radon inside buildings (non-binding recommendation 90/143/ Euratom), radioactive waste (Directive 2006/117/Euratom), the nuclear safety of nuclear installations (Directive 2009/71/Euratom), and so on.

3.3.1. The 1996 Basic Standards Directive

Broadly-speaking, the 1996 Basic Standards Directive, still in force in late 2012, is based on the principles of justification, optimisation and dose limitation defined by the ICRP (see 1.4.3.). Title VI of the Directive deals more specifically with protection of workers.

Exposure limits

The effective dose for exposed workers is limited to 100 mSv over five consecutive years (i.e. 20 mSv/year on average) subject to a maximum effective dose of 50 mSv in any single year. The limit on equivalent dose for the lens of the eye is 150 mSv/year. It is 500 mSv/year for the skin regardless of the area exposed - hands, forearms, feet or ankles. The dose limits for apprentices and students aged 18 or over, who in the course of their studies are obliged to use sources, are the same as for workers.

European legislation provides additional protection for certain categories of workers.

For apprentices and students aged 16 to 18 years, the dose limits are lower: the effective dose limit is 6 mSv/year; 50 mSv/year to the lens; 150 mSv for other parts of the body.

European legislation also protects pregnant workers. As soon as a pregnant woman informs the employer of her condition, the undertaking must ensure the unborn child of protection comparable to that provided for members of the public, i.e., not exceeding 1 mSv for the remainder of the pregnancy. Breastfeeding mothers cannot be assigned to work involving a risk of bodily radioactive contamination entailing intake of radionuclides.

For members of the public, the effective dose limit is 1 mSv/year; the equivalent dose limit for the lens is 15 mSv/year; and for the skin, 50 mSv/year.

Surveillance and monitoring of workers

The 1996 directive distinguishes two categories of exposed workers: Category A comprises those workers who are liable to receive an effective dose greater than 6 mSv/year or an equivalent dose greater than 3/10ths of the dose limits for the lens of the eye, skin and extremities; Category B includes exposed workers who do not fall within Category A.

Systematic individual monitoring is prescribed for category A exposed workers. For external exposure, it is based on measurements established by an approved dosimetric service. Where category A workers are liable to receive internal contamination, an adequate monitoring system should be set up. Monitoring of exposed category B workers must be at least sufficient to demonstrate that they are correctly classified in that category, based on the radiological surveillance of the workplace in particular.

Medical surveillance is part of health and safety at work. It must include a thorough medical examination of fitness prior to employment for category A workers, as well as periodic health examinations at least once a year. A medical record must be opened for each category of A workers and kept up to date so long as he remains a worker in that category. It must then be retained at least until the worker attains the age of 75, and in any case for not less than 30 years. The record must include the monitored doses record.

In workplaces where there is a possibility of exposure to ionising radiation which is liable to be in excess of the allowable dose limits for members of the public, areas must be classified and demarcated according to the level of risk.

The 1996 Directive requires Member States to carry out surveillance of workers and members of the public with respect to potential increases in exposure due to natural sources of ionising radiation.

Delays and different approaches in implementing the 1996 Directive

Drafting the 1996 Directive proved a long-winded affair. A first draft submitted for a preliminary opinion of the European Economic and Social Committee (EESC) in 1993 was criticised by the European Trade Union Confederation representatives for proposing standards which even though lower were still too high[15].

The final opinion adopted by the EESC was concerned by the protection of workers' health but also voiced serious economic concerns. The EESC's discussions were clearly heated as illustrated by its opinion on installations that fail to reach the new standards specifying: "there is a need for remedies if the installation in question is not to be shut down. The answer may be sought in capital investment to provide better protection. If so, the risk of cancer could be reduced. On the other hand, it may involve employing more people for shorter shifts. In this event, the number of cancers might not be reduced since the collective dose would stay the same. However, the individual risk will be reduced if the individual dose is reduced" (OJEC 1993).

Likewise, the Committee approved the inclusion of workplace exposure to natural radiation sources in the draft, but called for implementation of the new standards to be deferred, particularly in existing uranium mines.

In 1996, a new text was finally adopted by the Council of the European Union with the assent of the European Parliament but without seeking a second EESC opinion.

The Directive was to be implemented by 13 May 2000. Despite having a four-year breathing space to implement it, a number of Member States still failed to meet the deadline, although to be fair the implementation process was to some extent held up and complicated by other directives – like the Exposure to Ionising Radiation for Medical Purposes (Directive 97/43/Euratom) and the Control of High-Activity Sealed Radioactive Sources

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[15] The exposure limit for workers should have been reduced from 50mSv/year to 16 rather than 20 mSv/year, because the new dose-effect relationship derived from the latest Hiroshima and Nagasaki data was 3.2 times more harmful to the 18-65 age group and 4 times for the entire population (radiosensitivity of children).

(Directive 2003/122/Euratom) – which had to be applied across different spheres of States' national laws (employment, health, transport, etc.).

Broadly-speaking, EU states have taken two distinct approaches to transposing the Directive. One - chosen by Germany and Belgium - is to pass a general "nuclear act" containing all the provisions on employment, medicine, transport, environment, radioactive waste management, etc. The other tack – taken by France - is to implement the different EU directives by inserting their provisions in each of the existing codes of laws in the national legal system (labour, health, environment and other codes). Transposition was a particularly complex matter in France, entailing as it did a far-reaching shake-up in the legal system.

But legal complexity is only part of the reason for the delays in France's transposition process. The reduction of the annual dose limits for the public (from 5 to 1 mSv/year) and workers (from 50 to 20 mSv/year) did not get a ready seal of approval, especially from employers.

On a positive note, however, French lawmakers did introduce a mechanism linking the dose limit to the duration of the employment contract. This entirely new departure in employment law aims to prevent a worker on fixed-term or temporary employment (agency worker) contracts from receiving a dose greater than the annual limit during successive contracts. So, for a three-month contract, the maximum permissible dose is equal to one quarter of the annual limit.

The form chosen to carry the Euratom directives into law has clear consequences for public access to information on radiation protection. It will be easier for a worker to enforce the statutory protection measures in his workplace if all the nuclear regulation provisions are contained in a single enactment rather than having to scour many different legal codes for the protective provisions as in France.

3.3.2. The Outside Workers Directive

The development of nuclear power has from the start gone in hand with a shifting of risk from the big nuclear operators to a host of small and medium-sized firms (SMEs) (Zerbib 1979). There may be cases in which technical specialisation, the management and control of a technology, or requirements for large-scale one-off actions (scheduled reactor shutdowns) gave good grounds for that. But in most cases it was simply about offloading the risk of exposure to ionising radiation from national companies to SMEs, but also across borders through the use of specialised teams (e.g., for radioactive decontamination). These transfers increased significantly from the 1970s.

The collective dose for outside contractor firms for the 13 reactors operating in the Europe of Six in 1975 represented at that time 56% of the total dose. Where fuel reprocessing is concerned, the outside contractors accounted for 8.5% of Eurochemic's[16] staff receiving 8.2% of the aggregate collective dose between 1970 and 1977. Over the same eight year period outside contractors made up 40% of exposed workers (out of an average total 1338 employees) at the French reprocessing plant at La Hague (Manche), and the average collective dose received by them was about 42% of the total dose. In France, exposed outside contractor firms in the nuclear power industry accounted for 22,721 workers (36% of the total) in 2009, receiving a collective dose of 40% (IRSN 2010).

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[16] Eurochemic was the first joint venture of the European Nuclear Energy Agency set up in December 1957 by the governments of 13 European countries to develop international cooperation in recycling spent fuel from power plants to extract the residual uranium and plutonium.

A directive was introduced in 1990 aimed at closing the protection gap between outside and permanent workers[17]. It covered areas as important as the quality of the radiological monitoring system, the issuing of an individual radiological monitoring document, recording of doses received, assessment of the effective dose, medical surveillance, specific training, etc. to ensure outside workers of the same level of protection as the nuclear operator's workers.

The directive also refers to establishing a uniform Community-wide system of ionising radiation monitoring. Pending that, the Council called for Member States to implement either a centralised national network, or the issuing of an individual document - the dose passbook.

The Directive's provisions were to be implemented by 31 December 1993 at the latest, but the evaluation of its implementation found that several countries, who were Member States at the time the Directive was adopted, failed to transpose it until after the year 2000. Furthermore, some countries wrote it formally into law, but have still not yet taken all the steps to implement it fully.

The evaluation report on implementation of the directive issued in late 2010 based on data provided by 24 EU Member and non-Member States notes that 19 states reported having an individual ionising radiation exposure monitoring document for outside workers (European Commission 2010). Six of the 19 operators (from nine countries) who took part in the evaluation, and two out of five contractors, judged that outside workers benefited from the same social security coverage as permanent employees. The estimated number of outside workers affected is in the region of 100 000[18].

In June 2010, the association of the Heads of European Radiological Protection Competent Authorities (HERCA) approved the contents of a harmonised dose passbook and forwarded it to the European Commission for inclusion in the basic standards being revised. It will not be easy to apply in practice, however, as Member States are not in favour of bringing a European authority into existence with powers to run a network for the exchange and consolidation of data for each worker. This is compounded by the lack of a legal framework laying down data protection rules for workers.

3.4. Towards a new directive specifying basic standards

The publication of the new ICRP recommendations on radiation protection in 2007 (see Chapter 2) prompted the European and international official bodies to embark on a wide-ranging review of concepts and standards which would take into account the new basic standards developed in ICRP 103, especially the new estimate of the effective dose from the inhalation of radon-222[19]. It was also to reflect the ICRP's new distinction between protection of humans and the environment. Previously, the ICRP had considered that protection of humans would in turn ensure the protection of other living species in the environment. The review of EU legislation engaged by the Commission was also prompted

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[17] Council Directive 90/641/Euratom of 4 December 1990 on the operational protection of outside workers exposed to the risk of ionising radiation during their activities in controlled areas.

[18] Noticing that, in the medical sector in particular, such workers are often not classified as such, that the number of self-employed workers has been rising in some countries in recent years, and they are not covered by national legislation in six countries.

[19] The ICRP "Statement on Radon" (November 2009) estimates that an average concentration of 300Bq/m3 of radon in a unit volume of air incurs an effective dose of 10 mSv/year in one year. With this, the ICRP retains a relationship twice as harmful as the previous estimate that an average 600Bq/m3 was required to induce a dose of 10 mSv/year.

by the conclusion that the EU's legal framework for radiation protection had become too complex.

On 29 September 2011 the Commission presented its proposal for a new Council Directive to the European Economic and Social Committee. The new text is an amalgamation of five consolidated and revised directives: the Basic Standards Directive, the Medical Exposure Directive, the Outside Workers Directive, the Public Information Directive, and the High Activity Sealed Sources Directive.

3.4.1. The scope of the proposed new directive

The proposal for a directive applies to any planned, existing or emergency exposure situation which involves a risk resulting from exposure to ionising radiation which cannot be disregarded from the angle of protecting the health of workers, members of the public, or patients. Its scope includes natural radiation sources that lead to a significant increase in the exposure of workers or members of the public: exposure of crews (aircraft and spacecraft) to cosmic radiation; domestic exposure to radon gas in indoor air and workplaces; external exposure to gamma radiation from building materials. The inclusion of building materials in the Directive should widen the scope of radiation protection to many industrial practices not previously covered. Annex V of the proposal for a Directive contains a list of 16 industrial practices that use naturally occurring radioactive materials, including phosphate fertiliser production, cement production, mining, tin/lead/copper/smelting, and coal-fired power plants.

Approvals of authorised practices resulting in exposure to ionising radiation must be listed and regularly reviewed. New types of practices – such as the deliberate exposure of persons for non-medical imaging purposes: radiological assessment for health insurance purposes, immigration or the detection of concealed objects within the body, etc. - must be justified before being approved. Environmental protection now goes beyond the human exposure aspect.

3.4.2. The protection of workers in the proposed new directive

The Directive takes a graded approach to radiation safety controls commensurate with the hazard. Radiation protection arrangements must be made where there exists a possibility of exposure to ionising radiation in excess of an effective dose of 1 mSv/year.

Where the annual effective dose received is less than 6 mSv (category B workers), undertakings must at least keep exposures under review. Monitoring for category B workers must be ensured by individual measurements if needed. For flight crew, undertakings must assess the exposure of the crews concerned and take that assessment into account in the organisation of flight plans.

The rules for monitoring workers whose annual effective dose exceeds 6 mSv (category A workers), i.e., systematic radiological control based on individual measurements and medical surveillance, also apply to exposure to naturally occurring radioactive materials (radon, some phosphates, etc.) but in a separate category of existing exposures with more flexible standards.

For existing exposure situations (see 2.5.), reference levels are provided for radon levels inside buildings and for external exposure to ionising radiation from building materials. The workplace reference levels for radon must not exceed an annual average of 1 000 Bq/m^3.

For occupational exposures, the effective dose limit of 20 mSv is applied to each year of exposure, not averaged over five years as before. However, a higher effective dose of up to 50 mSv/year in a single year may be authorised by Member States provided that the average dose received over a period of five consecutive years does not exceed 20 mSv/year. The equivalent dose limit for the lens of the eye is reduced to 20 mSv/year. The equivalent dose to the skin and extremities remains unchanged at 500 mSv/year.

The new directive includes the specific requirements of the Outside Workers Directive. It introduces a clearer division of responsibilities between the employer and the undertaking where the work is performed. The data system for individual radiological monitoring of exposed workers and the minimum set of data to be communicated for outside workers have been updated in the light of recommendations by HERCA.

The new directive pays special attention to information and training of workers, particularly as regards potential exposure to orphan sources, especially in large scrap yards and big metal recycling facilities. It lays emphasis on the particular qualifications required by those in responsibility and by experts in medical physics and radiation protection.

The proposal for a directive makes no reference to the collective dose concept in connection with the optimisation of radiation protection, but the Article 31 Group of Experts has pressed for this operational concept to be retained. The Directive has chosen instead to focus on applying the ALARA principle to all exposure situations and categories through dose constraints by source, developed especially for the medical sector with the “derived reference level” (DRL) concept.

3.4.3. The limitations of the proposed directive

The Article 31 Group of Experts issued an opinion on a first draft text in February 2010[20]. Most of their comments were addressed in the draft directive presented for the EESC’s opinion on 29 September 2011, but some question marks still remain.

The proposal includes neither the transport of radioactive materials, nor nuclear safety, nor the exchange of information in the event of an accident, which will still be regulated separately.

The directive takes a traditional approach. Unlike the approach of the IAEA basic international standards, exposures remain classified according to the exposed persons - workers, patients, members of the public. The European Commission chooses to define sub-categories classified by type of exposure: planned, emergency, natural. Occupational exposures could therefore fall within three categories with different standards by type of exposure.

The Directive does not provide for the introduction of a European radiological passport which offers the only guarantee that all exposures incurred by workers, sometimes in different countries, will be recorded. Discussions are under way to assess the feasibility of a system for electronic information exchange between countries. More consideration should be given to emergency workers in light of the Fukushima accident.

Reducing the dose limit for the lens of the eye from 150 mSv to 20 mSv should benefit some occupational groups like cardiologists and interventional radiologists by averting the development of radiation-induced cataracts. However, the public limit of 15 mSv remains

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[20] Opinion of the Group of Experts established under Article 31 of the Euratom Treaty on the Revised basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation, 24 February 2010.

unchanged. This sends a bad message to medical practitioners who may be tempted not to take more precautions for the risk to the lens of the eye of patients exposed to intermediate doses, even for repeated radiodiagnostic examinations.

The safety of the dose limits applied to radon depends very much on the conversion factor chosen. ICRP Publication 103 estimated that day-round radon exposure at an average level of 300 Bq/m^3 induces an effective dose of about 10 mSv/year. Is this the conversion factor to be used? Presumably so, as it has also been taken up by the WHO and Unscear. Given a worker exposure of 8 hours/day, therefore, the Directive's annual radon exposure limit of 1 000 Bq/m^3 would correspond to an effective dose of 10 mSv/year. This is well above the 6 mSv threshold that defines category A workers and seems very high for a planned occupational exposure. This illustrates the inherent inconsistency in factoring exposure limits in for workers exposed to natural sources of ionising radiation. The same precept of categorisation and different standards is applied to survival in contaminated areas (existing situations).

Where building materials are concerned, the proposal for a directive takes into account only radioactivity levels that would result in an excess exposure to 1 mSv/year on top of natural exposure. The Article 31 Experts' opinion argued that generally where industrial residues were recycled into building materials[21], exposure should not exceed 0.3 mSv/year. This dose limit could well be exceeded in highly insulated houses, especially those built to "passive house" standards. In such cases, preventive measures should be put in place to limit indoor exposure to radon gas, whose health impact has been pointed up by the WHO and the ICRP (see box p. 23). This vexed issue of protecting the public against significant doses emitted by recycled building materials, along with many others, will be left to Member States.

The main practical aim of the proposal for a directive could be said to be cutting the costs of nuclear waste and waste from naturally radioactive materials, while limiting particular risks.

Materials that contain waste and residue from operations must not exceed the limit of 1 mSv. But for waste and residues as such, there is no standard. What to do about existing contaminated areas is left entirely to the Member States. One case in point is phosphate waste-containing landfills whose activity could lead to the limit for radon exposure being exceeded for houses built on such land even in the distant future. The same problem arises in areas of long-lasting residual contamination where habitation and the resumption of economic activities are allowed, or in the vicinity of uranium mines where barren rocks[22] may be used for road-making or concrete production.

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[21] Some branches of the building materials industry use raw materials that are comparatively rich in natural radioactive substances like uranium and thorium. These materials with enhanced natural radioactivity are often referred to by the acronym "NORM" (Naturally Occurring Radioactive Materials).

[22] Extracted rocks that contain very little uranium and are therefore not processed.

Key points

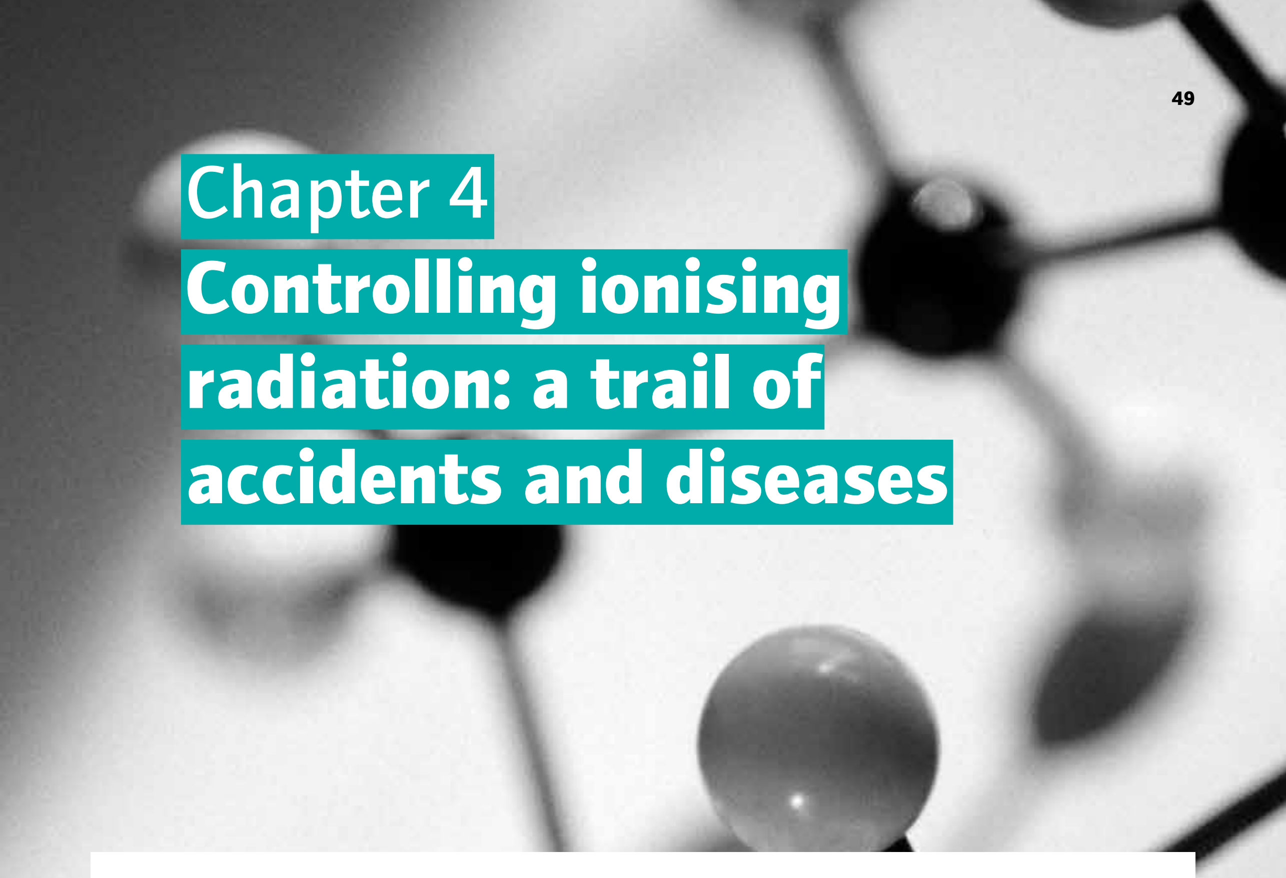
The first European directives on protecting workers and the public against ionising radiation came onto the books in 1959, since when they have been revised at approximately 15-year intervals (1980, 1996 and probably 2012).

The gap separating each of these stages has meant that new national legislation comes onto the books only every 15 years or so due to the build-up of deadlines for each stage, especially the fact that states have four years – cut down to two for the last draft directive - to carry the European directive over into law, but often fail to do so in time.

Depending on their particular legal culture and the specificities of their national law, States will either produce a comprehensive legal system that takes in all aspects of the problem (worker protection, transport, medical uses, waste management, radioactive discharge authorisations, etc.) or incorporate the directive's provisions in different legal codes.

The next European directive will be published in 2013, meaning that EU Member States will be required to make changes in the regulation of ionising radiation around 2015-2017.

The big change in the new directive will be that more sectors (in particular those affected by natural radioactivity, like air navigation) will be brought within the scope so that more workers will have their exposure monitored. The principle of justification, including the assumption of responsibility for occupational exposure, is expanded and tightened-up, especially for the medical sector. The principle of optimisation is developed with a special focus on the principle of risk awareness which is crucial in justifying work at risk. The proposal for a Directive also highlights information (including for patients), training (in-service) and the support and monitoring role of competent experts.



Chapter 4

Controlling ionising radiation: a trail of accidents and diseases

The dawn of the 21st century witnessed a rise in the use of ionising radiation. There is renewed interest in nuclear power as global warming becomes a reality and many States seek to reduce their dependence on oil. There is steadily increasing medical use of ionising radiation for radiotherapy and ever-more sophisticated diagnostic radiology equipment. The industrial use of ionising radiation sources for a range of applications is steadily rising.

Ionising radiation has been and continues to be responsible for serious incidents and accidents – the Fukushima accident in March 2011 was a tragic reminder. It also represents an exposure risk for millions of workers worldwide and a cause of occupational diseases.

4.1. The warning at Three Mile Island and the shock of Chernobyl

The civil nuclear industry has not been without incident since its inception , including a serious accident that occurred on 28 March 1979 at the Three Mile Island site in the State of Pennsylvania (USA). Following a chain of poorly understood events and errors, the core of one of the reactors suffered a partial meltdown. The containment building survived intact, such that only a small amount of radioactive noble gases was released into the environment, and no workers or members of the local population were harmed. The contamination caused by the release was very limited, but a full-blown disaster was only just averted. The accident was deeply consequential and nuclear power plant operators were obliged to change the design of similar plants and review safety procedures (USNRC 2009). The Chernobyl accident was something else entirely.

At 1.24 am on 26 April 1986, Reactor 4 at the Chernobyl nuclear power plant in the Ukraine, near the border with Belarus, exploded and caught fire during a test. In the report submitted to the IAEA, the Soviet authorities played up breaches of safety rules and procedures. While there was certainly unacceptable negligence and very serious errors of judgement, there is also no doubt that the scale of the disaster resulted from the technical characteristics of the type of reactor used at Chernobyl. It was a type designed for electricity generation but which could also have been used to produce weapons-grade plutonium, and lacked a sufficiently rapid emergency shutdown system or a large-scale airtight reactor containment building.

The destruction of the reactor and the resulting fire that raged for ten days released large amounts of radioactive substances - principally iodine-131, caesium-137 and caesium-134 - into the atmosphere. Iodine-131 has a relatively short half-life (eight days), but can be very quickly absorbed by breathing contaminated air or consuming contaminated milk and vegetables. Caesium-137 has a half-life of around 30 years, making it a long-term risk.

The highest doses were received by the 600 people on the site in the early hours of 26 April, mainly plant operating personnel, fire-fighters and rescue workers. Of these, 134 soon displayed the signs of acute radiation syndrome, 28 died within three months of the accident and a further 19 between 1987 and 2004. The main health problems experienced by acute radiation syndrome survivors are skin injuries and cataracts. The so-called “liquidators” (or “clean-up” workers) form a group of between 600 000 people according to Unscear, and 830 000 according to other sources (Yablokov 2009). The liquidators worked on and in the vicinity of the site removing radioactive waste, constructing the concrete sarcophagus, and decontaminating and restoring the site within a 30 km radius. They received doses estimated at between 0.01 Gy and 1 Gy; the average effective dose received was probably around 120 mSv. The first responders received higher doses than the relay teams – in some instances, over 250 mSv (Cardis and Hatch 2011). The liquidators run the risk of potentially developing radiation-related diseases in the long term, and in fact an increased incidence of leukaemias, malignant blood disorders and cataracts has been observed among them (Cardis and Hatch 2011).

The Soviet military authorities began evacuating the nearby city of Prypiat the day after the disaster and the area within a 30 km radius of the accident site from 2 May onwards. Unscear reports that 116 000 people were evacuated in 1986; other sources put the figure at 135 000. They may have received an average dose of 30 mSv.

After 1986, about a further 220 000 people were reported to have been evacuated from areas contaminated with radioactive material in present-day Belarus, Ukraine and the Russian Federation. All told, almost 350 000 people were forced out of their homes (Yablokov 2009). Some evacuation operations took place amidst chaos and with delays. Those who remained living in the contaminated areas for the next twenty years may have received a further average dose of 20 mSv (Unscear 2008).

In 1989, Belarusian specialists began reporting an increased incidence of thyroid cancer attributable to the accident. Before the Chernobyl disaster, there were only two to three reported cases a year in Belarus, compared to 29 in 1990, 55 in 1991 and an annual average of 70 during the period 1991-1998. In the countries and regions near Chernobyl, approximately 1 800 cases of thyroid cancer were reported in children in 1998 (Unscear 2008), and the disease was found to have developed with unusual speed and severity. In 2011, 25 years after the disaster, the risk of developing thyroid cancer was still very high among exposed young people (Cardis and Hatch 2011).

The 2008 Unscear report published in early 2011 on the health effects of the Chernobyl disaster for the period 1991-2005 reports 6 848 cases of thyroid cancer diagnosed in children and adolescents under the age of 18 in 1986 and living in the area contaminated by the accident. The incidence of thyroid cancer also continues to rise in this group, causing

15 deaths in 2005. Almost all of these cancers can be attributed to the consumption of milk contaminated by radioactive iodine, but some observers believe that direct inhalation by children living in the vicinity of the reactor was also an important factor. Children went to school on the morning of 26 April and many were playing outside. The markets were also open. The decision to issue potassium iodide tablets to prevent radioactive iodine accumulating in the thyroid gland had not yet been taken, and people living near the power plant would not be evacuated until the afternoon of 27 April (Molitor 2011).

Heart problems also appeared, especially in children, who suffered from conditions that usually affect elderly adults. A Franco-Russian programme to evaluate the diseases caused by caesium, called EPICE, is currently under way (Unscear 2008) and may reveal new diseases in the population.

The official tally of victims of the Chernobyl disaster is hotly contested by various members of the scientific community, including Russian experts who have organised a follow-up of the consequences of the accident. Taking the increase in mortality rates observed in the most affected areas as their starting point, these scientists arrive at the figure of 237 500 Chernobyl-related deaths in Belarus, Ukraine and Russia from cancer and non-cancer diseases during the period 1986-2004 (Yablokov 2009).

Extrapolating these results to areas contaminated outside the former Soviet Union, factoring in the different levels of radioactive fallout and adding the number of “Soviet” victims, they estimate that during the same period a total of 985 000 deaths may be attributed to the Chernobyl disaster due to radionuclide dispersal in all countries across the northern hemisphere[23].

The outlook is bleak, as the radioactive materials released into the environment have a long life and will do ongoing harm through absorption by and build-up in living organisms. Russian experts have laid great stress on the increased vulnerability of the exposed population, its greater susceptibility to disease and very much worse state of health, particularly among children.

Officials of the International Agency for Research on Cancer’s (IARC) Radiation Group offered up a less gloomy forecast in 2006.

A range of models, including the studies of the atomic bomb survivors, indicated that about 16 000 cases of thyroid cancer and 25,000 cases of other cancers could be expected in Europe due to radiation from Chernobyl in the 50 years following the disaster and that about 16 000 deaths from these cancers may occur.

Two-thirds of the thyroid cancer cases and half of the other cancers would be expected to occur in Belarus, Ukraine and the most contaminated territories of the Russian Federation (IARC 2006).

4.2. The nuclear accident count: a guessing game

Many radiological and nuclear accidents go unreported either because they are covered by official secrets legislation or are unidentified because they occur in poor countries. Information sharing to learn the lessons of these accidents came about very late in the day and remains woefully inadequate.

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[23] In fact, the doses received from the radionuclides dispersed have not been measured, but reconstructed using atmospheric pollution dispersion models and formulating various simplified hypotheses. The doses delivered by fallout of caesium-134 and caesium-137 (still radioactive today), strontium-90, alpha emitters and radioactive iodine are cases in point.

The 2008 report by the United Nations Scientific Committee on the Effects of Atomic Radiation (Unscear) summarises the known accidents and estimates the number of resulting casualties since the end of the Second World War divided into the main sectors (Unscear 2008).

Unscear reviews 38 serious radiation accidents that occurred in nuclear facilities between 1945 and 2007, 26 of them in facilities relating to nuclear weapons programmes. Of these 38 accidents, 34 resulted in employee deaths or injury and 7 caused off-site releases of radioactive materials.

Excluding the 1986 accident at Chernobyl, 29 deaths and 68 cases of radiation-related injuries requiring medical treatment are known to have occurred as a result of accidents associated with the nuclear fuel cycle.

In industry, where radioactive sources are in widespread use, Unscear identifies 85 accidents that involved high levels of radiation exposure. Twenty-five deaths and 164 contaminated workers were reported in connection with these accidents.

Accidents in radiation medicine generally involve errors in the delivery of radiotherapy (doses or equipment settings) that are often detected only after many patients have been overexposed. Unscear identified only 29 reported such accidents – involving 45 deaths and 613 injuries. According to the UN expert committee, many radiotherapy accidents go unreported. Nevertheless, the identified medical accidents alone appear to have claimed more victims than accidents in any other category.

Proof that the Unscear list of accidents is very incomplete is provided by data on the victims of radiation exposure treated by the Curie Institute in Paris, which specialises in care for radiation-related illnesses. Between 1951 and 1997, the Institute treated 602 people injured as a result of radiological incidents, comprising 478 work-related (204 from non-nuclear industries, 153 from research facilities, 62 from the nuclear industry and 59 from medical facilities), 88 patients and 36 members of the general public (CEPN 2006).

In a report published in 2007, the French Institute for Radiological Protection and Nuclear Safety (IRSN) estimated that there are 500 000 radioactive sources in Europe, some of which are not in use, poorly identified or simply no longer under proper regulatory control – what specialists call orphan sources (Nénot 2007).

Orphan sources have been responsible for several serious accidents and incidences of contamination. The 29 reported serious accidents involving orphan sources reviewed by Unscear resulted in contamination of the public, causing 33 deaths including children. One of the most infamous accidents in Goiâna (Brazil) caused several deaths and left hundreds contaminated (see box p. 53).

According to the IAEA, over 100 countries around the world have inadequate control and monitoring programmes in place to prevent or even detect the theft or loss of a radioactive source. Millions of these sources (cobalt-60, strontium-90, caesium-137 and iridium-192) have been produced and used since the 1950s. Orphan sources that are outside of regulatory control are thought to be commonplace in former Soviet countries. Georgia's rapid economic decline after leaving the Soviet Union led to a loss of control of radioactive sources used in industry. Since the mid-1990s, over 300 radioactive sources have been recovered, but have caused at least one death and many injuries. In Moldova, several relatively large radioactive sources have been found abandoned or stored in insecure conditions.

Orphan sources are not exclusive to former Soviet countries, however. Since 1996, it is thought that industrial companies in the United States have lost almost 1,500 radioactive sources, half of which have never seemingly been found. And the European Union estimates that more than 70 sources elude the regulatory system every year. These sources are sometimes found on scrap heaps or in metal salvage yards such as in India, for example (see p. 68). Fortunately, many are not highly radioactive, but could be used to produce dirty bombs or be mixed with other materials which would in turn become radioactive.

An orphan source causes four deaths in Brazil

In 1985, a private clinic in one of the poorest parts of the Brazilian city of Goiânia moved to new premises, leaving behind a radiotherapy machine equipped with a caesium-137 source. The abandoned premises fell into disrepair, and the former radiotherapy rooms soon became a refuge for homeless people.

In September 1987, two people – completely unaware of the radiological risk they were running – dismantled the radiotherapy equipment with a view to selling some of the parts. They removed the stainless steel capsule housing the radioactive source and carted it off in a wheelbarrow. Later, both began vomiting and one also suffered diarrhoea, dizziness and swelling of the hand. They saw a doctor who put the symptoms down to allergic reaction.

Some days after, in trying to remove the source, the least affected person pierced the capsule with a screwdriver. He then sold the capsule to a scrap merchant who noticed a blue glow emanating from the source, took it home and handed out fragments to his friends, some of whom applied the glowing powder to their body. In the days that followed, several people began complaining of gastro-intestinal symptoms. Suspicious of the strange powder, the scrap merchant's wife took it to the local clinic which referred her to the hospital where other contaminated people had already been sent. A doctor confirmed contamination using a scintillation detector intended for searching for uranium ore. His conviction and courage helped to reduce the health impact of the accident.

Even so, 249 people were found to be contaminated, including 129 both internally and externally. Forty-nine people were hospitalised, ten in a critical condition. Four of the casualties died a month later, among them the scrap merchant's wife and her six-year-old niece. Dozens of houses were demolished and over 200 people were evacuated. The city and the surrounding area were only considered to be clean six months later and it took ten years to process the waste. The entire region's economy felt the effects.

4.2.1. Learning the lessons of nuclear and radiological events

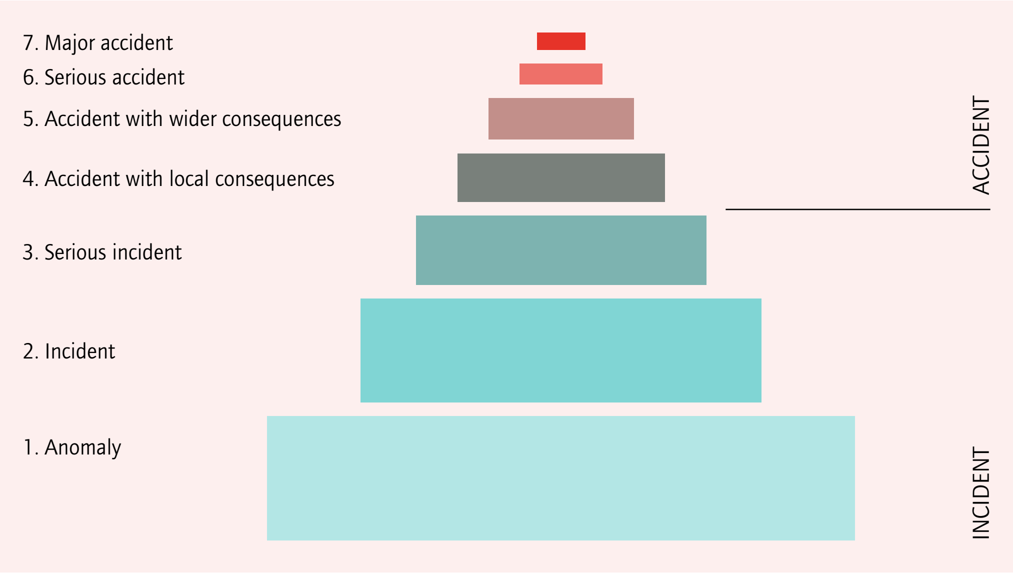
In 1999, the IAEA developed a database – the RADEV system (RADiation EVents database) – for reporting radiological incidents occurring in non-nuclear sectors. The database is accessible only to certain organisations in IAEA member countries in return for an undertaking to contribute to it regularly. An analysis of 179 events reported to the RADEV network indicates that 50% involved the non-nuclear industrial sector, 37% the medical sector and 24 events were caused by orphan sources (Croft 2002). In the industrial sector, radiography was the activity most often cited as the source of incidents, and deficiencies in safety procedures were the most commonly reported cause. These events resulted in below-dose-limit radiation exposure in 205 people, above-dose-limit radiation exposure in 44 people, 14 cases of radiation burns, 8 amputations and 5 deaths (Croft 2002).

The IAEA also developed the International Nuclear and Radiological Event Scale (INES) – an international scale to measure the severity of nuclear and radiological events (the word "event" being preferred to "accident"). The 7-level scale has been in use since 1990 and aims to communicate the safety significance of such events in consistent terms similar to the Richter scale used to rank the magnitude of earthquakes. INES was initially confined to the nuclear energy sector, but its scope was extended in 2006 to include the use of most sources of ionising radiation. The scale is designed to gauge the magnitude of events arising from various activities, including the use of radiation sources in industry and medicine (other than medical procedures), operations at nuclear facilities and the transport of radioactive material.

Events are ranked from 1 to 7. Levels 1-3 are “incidents”, whilst levels 4-7 are “accidents”. The severity of an event increases tenfold between levels and is assessed relative to three areas of impact: people and the environment; impact confined to the facility; and preventive measures not functioning as intended but no direct impact on people or the environment.

The Windscale fire in October 1957, which released radioactive material into the environment, was retrospectively classified at level 5 (see box p. 12); the release of a large amount of radioactive material into the environment following a fire in September 1957 at a radioactive waste storage facility in Mayak (Russia) was ranked at level 6 (see box p. 12); and the 1986 Chernobyl disaster at level 7. The INES scale proved inadequate to characterise the Fukushima accident, which involved several reactors on the same site.

Figure 4 International Nuclear and Radiological Event Scale (INES)



Source: http://www.fanc.fgov.be

The INES scale does not cover incidents and accidents involving the use of ionising radiation in medical procedures.

After a number of serious malfunctions in radiotherapy departments in France, the French Nuclear Safety Authority (ASN), in collaboration with the French Society of Radiation Oncology (SFRO), devised and introduced a classification scale. This ASN-SFRO scale has been in operation since 2008 and enables events affecting patients undergoing medical radiotherapy procedures to be ranked on eight levels. Declarations made to the ASN detail unexpected or unpredictable effects caused by inappropriate radiation doses or radiation areas. Potential side effects of radiotherapy treatment are not taken into account, regardless of their severity.

In the United States and Europe, various national agencies are tasked with monitoring nuclear safety and recording radiological protection events and incidents. In France, this is done by the Institute for Radiological Protection and Nuclear Safety (IRSN). In the United Kingdom, a new organisation – the Office for Nuclear Regulation (ONR) – has been responsible for radiological protection since April 2011 and looks after areas previously managed by the Department of Health and the Department for Transport. Both countries have also developed information systems to prevent nuclear events recurring.

One of the most effective ways of reducing the number and severity of radiological incidents is to share feedback from past incidents with the workers concerned. The United Kingdom took this conclusion as its starting point when creating the Ionising Radiation Incident Database (IRID) in 1996. This led in 1999 to the publication of a report containing around a hundred case studies of incidents on the database (Walker 1999). Each case study ends with a set of user recommendations. The incidents are divided into two main groups: those occurring in the non-nuclear industry and those associated with the transport of nuclear materials.

In 2001, France set up the RELIR network (experience feedback on radiological incidents), which includes an online database[24]. The aim of Relir is not to generate a complete list of incidents, but to select those events most useful for worker training and incident prevention. Any incident, regardless of severity and consequences, is included if it enables lessons to be learned.

Unfortunately, no such instrument currently exists at European level. A pilot study was done in the early 2000s following a European ALARA network[25] seminar where it was pointed out that the number of radiological incidents and average associated exposures was higher in non-nuclear industrial sectors. The study aimed to encourage the creation of a European system for feedback on radiological incident experiences called EURAIDE (European Accident and Incident Data Exchange). The European Commission-funded study was published in 2004 and provided an overview of the situation in member and candidate countries (CEPN 2006)[26].

It is remarkable that it took almost a century to create tools for analysing radiological and nuclear accidents, that there are still only a handful of them and that they are not always openly accessible. No doubt there were many economic, political and perhaps even cultural obstacles. Admitting to accidents or incidents means acknowledging the failings of a technology that “should benefit humankind”. And when information about an accident could not be covered up, the tendency was to focus on human error. As Jean-Claude Zerbib, former radiation protection engineer at the French Atomic Energy Commission (CEA), has stressed, “Analysing an accident often involves looking at the whole sequence of events to be sure that any triggers are not overlooked. This rethink, which requires cooperation from all those involved, is only possible if they believe that the analysis will be impartial, that no cause will be whitewashed, and that scapegoating will not be substituted for a painstaking search for all the factors capable of explaining why the accident happened.”

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[24] See http://relir.cepn.asso.fr for further information.

[25] A network created to help implement and spread the ALARA principle.

[26] Five countries (Austria, Belgium, Cyprus, Ireland and Portugal) had no radiological event information system; 12 countries (the Czech Republic, Finland, France, Germany, Lithuania, Luxembourg, the Netherlands, Romania, Slovenia, Spain, Sweden and the United Kingdom) did have a system; 3 countries (Iceland, Switzerland and Turkey) were developing a system; 5 countries had no such system but relied either on the INES system (Greece, Italy, Poland and Slovakia) or on the RADEV system (Norway).

4.3. Planned exposure

People who work daily in sectors where radioactive sources are used receive "planned exposure", i.e., predicted because foreseeable exposure situations. Such exposure is either external, e.g., persons exposed within a radiation field (gamma, beta or X-rays, or neutrons), or internal following the intake of radioactive material (handling unsealed sources, decontamination operations). In the European Union in particular, nuclear activities are subject to authorisation and declaration procedures. Workers at risk of external exposure are monitored by whole-body and/or extremity external passive dosimetry. The need to measure different kinds of radiation sometimes requires several dosimeters to be worn. Where there is a potential internal exposure risk, the worker is monitored either through examinations to measure the *in vivo* activity of radionuclides in the body or radiotoxicology analyses, i.e., measurements of radionuclide activity in samples of urine, faeces or nasal secretions. Such measurements chiefly serve to ensure that there is no contamination rather than to calculate the internal dose received, which is known as the committed dose and is the product of a complex calculation that takes both measurements and the fate of the radionuclides in the body into account. Known data relating to worker exposure are therefore usually the result of external exposure monitoring.

Of the 23 million workers around the world exposed to natural or artificial ionising radiation, 7.4 million are reported to be monitored (Unscear 2008). Various organisations gather data at international, European and national level, but a system for data management at European level is so far lacking.

At a global level, the Information System on Occupational Exposure (ISOE) has provided a forum for nuclear electricity utilities since 1992. It also brings together safety and radiation protection authorities from more than 25 countries, including 16 EU Member States[27]. Data collected by the ISOE network are used to compare doses received by all operatives working on different types of nuclear reactors (see chapter 6).

At European level, the ESOREX (European Study of Occupational Radiation Exposure) programme[28], initiated by the European Commission in 1997, seeks to determine the impact that regulation – primarily the Euratom Directive – has on the doses received by workers exposed to ionising radiation sources. In 2000, one million workers were found to have been occupationally exposed[29], and their dosimetric results were included in the study.

Among the workers who received a measurable exposure dose (35% of those monitored), the average annual dose was 1.3 mSv. In industry and the nuclear energy sector, average exposure levels are slightly higher (1.8 mSv and 1.5 mSv, respectively). In industry, 12 workers out of 10 000 received a dose exceeding 20 mSv, compared with 11 out of 10 000 in the nuclear energy sector and 4 out of 10 000 in the medical sector.

Workers exposed to naturally occurring ionising radiation received an average dose of 3 mSv, and 100 workers out of 10 000 received a dose over 20 mSv.

Natural radiation exposure of workers fell by half between 1996 and 2000. Worker exposure has also fallen significantly in the nuclear energy sector, and to a lesser extent in the other sectors. The study's authors conclude that the Euratom Directive has had a clear positive impact on the average doses workers receive.

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[27] ISOE has a joint NEA (the OECD Nuclear Energy Agency) / IAEA (International Atomic Energy Agency) secretariat. Four Technical Centres are responsible for gathering the data. For further information, see: www.isoe-network.net.

[28] The ESOREX project gathers data from monitoring carried out in European countries. The information collected should enable a harmonised radiation protection system to be set up. All 27 EU Member States participate in the project, as well as Iceland, Norway and Switzerland.

[29] ESOREX recognises two categories of workers depending on the dose received. Category A includes workers exposed to doses above 6 mSv; category B includes workers exposed to doses between 1 and 6 mSv.

The ESOREX network data indicate only a general scale and trend. Some countries provide more complete and more recent data on workers exposed to ionising radiation.

In France, the 2010 monitoring results indicate that the average external dose received by the 330 618 workers monitored was 0.19 mSv. Of this group, 61 959 workers received a dose above the recording threshold, of whom 12 207 received a dose above 1 mSv, 1 598 above 6 mSv and 46 above 15 mSv. Research, the non-nuclear industrial sector and the medical sector are the only sectors where the 20 mSv limit was exceeded, in one, three and four cases, respectively (IRSN 2010).

In France, 317 000 people were equipped with a personal dosimeter in 2007, 77% of whom worked in the medical sector. For the 57 000 people whose dose exceeded the measurable threshold of 0.05 mSv (i.e., 18% of the total), the average dose was 0.79 mSv.

In the United Kingdom, data from 2004 show that 38 869 workers were monitored as "classified persons". Average exposure for the year was 0.5 mSv, all sectors combined: 0.3 mSv in the nuclear power plant maintenance sector, 1.9 mSv for nurses, 2.3 mSv for doctors, 4.7 mSv for radionuclide transporters, and 5.1 mSv for miners. In 2004, 12 workers received a dose in excess of 15 mSv, including nine in on-site industrial radiography operations.

In the non-medical sector in the United States, half of the 126 869 workers monitored in 2007 received a measurable dose, averaging out at 1.9 mSv. Workers receiving the highest doses worked in industrial radiology, where the average dose was 5.9 mSv.

These data should be treated with caution, however, because they do not necessarily reflect what is happening at the work face, which is prey to some practices that are irregular at best. Workers have disclosed that dosimeters are not always worn as a matter of course, even in a sector as highly regulated as the nuclear industry. Complex safety procedures, fear of losing their job if they exceed the annual maximum dose of 20 mSv early and simple neglect from the lack of a safety culture are among the factors that conspire to make some people not wear their dosimeter (read the account on p. 84).

Dosimeter manipulation may also be a contributory factor, as evidenced by this example in a case brought by workers. In December 2009, an American nuclear waste processing firm agreed to compensate 23 black employees who had been exposed to high levels of ionising radiation. Their dosimeters were found to have been tampered with so as to give lower readings than the doses actually received. The black employees were exposed to higher levels of ionising radiation than their white colleagues (USEEOC 2009).

It must also be borne in mind that the figures given above are for whole-body exposures. Doses to the extremities or the lens of the eye are rarely monitored. As will be seen in the chapter on the medical sector, these can be very high. Failure to take them into account means that the dose actually received is underestimated.

Mindful of the need to develop a tool for monitoring workers common to all Member States, the EU is looking into creating a European dosimetric passport. In June 2010, HERCA (the association of the Heads of European Radiological protection Competent Authorities) submitted a proposal for a harmonised radiation passport to the European Commission, with a view to its inclusion in the Basic Safety Standards. The passport proposed by HERCA aims to guarantee so-called outside workers the same level of protection as the nuclear operator's own employees. However, technical problems mean that the tool has yet to be implemented at European level (see Chapter 3).

4.4. Occupational diseases

The first radiation-induced occupational diseases appeared soon after the discovery of X-rays in the form of bodily injuries caused by acute, one-off exposure to radiation or chronic exposure at varying levels occasionally exceeding the dose limit. The injuries were mainly to the hands and forearms, and consisted of skin burns, some so bad as to cause necrosis of the basal layer of the epidermis, and even bone necrosis. The first radiological burns and cases of radiation-induced skin cancer initially affected manufacturers of X-ray equipment and researchers who used it. The use of X-rays for diagnostic and therapeutic purposes then led to healthcare professionals, radiologists, nurses and surgeons being exposed. Dentists and vets then joined the list of exposed professionals, which now also includes many others.

The list of recognised and compensated ionising radiation-induced occupational diseases has changed over time and also varies from country to country, even within the European Union (see Annexe 1).

In 2010, the EU still had no binding legislation (directives or regulations) to harmonise systems for the recognition of occupational diseases. There is a European schedule of occupational diseases, but it is based on a European Commission Recommendation, which does not have the force of law and so is not binding on Member States (European Commission 2003). This list of diseases scientifically recognised as being occupational in origin and liable for compensation includes “diseases caused by ionising radiation” without further qualification[30]. Each Member State therefore interprets this as it sees fit. Consequently, the list of compensable occupational diseases caused by ionising radiation varies with the Member State. For example, the German list includes cancers of the liver, larynx, skin, pleura and thyroid, which are not recognised in France (see Annexe 1). These disparities lead to glaring inequalities between European workers.

The European Commission’s 2003 Recommendation urged Member States to ensure that all cases of occupational diseases were reported and to make their statistics compatible with the European schedule. However, data collection is still fairly rudimentary. The most recent Eurostat publication on occupational diseases dates from 2004 and refers to cases recognised in 12 Member States in 2001[31]. According to these incomplete statistics, ionising radiation was responsible for 12 cases of disease and five deaths. The value of these data may reasonably be questioned, given the figures available in some European countries, such as France and Germany.

The tables of occupational diseases in France identify those that are liable to compensation and the compensation claim times, and give an illustrative list of the main types of work likely to cause such diseases. Table 6, which deals with conditions caused by ionising radiation, was drawn up in 1931 and has not been updated since 1984. In 2006, 27 cases of Table 6 occupational diseases were recognised including nine cases of leukaemia, 14 cases of primitive bronchial/lung cancer and two cases of cataracts. In 2007, 33 cases of Table 6 occupational diseases were recognised including 13 cases of leukaemia, seven cases of primitive bronchial/lung cancer, three cases of bone cancer and eight cases of cataracts.

Between 1978 and 2003, 3 531 cases of cancer were recognised in Germany as being associated with ionising radiation, specifically lung cancer (3 498), leukaemia (18), skin

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[30] ILO (International Labour Organisation) Recommendation 194 on the list of occupational diseases is no more explicit.

[31] Belgium, Denmark, Spain, Ireland, Italy, Luxembourg, the Netherlands, Austria, Portugal, Finland, Sweden and the United Kingdom.

cancer (13) and cancer of the pleura (2)[32]. The high incidence of lung cancer may be explained by uranium mining in the 1950s and 60s, particularly in former East Germany. Germany recognised 125 cases of occupational cancer caused by ionising radiation in 2009, and 104 in 2010 (www.dguv.de).

A EUROGIP report from April 2010 gives some information on occupational cancers recognised in other European countries (EUROGIP 2010)[33]. In some countries, the causal agent, but not necessarily the type of cancer, is known. Between 2000 and 2008, Belgium paid compensation for two cases of leukaemia and 16 cases of thyroid cancer caused by ionising radiation, compared with seven cases of cancer in Spain, and 27 cases of skin cancer and 202 of lung cancer (probably caused by uranium mining, as in France) in the Czech Republic. There were 57 compensation awards for cancer caused by ionising radiation in Italy between 2001 and 2008, and three in Switzerland between 2000 and 2007.

Like many occupational diseases and cancers, the number caused by occupational exposure to ionising radiation is, without doubt, underestimated. Broadly, there are two main reasons why: the list of diseases that may be awarded compensation is restrictive; and work-related diseases are often unrecognised and hence under-reported.

Key points

The peaceful use of ionising radiation has resulted in accidents and disasters. Chernobyl will not easily be forgotten, and Fukushima 25 years later serves as a salutary reminder of the inherent risks of developing nuclear power. The INES scale developed by the International Atomic Energy Agency (IAEA) has since 1999 given an international measurement of the severity of incidents and accidents. Of the 23 million workers exposed to natural or artificial ionising radiation, 7.4 million are subject to radiation monitoring. Various organisations gather information from these checks, but pan-European oversight is still lacking.

Worker exposure has fallen around the world, although the figures should be treated with caution because they do not necessarily reflect what is actually happening. There is little in the way of concrete information about the number of occupational diseases caused by ionising radiation. Some countries have data on cases of occupational diseases that they recognise. In Europe, the list of compensable occupational diseases caused by ionising radiation varies from one Member State to another.

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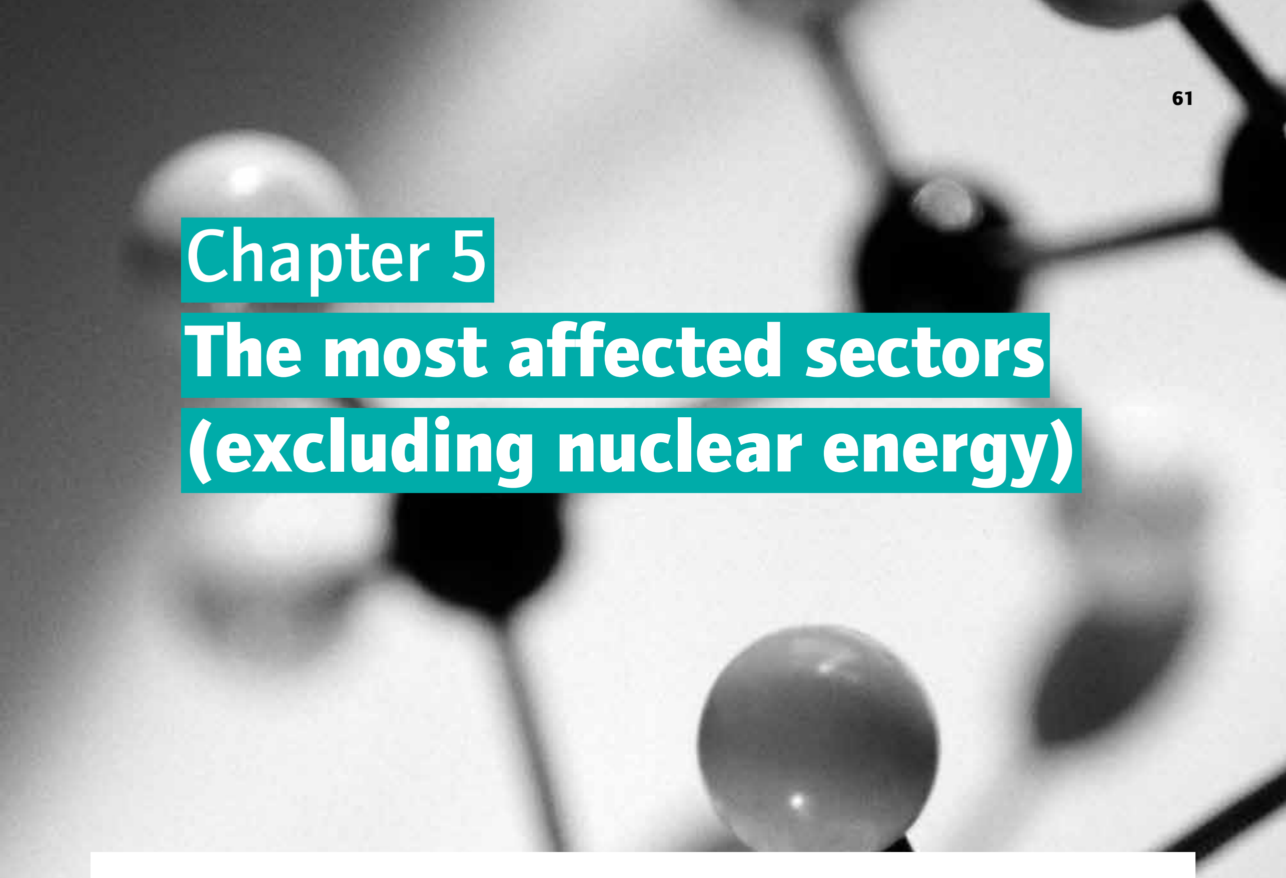
[32] The question arose as to whether mesothelioma – cancer of the pleura typically caused by exposure to asbestos – could be the result of exposure of the pleura during radiotherapy. This causal relationship has been seen in animals and was considered to be anecdotal in humans. However, two studies published in 2005 and 2006 observed a higher – low but statistically significant – risk of developing mesothelioma in patients who had previously had radiotherapy for certain types of cancer.

[33] EUROGIP was set up in 1991 by the Occupational Injuries and Diseases branch of the French social security system. It focuses on the European aspects of insurance and prevention of work accidents and occupational diseases.



Chapter 5

The most affected sectors (excluding nuclear energy)

The general public and mainstream media traditionally associate ionising radiation-related health risks with the nuclear industry, as is evidenced by various publications, including novels, press articles and television reports that have appeared in recent years. While workers in this industry run undeniable risks, focusing the debate on nuclear energy almost completely detracts from the risks incurred by workers in many other sectors that use natural or artificial sources of ionising radiation on a regular, even daily, basis. The fact that they are overshadowed like is particularly regrettable. Risk prevention and awareness-raising measures for the workers affected tend to be seriously under-developed compared to the traditional nuclear sector.

5.1. The health sector

While the medical sector was the first to make large-scale use of ionising radiation for the diagnosis and attempted treatment of diseases, paradoxically, risk awareness developed very slowly. In 1944, an American physician named Herman C. March showed that leukaemia was more common in radiologists than in other doctors. This was confirmed by a study published in 1956, which found that between 1930 and 1954, mortality due to leukaemia was 3.7% among radiologists compared to 0.6% among other doctors, i.e. a six-fold greater risk (Warren 1956). Life expectancy during this period was also 5.2 years shorter for radiologists compared to medical practitioners working in other fields. In 1936, radiologists received an annual dose assessed at 36 mSv/year, representing a lifetime dose of over 1 Sv.

In the 1940s and 1950s, handling of unsealed radioactive sources (radium and radioisotopes) also led to repeated contamination of medical staff.

A 2002 American study analysed breast cancer mortality in almost 70 000 female radiology technicians (Mohan 2002). The risk of dying from breast cancer was higher for women who started working young, before the age of 24, and for all those who worked before 1950. It was three times higher for women who started work before 1940 compared with those who worked after 1960. The researchers attributed this difference to lower exposure limits, which were six times lower in 1960 than during the period 1934-1949.

In 2010, the health sector still had by far the largest number of affected workers (doctors, nurses and technicians), but the average dose received was relatively low. Worldwide for the period 2000-2002, Unscear estimates that 6.7 million workers were monitored in radiology, and 120 000 in nuclear medicine. The average dose received was 0.5 mSv/year in radiology and 0.7 mSv/year in nuclear medicine (Unscear 2008). The internal contamination dose and the external dose received by the skin are rarely measured.

According to ESOREX project data from 2000, the average radiation exposure of medical sector workers in 20 European countries was 0.9 mSv/year. In ESOREX, the number of cases exceeding the 20 mSv/year dose in this sector was 4.4 per 10 000 workers.

There are many sources of ionising radiation in hospitals, such as gamma rays emitted by cobalt-60, caesium-137 and iridium-192, X-ray equipment, electrons and gamma rays produced by linear accelerators, isotopes used in nuclear medicine, etc. Many different departments are involved, too, including conventional and interventional radiology, radiotherapy, nuclear medicine and brachytherapy (where patients become “walking radioactive sources”). For all planned activities, codified procedures are drawn up and means of protection provided such as lead aprons and shields. In many French hospitals, however, exposed workers do not always wear their dosimeters. In most cases, only the dosimeter worn under the apron is taken into account, which underestimates the effective dose by more than twofold. Belgium has introduced a double dosimeter system (dosimeters over and under the lead apron) in interventional radiology.

5.1.1. Interventional radiology

Of all medical activities involving ionising radiation, interventional radiology (coronary angiography, cardiac catheterisation[34] and surgery) presents the highest exposure risk for healthcare professionals, and is spreading rapidly. The length and difficulty of procedures requiring lengthy examinations and multiple image acquisition often result in exposure to X-rays yielding high doses. Exposures may sometimes be so great as to cause radiological injuries in patients, particularly to the skin. Cardiologists, surgeons, radiologists and anaesthetists performing interventional radiology procedures have to stay physically close to their patients and may themselves receive much higher doses than in conventional radiology.

Few countries provide data by which to differentiate the exposure of conventional and interventional radiology workers. Existing data seems to indicate that average annual exposure is 0.5 to 1.2 mSv in conventional radiology, and 1.6 to 3.1 mSv in interventional radiology, with a maximum of around 30 mSv. Greece has provided data for different professions (nurses, doctors, cardiologists, orthopaedic surgeons, etc.) working in interventional radiology. These show that cardiologists are the group most exposed, receiving an average dose of 4 mSv, a factor of 6 higher than that received by other specialists and nurses (Unscear 2008).

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[34] In this case, interventional radiology involves inserting a narrow tube called a catheter into the groin and guiding it all the way up to the vessels of the heart. X-rays are taken at regular intervals to monitor progress.

For female healthcare staff, the possibility of pregnancy is an additional concern (see box).

The dose received at the extremities and in the lens of the eye is poorly monitored. The actual doses received by doctors and assistant staff in the hands and arms can exceed 500 mSv (Unscear 2008). More seriously still, their whole-body dose is underestimated, often being calculated only from the under-apron dosimeter. This practice means that the dose received by all unprotected parts of the body is overlooked. Measurements done in France in the late 1990s, taking into account the dose received by uncovered parts of the body, showed that actual exposure was underestimated by a factor of 3 to 5 (Mol 1999).

Special attention should be paid to the doses operators receive in the hands, thyroid gland and lens of the eye. Leaded glasses, thyroid protectors and lead aprons adapted to the wearer's body shape would be a start to reducing exposure. A further reduction could be achieved by studying workstations so as to install transparent or non-transparent screens to reduce the intensity of scattered radiation.

Cardiac catheterisation nurses worried

A European Directive requires EU employers to take measures to prevent pregnant women being exposed to ionising radiation at work (OJEC 2002). Pregnant nurses must therefore be moved from departments where there is a potential risk of exposure to ionising radiation. This precaution does not, however, apply to the period between conception and confirmation of pregnancy, which is a matter of serious concern in the profession.

As a nurse working in cardiac catheterisation explained on Belgian public television in 1992 (Nay 1992), "If ever I'm a bit late, I'll definitely be a lot more careful (...). Normally you have a lead apron and the rest in theatre. But sometimes you have to go and find something at the last minute in an emergency or someone steps on the button of the tube at the wrong time. Then you get a bit worried. I'm sure just stepping on the tube isn't enough to be a real risk, but you still worry. Once you know that you're pregnant, you're moved to a different department, on admin or something. But it's that little bit of time first that can be worrying..."

5.1.2. Nuclear medicine

Nuclear medicine involves using radioactive sources for diagnostic purposes. Added to other substances, radionuclides (also called radioisotopes) form radiopharmaceutical solutions that can be administered in injectable or drinkable form. Their chemical and physical properties vary depending on the target tissue (bone, brain, etc.). The radiation emitted by the patient's body is then analysed to provide information about his/her anatomy and the functioning of certain specific organs. This diagnostic technique is in increasingly widespread use in the most developed countries.

The radionuclides used emit highly penetrating gamma radiation that may be a source of increased exposure for the staff of a medical imaging department, particularly when administering radiopharmaceuticals and while positioning the patient and imaging device. Internal exposure of staff is usually lower than external exposure and contamination can be controlled by monitoring radioactive particle concentration on work surfaces and in the air. Exposure levels depend on the procedures performed and protective equipment used. Radiopharmaceutical preparation personnel are most at risk and can receive annual doses exceeding 5 mSv. Doses to the hands and fingers can be up to 500 mSv. In this case, shielding devices can be used to reduce extremity doses. An evaluation of the average doses received by the staff involved in this technique has shown that the average annual values range from 0.4 mSv to 3.3 mSv (Unscear 2008).

Positron emission tomography – more commonly known as a PET scan – has been increasingly used since the 1990s. It combines a new image acquisition process and the development of new tracers emitting beta radiation, which has the advantage of being totally absorbed in a small tissue volume. PET enables the activity of an organ to be observed in three dimensions thanks to gamma ray emissions produced by positrons resulting from the decay of the injected radioactive product. The average external dose received by doctors using this technique is around 2 mSv/year, compared with more than twice that for technicians (ranging from 4.6 to 8 mSv/year). Assessments performed in France suggest that the annual internal dose for workers involved in PET scanning was around 2 mSv – a hundred times more than the doses received by workers operating conventional nuclear medicine imaging equipment. Solution preparation and waste handling can incur short-term but high and repeated skin doses, which in some cases could exceed the annual limit of 500 mSv.

This use of beta-emitting solutions is not confined to nuclear medicine; it is also applied in radiotherapy, particularly in thyroid treatment and, to a minor extent, in the treatment of inflammatory rheumatic conditions, which greatly increases the number of workers affected.

5.1.3. Medical exposure of patients

The medical exposure of patients to ionising radiation is not the main focus of this publication. Nevertheless, as workers may also be patients, it is something that cannot be ignored.

X-rays have been used to treat conditions as benign as acne, a practice that persisted until the 1950s. They have also been used to treat patients with tuberculosis or joint problems. In England, people suffering from a debilitating spine disease who underwent ten X-ray treatment sessions a month later showed ten times more leukaemia cases (Boyle 1979). The use of thorium-232 as a contrast medium in angiograms led to an increase in cancer of the liver, bone and pleura. Radiation-induced breast cancer has been seen in tuberculosis patients who were treated with artificial pneumothorax and monitored using chest X-rays. These treatments have fortunately now been discontinued, but other risks have subsequently appeared.

Since the 1990s, an increase in medical exposure to ionising radiation, with increasing use of radiography and scans, has affected workers and their families. Furthermore, patients more than healthcare staff are now concerned by radiological accidents in hospitals, particularly in radiotherapy and nuclear medicine[35].

Patients need to be aware that doctors who are dealing with disease and death on a daily basis are not always receptive to the risks associated with low doses of radiation. Broadly-speaking, the public has misgivings about both civil and military nuclear activities, but expresses little disquiet about natural and medical exposure to ionising radiation, notwithstanding that it accounts for the biggest share of the collective dose received. Radiological examinations currently give annual doses ranging from 0.1 to 5 mSv, but can rise to 20 mSv and beyond for some examinations (in interventional radiology) (Tubiana 2005).

Various countries, the European Commission and the IAEA have organised conferences to help raise awareness and have instigated information and training programmes to improve protection for both patients and healthcare staff. In its 2007 recommendations,

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[35] For more on the risks and benefits of the growing use of techniques using ionising radiation, see US investigative journalist Walt Bogdanich's articles on the New York Times website: http://topics.nytimes.com/top/news/us/series/radiation_boom/index.html.

the ICRP stresses that in medicine, too, the focus should be on justification for procedures – which generally is the responsibility of doctors rather than of governments or regulatory authorities – and on the optimisation of protection, meaning that exposure should be kept as low as reasonably achievable.

In an attempt to apply these recommendations, doctors in a radiology department at Belgium's Katholieke Universiteit Leuven (KU Leuven) sought, as part of doctoral research, to reduce exposure levels during repeated radiological examinations performed on premature babies by developing strategies to optimise such aspects as the X-ray spectrum, image acquisition parameters and doses (Smans 2009).

5.2. The non-nuclear industrial sector

Ionising radiation sources, including sealed sources, X-ray equipment and particle accelerators, are used for a range of industrial applications. Although once widespread, the use of radioactive materials, especially radium, to make paint, phosphorescent articles and lightning conductors is now a thing of the past (see box p. 8). But it is a period that has left abandoned objects and contaminated sites strewn around the world.

Ionising radiation is primarily used in industry for irradiation, radiography, gauges to assess level, thickness or density of a material, and other radioisotope applications. In the early 2000s, there were around 870 000 monitored workers worldwide involved in practices related to industrial uses of radiation (Unscear 2008).

According to ESOREX data, the average annual dose received by workers in the non-nuclear industrial sector in Europe is 1.8 mSv/year[36]. The number of people exposed to doses above 20 mSv/year is 13 per 10 000 workers. Again, it must be pointed out that these averages do not reflect the high exposure levels that some workers can experience, especially in incidents or accidents. According to IAEA data, most accidents occur in the irradiation and industrial radiology sectors.

5.2.1. Industrial irradiation

At the turn of the 21st century, there were 160 high dose industrial irradiation facilities around the world using gamma ray sources (cobalt-60 or caesium-137), and 600 using electrical equipment intended to produce X-rays. There are also facilities equipped with particle accelerators. The most common uses include: sterilisation of medical equipment and pre-packed drugs; irradiation of food or crops to sterilise them – by eradicating mould, parasites and insects – and prevent germination; and polymer synthesis.

The high radiation levels that these facilities can generate make it essential to organise prevention and to closely monitor safety aspects. Under normal operating conditions, worker exposure levels should be very low, but can be substantial in the event of a loss of control of the radioactive source or untoward entry into the radiation room in breach of safety procedures (see box p. 66). In some cases, such incidents have caused serious and even fatal radiation exposure.

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[36] This figure is higher than the averages reported in the IARC 15-country study. It is also higher than French, German, British and even American data. This may indicate that in the 30 countries in the ESOREX network (the 27 EU countries plus Iceland, Norway and Switzerland), workers receive doses that are considerably higher than in the countries cited above.

A worker's serious radiation injuries in a sterilisation plant

On 11 March 2006, a serious incident occurred at Sterigenics, a medical equipment and food product sterilisation facility located in Fleurus near the Belgian city of Charleroi, when a company employee was exposed to high levels of radiation. The company's procedures allowed the irradiation chamber alarms to be turned off when the chamber was not in the irradiation phase and the entrance door was open. Before closing the chamber door, the technician made sure that no-one was inside, in line with company procedure. Thinking that the cobalt-60 source was in a safe storage position, he went right into the chamber and pressed the "check OK" button. It was during this operation – which took around 20 seconds – that he was exposed to the cobalt-60 source, which had not fully descended into its storage pool. He soon began to show symptoms, but their real cause was only ascertained three weeks later when the occupational doctor diagnosed the onset of alopecia (partial or generalised loss of hair from the head or body). The victim was transferred to a specialist unit in France where severe bone marrow damage was diagnosed.

Experts at the French Institute for Radiological Protection and Nuclear Safety (IRSN) estimated the worker's exposure at 4 Gy. The accident was classified as level 4 on the International Nuclear Events Scale (INES) (accident with local consequences). The plant operator was required to take a series of actions, including implementing multiple hydraulic, electrical and mechanical safeguards.

Particle accelerators also represent a significant ionising radiation exposure risk. They are primarily employed in nuclear research laboratories but also increasingly have medical applications. They are instrumental in the production of short-lived radionuclides and radioisotopes used for cardiac and bone scintigraphy and for brain imaging. They are also used to irradiate food and drugs. Exposure to ionising radiation from particle accelerators can occur when equipment is being serviced, modified or repaired. This indeed is how three workers were heavily irradiated in Forbach in eastern France in 1991. The most seriously irradiated victim, now deceased, received a total estimated dose of 1 Sv. The equipment involved – an electron accelerator originally intended for the sterilisation of pharmaceutical products and surgical equipment – was being used to ionise teflon granules / shavings at the time of the accident. To save time, the company that had bought the accelerator was wont to switch off the electron source during maintenance but leave the accelerator voltage on. Company bosses were unaware that the residual exposure dose around the scanner remained very high (Zerbib 1993, 1994).

5.2.2. Industrial radiography

Industrial radiography is undertaken both in fixed facilities and in mobile units on work sites. Fixed facilities are deemed to be safer than mobile units. Nonetheless, poor maintenance and system deterioration can lead to high exposure levels if faults are not picked up in time.

Since the most commonly used radioactive sources are iridium-192, selenium-75 and cobalt-60 - all gamma ray emitters - the term "gamma radiography" is also used for these operations. Industrial gamma radiography is used in metallurgy to check the quality of metal parts.

Site radiography is inherently more hazardous. The work has to be done in remote locations that are difficult to access and at times when there is nobody in the immediate vicinity (which often means at night). In general, the radioactive source, which moves through a guide tube (protective sheath), is located in a source container attached to the end of a flexible cable, which makes it possible to control the source (move it in and out) using a remote wind-out mechanism called a crank. During the radiography operation proper, the source is projected out of its container, into the guide tube, until it reaches a pre-set position. One of the most common accidents is the loss of the radioactive source (if the source container becomes detached from the cable). If the operator does not make sure that the source has fully returned to its container, the anomaly may not be detected immediately and may have serious consequences.

Excluding accidents and incidents, it is not uncommon for operators to receive doses of around 10 to 15 mSv, and even higher, during on-site radiography operations. In 2004 in France, of the 12 monitored workers who received an annual dose of over 15 mSv, nine were engaged in on-site industrial radiography operations. These operations sometimes take place very regularly, particularly during the construction of nuclear power plants, pipelines and petrochemical facilities, which leads to unsafe overwork and rushing.

5.2.3. Metal recycling: a risky sector

The loss of medical or industrial radioactive sources can affect workers who are not considered to be occupationally exposed and are therefore not monitored for their nuclear risk, such as metal recycling industry workers. This problem is so serious that businesses in this sector invest in detection systems. And they should not be the only ones to do so. The problem of lost radioactive sources – known as orphan sources – requires a comprehensive approach in order to identify the waste streams in which they may end up and the sectors likely to be affected. Several incidents demonstrate the potential hazard that an undetected orphan source may represent and illustrate flaws in the traceability mechanisms for these very high-risk products.

Radioactive lift buttons

In October 2008, the French nuclear watchdog ASN was notified that the US authorities had detected radioactivity on a parcel sent by the French company Mafelec, which manufactures lift buttons amongst other things. Investigations found the source of the problem to be a consignment of cobalt-60-contaminated steel from India that had been used to manufacture lift buttons. Reconstruction of the doses to which the different workstations were likely to have been exposed revealed that around 20 workers had been exposed to doses of up to 3 mSv – three times the regulatory maximum annual dose for the general public and for workers not occupationally exposed.

An inspection at Paris' Roissy airport should have flagged up the radioactivity on the package, but the triggering of the detection gate was not reported (ASN 2008). The package was then shipped to the United States, where its radioactivity was detected on arrival. In India, no fewer than five companies may have sent products contaminated with cobalt-60 to several countries.

A Mafelec executive said that the subsequent investigation had revealed that the steel processed in India was itself composed of European radiology products (Metzger 2009), and queried the traceability and monitoring of products entering and leaving France. Other companies that do not export to the United States may also be unwittingly affected. Mafelec now has four devices to check everything that enters the company. Even so, the radiation detection gates have to be working properly.

In an incident involving production at a metallurgy factory in La Louvière (Belgium) in 2011, radioactivity was detected in a shipment from the factory arriving at a plant in France. An investigation revealed caesium-137 contamination which had gone undetected despite radiation detection gates at the entrance to the Belgian factory. Production was halted by the safety authorities after radioactive dust was detected in the furnace dust removal system. Decontamination work was started and the incident was classified level 1 on the INES scale.

Recycling workers hospitalised in India

Several containers of Indian steel are reported to have been held up in European ports after high levels of radioactivity were detected in 2009 (Yardlev 2010). In India itself, scrap metal contamination by radioactive sources is a particularly acute problem, as illustrated by an accident that occurred in 2010.

Tens of thousands of people are employed in often very small metal salvage yards in Mayapuri, West Delhi. They sort scrap metal from around the world, which is then sold on to foundries. In April 2010, eight people from the same scrap yard were hospitalised for diarrhoea and skin and nail discoloration. After some indecision, doctors attributed the problems to radiation exposure and the Indian nuclear safety authorities were informed. The police closed the scrap yards, and inspectors discovered no fewer than eight radioactive items where the hospitalised workers were employed, and two more in a neighbouring scrap yard.

The source of the contamination was an irradiator belonging to a chemistry laboratory at the University of Delhi, imported in 1969, but unused since 1985. It had never been registered with the regulatory authorities and had been sold as scrap in February 2010. It originally contained 16 radioactive sources. The accident was classified level 4 on the INES scale (accident with local consequences). One of the radiation victims died.

The Indian government plans to install radiation detectors at ports and airports. According to some sources, however, it is reluctant to tighten up regulation and monitoring due to the size of the metal recycling sector, which is a big employer and helps meet the country's huge steel needs.

Contaminated reinforcing bars

In 1992, a journalist on Taiwan's *Liberty Times* revealed that cobalt-60-contaminated reinforcing bars had been used in the construction of a building in Taipei. The official investigation found that half of the apartments in the building were affected and that their occupants had received an average dose of 15 mSv/year. As the building had been erected in 1983, the dose received by tenants who had lived there since the beginning would have been at least 240 mSv! The Taiwanese Atomic Energy Commission estimated that 50 buildings had been constructed with contaminated steel in 1983. In September 1997, an article published in *Health Physics* showed that a total of 100 public and private buildings were affected. Over 4 000 people were living in these buildings, including young students, and were receiving doses of over 1 mSv/year (Chang 1997).

Risky lightning conductors and smoke detectors

In a country as small as Belgium, several thousand lightning conductors equipped with one or more radioactive sources (mainly radium-226, americium-241 and krypton-85) were installed before being banned in 1985. In 2003, a campaign was launched to have them taken down. At the end of 2010, the Belgian Federal Agency for Nuclear Control (FANC) confirmed that around 3,500 conductors (i.e., 95% of those identified by the authorities) had been removed (EE 2010).

In France, a study by the Commission for Independent Research and Information on Radioactivity (CRIIRAD) drew the authorities' attention to the "not insignificant" risks to France Telecom operatives from radioactive lightning conductors installed on telephone lines in France up until the late 1970s. According to a preliminary inventory drawn up by France Telecom in 2002, there were still at that time between 700 000 and 1 000 000 lightning conductors containing radioactive material (AFP 2010).

Still in France, the head of the French Nuclear Safety Authority (ASN) estimated in April 2010 that there were at least 7 million radioactive smoke detectors (so-called ionisation smoke detectors) in business premises and homes. These smoke alarms contain americium-241, which emits alpha and gamma radiation. In France, as in many European countries, their gradual removal is planned and proper disposal methods are being set up.

5.3. Air transport

While in flight, aircrews can be exposed to high levels of cosmic radiation because they are no longer protected by the Earth's atmosphere and magnetic field at high altitude. This has been long known, but has only really come into sharp focus in the past 20-odd years since a 1990 reassessment of the biological effects of aircrew exposure by the ICRP. This scientific organisation then recommended that aircrews flying at very high altitude (up to 20 km) should be regarded as an occupationally exposed group. According to Unscear, this concerns around 300 000 people employed in air transport worldwide (Unscear 2008). Exposure is higher for crew flying in air corridors close to the North and South Poles[37].

5.3.1. Higher average exposure than in other sectors

The doses aircrews receive vary with altitude, latitude, the Earth's magnetic field (concentration of charged particles) and solar activity. Their effective dose is typically around 3 microsieverts per hour (µSv/h) in temperate latitudes at an altitude of 8 km. A measurement programme undertaken in 1993 by Lufthansa showed that at altitudes between 10 and 12 km, the average effective dose received was around 5 - 8 µSv/h. A report by the European Radiation Dosimetry Group (Eurados) revealed that, in the late 1990s, the radiation dose was around 12 µSv/h at an altitude of 16 km, and over 13 µSv/h at an altitude of 20 km and higher (EURADOS 2004).

Using British flight data, Unscear has calculated that a long-haul flight crew flying for around 600 hours per year would receive an average annual effective dose of 3 millisieverts (mSv). For medium-haul crews with an equivalent period of flight time, the average annual dose was 2 mSv. However, some crews, particularly in cargo aircraft, can spend up to 1,200 hours in the air per year, which means an average effective dose of up to 10 mSv per year. These average radiation doses are markedly higher than those received by workers in the medical sector and industry.

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[37] In 1994, Alitalia staff managed to get the Pole route abandoned and flights to the Far East rerouted via Moscow (Der Spiegel 1994).

5.3.2. Health effects still being assessed

In 1994, German radiobiologist Horst Traut discovered certain chromosomal anomalies typical of radiation exposure while examining blood samples taken from around a dozen long-serving pilots and flight attendants (Der Spiegel 1994).

One year later, a Finnish study looked at cancer incidence in a cohort of 1 577 women and 187 men who were members of flight crews for Finnish airlines from 1967 to 1992 (Pukkala 1995). The annual radiation dose received was estimated to be between 2 and 3 mSv. For female flight personnel who had flown for more than 15 years, the risk of developing breast cancer was doubled. Received cosmic radiation was the suspected cause. The following year, a Danish Cancer Registry official revealed that in Denmark, female flight attendants had a higher breast cancer risk than women in the same social class who did not work in the air transport sector (Lynge 1996). In 1998, an American publication confirmed that the risk of developing breast cancer was twice as high among a US airline's retired female employees (Lynge 1996).

A 2003 study looked at the mortality statistics for over 40 000 flight personnel (pilots and cabin crew) in eight European countries (Zeeb 2003)[38]. No increased mortality – from cancer or other causes – was noted among female staff. Excess mortality, mainly due to skin cancer (melanoma), was observed among male cabin crew but could not be attributed to cosmic radiation.

A 2007 review paper concluded that the probability of airline crew or passengers suffering adverse health effects as a result of exposure to cosmic radiation was very low. According to its findings, for an accumulated cosmic radiation dose of 5 mSv/year over a career span of 20 years, the likelihood of crew members developing cancer is 0.4%, and 0.6% after 30 years (Bagshaw 2008). An increased risk of developing a radiation-induced cataract due to cosmic radiation is possible, but this has only been observed in astronauts who receive markedly higher doses than airline pilots.

In 2008, an American study found a greater frequency of biological changes in pilots with more flying hours than their colleagues (Yong 2009).

5.4. The military sector

The estimated number of people employed in regular military activities worldwide and whose ionising radiation exposure is monitored is between 300 000 and 400 000 (Unscear 2008). Of all the sectors in which ionising radiation is used, the military sector is that in which the risk-benefit ratio of using nuclear technology is the most problematic, controversial and political. It has a complicated and painful history, including the Hiroshima and Nagasaki bombings, accidents during the arms race, the exposure of military personnel and the civilian population during nuclear testing, and the recent use of depleted uranium weapons. Not to mention the arsenals that various countries have accumulated and the ever-present threat that they will be used. This section considers only selected aspects of this topic.

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[38] Germany, Italy, Denmark, Norway, Sweden, Greece, Finland and Iceland.

5.4.1. The health of personnel involved in nuclear testing

Several follow-up studies on military personnel involved in nuclear testing have been done in the US and the UK. No statistically significant increase in cancer and leukaemia mortality has been found. However, the US Congress passed the Radiation-Exposed Veterans Compensation Act in 1988 enabling compensation to be paid to soldiers who took part in combat operations in Japan and in subsequent nuclear tests, and were suffering from radiation-induced illnesses. In 1990, Congress also decided to create a compensation programme for people with serious illnesses associated with nuclear tests carried out in the United States (see annexe 2). This was initially intended for residents affected by fallout in certain areas in Nevada, Utah and Arizona, personnel involved in the tests and workers in uranium mines situated in the US, but was extended in 2000 to cover uranium mill workers and uranium ore transporters. By February 2011, 23 447 people had received compensation through the programme: 14 856 residents, 1 526 test participants and 7 065 uranium workers.

The French Parliament finally passed legislation on 5 January 2010 to give recognition and compensation to victims of nuclear testing (French Official Gazette 2010). Implementing regulations set out the list of compensable diseases and the areas where people suffering from a radiation-induced disease must have lived or stayed during the test period. The French list of cancers that are eligible for compensation is more restrictive than the American list (see Annexe 2).

In early October 2011, the French nuclear test veterans association (AVEN) was outraged that of the 129 applications submitted to the compensation committee, 127 had been rejected. According to AVEN, some 40 deaths per year are linked to exposure during the 210 French nuclear tests, and 150 000 people (both military and civilian) are affected.

5.4.2. Gulf War Syndrome

Some 697 000 American soldiers took part in operations in the First Gulf War between January and June 1991. Returning veterans complained of a range of symptoms, including fatigue, headaches, sleep disorders, memory problems and joint pain. Newspapers coined the term “Gulf War Syndrome”. Later, the press also began referring to higher mortality among veterans, as well as an increase in deformities among children they conceived after the war.

But what were the Gulf War veterans suffering from? Several studies in the late 1990s sought to unravel the mystery. Two American studies of almost 9 000 military personnel compared the health of soldiers deployed in the Gulf to that of soldiers who did not serve in that theatre (Fukuda 1998, JAMA 1997). The results found no evidence of significant diseases or abnormal clinical or biological parameters in the veteran population, yet veterans reported symptoms and health complaints two to four times more often. A British study compared three groups of soldiers: one deployed in the Gulf, one group that was not deployed, and a third deployed in Bosnia (Unwin 1999). The three groups reported the same symptoms, but Gulf veterans reported them three times more often. Another study found no evidence of excess mortality or children born with deformities among Gulf veterans (Bolton 2002).

In 2001, the US Congress passed a law granting compensation to Gulf veterans suffering from chronic fatigue, irritable bowel syndrome and fibromyalgia. Those with multiple symptoms including fatigue, weight loss, headaches, joint pain and gastro-intestinal, neurological or respiratory problems also received compensation.

The causes of the Gulf War Syndrome have still not been identified. Veterans were exposed to a range of chemical and bacteriological risks during military operations in the Gulf, but many researchers and observers have focused their attention on depleted uranium.

5.4.3. Use of depleted uranium weapons

Depleted uranium is what is left over when a fraction of the most radioactive isotopes of natural uranium, particularly uranium-235, has been extracted to produce enriched uranium, which is used as fuel in nuclear reactors. There are therefore large amounts of depleted uranium in waste storage but also on the market.

The expression "depleted uranium" is also used – incorrectly some experts feel – to refer to the by-product of spent fuel reprocessing. In this case, in addition to the three isotopes of natural uranium, it contains U-232 and U-236, as well as traces of fission products (plutonium, americium and curium) – radionuclides formed during nuclear fission and activation reactions that take place in nuclear power reactors.

Depleted uranium's very high density (more than one and a half times that of lead), relatively low melting point and ability to self-sharpen on impact are all properties that have been used in the production of weapons and munitions that can rapidly penetrate less dense materials such as concrete and metal. Depleted uranium has also been used to reinforce American army tank armour (e.g., in Abrams tanks)[39].

The 1991 Gulf War was the first armed conflict to use depleted uranium in weapons. The US army subsequently deployed these types of weapons during the Balkan conflict (in Bosnia in 1994 and 1995, and in Kosovo in 1999) and during the 2003 Iraq War. In the course of the First Gulf War, some 800 000 projectiles of this type were dropped by American and British aircraft, representing around 250 tonnes of depleted uranium. An additional 50 tonnes was fired from tanks.

When a projectile hits a particularly solid target, it fragments and ignites. Combustion of molten uranium droplets is accompanied by a shower of sparks and projections forming an aerosol of vapours and fine uranium oxide dust, 80% of which is insoluble. This fine dust can be inhaled or ingested and can also contaminate wounds. In the entire production and usage chain for depleted uranium weapons, these contamination routes have been identified as posing the most significant risks. Shrapnel that becomes lodged in the body and cannot be removed is another hazard. Although American tanks were never penetrated by Iraqi fire during the Gulf War, they did fall victim to some "friendly" fire.

Natural and depleted uranium have identical chemical properties. Natural uranium is the only radioactive substance whose chemical toxicity exceeds its radiotoxicity. The U-235 content needs to be enriched to around 7% for radiotoxicity to overtake chemical toxicity.

According to toxicology manuals, soluble uranium salts are partially absorbed by the body and uranium is eliminated primarily through the kidneys. The fraction retained in the body accumulates preferentially in the bones and kidneys. The main toxic risk is kidney damage. An excess of chromosome abnormalities has been observed in the lymphocytes (a type of white blood cell) of people exposed. This is independent of the radioactive risk, as it is a result of the metal's chemical toxicity. Urine samples taken from people working with

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[39] Depleted uranium also has civilian applications: in research; in medicine, in the composition of protective shields (against gamma radiation) and in the reinforcement of containers used for transporting radioactive material; as a catalyst in the oil industry; and as a counterweight and ballast in aircraft and ships.

uranium are checked so that internal contamination can be monitored through an evaluation of the amount of uranium absorbed in the lungs or digestive tract (Lauwerys 2003).

Inhaled insoluble uranium salts (uranium oxide) are retained in the lung tissue, where they cause local radiation exposure that could lead to cancer. However, available epidemiological studies of occupationally exposed people do not evidence this. Uncertainty remains as regards civilians and military personnel who have been contaminated during massive bombardments.

In 1993, the US Defense Department proposed monitoring 160 veterans who were thought to have been heavily contaminated by uranium dust. In 1999, the most affected veterans, particularly those found to have uranium shrapnel in their body, still showed a high urine uranium level. However, no abnormalities have as yet been found and no deformities have been reported in children conceived between 1991 and 1997. Nonetheless, it was judged prudent to continue monitoring their health, particularly their kidney function. Since then, American soldiers who have been exposed to uranium have been included in the category of veterans liable to receive compensation in the event of contracting diseases associated with exposure to ionising radiation.

In October 2007, the Italian Defence Minister revealed that between 1996 and 2006, 37 Italian soldiers had probably died as a result of exposure to uranium weapons during missions in Iraq and the Balkans. Conversely, studies in Finland, Spain and Germany on personnel sent to Kosovo for peacekeeping operations have not found significant uranium exposure (United Nations 2008).

What impact has uranium had and what impact will it have on civilian populations living in cities and sites that have been bombed? Might not the tonnes of uranium dust swallowed or breathed in become weapons of destruction? In 1999, the United States officially acknowledged that it had used depleted uranium weapons in Bosnia and Herzegovina. A total of 10 800 pieces of ammunition were fired, which corresponds to approximately three tonnes of uranium. And uranium weapons were deployed again in 1999 in Kosovo and in southern Serbia. Dozens of sites were contaminated, and some still cannot be entered due to the presence of mines.

The United Nations and the IAEA have carried out various studies and inspections to assess the impact of depleted uranium on people and the environment, but all have been done after the conflicts. None has examined the effect that these types of weapons have on troops and populations during combat. Their findings are that uranium residues dispersed in the environment do not represent a radiological risk for the populations; and that areas where fragments of weapons and unexploded ordnance are present should be cordoned off, and the debris removed to appropriate sites.

In 2008, the World Health Organisation (WHO) concluded that irradiation caused by the exposure of military personnel and civilians to uranium has not, generally, reached doses above normal background levels. The WHO recommended that the most contaminated military personnel should have their kidney function checked regularly. Polluted sites should be monitored and clean-up operations should be undertaken in areas where experts judged the level of contamination to be unacceptable (respirable suspended dust particles or groundwater pollution). Special attention should be paid to children who may have been most exposed and information should be given to affected populations.

On 22 May 2008, the European Parliament passed a resolution urging all EU Member States and NATO countries to impose a moratorium on the use of uranium weapons and to redouble efforts towards a global ban. The resolution also called on the European Commission to commission scientific studies into the use of depleted uranium. The European Scientific Committee on Health and Environmental Risks (SCHER) announced its initial conclusions in the spring of 2010 (SCHER 2010), confirming previous evaluations by the WHO and the IAEA.

5.4.4. Secrets and denials

Uranium is not the only toxicant soldiers had to deal with on the battlefields of the Gulf and the Balkans. Other possible explanations for veterans' health problems have been advanced: the use of biological and chemical weapons; vaccines and treatments designed to protect soldiers from Saddam Hussein's presumed chemical arsenal; insecticides and pesticides used, etc. (Teugels 2003). Veterans' associations have been set up in several countries involved in the Gulf War and in the conflicts in former Yugoslavia, prompted by the fact that veterans appear to be suffering from complaints resembling chronic fatigue syndrome and their conditions are not being recognised.

Nuclear military history abounds with secrets and denials. In 1994, when secret documents held in military archives were declassified, Americans were horrified to discover that thousands of US citizens had been used as guinea pigs in nuclear experiments. A study published in 1995 identifies 47 such experiments conducted on over 3,200 individuals between 1940 and 1970, with federal funding, chiefly provided by the US Atomic Energy Commission (AEC) (Samei 1995). It transpires that some experiments were conducted to observe the biological effects of radionuclides administered by different routes (ingestion, inhalation and injection) to elderly and incurably or terminally ill patients. Other experiments aimed to study the effects of radiation on the skin, on easing childbirth and on sterilisation. Some of these experiments were performed on volunteers or on consenting prisoners, in return for payment. The studies often gloss over how consent was obtained. What particularly stirred public anger was that when the experiments were done, the basic ethical rules governing tests and clinical research on humans were already in place (Mossman 1995)[40].

The media storm surrounding these revelations put scientists on the defensive. The tests that were known about were scrutinised; not all were judged contrary to ethical rules. But some that had been carried out on dying patients, prisoners and disabled children led to a rethinking of the notion of informed patient consent and changes to the rules protecting people taking part in clinical trials.

Inhabitants of the Marshall Islands and its atolls, such as Bikini Atoll – where the Americans carried out large-scale nuclear testing until 1958 – feel that they, too, were used as guinea pigs. They were told that it was "for the good of humanity"! (Lips-Dumas 2009)

Dozens of little monuments to the victims of nuclear accidents, not just those at Chernobyl and Mayak, are thought to be tucked away across the former Soviet Union.

The environmental and human consequences of the nuclear tests that France conducted in the Sahara between 1960 and 1966 – code-named Gerboise – are still largely unknown. There are few data on the radioactive fallout in the test zones or on the doses received by the populations living in villages located 50 km and 150 km from these zones. Military personnel and conscripts involved in the tests were also exposed to radiation and even seem to have been used as guinea pigs, at least according to the French press, which gained access to a confidential Ministry of Defence report in February 2010 (Touati 2010).

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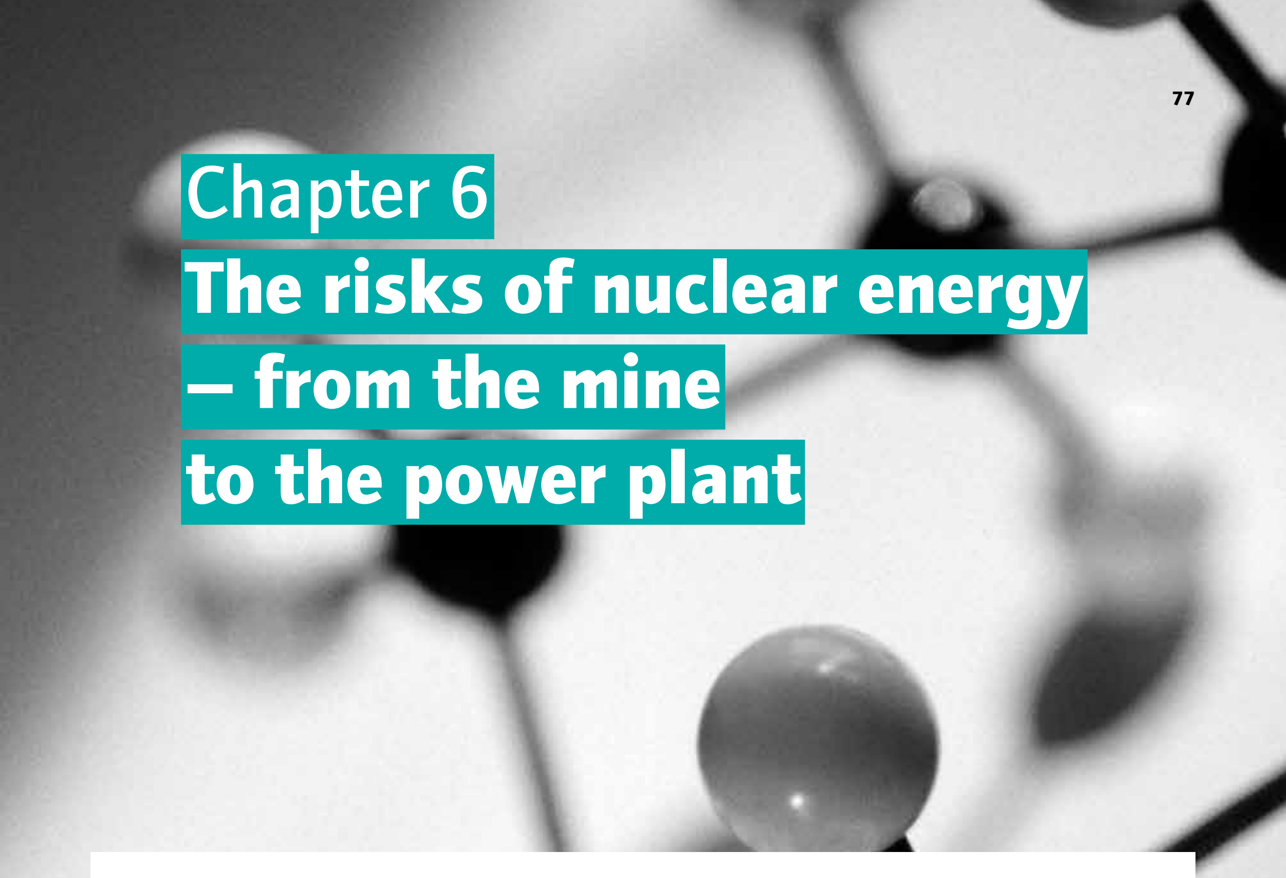
[40] During the 1947 Nuremberg trial of the German doctors who had conducted experiments in the concentration camps, the public prosecutors had to create a conceptual framework in order to judge the acts perpetrated by the accused, and draft what is known as the Nuremberg Code.

Key points

In the public perception, the risks of exposure to ionising radiation tend to be associated with the nuclear energy sector. Sources of ionising radiation are, however, to be found in many other fields of activity where measures to monitor the doses workers receive are not necessarily carried out as strictly as in the nuclear industry. The health sector clearly tops the list in terms of the number of workers exposed to sources of ionising radiation – a trend that is set to grow with the more routine use of radiological examinations in hospitals and increasingly frequent use of radiopharmaceuticals.

Air transport is another sector that is greatly affected, although here the source of the exposure is natural. Flight personnel are exposed to cosmic radiation and can accumulate particularly high exposure doses after a number of years on the job. Nor is traditional industry spared, particularly metallurgy where there are numerous risks ranging from the use of equipment emitting ionising radiation to exposure to scrap metal contaminated with radioactive material.

Finally, despite international nuclear disarmament agreements, atomic energy is still very much present on battlefields. Veterans, both from the US Army and from European armies, complain of unfathomable health problems, one possible cause of which may have been the use of depleted uranium in weapons.



Chapter 6

The risks of nuclear energy – from the mine to the power plant

As of April 2011, 30 countries had nuclear power plants, and 437 reactors were in operation worldwide (Schneider 2011). Electricity generation from nuclear energy began in 1956 and expanded rapidly between 1970 and 1985, particularly in the wake of the 1974 oil crisis. This expansion was questioned in some countries after the 1979 accident at the Three Mile Island power plant in Pennsylvania (USA). President Jimmy Carter even went so far as to propose suspending nuclear plant construction in the US, but the threat never materialised. By contrast, a freeze on all new nuclear projects was ordered in Sweden following a referendum held in 1980[41].

The real death blow to the construction of new nuclear power plants would be dealt seven years later, in 1986, in the wake of the Chernobyl disaster. Italy chose to phase out nuclear power following a 1987 referendum, and in the early 2000s, Germany (2001) and Belgium (2003) voted to end their nuclear programmes.

By the end of the decade, however, the tide had clearly turned. There was renewed interest in the idea of using nuclear electricity to meet energy needs, sparked mainly by concerns about the foreseeable decline in oil reserves, gas supply and price uncertainties (particularly in Europe), dependence on imported oil (especially in the US) and international agreements to tackle global warming. By early 2011, 64 reactors were under construction, and 35 projects were awaiting the IAEA's go-ahead (Schneider 2011).

The events that occurred at Japan's Fukushima nuclear power plant in the wake of the tsunami on 11 March 2011 could potentially thwart the plans of the

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[41] In February 2009, the centre-right government, led by Conservative Prime Minister Fredrik Reinfeldt, decided to lift the moratorium.

staunchest advocates of nuclear power and put the issue of public safety and – hopefully – worker safety firmly back at the centre of the debate. Nuclear power generation comprises a great many steps, all of which involve exposure and contamination risks to workers. This chapter considers some aspects of the key steps in the process, ranging from uranium extraction to processing of the ore into nuclear fuel through to nuclear power plant operation. Unscear estimates the number of workers monitored for exposure to ionising radiation in the commercial nuclear fuel cycle at 660 000 worldwide (Unscear 2008).

6.1. Uranium ore extraction

Metals such as gold and especially silver have been mined in the Bohemian mountains and in southern Germany since mediaeval times. Four hundred years ago, the German physician Georg Bauer, also known as Georgius Agricola, who was a true pioneer in the prevention of occupational injury and illness, described an epidemic of lung disease causing premature deaths among miners. The cause was another black and very dense ore found in silver mines: pitchblende, also called “stone of misfortune”. In 1789, the German chemist Martin Klaproth identified a metal in pitchblende, which he called uranium after the recently discovered planet Uranus. Throughout the nineteenth century, uranium was used to colour crystal, glaze ceramics and decorate porcelain. In 1879, German physicians diagnosed the miners’ disease known as “mountain sickness” as being lung cancer, but it was not until 1951 that American experts at the Atomic Energy Commission demonstrated that alpha particles emitted by radon decay – essentially polonium-218 and polonium-214 – could become attached to dust, which, if inhaled, could potentially contaminate the lungs.

Many epidemiological studies would subsequently confirm this risk, which was further exacerbated by the lack of ventilation in mines. An Australian study of 2 574 workers in a uranium mine, who were followed up from 1952 to 1987, found that underground workers were five times more likely to die from lung cancer than surface workers (Woodward 1991). A 1993 study of 4,320 uranium miners in Bohemia showed a four-fold risk of lung cancer compared with the general population (Tomasek 1993). More recently, a study of 48 000 people who worked in the Pribram mine during the time it was being worked (1949-1991) showed that workers with the highest radon exposure were at greater risk of developing leukaemia than workers with lower exposure (Rericha 2006).

The region of Bohemia, now part of the Czech Republic, still has the largest operating uranium mine in the European Union. Opened in 1957, the Rozna mine, which has an annual production of around 300 tonnes of uranium, was long a significant source of the precious metal required for the Soviet nuclear arsenal. It now supplies the two Czech nuclear power plants with fuel. The mine’s 350 underground workers wear personal dosimeters and may not work below ground for longer than ten years.

Following the discovery of radioactivity and the properties of radium, the search for uranium ores was at times reminiscent of the gold rush, particularly in the US, which boasted some 2 500 mines on the Colorado Plateau between 1940 and 1960. Like other European countries, France also experienced a boom in uranium prospecting and extraction after World War II. A mortality study of 5 086 workers employed as uranium miners for at least a year between 1946 and 1990 showed an excess of radon-related lung cancer death, as well as an excess incidence of kidney cancer (Vacquier 2008). More than 210 sites in France were involved in activities relating to uranium ore exploration, production, processing and storage. The last mine closed down in 2001. In Germany, compensation is paid out for around a hundred cases of ionising radiation-induced cancer each year. According to a senior official in Germany's statutory occupational accidents and diseases insurance scheme *(Deutsche Gesetzliche Unfallversicherung)*, this particularly high figure is due to uranium mining activities in former East Germany during the 1950s and 1960s.

The hunt for uranium would leave its mark. Former mines and storage sites pose problems in terms of radiation protection of the public. A European Commission document published in March 2011 reports 12 Member States as being concerned (European Commission 2011), the total volume of tailings for which is about 314 million m^3, covering an area of some 2 530 hectares. The long-term fate of these deposits is often unclear, especially in Central and Eastern Europe. The Euratom Treaty requires an inventory of abandoned sites to be drawn up for 2012. Member States must establish waste management programmes. The European Commission is considering issuing more specific instructions to ensure better coordination of radioactivity monitoring of former uranium mining sites, and also wishes to avoid such legacies in future, as responsibility for their management and cost ultimately falls on the community.

In the past, tailings (ores containing too little uranium to be economically usable) have often been re-used in foundations for roads or car parks without any records of this use being kept.

In 2010, the main uranium producers in the world were Canada (30%), Australia (14%) and Niger (10%). The ore is also mined in Kazakhstan, Namibia, the Russian Federation, South Africa, Ukraine, the United States and Uzbekistan.

At the beginning of the 2000s, about 12 000 workers were employed in uranium ore extraction and milling worldwide, compared with more than 300 000 in the early 1980s.

Africa: rich uranium deposits, poor protection

A French NGO, the Commission for Independent Research and Information on Radioactivity (Criirad), has denounced the conditions under which uranium is mined in Niger by subsidiaries of the French companies Areva and Cogema (now merged). Criirad believes that mining leads to exposure of the population and workers to ionising radiation through contaminated water, air and everyday objects. In a document published in 2005, Criirad quotes an Areva-Cogema report, in which the French nuclear giant is said to admit that several dozen workers at the Arlit underground mine (Niger) were exposed to annual doses above the European limit (Criirad 2005).

Elsewhere in Africa, in Katanga, it is less radioactivity than the contamination resulting from the chemical toxicity of the ores mined that is the issue. The province of Katanga in the south-east of the Democratic Republic of Congo has been the site of intense mining activity for centuries. During the colonial era, the extraction of copper, cobalt and uranium was the Belgian colony's main source of revenue. After independence, mining continued and has even been stepped up since the early 2000s to meet rising demand from emerging Asian economies for mineral resources. Ore extraction developed in a makeshift manner throughout Katanga and tens of thousands of young people, including children, work as "diggers" in particularly dangerous conditions.

A study conducted by Belgian and Katangese scientists and published in 2009 measured the exposure to metals of 311 mining community residents, aged between 2 and 74. The results showed a high level of exposure among people living close to the mining areas, especially children, with urinary concentrations of cadmium, cobalt, lead and uranium that were respectively 4, 43, 5 and 4 times higher than in the US general population (Banza 2009).

* The chemical toxicity of uranium is greater than its radiological toxicity (renal toxicity). Cobalt's toxicity in the workplace mainly affects the heart, thyroid gland and lungs (Lauwerys 2003).

6.2. The nuclear fuel cycle

Once it has been extracted from the ground, uranium ore is purified and concentrated in the form of UOC (uranium ore concentrate, or yellowcake[42]). Before being made into nuclear fuel, the uranium-235 content of UOC must be enriched. Since U-235 is the only one of the three isotopes of natural uranium that splits on impact with a neutron[43], it is said to be fissile. This fission reaction is accompanied by the emission of energy. Natural uranium contains about 0.71% U-235. The pressurised water reactor system, which is used in most of the world's nuclear power plants, requires uranium containing 3 to 4.5% U-235. In scientific research reactors, medium-enriched uranium (up to 20% U-235) tends to be used instead of highly enriched uranium (up to 93.5% U-235). Fearing the diversion of uranium for military purposes, the US government is now putting pressure on its allies to stop using highly enriched uranium.

In 2003, there were 50 uranium conversion and enrichment units in operation throughout the world. Exposure records were kept of some 18 000 people working in this part of the nuclear fuel cycle, and a further 20 000 fuel fabrication workers were monitored.

6.2.1. Use and re-use of nuclear fuel

Before it can be enriched, natural uranium must be chemically converted into uranium hexafluoride, a process known as conversion. The gaseous form of this chemical is then enriched using one of several techniques, usually gaseous diffusion or centrifugation. The enriched uranium hexafluoride is then chemically converted into uranium dioxide powder, which is pressed into pellets and inserted into long zirconium alloy tubes ("cladding"). These fuel rods are then assembled into bundles known as fuel assemblies, which make up the core of nuclear power reactors. The number of fuel assemblies varies depending on the power of the reactor.

When a power plant is first started up, all the assemblies are new. A fraction of the core (one-third or one-quarter) will be refuelled during scheduled plant shutdowns, i.e., every 12-18 months. After about four years in use, the spent fuel from an entire core will have been removed from the reactors and stored in a spent fuel pool on the same site for at least one to five years – and often much longer – in order to keep it cool. Spent fuel can be recycled after reprocessing. For this purpose, it is sent to a reprocessing plant, e.g., La Hague in France, Sellafield in the UK or, to a much lesser extent, Tokai Mura in Japan. Some countries do not intend to reprocess their spent fuel, preferring the final disposal option after the necessary fifty-year cooling period. It should be pointed out that between 1976 and 2009, only 15% of the fuel removed from the world's nuclear power reactors was reprocessed, which means that 85% has been stored "as is", pending disposal, since 1976. Even in France, a pioneer in reprocessing techniques, 54% of irradiated fuel was not reprocessed between 1976 and 2009 (Guillemette 2011).

Spent fuel still contains uranium, specifically isotopes 238 and 235, respectively accounting for about 93% and 0.7% of the initial weight of the fuel, in addition to other substances such as U-232 and U-236, both artificial non-fissile isotopes of uranium. These two isotopes are "neutron poisons" that greatly decrease the reactivity of reprocessed uranium.

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[42] Dried uranium concentrates are bright yellow and powdery in appearance, hence the name "yellowcake". Yellowcake contains about 75% uranium, or 750 kg per tonne. This product is then packaged and shipped to conversion plants for further chemical treatment. Source: http://www.areva.com.

[43] More than 8 kg of natural uranium is needed to make 1 kg of enriched uranium.

Spent fuel also contains plutonium (about 1% of the initial weight of the fuel), alpha emitters (e.g. neptunium), americium and curium isotopes, and highly radioactive fission products (4.8% of the initial weight). Plutonium is not a natural element, but rather an inevitable by-product of nuclear energy production.

The uranium and plutonium are separated in the reprocessing plant. Whereas re-using reprocessed uranium is not always economically viable, part of the plutonium is recycled to make new nuclear fuel, particularly MOX, which is composed of mixed oxides of uranium and plutonium.

During the 1950s, the Belgian Nuclear Research Centre in Mol (Belgium) conducted research on spent fuel reprocessing, which culminated in the production of MOX fuel in the late 1960s. MOX would subsequently be produced in Germany, followed by Switzerland, and then France from 1985 onwards.

All plutonium isotopes emit alpha radiation, which can be stopped by a sheet of paper. Plutonium and plutonium-contaminated objects are therefore manipulated in what is known as a glove box, where the operators are shielded by glass, use robotic systems and are protected by gloves. Plutonium is nevertheless a particularly hazardous radioactive element because of its very long life (it has a half-life of 24 000 years) and high toxicity. In the event of internal contamination, the effects of its extreme radiotoxicity are concentrated in a few organs (lungs, liver and skeleton). It also has significant chemical toxicity in some organs (the kidneys and nervous system in particular).

Plutonium also poses a criticality risk (risk of a nuclear chain reaction), which calls for additional precautions to protect workers in facilities where it is used (reprocessing, transport of plutonium oxide, manufacture of fuel pellets, transport of fuel to the reactor and interim storage at each industrial stage).

Not all of the plutonium arising from reprocessing spent fuel is re-used. According to the IAEA, 20% of spent fuel is recycled, which means that hundreds of thousands of tonnes of radioactive materials are in storage.

6.2.2. The risks for nuclear workers

Hundreds of thousands of workers employed in the nuclear industry have been exposed to low or very low doses of ionising radiation, so it is particularly worth looking at the data from epidemiological studies on them.

One study that looked at the causes of death of 75 000 employees of three British nuclear facilities between 1946 and 1988 did not show any excess mortality among exposed workers compared with the national average, except for leukaemia (Carpenter 1994). The same conclusion was reached in a 1995 study focusing on British, Canadian and American workers at six nuclear sites (Cardis 1995). An American study examined the mortality of a cohort of 4 000 workers employed at a uranium processing facility during the company's period of operation, i.e., 1951-1989 (Ritz 1999). The results show a worker mortality rate below that of the US general population, but a slightly higher mortality rate for all types of cancer. This rate increases with the radiation dose received and the exposure time. The author of this study stresses the importance of an extended follow-up of the workers concerned.

Many studies consider an insufficient number of workers, or cover too short a period of time for symptoms of diseases such as cancer to show. Furthermore, some research is marred by bias, for instance comparing a group of workers with the general population, which will result in the risk to exposed individuals being underestimated because of the "healthy worker effect". The nuclear industry tends to recruit its employees (technicians and managers) based not only on their skills but also on their specific health profile. The applicants accepted are therefore in better health than the general population.

Nuclear power plants: several reactor types

Several types of reactors are used in electricity-generating nuclear power plants. Most of the reactors in operation around the world are second-generation designs. About one-fifth of the global operating fleet comprises boiling water reactors (BWR), while 60% are pressurised water reactors (PWR). European reactors are primarily PWR-type (80%). Both types of reactors were developed using American technology, PWR by Westinghouse for the propulsion of US Navy submarines, and BWR by General Electric. Originally, the first generation of reactors used natural uranium as fuel, as enriched uranium was not yet commercially available. Second-generation reactors use low-enriched uranium and need large volumes of water to cool the reactor and create motive power. This explains why they are located beside a river or close to the sea.

In a PWR, the primary coolant (water) that cools the reactor core is under high pressure, which prevents it from boiling. This water is pumped into between two and four steam generators (heat exchangers) connected to the reactor pressure vessel and its heat is transferred from the primary to the secondary system. This secondary coolant is turned into steam, activating the steam turbine, which in turn drives an electrical generator. The plume of steam escaping from the cooling tower of a nuclear power plant comes from a tertiary system that cools the condenser. In the event of an accident, safety is provided by the three barriers that separate the radioactive material from the environment (the fuel cladding, the reactor pressure vessel and the containment building). The most serious accident in this type of reactor occurred at Three Mile Island in 1979 (see 4.1.).

In a BWR, the heat released by the fission reaction boils the primary coolant as it flows upwards through the fuel rod assemblies. The water-steam mixture is separated at the core outlet. This type of reactor has one barrier less between the radioactive fuel and the environment, but generally has a containment building. BWRs were in operation at the Fukushima Daiichi power plant in Japan.

The Soviets developed their own enriched uranium reactor system, called RMBK, which is graphite-moderated and water-cooled, with no containment building. It was a reactor of this type that exploded at Chernobyl. RMBK reactors had safety systems that could have been engaged, but at Chernobyl they were deliberately disabled in order to run tests.

With the emergence of new safety and efficiency criteria, the next generation of reactors was developed, dubbed Generation III. Several types of reactors are in competition: the European Pressurised Reactor (EPR) of the European Siemens-Areva consortium, the AP1000 pressurised water reactor of the American-Japanese Westinghouse-Toshiba consortium and the Advanced Boiling Water Reactor (ABWR) and Economic Simplified Boiling Water Reactor (ESBWR) of General Electric-Hitachi – not to mention the new Russian and Canadian reactor designs.

Until the events that unfolded at Fukushima, there seemed to be considerable renewed interest in nuclear energy, as demonstrated by the launch of programmes to develop other types of reactors, known as Generation IV.

A final thing to note is the start of construction work at Cadarache (France) in 2010 on a reactor prototype called ITER (International Thermonuclear Experimental Reactor), which is based on nuclear fusion instead of the nuclear fission technology currently used. This project brings together seven partners (Euratom, China, India, Japan, South Korea, Russia and the United States). The ultimate aim is essentially to reproduce the sun's activity. Nuclear fusion will eventually provide electricity, but it is unlikely to happen before the end of this century.

Larger epidemiological studies produce much less reassuring results. By collating data from a dozen studies of workers at nuclear sites in the United States, Canada and the United Kingdom, authors have come to the conclusion that the risk of cancer and leukaemia was higher for workers with a cumulative exposure exceeding 10 mSv compared to those with a cumulative exposure below 10 mSv. The risk increased with cumulative exposure dose. These researchers regard leukaemia as a “sentinel cancer” for evaluating the effects of low-dose ionising radiation, as it has a shorter latency period than other diseases and is thus the first to develop (Dodic-Fikfak 1999).

A study by the International Agency for Research on Cancer (IARC), known as the 15-country study, is very much along the same lines. It takes into account radiation doses received between the 1960s and the mid-1990s by more than 400 000 nuclear industry workers in 15 countries. According to the study findings, there is an increase in cancer risk even at the low doses typically received by nuclear workers in this study (Cardis 2005).

Besides epidemiological data, dose monitoring is another way of keeping tabs on the exposure of workers to the risks associated with ionising radiation in the workplace.

For the past twenty or so years, monitoring data on workers have shown a decrease in average doses. At the Sellafield nuclear reprocessing plant in the UK, for instance, the annual average exposure dose was 10 mSv in 1980, with about 1 200 workers exceeding 15 mSv. In 1998, the average dose had dropped to 1.4 mSv and no workers exceeded 15 mSv.

Now, in the early 21st century, the average dose received by nuclear workers has fallen still further. In a group of 16 of the countries participating in the European Study on Occupational Radiation Exposure (ESOREX), the average annual worker dose in the nuclear industry fell from 2.23 mSv in 1996 to 1.51 mSv in 2000. The number of incidences of workers exceeding an annual dose of 20 mSv was 40 per 10 000 in 1996, compared with just 11 per 10 000 in 2000. Since then, some countries have improved on this even further.

In the UK, average exposure in the nuclear energy sector was between 0.3 and 0.6 mSv in 2004. Of the 18 969 British workers monitored, just one (a maintenance worker) received a dose higher than 15 mSv. In 2007, the average dose received in the German nuclear industry was between 0.5 and 1 mSv.

However, all is not always well in the world of nuclear power plants, as is apparent from the situation of nuclear subcontractors.

6.3. Maintenance and decommissioning of nuclear power plants: a recurring concern in France

France has the largest number of nuclear reactors in operation in Europe (58 in 2010), providing nearly 200 000 direct and indirect jobs. In the nuclear industry alone, nearly 58 000 workers were monitored for radiation exposure in 2008.

6.3.1. Subcontracting and "servitude"

Eighty per cent of the maintenance work on French nuclear power plants is done by employees of outside contractors to the operator EDF (Électricité de France). The following table of exposures of monitored nuclear workers shows that subcontracted workers bear the brunt of the collective dose received by employees required to work with nuclear reactors.

Table 2 **Monitoring of workers exposed to ionising radiation in France – nuclear energy sector (2009)**

Company	Number of employees	Collective dose in man – sieverts/year*	Average individual dose (mSv/year)**
EDF	19 647	6.70***	0.34
Areva	13 333	5.89	0.44
Contractors	17 743	11.83	0.67

* The collective dose received by all exposed workers or by a group of workers is the sum of the individual doses and is expressed in man-sieverts per year. It indicates the total exposure of a group of workers as a whole that can be compared with that of another group of workers, and followed up over time.
** The average dose is calculated by dividing the collective dose by the number of exposed workers.
*** This value only takes into account exposure to photons, since the dosimetry laboratory does not provide neutron dosimetry results.
Source: French Institute for Radiological Protection and Nuclear Safety (IRSN) (2010), p. 32

The doses received by employees of outside contractors are mainly recorded during unit outages at nuclear power plants, i.e., when nuclear reactors are shut down for refuelling or for maintenance and repair. For example, people working on the steam generators (of which there are between two and four per reactor), setting up inspection robots to check the internal nozzles, generally receive a dose of 4-6 mSv when exposed for about two minutes. The dose rate there is around 150-200 mSv/h. It should also be pointed out that contractors often put pressure on their employees not to accumulate significant doses carrying out a given job in order to prevent the risk of exclusion or the loss of a contract. According to trade union sources, this results in some employees not wearing their personal dosimeter during potentially high-dose operations, or even wearing someone else's dosimeter.

In the 1990s, the growth of contingent employment and the occupational and health risks facing subcontracted workers in the French nuclear industry were repeatedly denounced, especially by CGT trade union official Michel Lallier and labour sociologist Annie Thébaud-Mony who, in a work published in 2000, described the working conditions of these workers as "servitude" (Thébaud-Mony 2000, Lallier 1995).

In a more recent work, *Travailler peut nuire gravement à votre santé* (Working can seriously damage your health), the sociologist presents personal testimonies from "outside workers" in the nuclear industry (Thébaud-Mony 2007).

Éric is a seasonal plumber. He sometimes has to open the manholes of steam generators, a job he dislikes. He says: "You go in, you come out – three minutes, and you've already received 1 or 2 mSv! It's the primary cooling system, where radioactive water is flowing. Radioactive particles get deposited on the metal. You have to work fast. (...) They tell us if we stick to the limits, we'll be fine! But we've worked there for more than 10 years and get much more than 20 mSv a year."

Martial inspects plant piping, checking for cracks and corrosion. He is exposed from two sources: the plant itself if the structure on which he is working is radioactive, and his testing equipment, which has a cobalt source. He says: "I've worked in radiographic inspection on an aerospace site, but in a protected environment – in other words, in a booth where you're not exposed to radiation, except if there's a leak. The working conditions in a nuclear power plant are completely different from those in other industries, because you're working in places where it's difficult to install protection due to space limitations. There are no booths."

Antonio has also been a victim of "nuclear servitude", the tasks carried out in the nuclear industry by outside contractors, such as decontamination and various radiation protection activities. He says, "I remember one time when I was working at night. There weren't any health physicists around. My boss asked me to take off my Saphymo (dosimeter) and do something that would have doubled my dose. I refused and got the sack. That's how it is!"

In 2008, journalist Alexandra Colineau wrote an article on the "nuclear nomads" who travel all over France from one power plant to the next, carrying out maintenance in the most radioactive areas, and who call themselves "nuclear slaves"[44]. They are paid the minimum wage, but are employed by major industrial groups (Vinci, Areva, Suez), each of which has several dozen subsidiaries. Tender-based outsourcing puts subcontracting firms under pressure. Workers talk about the fact that a unit outage used to last two or three months in the early 1990s; in 2008, the longest took a month and a half. According to trade union official Michel Lallier (Colineau 2008), "The problem is that the outside contractors are constantly changing from one power station and company to another. All at once there's a huge amount of confusion regarding the distribution of the exposure certificates that these firms are supposed to provide to their employees. What we're seeing now is that most of the guys retiring have no certificate of the toxic dose they've received over their working lives (...) so when the first cases of cancer develop, these employees won't be able to get their illness recognised as an occupational disease."

In an investigative survey done in July 2011, the Mediapart information website condemned the fact that contract maintenance workers were pushed to enter reactor buildings when the reactor was operating, sometimes at 100% power[45], thereby increasing their risk of exposure to neutron radiation. Depending on their energy, neutrons have biological effects 5 to 20 times greater than those of gamma or X-rays. Under normal conditions, these neutrons remain inside the reactor containment, but cracks in the fuel cladding may cause radioactivity to leak into the primary cooling system. Maintenance work in the containment of operating reactors, which is exceptional in principle, is in fact thought to be carried out relatively often, to the alarm of French Nuclear Safety Authority inspectors. The Mediapart article stressed that a unit outage to enable contract employees to work without putting themselves at too much risk is very expensive, costing several hundred thousand euros for a few hours.

For the past few years nuclear workers have not only been worried about their health; the actual safety of nuclear power plants has also been a matter of concern. In a documentary shown in spring 2009 on the Belgian French-language channel RTBF and the Franco-German channel Arte, one worker commented, "I remember my manager saying to me: *Now we're going to go from zero risk to a calculated risk. I think they forget we're working in a nuclear company and that there can't be any such thing as a calculated risk*" (de Halleux 2009).

In September 2009, the *International Herald Tribune* echoed the concerns of French nuclear subcontractors about the considerably shorter maintenance period during outages. Yves Marignac, an expert with the WISE-Paris organisation, confirms the workers' accounts[46]. He says that safety margins in French nuclear power plants are shrinking as plants age, economic pressure mounts and experienced staff retire, and points out that "even if it remains very unlikely, the probability of a serious nuclear incident is rising because of the way things are evolving, and this in itself is very worrying".

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[44] More recently, a novel has even been written about them. See Filhol, E., *La centrale*, P.O.L, Paris, 2010, 140p.

[45] For more information (in French): http://www.mediapart.fr/journal/france/240711/edf-banalise-l-exposition-l-atome-de-ses-travailleurs.

[46] Yves Marignac is Executive Director of WISE-Paris, the World Information Service on Energy. WISE also works for environmental organisations like Greenpeace and for government agencies. For further information: www.wise-paris.org.

6.3.2. Decommissioning operations

Owners of nuclear power plants that have reached the end of their operating lives can choose between three options: immediate dismantling and removal of contaminated material to specialised sites (storage, burial), safe enclosure of the facility to allow the radioactivity of the contaminated material to decay to a safe level before dismantling occurs, or monitored entombment of radioactive parts of the plant.

The workers employed in decommissioning operations are exposed to a potentially higher radiation risk, and also to toxicants such as asbestos, silica, beryllium and other heavy metals.

Little information is available about the decommissioning of old nuclear facilities. Unscear has data on the monitoring of 2 000 workers involved in decommissioning 13 nuclear power plants in the United States during the period 1995-2002. The average annual effective dose for these workers was around 2 mSv. In France, EDF has nine reactors in its decommissioning programme (IRSN 2008). In 2009, the Cadarache site in southern France encountered serious problems during decommissioning of a MOX unit[47] (see box below).

Decommissioning in France: a risky business

On 12 October 2009, the French Nuclear Safety Authority (ASN) drew up a report and suspended decommissioning of the plutonium technology facility (ATPu) at the Cadarache nuclear research centre in southern France. Whereas plutonium deposits in the facility's glove boxes had been estimated at around 8 kg during the operating period, the investigators now think that the total quantity to be recovered could be in the region of 39 kg. The ASN takes the view that the failure to detect this underestimation of plutonium deposits while the facility was operational, and the delays in reporting the event to the ASN – the company had known about it for five months and claimed to have informed the regulatory authorities verbally – show up failings in the operator's safety culture. The ATPu produced MOX fuel for nuclear reactors for 40 years and was authorised for decommissioning in March 2009. According to the ASN, underestimating the quantity of plutonium drastically reduced safety margins designed to prevent criticality* accidents, which could potentially have serious consequences for the workforce. A second irregularity was also discovered in the ATPu, when 10 kg of powder used to fabricate MOX fuel pellets was found in one of the facility's cells. This quantity is close to the critical limit of 11 kg, although safety regulations usually allow no more than 4 kg.

Generally speaking, all radioactive material is removed before a start is made on decommissioning a plant. In the case of Cadarache, these two operations were combined.

* The criticality risk is defined as the risk of spontaneously starting a nuclear chain reaction when a quantity of fissile material exceeding a certain threshold value (the "critical mass") is located in the same place, and in the presence of a substance such as water, for example.

6.4. The rebirth of nuclear power and its possible demise post-Fukushima

In 2009, the IAEA reported that more than 60 countries – mainly in the developing world – were interested in launching nuclear power programmes, and projected that 250 new

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[47] Cadarache has been chosen to host the prototype nuclear fusion reactor known as ITER. This project brings together seven partners (Euratom, China, India, Japan, South Korea, Russia and the United States). There is also a new high-flux fission test reactor under construction on the same site.

nuclear power plants would be built by 2030 (IAEA 2009). Until the Fukushima accident, nuclear energy proponents once again seemed to be on the up, particularly in Europe.

Evidence of this can be seen in the European Parliament's approval in 2007 of a report on energy resources, one conclusion of which was that "nuclear energy is indispensable if basic energy needs are to be met in Europe in the medium term" (European Parliament 2007). Despite some dissenting voices, the revival of nuclear power appeared to be well under way. Two new third-generation EPR-type reactors (European Pressurised Reactor) are under construction, one in Olkiluoto (Finland) and the other in Flamanville (France). In the UK, the new generation of reactors was scheduled to come online starting in 2018, but is still in planning phase.

Sweden had a dramatic change of heart in 2009, when it decided to end its nuclear moratorium. The construction of new reactors was once again authorised, provided that they were built on existing sites and replaced end-of-life reactors. Italy had also reversed its phase-out of nuclear power. France and Italy had signed a cooperation agreement in 2009, under which France would build four nuclear power plants in Italy. Early in 2011, Poland decided to start a nuclear energy programme. The first Polish power plant should be operational by about 2022. In February 2011, the Spanish government voted to scrap the 40-year operating limit on its nuclear power plants. At the same time, France and Belgium were also preparing to increase the lifespan of their current power plants beyond 40 years. In October 2010, the lower house of the German Parliament approved a bill submitted by Angela Merkel's government to extend the life of the country's 12 nuclear power stations.

All that was before Fukushima, of course. The German government was the first to react strongly to the Japanese tragedy. On 15 March 2011, barely two days after news broke about problems at the Fukushima power plant, Chancellor Angela Merkel declared first a three-month moratorium on nuclear power plans, then an immediate shutdown of all reactors that had been in operation for more than 30 years. Finally, on 30 May 2011, the German government decided to phase out nuclear power by 2020.

In a referendum on 12 and 13 June 2011, 94% of Italian voters opposed the government's plans to resume nuclear power. No Italian region seems inclined to host a nuclear power plant, particularly since the risk of an earthquake is higher in Italy than in the rest of Europe.

In September 2011, the Swiss Parliament voted to phase out nuclear power. The five Swiss reactors will gradually be taken off the grid between 2019 and 2034. In October 2011, the agreement to form a coalition government in Belgium provided for shutdown of the oldest reactors by 2015, with a full nuclear exit scheduled for 2025.

On 25 March 2011, the Heads of State or Government of the EU Member States decided to subject the EU's 143 nuclear reactors to "stress tests" as part of a safety assessment. The scope of these tests was defined at the end of May after heated discussion. Only the consequences of earthquakes, flooding and major climate variations would be examined at European level. Scenarios involving aircraft crashes, malevolent intent or terrorist acts, which the European Commission wished to have included, were generally not included in the mandate due to opposition from some countries. In November 2011, the European Commission announced that the results of the stress tests on nuclear power plants were expected in 2012, but that plans to tighten up safety policy were already being considered.

In the US, the nuclear safety authority (NRC) asked the operators of 104 American reactors to review their accident management plans, pending inspection by the NRC.

Will there be a pre- and post-Fukushima? At the time of publication (February 2012), it is too soon to say either way. One thing is certain: despite the public's renewed fears about nuclear power, fuelled by the events in Japan, the chances are that the nuclear industry, its powerful lobby and the governments most in favour of this technology – France first and foremost – are not going to simply throw in the towel. A great deal of money has already been invested and the political, economic, social and environmental stakes are huge, not least because the European industry will be defending its expertise in an increasingly competitive market. There is a growing trend to invite international tenders for the construction of new power plants and the battle is tough. Private firms, with government support in some cases, are evolving in a highly competitive environment. The European – and particularly French – industry is being severely tested, especially with the mounting demand for reactors that have a lower power output, are less costly and take less time to build than EPR. The nuclear reactor manufacturing industry in the US is focusing on the development of smaller reactors that require less capital outlay. Meanwhile Russia is committed to building very small floating reactors to supply electricity to remote regions like the Arctic.

Some energy analysts, however, are convinced that nuclear power is doomed to a slow decline, which in fact started well before Fukushima (Schneider 2011). According to a nuclear industry report submitted to the European Commission in February 2011, the industry hopes to deploy 160-170 gigawatts (GW) in order to maintain the current 30% share of nuclear electricity in the EU's overall energy mix through to 2050 (Foratom 2011a). This is significantly higher than the 134 GW nuclear electricity generated in 2011, and would require five new reactors to be built every year. Even were there to be political and popular support for this objective, which is far from being the case even in France, the delays and additional costs of the reactors currently under construction would seriously jeopardise it – not to mention the increasingly important role that alternative energy sources are set to play in the future.

By the end of 2011, however, the strength of feeling aroused by the Fukushima accident had subsided somewhat. According to Foratom, the trade association for the nuclear industry in Europe, 13 EU countries still held the view that nuclear energy would be integral to their energy supply, and that nuclear power plants would still be operating within their borders in 2050. Poland, Finland and the UK, which had briefly considered reviewing whether or not to build new power plants, have since confirmed their previous decision (Foratom 2011b).

On 9 February 2012, almost a year after Fukushima, the United States Nuclear Regulatory Commission (USNRC) approved licences to build two new nuclear reactors on the Vogtle site (in Georgia), the first authorised since 1978.

The human and environmental consequences of Fukushima are still not fully known at the time of writing, but were it to be just a blip in the history of the development of civil nuclear power, the public would still be entitled to demand transparency in an industry lacking this quality and to question those in power on the many unknown variables. Among a long list of questions to be addressed, the debate should focus on the health risks associated with extending the lifespan of existing nuclear facilities, the growing number of people and countries exposed to the risk of a nuclear accident, the concerns about the development of low-cost reactors with lower safety standards, the intense competition for uranium supplies and the problem of leaving nuclear waste as a legacy for future generations. Not to mention the price paid in terms of diseases contracted by workers employed in maintaining operating nuclear power plants and decommissioning end-of-life reactors.

Key points

A major WHO epidemiological study of more than 400 000 nuclear industry workers showed excess mortality compared with the general population, even at low doses, thus confirming the hypothesis of a linear no-threshold relationship. Even though the average dose of ionising radiation received by workers in this sector continues to decrease, this trend offers only a semblance of reassurance. In fact, dosimetric records do not necessarily reflect the actual exposure of all workers, in particular employees of outside contractors carrying out maintenance on nuclear power plants. The nuclear energy sector is still very high risk, as the accident at the Fukushima power plant on 11 March 2011 proves. Will its expansion, which seemed promising in early 2011, really be called into question, in spite of the decision by several nuclear states to shut down their reactors within the next ten years?

Conclusion

The exposure to low dose ionising radiation that workers in many sectors face in the workplace is increasingly a nightmare of uncertainties about the health impacts, and greeted with little better than doublespeak from officialdom. So the European trade union movement is more than ever duty-bound to press the overriding importance of a collective and individual protection approach based on the precautionary principle.

Exposure to ionising radiation has become widespread with the growth of industries using natural radioactive materials, the expansion of air travel, nuclear power and the increased use of radioactive sources in civil engineering and especially so in the medical sector where the development and marketisation of computerised medical imaging have increased the doses to workers and patients, and brought risks of accidental patient exposure.

Current scientific knowledge shows that individuals' physiological responses to ionising radiation exposure vary widely. The health effects should become clearer as knowledge in molecular biology advances. A better understanding of biological mechanisms could well throw the abstract concept of dose as the single risk indicator – on which Community radiation protection legislation is based – into question.

But even understanding the risks of low dose ionising radiation better, the precautionary principle and collective prevention measures must still take precedence.

In what can at best be described as the highly-charged debate about the future of nuclear energy, some traditionally pro-nuclear groups are mounting an international campaign to downplay the human health effects of exposure to low dose ionising radiation.

The monumental implications of Fukushima for power generation and medical insurance mean that this lobby could try to inculcate a passive public acceptance of major accident situations.

At the time of writing (February 2012), European radiation protection legislation was still under review. A Commission proposal for a directive had just been put out to various stakeholders, including the European Economic and Social Committee on which the unions sit. It is a redline issue for the trade union movement that the basic rules remain rooted in the ALARA principle that any exposure must be kept "As Low As Reasonably Achievable", economic and social considerations being taken into account. That in turn means strengthening the ALARA principle's underlying concepts, i.e., the "justification" of practices, with increased accountability of the different players involved, and the "optimisation" of protection.

Measurement of whole body and body part (limbs, lens of the eye) doses received by workers requires better follow-up that allows for the growing internationalisation of the labour market and increased outsourcing by the nuclear power industry.

The Fukushima accident showed that the international trade union movement must give particular attention to standards of protection in crisis and emergency situations. They need to be clarified, not least by defining the roles of prevention services, improving medical surveillance and extending their scope to temporary and outside workers.

The nuclear power industry is where the dose received by outside workers - often on short-term contracts – tops the dose distribution scale. This makes it vital that not only a Europe-wide system for recording doses received should at last be got going, but also for greater protection to be given to these vulnerable workers. Stricter limits and carefully elaborated dose constraints need to be looked at.

Optimisation of protection based on the ALARA principle should be extended to all sectors and strengthened in practice. This is especially urgent in the medical sector where the growth of nuclear medicine has increased the number of radiation sources in recent years. The growing number of exposed workers in what were even recently considered as non-nuclear industries means that protection must be extended to sectors like mining, the phosphate and refractory industry, aerospace, etc.

Appropriate training and updated information on risks are required for proper optimisation. Experience has shown that safety culture must be integrated into work organisation.

Effective measures must be taken to prevent the spread of radioactivity in work environments. Records of contaminations should be linked to dose tracking and be taken into account in epidemiological studies. The stochastic risk (potential long term health effects, in particular the cancer risk) should be recognised in employer's liability and public and private occupational accident and diseases insurance.

The Fukushima accident again elicited a weak nuclear safety response from the European Commission, not least in the debate on stress tests, which were dominated by Member States' self-interest. The European trade unions are hoping that the Euratom Treaty will be revised to give it a broader remit in radiation protection, nuclear safety and waste, metal-detector checks, among others, and provide for combined risk management (heavy metals, chemicals , UV, etc.).

Nuclear regulations also need to be better integrated into the prevention of workplace risk covered by the 1989 Framework Directive on health and safety at work. This will require the Euratom Treaty to become a functional part of the EU legislative framework and recognition of the social partners' role.

There is little transparency about initiation and implementation, which are currently the responsibility of multilateral networks of cooperation and the regulatory authorities of the 27 member countries. The European Union needs to create an authority of stature that incorporates the related competencies and services.

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Annexes

Annexe 1
Occupational diseases recognised in France, the United Kingdom and Germany

France

Table 6-type occupational diseases in France, in 2010 include:
- anaemia, leukopenia, thrombocytopenia or haemorrhagic disease resulting from acute radiation exposure;
- anaemia, leukopenia, thrombocytopenia or haemorrhagic disease resulting from chronic radiation exposure;
- blepharitis or conjunctivitis;
- keratitis;
- cataract;
- acute and chronic radiodermatitis;
- acute radiation damage to the mucosal epithelium;
- chronic radiation injury to the mucosa;
- radiation-induced osteonecrosis;
- leukaemia;
- primitive bronchial / lung cancer due to inhalation;
- bone sarcoma.

United Kingdom

Disease Number 1 of the United Kingdom's list of diseases covered by Industrial Injuries Disablement Benefit covers the following ionising radiation-induced cancers: leukaemia (other than chronic lymphocytic leukaemia) and cancer of the bone, female breast, testis or thyroid.

The types of job concerned are those where exposure to ionising radiation could double the risk of occurrence of one of these conditions. UK occupational diseases legislation does not recognise radiation-induced cataracts and dermatitis. The philosophy underlying this decision may be that the level of exposure required to cause these two conditions would be so high that they would classify as an "industrial injury", the consequences of which would be covered by industrial injuries legislation.

On the question of how many ionising radiation-induced diseases are compensated in the UK, the British Secretary of State for Work and Pensions said in an e-mail to the ETUC, "The only claims in this category would be for leukaemia or cancer of the bone, female breast, testis, or thyroid – where there has been occupational exposure to high levels of electro-magnetic radiation or ionising particles. The number of these claims is too small to be statistically significant and is not published" (DWP Press Office).

In the UK, a large proportion of the compensation received for occupational diseases is won in the courts.

Germany

Ionising radiation-induced occupational diseases compensated in Germany

	2006	2007	2008	Total
Liver, unspecified	4	0	3	7
Malignant neoplasm of larynx	5	2	1	8
Upper lobe, bronchus or lung	45	27	30	102
Middle lobe, bronchus or lung	5	2	2	9
Lower lobe, bronchus or lung	29	14	17	60
Bronchus or lung, unspecified	74	64	56	194
Malignant neoplasm of skin (other than melanoma)	2	4	1	7
Malignant neoplasm of thyroid gland	8	2	0	10
Lymphoid leukaemia	0	0	2	2
Myeloid leukaemia	1	1	1	3
Other diseases of blood and blood-forming organs	1	3	1	5
Other specified cataract	1	0	1	2
Acute pulmonary manifestations due to radiation	10	9	6	25
Radiodermatitis	1	2	0	3
Other/unspecified	0	2	3	5
Total	186	132	124	442

Translation taken from the website of the International Statistical Classification of Diseases and Related Health Problems.
See: www.icd10.ch
Source: DGUV Referat BK-Statistik/ZIGUV D-53757 Sankt Augustin; erstellt am 22. Okt. 2009

Annexe 2
Lists of veteran diseases compensated in France and in the USA following nuclear testing

France

For civilian and military victims of French nuclear testing, the list of radiation-induced diseases liable to be recognised and compensated (subject to compliance with certain timing and residency conditions) was published on 13 June 2010.

This list comprises:
– leukaemia (other than chronic lymphocytic leukaemia);
– breast cancer (female);
– thyroid cancer due to exposure during the growth period;
– skin cancer (other than malignant melanoma);
– lung cancer;
– colon cancer;
– salivary gland cancer;
– oesophage cancer;
– stomach cancer;
– liver cancer;
– bladder cancer;
– ovarian cancer;
– brain and central nervous system cancer;
– bone and connective tissue cancer;
– uterine cancer;
– small intestine cancer;
– rectal cancer;
– kidney cancer.

Source: Executive Order 2010_653 of 11 June 2010 implementing the French Nuclear Testing (Recognition and Compensation of Victims) Act, Official Journal of the French Republic of 13 June 2010, text 10 of 42

United States

The 1988 Radiation-Exposed Veterans Compensation Act relates to servicemen, known as veterans, who have been exposed to ionising radiation whilst on military service. Veterans may receive a monthly incapacity allowance, which varies depending on the disability, if they suffer from one of the conditions on the list of diseases presumed to result from exposure to ionising radiation during their service. Besides the diseases on the French list, this list includes cancers of the urinary tract (other than kidney cancer), non-Hodgkin lymphomas and multiple myeloma. Thyroid and breast cancer are not subject to any sex or age conditions. Other diseases not on the list, but that may potentially be linked to exposure to ionising radiation, may also be compensated subject to certain conditions relating to the level of exposure and the latency period.

The 1990 Radiation Exposure Compensation Act (RECA) relates to workers employed during the test period in uranium mining, milling or transportation, and also to persons present on the test sites or in the zones affected by fallout from atmospheric testing in Nevada. RECA grants lump-sum compensation (from $50 000 to $100 000) for a list of diseases that vary depending on the category of the affected individuals.

For miners, only lung cancer and certain non-malignant lung diseases are taken into account. For uranium mill employees and ore transporters, kidney cancer and several renal diseases are also added to the list. For persons exposed on-site or in zones affected by test fallout, the list is similar to the French list, but has no restrictions for breast or thyroid cancer. As of 13 February 2011, 23,557 people had received compensation under RECA, including almost 15 000 people present in contaminated zones.

Sources: www.publichealth.va.gov and www.va.gov

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