NUCLEAR POWER: ISSUES AND MISUNDERSTANDINGS

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Abstract

A sizeable sector of the public remains hesitant or opposed to the use of nuclear power. With other groups claiming nuclear power has a legitimate role in energy programs, there is a need to openly and objectively discuss the concerns limiting its acceptance: the perceived health effects, the consequences of severe accidents, and the disposal of high level waste. This paper discusses these concerns using comparisons with other energy sources.

1. RADIATION REALITIES

1.1. Radiation exposures

Fear of radiation effects on health, particularly from severe accidents and radioactive waste, is central to public concerns about nuclear power. A better understanding of radiation and radiation exposure encountered in everyday life is fundamental to a balanced view of nuclear power's health impacts.

Radiation is a fact of life. Radioactive elements have been an integral part of the environment since the universe was created 15 billion years ago. Radiation is a natural component of the air we breath, of the earth we walk on, of the homes we live in, of the food we eat and of human tissues. We are continuously exposed to cosmic radiation, ionizing radiation of extraterrestrial origin, particularly at higher elevations and during air travel.

On a global average, it is natural background radon gas released from the earth that accounts for almost 49% of the radiation exposure an individual receives annually. Additional exposure from cosmic radiation and radioactive materials in the earth and internal to our body, accounts for somewhat more than 40%. The remaining 11% is man-made almost totally due to medical diagnostic X-rays and therapeutic radiation. Radioactive material from past nuclear test explosions amounts to a small 0.2% and nuclear power related activities a minimal 0.006%.

The amount of background radiation depends on location. Many of the millions of Europeans living in high radon gas locations in Austria, Finland, France, Spain, Sweden and the United Kingdom receive 10 to 20 times the global average background exposure than is received by residents of New York City, where radon gas levels are significantly lower. Even these high exposures are exceeded in local areas, such as parts of Brazil and India where the individual exposure is more than 100 times the global average and more than one million times the exposure from nuclear power related activities.

Radioactive atmospheric and ground contamination from the 1986 Chernobyl accident led to widely varying increases in individual exposures. But even in this extreme situation, a comparison to normal daily exposure gives perspective. Since areas affected by the Chernobyl accident are relatively low in radon gas, the current daily individual radiation exposure - even of those living in the areas of highest contamination - is below the daily exposure levels of the many hundreds of thousands of people living in high radon gas locations of Europe.

In fact, for the overwhelming majority of those who lived and will continue to live in the areas of highest contamination at the time of the accident, their accumulated total lifetime radiation exposure will be less than that of Europeans living in high radon gas locations. Although still small, the possibility of radiation induced health effects during a lifetime is on average greater for inhabitants of Europe exposed to high radon than for populations exposed at Chernobyl. A detailed discussion of radiation exposures to the main groups affected by the Chernobyl accident is presented later.

1.2. Radiation health effects

The biological effects of radiation depend on the amount of exposure. Very high exposures can damage or kill a sufficient number of cells to destroy organs and interrupt vital body functions leading to disability or death within a short time. Their effects are well documented. On the other hand, low level radiation related health effects cannot be identified since they principally occur as cancers late in life, leading to premature deaths of several years. They would be an indistinguishable fraction of the anticipated 20% of populations that die of cancer due to multiple other causes - the 20% value itself varies by several percentage points for different populations due to specific environmental, dietary and genetic influences.

To study long-term health effects, over the past five decades the Radiation Effects Research Foundation (RERF) in Hiroshima conducted extensive investigations of the Japanese survivors of the 1945 atomic bomb explosions at Hiroshima and Nagasaki. Some 87,000 people who received relatively high radiation exposures have been continuously monitored. Contrary to initial expectations of high numbers of radiation induced cancer deaths, the study of this Japanese population projects some 600, in addition to some 16,000 anticipated cancer deaths due to other causes - a small 0.7% increase in the anticipated cancer death rate. The several year loss expected in the average life expectancy will not materialize as above average health care for the survivors, though early diagnosis and treatment of medical disorders, including cancer, is leading to increased longevity.

Results of the RERF study have been used to extrapolate effects for exposures close to zero above the natural background radiation exposure. As exposure decreases, the likelihood of radiation induced cancer death is assumed to decrease linearly, only reaching zero at zero exposure above the background. Some scientists are critical of this type of extrapolation assuming that a natural threshold exists for radiation effects with very small incremental doses, above a significantly greater natural background exposure posing no risk at all.

1.3. Radiation from nuclear activities

There has been no credible documentation of health effects associated with routine operation of commercial nuclear facilities anywhere in the world. Widely accepted investigations, such as the comprehensive 1990 U.S. National Institutes of Health (NIH) study involving some one million cancer deaths in people living near nuclear power plants in the United States, demonstrate no correlation between cancer deaths and plant operations. Investigations carried out in Canada, France, Japan and the United Kingdom support the NIH results. A number of widely publicized studies reporting a linkage of radiation from nuclear power activities to occupational or public health consequences, such as the Sellafield occupational exposure study published in 1990, have been shown to be incorrect.

Comprehensive studies of various cancer types carried out by the European Union show wide variability in cancer rates throughout Europe, likely due to environmental, dietary and genetic influences. High incidences of male leukemia are found in non-nuclear power countries such as Denmark, Ireland and Italy as well as in countries with nuclear power, such as France and Germany.

To consider health effects from nuclear power activities, any postulated risks from low level radiation exposures must be put into perspective with the known risks from the toxic pollutants released from other energy production. Unfortunately the task of comparison is difficult, as there is vastly more scientific information about health effects from radiation than from the various toxic pollutants.

1.4. Toxic pollutant health effects

Fossil fuel combustion produces, in addition to CO_2, noxious gases and a wide range of toxic pollutants that are a large source of atmospheric pollution. In general, the level of pollution depends on the quantity of non-combustible material in the fuel, natural gas having the lowest level, followed by oil and coal. The pollution potential also depends on the combustion technology and pollution controls.

Coal combustion always produces gaseous nitrous oxides; sulfur impurities are emitted as gaseous sulfur dioxide. Inorganic impurities are released as a wide range of metals including radioactive elements; the volatile heavy metals, such as mercury, are emitted as vapor, while others such as cadmium and lead largely remain in the ash. The incomplete burning of coal that always occurs adds black smoke - finely divided carbon and hydrocarbon particles known as particulate matter - along with carbon monoxide and a wide range of organic compounds.

As with radiation, health effects from energy related pollutants depend on exposure. For high levels of toxic pollutant exposure there is no doubt about the potential health effects. Acute respiratory disorders are well documented for high levels of atmospheric pollution as are a number of respiratory disorders at more moderate levels. Heavy metal ingestion can cause a wide range of substance specific health disorders. Coal containing arsenic used in the Czech Republic for many years caused high levels of contamination, and arsenic specific health effects have been documented in children living in the vicinity of affected areas.

As with radiation, there are formidable difficulties in developing a relationship between continuous exposures to low levels of pollutants in air, food or water and long-term health effects occurring years later as additional illnesses, including cancer. The higher overall death rates particularly from cardiovascular and pulmonary disorders observed in areas with persistent atmospheric pollution, is a strong indicator that long-term health effects from continuous low level exposures do develop. The World Health Organization (WHO), in their 1997 report on sustainable development, estimates that annual deaths due to indoor and outdoor air pollution from energy related activities account for 6% of the total 50 million annual global deaths.

Multiple indirect health effects from energy related environmental pollution is even more difficult to assess. Acidification of land areas and waters can result in damage to both terrestrial and aquatic ecosystems. It can affect the mobility of some heavy metals such as mercury and other metals of significance in the ecosystem. Lake acidity and increased mercury concentrations in lakes are factors influencing the quantity of mercury accumulating in fish and entering the human food chain.

Health Effects From Fossil Fuel Releases

- Sulfur dioxide (SO_2) - Respiratory irritant, impaired breathing
- Nitrous oxide (NO_x) - Respiratory irritant, infections, pulmonary diseases
- Carbon monoxide (CO) - Fatal angina, various other effects
- Ozone (O_3) - Respiratory irritant, impaired breathing, asthma, edema.
- Particulate mater (PM_{10}) - Various toxic particle (organic matter, carbon, mineral dusts, metal oxides and sulfates and nitrate salts) effects - main mortality factor due to fossil fuels.
- Toxic substances - Heavy metals, specific substance effects.

1.5. A misconception

Although exposure to fossil fuel related toxic pollutants through air and contaminated water and food is a daily experience, there is a widely held public belief that nuclear power is a greater health risk. Concerns about radiation are demonstrated by a common conviction that plutonium - in spent fuel and from reprocessing - can be significantly more harmful than toxic pollutants. Plutonium is not very radioactive - as a long lived material with a half-life of more than 24,000 years it decays very slowly. Its radiation will not penetrate paper. As it is not highly soluble in most forms, it is not very hazardous when small quantities are ingested in liquids because the major portion passes through the body unabsorbed.

In fact, plutonium is extremely hazardous to health only when finely dispersed in sufficient concentration and inhaled, where it - similar to very small particles of inhaled toxic pollutants - passes through the lung tissue into the blood. Fortunately, a scenario to disperse sufficient amounts of plutonium, which is transported in strong structural containers, into the atmosphere to cause significant population health effects would be difficult. By contrast, many energy related toxic pollutants, including easily inhaled particulates that are the main mortality factor due to fossil fuels, have high potential health effects and health related costs.

2. SAFETY AND SEVERE ACCIDENTS

2.1. The safety concept

Nuclear power plants are built to high safety standards. Nevertheless, there have been two serious accidents. The first occurred in 1979 in a widely used reactor type, at Three Mile Island (TMI), resulting in serious reactor core damage, but inconsequential environmental releases. The second occurred seven years later in 1986, at Chernobyl, in a unique reactor type used only in the former Soviet Union, resulting in serious environmental consequences.

Many lessons were learned from these two events. The Chernobyl accident brought out a failing in the graphite reactor design which permitted a rapid power escalation under abnormal operating conditions. The loss of coolant water flow that occurred did not lead to an automatic shutdown required in other reactors. Most importantly, the environmental consequences of the Chernobyl accident compared with the negligible consequences of the TMI accident confirmed the importance of the principal reactor safety concept incorporating three protective barriers to prevent radioactive releases.

The first protection barrier, the ceramic fuel and its cladding, retains the radioactive products of nuclear fission. The second, the strong metallic primary circuit consisting of the reactor vessel and connecting pipes, retains radioactive material released in the event of fuel damage. The final and ultimate barrier, typically a large cylindrical containment of pre-stressed concrete enclosing the reactor primary system - many with inside steel liners and some with double walls, as in a large number of standardized French plants - retains radioactive material that could be released from a primary circuit failure. Lack of a sufficient containment barrier at Chernobyl led to the serious environmental consequences.

Containment designs also exclude external events. Experiments to simulate direct hits from jet aircraft, with high speed projectiles fired into walls of concrete and steel, demonstrate little damage. Containment damage from postulated severe accidents would cause structural cracks, allowing only minimal environmental releases.

2.2. The Chernobyl impact

The consequences of the disastrous Chernobyl accident remain a focus of concern. Some 6 percent of the radioactive contents of the reactor core were released into the atmosphere, with radioactive iodine and cesium of greatest relevance to human health.

The accident resulted in 31 short-term deaths with 28 due to extremely high radiation exposures. An additional 106 people experienced serious radiation effects. Some 200,000 workers, known as liquidators, involved in clean-up activities during 1986 and 1987 received average exposures of 50 mSv, two times the annual occupational exposure permitted and similar to annual exposures by individuals in high radon areas of Europe. A few thousand received greater than 10 times the permitted occupational exposure and several dozen workers received exposures considerably higher. The total number of listed liquidators eventually rose to more than 600,000 with most of the additional individuals receiving limited exposures.

Of the 116,000 inhabitants evacuated from the 30 km exclusion zone around the Chernobyl site, 95 percent received less than the average for the initial group of liquidators. More than 400,000 residents living in areas classified as strict control zones received significantly less than that, their exposure occurring principally during the early months following the accident.

For the 1,116,000 total individuals in the three major groups (600,000 liquidators, 116,000 exclusion zone evacuees and 400,000 residents of strict control zones) who received the highest exposure from the Chernobyl releases, the predicted long-term radiation induced cancer deaths and normally non-fatal thyroid cancers are reported in the proceedings of a 1996 international conference cosponsored by the IAEA, WHO and the European Union (EU). The report projects some 3,500 radiation induced cancer deaths, mainly late in life, in addition to some 200,000 anticipated cancer deaths from other sources - somewhat more than a 0.3% increase in the cancer death rate. The estimate is consistent with the atomic bomb survivor studies which project a 0.7% increase for the survivors who received a larger as well as a more harmful rapid radiation exposure.

The single radiation related health impact observed to date is a sharp increase in thyroid cancers among children exposed to short-lived radioactive iodine. Some 800 cases in children under 15, three of which were fatal, were documented by 1996 with the total incidence of this treatable illness projected to rise to several thousand. There is no evidence to date of an increased incidence of other malignancies including leukemia, the most sensitive indicator of radiation induced effects (UNSCEAR, May 1997).

Numerous reports of cancer deaths for those living in the contaminated zones of Belarus, Russia and Ukraine and among liquidators have not been substantiated. Significant mental health disorders could be a consequence of the accident's broad and severe psychological, economic and social impact. The effects of measures intended to limit radiation exposure causing lifestyle changes through resettlement, changes in food supplies and restrictions in activities were compounded by a deteriorating economic and social environment.

There were short term environmental impacts including lethal exposures to coniferous trees and some small mammals within a 10 km zone from the reactor site. The natural environment had begun to recover visibly by 1989 and sustained impacts on ecosystems have not been observed. An evaluation of long term hereditary effects in plants or animals will take many more years. No statistically meaningful hereditary effects have ever been observed due to human exposure to significant levels of radiation.

2.3. Some nuclear power facts

How likely is another serious environmental release? There are currently 15 Chernobyl type nuclear power plants that have operated on average for about 17 years each. Although some may be shutdown early, others may operate at least through their 30 year design life. No more plants are expected to be built of this type. With the exception of some of the early Soviet designed units, the remaining 427 nuclear power plants in the world have structural containments around the principal reactor primary system components. There has been a large ongoing global cooperative effort to improve the safety of all operating Soviet designed plants including modernization of instrumentation and equipment.

There are already more than 8,000 reactor-years of accumulated operational experience worldwide, equivalent to an average of 20 years of operation for each nuclear power unit. Building on this base of experience, today's reactors incorporate improved safety measures and are designed to exclude an environmental release in case of a severe accident. Designers believe the newest plants would suffer no more than 1 severe core damage accident in 100,000 reactor years of operation and this without a subsequent environmental release.

2.4. Advanced designs

Advanced nuclear power plants with even a smaller severe accident possibility are under development. The full spectrum of advanced designs ranges from evolutionary, with enhanced safety features, to entirely new designs introducing innovative safety concepts. The new concepts include passive - sometimes referred to as inherent - safety features based on natural convection coolant flow, making safety less dependent on active components like pumps and valves and on human performance. A high temperature helium gas cooled reactor with a unique fuel design has been developed and operated. It employs spherical fuel particles coated with layers of ceramic that remain intact and retain virtually all fission products at temperatures as high as 1600°C. Any fuel failure during severe accident conditions would be gradual and a rapid release of fission products would not occur.

Some advanced design characteristics

- Evolutionary - large size (1400 MWe), improved reliability, enhanced safety features;
- Smaller and Simpler - medium size (600 MWe), simplified systems, passive safety features;
- Modular Gas Cooled - variable size (200-400 MW), helium coolant, inherent fuel safety;
- High Temperature Gas Cooled - large size (1000 MWe), high efficiency, helium coolant, inherent fuel safety;
- Innovative - new concepts, passive safety features.

2.5. A developing global nuclear safety culture

Over the years a global nuclear safety culture has evolved through international efforts to strengthen safety worldwide. Binding international agreements, codes of practice, non-binding safety standards and guides along with international review and advisory services now exist.

Binding International Agreements

- Civil Liability for Nuclear Damage (1963) as amended (1997);
- Physical Protection of Nuclear Materials (1980);
- Early Notification of a Nuclear Accident (1986);
- Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986);
- Nuclear Safety (1996);
- Safety of Spent Fuel Management and Safety of Radioactive Waste Management (1997);
- Supplemental Funding (1997).

A Convention on Nuclear Safety entered into force in October 1996. At the first Meeting of the Parties to take place in April 1999, national safety reports covering civil nuclear power operations will be examined and a summary report of findings made available. The recent updating of the international regime for civil liability for nuclear damage that includes a Convention on Supplementary Funding along with the new Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management are further evidence of the growing of legal and other commitments binding countries in nuclear safety.

Nevertheless, the most convincing demonstration of the global nuclear safety culture will be performance of existing plants and avoidance of major future safety events. Through the activities of national regulatory bodies, the World Association of Nuclear Operators (WANO) and numerous national and international utility organizations, the nuclear industry is highly scrutinized to promote safety. The IAEA has developed a broad range of well used safety services allowing international experts to review and advise on safety matters.

2.6. A perspective

Beyond doubt, the Chernobyl accident was a severe accident in all dimensions. A review of other large energy related and industrial accidents is needed for comparative purposes. While the perception of nuclear accidents may not change, such a review offers some perspective. In industry, the well known 1984 Bhopal accident at a chemical plant in India caused some 3,000 early deaths and several hundred thousand severe health effects.

In the energy sector, hydroelectric incidents are not benign - dam failures and overtopping have caused thousands of deaths and massive disruption in social and economic activities with the displacement of entire towns - the Varont dam overtopping in Italy and dam failures in Gujarat and Orissa in India are three such examples, each with several thousand fatalities. Coal mine accidents causing several hundred fatalities are not rare and explosions and major fires in the oil and gas industry have involved both occupational and public fatalities and injuries. A pipe line explosion in the Urals involved 500 fatalities. Energy sector accidents have also led to severe environmental damage, such as the 1989 Exxon Valdez oil tanker accident in Alaska.

If risk assessments considered only short-term severe accident fatalities, data would indicate hydroelectric and gas fuel cycles have led to the largest single event fatalities. However, to draw conclusions about the relative safety of the various energy systems, fatalities and morbidity - occupational as well as public - must be considered over the longer term. This is discussed in a subsequent section on External costs of energy generation. Equally important is the maturity of the technology, the quality and maintenance of equipment and safety and environmental controls.

3. CONCLUSION

For nuclear power to play its legitimate role in the future, acceptance by the public and by political forces is vital. This paper has attempted to clarify some of the issues currently limiting the achievement of this goal.