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Managing Radioactive Waste: Issues and Misunderstandings

Morris Rosen

We are all continually exposed to cosmic radiation, and natural radioactive elements are in the air we breath, the earth we walk on, the homes we live in and in the food we eat, as well as in our bones and tissues. In comparison to this ongoing and unavoidable exposure from *natural* background sources, exposure from *artificial* sources has a small impact. The artificial radiation exposure is almost totally medically related, with routine nuclear power activities contributing only a very small fraction of one percent to the daily exposure, an addition which can be best characterised as minor (see Figure 1).

Natural background exposure, both from external and from internal radiation due to inhaled or ingested radioactive substances, is location dependent. Cosmic radiation varies with altitude and natural radioactive substances in the ground vary significantly by location.

Millions of Europeans living in locations with high levels of naturally occurring radioactive radon gas in Austria, Finland, France, Spain, Sweden and the United Kingdom receive some ten and many even 20 times the average world background exposure that is received by residents of New York City, where the radon gas levels are significantly lower. These higher radiation exposures are further exceeded in localised areas, as in parts of Brazil, India and Iran, where individual exposures can be more than one hundred times the world average and more than one million times the average exposure from routine nuclear power activities.

High and Moderate Level Exposures

The biological effects of radiation are exposure dependent. High level exposures, 3000 to 4000 times the natural background, can damage and kill sufficient cells to destroy organs and cause a breakdown in vital body functions, leading to severe disability or death within a short time. Exposures that could result in such early effects occur only in near proximity to a high intensity radiation source, which can cause a rapid and large exposure. There have been instances of direct exposure to industrial and medical radiation sources that have resulted in death within several days.

Moderate level exposures do not cause early effects, but can lead to delayed effects that appear as cancers in the longer term. The Radiation Effects Research Foundation (RERF) in Hiroshima has carried out over the past five decades an extensive investigation of 87 000 survivors – those not killed by the initial blast of pressure, heat and intense radiation – who were exposed in the 1945 atomic bomb explosions at Hiroshima and Nagasaki (see Figure 2).

As with any population, about 20% of the 87 000 survivors (somewhat less than 20 000) would be expected to die from non-radiation induced cancers. Now, half a century later, epidemiological studies are indicating additional cancer deaths, estimated at a few hundred for the common cancer types and a few dozen for the rare types. Follow up studies continue with a projected eventual total of some 600 radiation induced cancer deaths, an overall addition of 0.7% to the normal 20% cancer

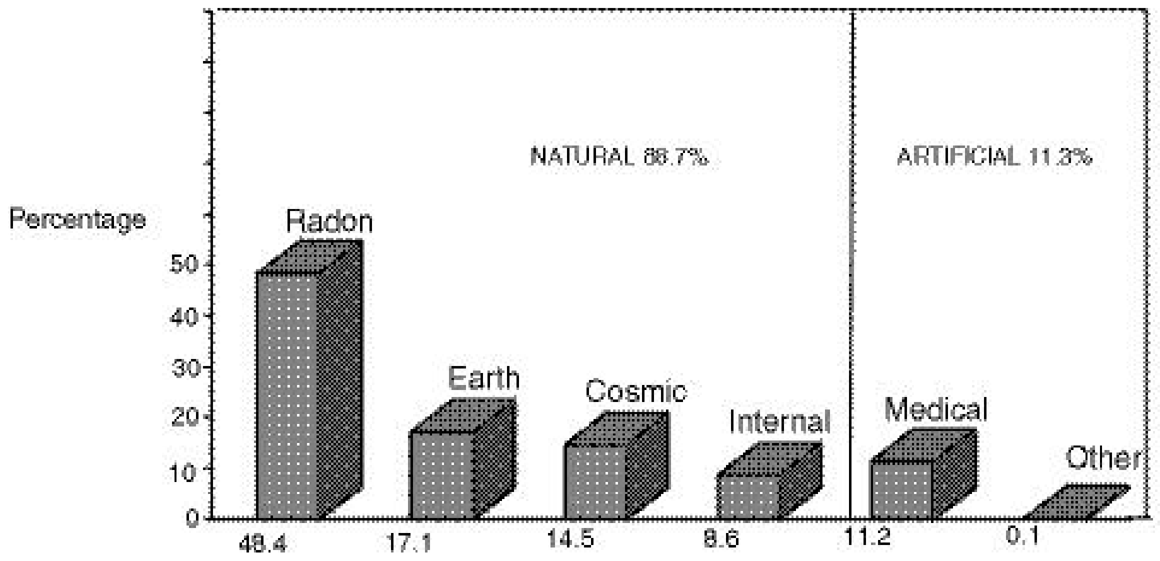

Figure 1. Annual average individual radiation exposure from natural and artificial sources (2.7 mSv total) (Source: UNSCEAR, Effects and Risks of Ionizing Radiation, UN, New York, 1993).

death rate. An expected several-year loss in the survivors 'life expectancy will not materialise, as above average health care through early diagnosis and treatment of medical disorders, including cancer, is leading to increased longevity.

Small Exposures

Low level exposures include those from diagnostic x-ray examinations and nuclear power activities. They also include the average yearly natural background as well as the higher background exposures received in many locations. Any delayed effects from low level radiation exposure would be extremely small and could not be demonstrated through epidemiological studies. Environmental, dietary and genetic influences cause the fatal cancers that occur in some 20% of the population of industrialised countries. The specific yearly number fluctuates by several percent, making it practically impossible to establish the influence of low level radiation exposures.

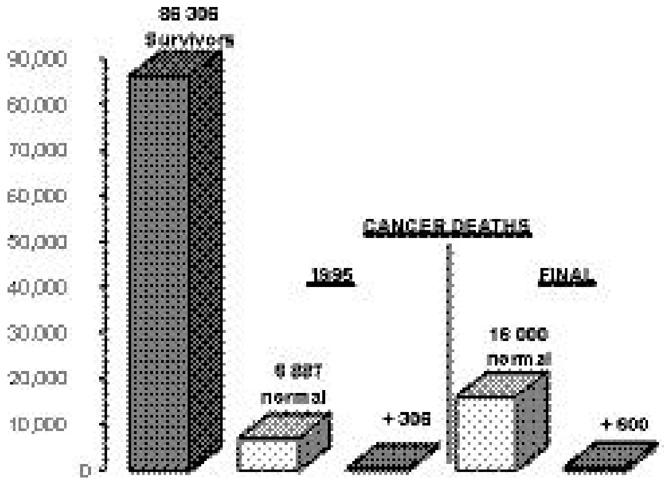

Figure 2. Radiation Effects Research Foundation (RERF) life span studies, showing A-bomb survivor cancer deaths to 1995, and projected total (Source: UNSCEAR, Effects and Risks of ionizing Radiation, UN, New York, 1995).

In an attempt to quantify the low level radiation risk, several extensive mortality studies have been carried out on radiation workers — a group that receives exposures higher than the public — but no statistically significant relationship has been found, except for possible synergistic effects due to smoking or other pollutants. Neither has an increased occurrence of cancer deaths been observed in populations living in the high natural background radiation locations, which are also in the low level range. However, the mainstream of radiation biologists maintains it is prudent to assume there is no threshold below which radiation is entirely harmless, i.e. that an extremely low cancer risk exists for any exposure. The public understandably focuses on this assumption that a risk exists for any exposure, but loses sight of the overriding fact that not only is this a cautionary assumption, but more significantly that the risk is also indiscernibly small.

Demanding Regulations

Stringent safety regulations and procedures have been developed to protect against small exposures, which add to the larger unavoidable and very variable natural background exposure that is not regulated. Such measures cover the small environmental releases from nuclear power

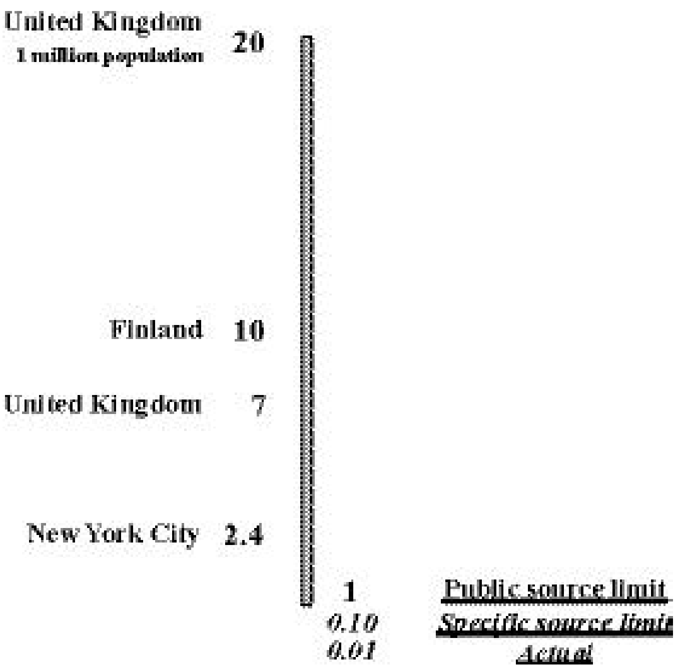

Figure 3. Variations in background radiation exposure (left), and regulatory limits for exposure (mSv/year) (Source: IAEA).

facilities. Although some countries recommend measures to reduce persistently high indoor radon gas levels in homes, the unavoidable natural background exposure – due to radon gas as well as cosmic radiation – is overwhelmingly excluded from strict regulations, as it is simply not feasible to reduce this exposure except through relocation and unacceptable restrictions on individual lifestyles.

There are numerous relatively high exposure situations that are also not regulated because control is impractical or they are judged beneficial. Exposures to airline passengers and crews, and the relatively large exposures to cosmonauts, are not regulated. A Paris to New York flight would be similar to one year's exposure from living near a nuclear power plant. Airline pilots commonly receive higher exposures than radiation workers at nuclear power plants. Cosmonauts can receive several times one year's natural background exposure during a typical voyage.

The stringent nature of radiation protection standards for the additional exposures above natural background is shown by the total annual exposure limit established for an individual member of the public. The total additional exposure above the natural background permitted from all regulated sources is limited to some 40% of the world average background exposure, that is 1 mSv of a 2.4 mSv average, and is far below the exposure in the many high natural radon gas locations (see Figure 3). Based on a model predicting an upper value for radiation health effects, an exposure over one year of every person in a population of one million people to this total individual limit would cause an estimated 50 radiation induced fatal cancers in addition to the approximately 200 000 normally expected cancer deaths.

However, the maximum exposure limit for a single regulated source, such as a nuclear power plant, is limited in some countries to as low as 10% of the total 1 mSv limit. For this lower individual source limit the potential cancer deaths are reduced to 10% of the estimated 50 fatal cancers, or to five in a one million population if every person were exposed to the limit. However, only a small fraction of the population could possibly be continuously exposed over an entire year and accumulate even this lower limit of exposure. Today's regulatory requirements in effect would result in a small fraction of the estimated five fatal cancers, or likely not one cancer death in a one million population attributable to this regulated source.

Is such a zero health effects policy reasonable or sensible? This degree of public protection is not applied to vastly greater hazards and more likely effects. The actual yearly individual risk to incur a radiation induced cancer from the routine operation of a nuclear power plant has a probability comparable to initially drawing all four aces from a full deck of playing cards and having the first card of a second deck also being an ace. Over a plant's 50 year lifetime, the risk would be equivalent to drawing between three and four aces as the first cards from a single deck and this, as already noted, using a cancer risk model predicting an upper range of health effects.

In reality, the demanding regulations govern radiation exposures that are not only commonly exceeded by normal variations in natural background exposures and some routine activities, but also could result only in exceedingly small or possibly even zero health effects. This is not to argue for less stringent limits. This is only to point out that the extremely high level of protection, and associated requirements, is contributing to a misunderstanding and exaggerated perception of radiation health effects.

As discussed in the following sections, the philosophy and guidelines governing radiation protection have a critical impact on the management of radioactive waste. It can contribute to a misunderstanding of both the hazards and the technologies available.

Waste Facts

Waste can be broadly categorised as domestic, industrial and agricultural. In the OECD countries alone, some 9 billion tonnes of solid waste is produced yearly with 300 million tonnes classified as hazardous. Radioactive waste is a minuscule proportion of all waste. The small radioactive portion can be seen by the tonnes of waste produced annually in France, where nuclear power supplies 75% of electricity to a population of some 60 million. About 84 000 tonnes of the 650 million tonnes of total waste produced yearly (including 60 million tonnes of hazardous waste) is radioactive. Another illustration is provided by the data from the United Nations Environmental Programme showing that of the 200 million tonnes of hazardous industrial waste produced in the United States annually, less than 100 000 tonnes or 0.05% is radioactive waste, comparable to the small 0.015% share in France.

As the quantities of radioactive waste are exceedingly small a confinement strategy is possible, beginning with the uranium fission process through waste disposal, essentially isolating it from the environment. In sharp contrast, the large quantities of toxic chemical waste from many industrial activities, including fossil energy production, allow mainly a dispersion strategy. Much of the waste is dispersed into the environment at concentrations considered not harmful with some buried in shallow ground, there being no practical economic alternative. While the immediate impact can be small, over many years the cumulative waste from a dispersion strategy can have a significant negative impact.

Radioactive waste falls into three principal categories depending on the type and more importantly on the concentration of radioactive elements — a measure of the overall radiation level. Low level waste, with relatively low concentrations of radioactive substances, originates from a variety of sources. Most intermediate and all high level waste, with high concentrations of radioactive substances, originates from nuclear power and military activities.

Low level radioactive waste is defined as waste not exempt from regulations, the precise conditions varying from country to country. The radiation level is sufficiently low that shielding, even for highly compacted waste, is not necessary. Simple protective measures are adequate during handling with consequential radiation exposures and health effects not possible, although the public perception is quite different. The levels are low enough that if fertiliser, Brazil nuts and coffee beans were produced at a nuclear power plant site they could be treated as low level waste since they contain natural radioactive substances, such as radioactive potassium and radium.

In contrast, the radiation level of intermediate level waste requires metal or concrete shielding, and remote handling devices can be utilised. For high level waste, thick shielding and remote handling devices are necessary.

Radioactive waste can also be categorised by the decay period of its radioactive contents, a measure that is useful for waste disposal considerations. Very short lived substances with half lives measured in days or months, such as used for some medical purposes, need be stored for only relatively short periods to allow the radioactivity to decay to insignificant values. Short lived substances with half-lives measured in tens and even a few hundreds of years require confinement in near surface facilities for periods of several hundred years. It is only the long lived substances, contained principally in high level waste, that may require deep geological disposal for thousands of years.

Chemical toxic waste can also be categorised by the period for which it remains toxic. Some chemical compounds can be treated initially to reduce their toxicity, and others become less toxic as they decompose with time. However, many of the chemical substances in hazardous waste remain toxic permanently.

Diverse Sources

Nuclear power

Radioactive waste arises at each stage of the fuel cycle, with the vast majority of radioactive substances being contained in spent fuel or in the solidified reprocessing waste. Front end waste consists principally of waste rock and so called mill tailings that contain relatively minor amounts of radioactive substances. The small quantity of radon gas released from the waste tailings does not result in significant public radiation exposures as it can only add a small fraction to the natural radon gas exposure that exists everywhere. Nevertheless, efforts are made to reduce the emissions, such as by covering disposal areas with silt or clay.

The total quantity of waste from uranium mining activities is minute compared with the huge amounts from coal mining due to the small quantity of uranium required to generate large amounts of energy. Drilling for oil and gas along with fuel preparation activities at refineries also results in significant waste quantities in the form of treatment waste, sludge and scale, which as noted later contain radioactive substances.

Nuclear power plant operations involve all three categories of radioactive waste. Low level waste includes contaminated clothing, cleaning residues, used machine parts, chemical resins and air filters containing short lived radioactive elements. A typical 1000 MWe nuclear power plant produces some 200 cubic metres of low level waste annually. The current worldwide total is estimated at under 100 000 cubic metres annually, equivalent to a cube somewhat less than 50 metres on each side.

Intermediate level waste consists of contaminated equipment and reactor parts, resins and filters containing both short lived and long lived radioactive elements. For the 1000 MWe plant, its volume is some 70 cubic metres, about 30% of the low level waste quantity.

High level waste is the smallest portion of the waste from nuclear power plant operations, containing well over 99% of the radioactive substances. It consists of spent fuel for disposal and concentrated liquid waste from reprocessing that is generally vitrified. Because of the high concentrations of radioactive substances, many of which are long lived, several decades of cooling is routine to allow the high residual energy to decrease. The 30 tonnes of spent fuel associated with one year's operation of a 1000 MWe plant has a volume of 10 cubic metres. Vitrified waste from reprocessing the spent fuel is a relatively small 2.5 cubic metres, consisting of one tonne of residues.

The worldwide total of high level waste annually is some 4000 cubic metres, equivalent to a cube 15 metres on each side. The total volume of high level waste produced over the next 30 years from today's operating power plants would be somewhat more than 120 000 cubic metres, equivalent to a cube some 50 metres on each side.

Nuclear power plant decommissioning involves removing any stored spent fuel, and the structures, assorted materials and worn out equipment, some of which are radioactive. When the spent fuel is removed only 0.01% of the radioactive material remains, with 95% of this amount in the reactor pressure vessel and surrounding shielding. The radioactivity of the vessel and shielding decreases rapidly with time and they are removed after several years when they essentially can be treated as low level material. As the major portion of a nuclear power plant has no radioactive contamination, most of the decommissioning and dismantling waste is scrap metal and other debris common to the decommissioning of industrial sites. The decommissioning can be technically less difficult than for plants containing more hazardous materials.

Since 1960, almost 70 nuclear research reactors and small nuclear power reactors have been decommissioned. Estimates are that decommissioning a modern 1000 MWe plant would result in a few thousand cubic metres of low level waste and a few hundred cubic metres of higher level waste requiring deep disposal.

Medical, Industrial and Research Activities

Radioactive substances are used extensively in nuclear research centres, in medicine for clinical diagnosis and therapy, in industry for quality control of materials and the geological exploration of oil, in agriculture to optimise food production, and even in home appliances such as smoke detectors. Data from the USA indicates the large share of low level waste from these activities. With more than 100 nuclear power plants (almost 25% of the world total) some 60% of low level waste by volume is from commercial nuclear power activities, with a 25% share from industry.

Naturally Occurring Radioactive Materials

During the past ten years, a radioactive waste source not related to nuclear energy applications has received growing attention. Large quantities of low level waste arise from industrial activities involving raw materials containing naturally occurring radioactive material (NORM), such as uranium, thorium and potassium. These activities include phosphate ore processing and the production of phosphate fertiliser, along with oil and gas extraction.

The vast waste quantities involved is indicated by an American Petroleum Institute survey in the early 1990s of scale and sludge from oil and gas production in the United States. The results showed that NORM waste equivalent to some 10 million 55-gallon drums had accumulated in production and process equipment, water ponds and treatment pits. Some had been routinely disposed of as scrap steel for recycling and as treated waste used in agriculture. In addition to the already accumulated waste, about 140 000 drums of NORM waste (some estimates are four times higher) are being produced annually.

Although regulatory concerns vary widely, unlike low level waste from nuclear power facilities, this type of waste generally receives little attention. At the same time, some NORM waste is being managed as low level radioactive waste at significant and perhaps unnecessary cost.

Energy Comparisons

As nuclear power is used almost solely for energy production, it is useful to compare the quantities of radioactive waste it produces with the quantities of hazardous waste from the fossil fuels that are the major source of world energy. Nuclear power waste consists principally of a wide range of radioactive elements formed as the uranium atom splits and releases energy. Virtually all of the waste products are retained in the fuel and not released to the environment. Fossil waste consists of greenhouse gases, principally carbon dioxide, that are formed from the burning of the fuel, along with noxious gases such as sulphur dioxide and nitrous oxides, and a wide range of toxic elements that are impurities in fossil fuels. Except for some remaining ash, the waste products are released into the environment. Generally the level of pollution depends on the fossil fuel impurities, with natural gas giving the lowest, followed by oil and then coal.

What is strikingly dissimilar between the two energy sources is the enormous difference in the amount of fuel required to produce a specific amount of energy, and the quantity of waste produced. More than 10 000 times as much fossil fuel is required than uranium for the same energy output, with correspondingly larger quantities of hazardous waste. This is the dominating factor in any waste management comparison. This feature by itself decisively lessens the negative environmental impacts of radioactive waste compared to fossil fuel waste.

The energy produced from an equal amount of fuel is significantly lower for the fossil fuels than for the nuclear fuel. One kilogram of firewood could generate about 1 kilowatt hour (kWh) of electricity. The approximate values for the other solid fuels and for uranium are:

- 1 kg coal: 3 kWh.
- 1 kg oil: 4 kWh.
- 1 kg uranium: 50 000 kWh (3 500 000 kWh if recycled).

A 1000 MWe power plant consequently requires some 2 700 000 tonnes of coal, or 2 000 000 tonnes of oil, or 30 tonnes of uranium annually. Because of the small fuel requirement, the total quantity of waste produced by nuclear power is minute when compared with quantities from fossil fuels. Thirty tonnes of spent fuel are discharged annually from a 1000 MWe power plant and some 800 tonnes of low and intermediate level waste are accumulated. There are virtually no releases of toxic chemical pollutants, noxious gases or greenhouse gases.

Toxic pollutants and noxious gases

Small amounts of radioactive substances are permitted to be released during nuclear power plant operations. Coal plant operations also release radioactive substances, as coal always contains trace quantities of naturally occurring radioactive elements, such as uranium, thorium and their radioactive decay products. These radioactive substances are released into the atmosphere or contained in remaining ash, some of which is used for land fill and in building materials. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in its 1997 report estimated that on average radiation exposures from nuclear and coal power plants are similar.

Because of fuel impurities, a 1000 MWe coal plant produces annually on average some 320 000 tonnes of ash containing 400 tonnes of hazardous heavy metals, consisting of 63 t of vanadium, 38 t of mercury, 15 t of cobalt, and 13 t each of lead and nickel, along with smaller amounts of antimony, arsenic, beryllium, cadmium, selenium, tellurium, and thallium, all categorised as hazardous under the Basle Convention. Additionally, without abatement technology, 44 000 tonnes of sulphur oxides and 22 000 tonnes of nitrous oxides are waste products that are dispersed into the atmosphere. These quantities do not include large amounts of waste from associated energy chain activities, principally from vast mining and transportation requirements (see Figure 4).

Fossil power plants using modern abatement technology can decrease noxious gas releases as much as ten-fold, but significant quantities of solid waste are produced in the process. Depending on the sulphur content, solid waste quantities from sulphur abatement procedures for a 1000 MWe plant are annually as much as 500 000 tonnes for coal, more than 300 000 tonnes for oil and some 200 000 tonnes for natural gas sweetening procedures. Much of the waste, which contains small quantities of toxic substances, is commonly stored in ponds as slurry or used for landfill and various other purposes. Regulatory bodies are increasingly classifying some of this waste as hazardous.

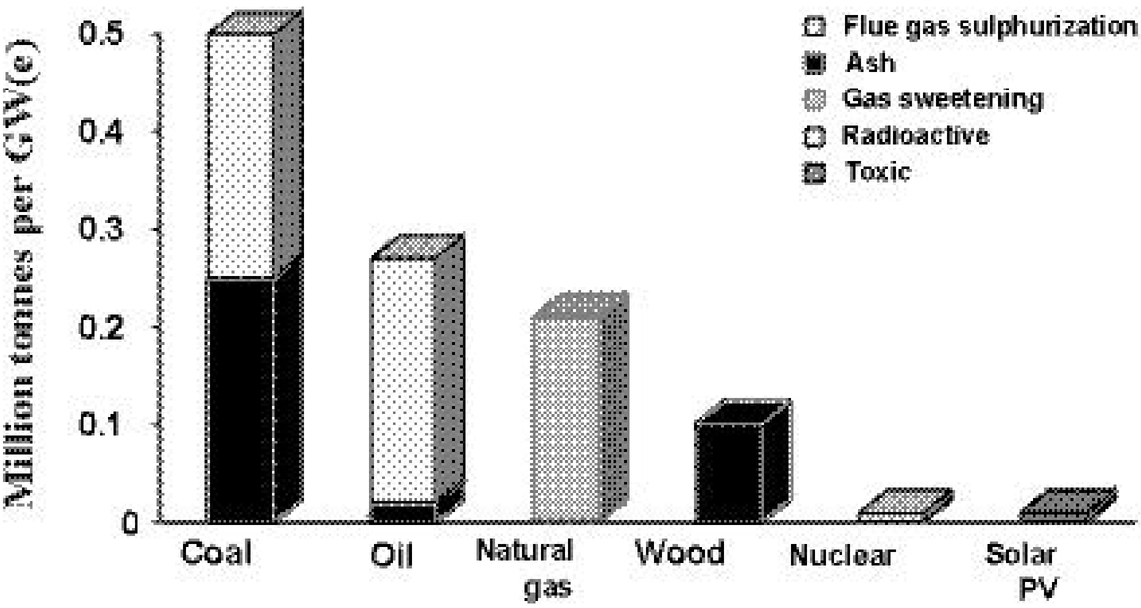

Figure 4. Waste produced in fuel preparation and plant operations annually per GWe for fossil fuels, wood, nuclear and photovoltaics (Source: IAEA).

Greenhouse Gases

Although not commonly considered waste, greenhouse gases such as carbon dioxide (CO_2) are waste products produced in large quantities from fossil fuels. A 1000 MWe coal plant emits some 6000 tonnes of CO_2 annually. Burning methane natural gas which has a low carbon content produces smaller amounts of greenhouse gases. However, gas leakage during extraction and pipeline transport, which are more than 5% in some areas, can offset much of this advantage since the escaping methane is a more effective greenhouse gas.

Estimates of greenhouse gas emissions require identification of all sources in the complete energy chain, as significant fuel extraction, transport, manufacturing and construction activities can be involved (see Figure 5). Some sources are not always apparent. Hydropower assessments generally show comparatively low greenhouse emissions despite large construction activities. However, if methane gas released from the decomposition of inundated organic material at the bottom of some water reservoirs is included, emissions could approach coal values.

Nuclear power and wind are on the low side of complete chain emissions, while solar photovoltaic releases are higher, owing to various greenhouse gases released during silicon solar chip

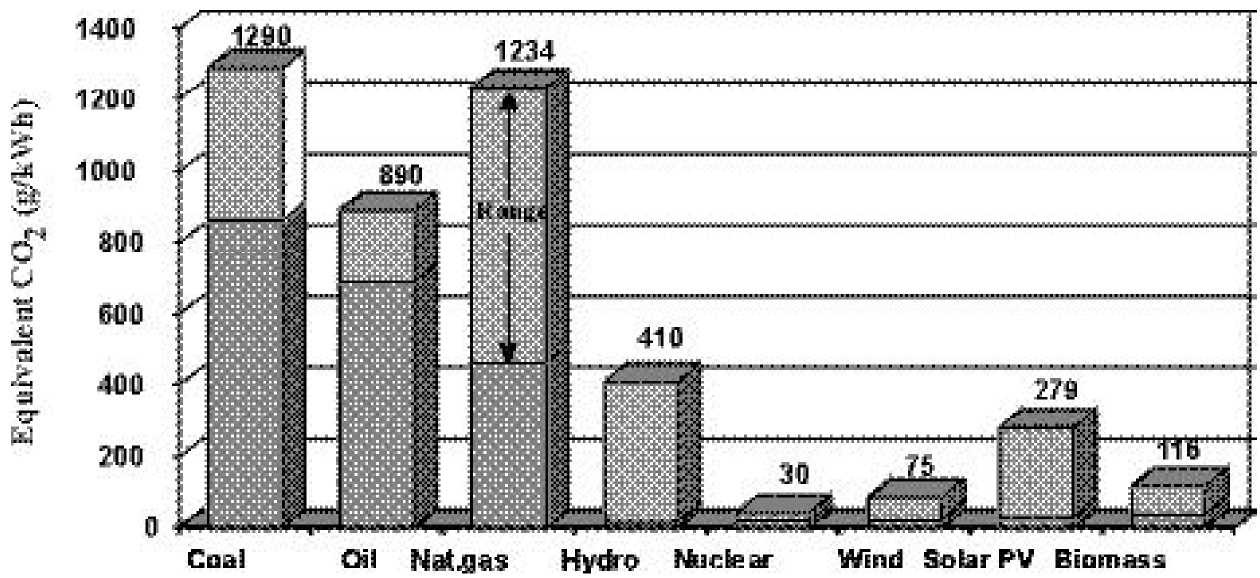

Figure 5. Full energy chain CO_2 equivalent emission factors for fossil fuels, hydropower, nuclear, wind, photovoltaics and biomass (Source: IAEA).

manufacturing. Nuclear power and hydropower are significant contributors to reducing global CO_2 emissions. They supply about 6% each of the world energy needs, avoiding annually some 16% of CO_2 emissions that would have arisen through the use of fossil fuels.

A Perspective

Some perspective on energy related waste can be gained from the quantities produced in Canada during 1994 from nuclear and fossil plants, each having a 19% share of total electricity supply. Table 1 shows the fuel and waste quantities reported by a 1998 report from a Canadian government panel on nuclear waste. The values vary yearly, but the illustration clearly shows the large differences in uranium and fossil fuel quantities, and the relative waste quantities, for electricity production.

Strategies

Low Level Waste Strategy

Low level radioactive waste is generally put into standard steel drums similar to those used for hazardous waste. The drums provide sufficient protection against the low radioactivity levels. The waste can be disposed of in simple near surface trenches above the groundwater table. Although not dictated by radiation protection purposes, it is routinely isolated in engineered structures such as concrete lined trenches and vaults, typically some 10 m deep, 25 m wide and 100 to 200 m long. As already noted, a typical 1000 MWe nuclear power plant produces some 200 cubic metres annually, with a total of under 100 000 cubic metres from all operating power plants worldwide.

Time Period Considerations

As the vast majority of radioactive substances in low level waste have less than 30 year half-lives, the radioactivity level decrease rapidly, about tenfold in 100 years. In another 100 years it decreases tenfold more, i.e. it becomes some 100 times less than initially, and is no longer a radiological concern. Institutional controls such as surveillance and restrictions on land use would no longer be necessary. For relatively short time periods, leak proof containment is assured as the corrosion resistance of metals and materials can be confidently predicted.

About 25% of nuclear power plant waste is intermediate level with higher radiation intensity or longer half-lives than low level waste. This waste is commonly immobilised in cement inside steel drums and can also be disposed of in near-surface engineered structures. Based on national policies, disposal in some countries is at greater depth and in rock cavities. During the past 35 years, some 40 near-surface disposal facilities, mostly for low level waste, have been safely operating worldwide. During the next 15 years an additional 30 facilities should become operational.

High Level Waste Strategy

The IAEA estimates that in 1997 about 10 500 tonnes of spent fuel (4000 cubic metres) was removed from commercial nuclear power plants worldwide, with some 30% to be reprocessed. By 2010 the total accumulated amount of spent fuel would be some 340 000 tonnes, with about 110 000 tonnes having been reprocessed. Countries reprocessing spent fuel intend to vitrify all associated high level liquid waste by immobilising it in a stable matrix such as

Table 1. Quantities of fuel used in Canada in 1994, and waste materials produced.

Fuel Source/Waste Material	Quantity
Uranium used as fuel (tonnes)	**1 914**
— Spent fuel (tonnes)	2 420
— Low level waste (tonnes)	30 000
Oil and gas used as fuel (cubic metres)	**6 100 000**
Coal used as fuel (tonnes)	**50 000 000**
— Ash (tonnes)	4 600 000
— Heavy metals in ash (tonnes)	4 160
— Emissions (tonnes):	
escaped ash	23 200
carbon dioxide	104 000 000
sulphur dioxide	596 000
nitrogen oxide	185 000

borosilicate glass, which will be stored until disposal.

A storage period is necessary for all high level waste to allow its radioactivity and the residual heat generated to decrease, disposal being more practical after several decades. A modern nuclear power reactor contains several hundred fuel elements. A newly discharged spent fuel element produces several hundred kilowatts (kW) of heat; after one year it is about 5 kW, in five years only 1 kW. After 30 to 50 years heat output is at negligible levels, equivalent to less than a 100 watt light bulb. Storage of spent fuel is initially on-site under water. Over the longer term, before final disposal, storage is either under water or above ground in dry storage.

There is general technical agreement that disposal of high level waste will be in deep underground repositories in stable geologic formations such as granite, salt, clay or basalt. A repository would have a system of engineered and natural barriers to protect against human intrusion and contact with water. Test results indicate that corrosion resistant containers from ceramics, stainless steel, titanium alloys or copper would keep moisture from reaching vitrified waste or spent fuel for many thousands of years. Should radioactive substances eventually leak out, surrounding backfill material and rock would slow or even prevent their movement to the surface.

With the relatively small quantities of high level waste produced annually from nuclear power activities worldwide, it would be reasonable for a single repository to meet the needs of many countries. However, the public concerns with siting make such common repositories unlikely in the near future. A number of nuclear power countries require disposal within their borders.

Natural Analogies of Repositories

To obtain data to assess deep underground repository concepts, many countries have constructed underground research laboratories to carry out in-situ research. These can provide information on the impact of excavation on the surrounding rock, the performance of engineered and natural barriers, and the processes involved with long term phenomena. There are also important examples in nature of natural analogues of repositories that demonstrate the basic feasibility of geological containment. Radioactive substances have been effectively isolated by natural barriers for extremely long time periods.

A particularly important analogue exists at Oklo in Gabon. About 1.8 billion years ago – two fifths of the earth's lifetime – a spontaneous nuclear fission process took place in nature. In a rich uranium deposit, a group of six natural reactors ran for several hundred thousand years producing about 8 tonnes of highly radioactive waste products – the same type as from man-made nuclear reactors. The waste was produced at random by nature, without the protection that will be given to today's high level waste, yet most of it remains where it was left ages ago. Detailed measurements at the site have shown that most of these materials, particularly the long lived products such as plutonium, have moved less than 1.8 metres from where they were formed.

The Cigar Lake uranium ore deposit in Canada is another natural analogue. It is 1.3 billion years old and has one of the highest uranium concentrations in the world. The radioactive substances in the 450 metre deep deposit, mainly uranium and its decay products (similar to components of radioactive waste), have been effectively retained by the natural retention barriers and mechanisms at the location – the clay rich envelope, the low radionuclide solubility and absorption in the rock – even though the 10 to 50 metre thick clay envelope and surrounding sandstone are penetrated by fault zones.

The containment of the uranium and radioactive substances has been so effective that neither a chemical or radiological indication exists at the earth's surface to disclose that the ore deposit exists. The presence of the uranium ore was predicted using geophysical methods and knowledge of other deposits, and confirmed by drilling boreholes. The characteristic of a repository in this host rock would basically be the same, but would have additional depth (located at some 1000 metres) and a number of technical measures to make transport of radionuclides to the biosphere even more difficult.

Other uranium ore bodies are a useful source of information on the effects of water intrusion. There are a number of rich uranium ore bodies located in geological formations through which groundwater flow is relatively rapid, such as the one at Alligator Rivers in Australia. The irregular shaped ore body extends from near the surface to several hundred metres deep. A series of boreholes has been used to study the movement of uranium and its decay products. It was found that in the weathered layers near the surface, radionuclides have moved only a few tens of metres away from the ore body. No detectable movement has occurred in the undisturbed deeper layers.

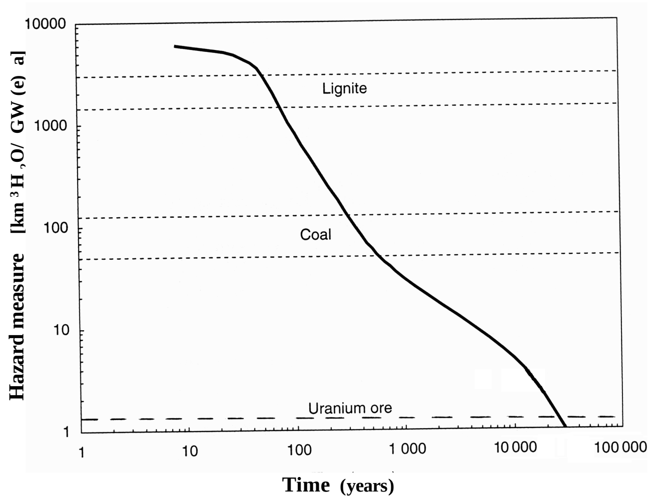

Figure 6. Hazard potential of radioactive and fossil fuel waste, in terms of acceptable water concentrations vs. time (Source: IAEA Sustainable Development and Nuclear Power booklet).

Generally, the natural analogues show that if radioactive waste is returned to rock types and formations similar to uranium ore sites, the material will stay in place well beyond the thousands of years necessary for its radioactivity to significantly decrease.

Note that the final disposal of chemically toxic waste requires attention to the same safety issues as high level radioactive waste and can be solved by geological disposal. The Federal Ministry for Science, Research and Technology in Germany has combined its research activities for long term underground repositories to cover both types of waste.

Safety Assessments

At a chosen site location, what assurance is there that the multiple barriers to isolate the radioactive substances will be sufficient under all conceivable circumstances? Tests and measurements can certainly confirm structural integrity, heat resistance and leak tightness in the short term. But long term issues involve developing scenarios and describing processes and conditions that require considerable mathematical models.

A number of extensive safety assessments have been carried out in OECD countries. Although these long term assessments contain many modelling uncertainties, potential radiation exposures have been calculated to be close to zero for periods of some 100 000 years for all scenarios and sites considered. For longer time periods, although inescapably with greater uncertainties, calculated exposures do not exceed a small fraction of regulatory limits.

Nevertheless, the public believes it is extremely difficult or even not possible to assure safe management of high level radioactive waste. The perception is that safety requirements for disposal centre on protection against high level radiation exposure. On the contrary, they centre on potential exposures well below natural background levels. The waste contains only residual heat energy and a chain reaction or chemical explosion is physically not possible. Radiation from sources hundreds of metres below ground cannot reach the surface as it is absorbed in the engineered barriers that isolate the radioactive waste. The only credible radiation exposures would be in the distant future involving incidents caused by long term corrosion or mechanical forces. They would result in a limited and slow movement of radioactive substances to the surface, greatly diluted by underground water, potentially leading to minimal individual exposures well below natural background levels.

Although safety assessments demonstrate that the multiple barrier concept would limit potential exposures to values far below regulatory limits, the current regulatory approach may in fact be inappropriate. The application of the current low limits for normal conditions to those for highly unlikely events in the distant future is a practice common to all national waste management strategies. In some countries exposures from a future release at a waste repository site must be shown to be no more than some 4% (0.1 mSv) of the average world natural background exposure, similar to the limit established for normal releases from operating nuclear power plants. The approach can result in inordinate and costly techniques to limit potential health effects from an incident that may never occur to exceedingly low levels and not to more reasonable higher levels, which would be more appropriate and acceptably safe.

Timeframe Considerations

Although there is a deep concern about the long lived nature of high level radioactive substances, time actually works in favour of radioactive waste, as radioactive decay decreases the hazard potential with time. Toxic chemicals can remain hazardous indefinitely. But time is only one factor influencing the hazard potential, the quantity of waste being another. Hazard indicators that consider both factors have been developed to compare radioactive with fossil fuel waste. One such indicator compares the amount of water necessary to dilute the radioactive substances in nuclear power waste and the toxic substances in fossil fuel waste to admissible drinking water standards – the less water needed, the lower the hazard potential (see Figure 6).

In some 100 years, high level waste from reprocessing would require less water than lignite waste, and in some 500 years less water than coal waste. It would require less water than uranium ore in under 10 000 years. The principle reasons for the striking reduction in the hazard potential is the relatively small amount of radioactive waste compared with the large quantities of hazardous fossil fuel waste from the production of equal amounts of energy, and the relatively rapid decay of reprocessing waste as much of the long lived elements, such as plutonium, have been removed. Without reprocessing, the time periods increase, with the radioactive waste approaching coal in several thousand years and uranium ore in some tens of thousand years, but not the millions of years commonly perceived.

Ethical Issues

Long term environmental considerations commonly involve ethical questions. The debate about fairness to future generations has centred on radioactive waste, although concerns about toxic chemical waste can be more relevant as it remains hazardous indefinitely. Time span issues are not limited to waste, but also cover a very wide range of issues that include depletion of natural resources and the effects of global warming, as well as many recent technological and bio-genetic developments. A clear case is the current depletion of natural resources in the earth's crust that involves a fundamental change to our environment. The present huge and increasing consumption of fossil fuels, which began in the mid 1980s, will within several centuries exhaust irreplaceable resources built up over millions of years.

Nuclear power with reprocessing, perhaps more appropriately called recycling, can significantly extend the resource base. The use of breeder reactors employing plutonium to produce fissionable material from non-fissionable uranium would increase the energy potential of today's known uranium reserves by up to 70 times.

Outlook

International Co-operation

With hazardous waste concerns no longer considered solely a national issue, there are responsibilities and challenges that should be handled collectively. An international framework to promote the safe management of hazardous waste is being developed. The Basle Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, which entered into force in 1992, defines the characteristics of hazardous waste and provides requirements for its environmentally sound management, particularly its disposal. A Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management was opened for signature in September 1997; it obligates parties to establish a regulatory framework and procedures to ensure safety requirements are met.

International co-operation is increasing rapidly for both radioactive and toxic chemical wastes. In addition to large national programmes and bilateral co-operation, there are a number of large joint research projects studying deep underground disposal of radioactive waste that are co-ordinated by intergovernmental bodies, such as the IAEA and OECD Nuclear Energy Agency (NEA). These involve the exchange of information, data and personnel. With the growing awareness that toxic chemical and radioactive waste warrant a harmonised approach based on common standards, possibly codified under a single regulatory category, the results are increasingly being considered for toxic waste disposal.

Public Understanding

The recognition that all large industrial activities have negative environmental effects, including long term impacts, is enabling the radioactive waste debate to be conducted in a wider context. This paper has sought to present facts and perspectives to clarify the radioactive waste issues and underline the fact that the strategies and technologies for handling radioactive waste exist. The issues are common with non-radioactive waste, which in fact can pose a much greater risk to human health and the environment.

In the energy area, the much larger specific requirement for fossil fuels, more than 10 000 times that for uranium, is the dominating factor in any waste management comparison and decisively lessens the negative environmental impacts of radioactive waste compared to fossil fuel waste. However, the current public perception of radioactive waste hazards has precluded the possibility of moving ahead with the deep underground disposal option for high level waste, and continues to make even low level waste controversial. Radiation is an abstract concept to most people. Today's nuclear specialists must learn to communicate the realities of radiation and its health effects. Building public understanding requires this.