Environmental Impacts of the Production and Use of Nuclear Energy: A Summary of the United Nations Environment Programme Study

by J.U. Ahmed and H.T. Daw

BACKGROUND

At its fourth session held in 1976, the United Nations Environment Programme's (UNEP) Governing Council requested the UNEP Executive Director to make a comparative review of the various forms of energy production. UNEP initiated this study by holding a panel on fossil fuels in Warsaw in 1978. Two panel meetings were held on nuclear energy, one in Geneva in November 1978 and the other in Nairobi in April 1979. The panel on renewable sources of energy was held in Bangkok in January 1980. For the comparative assessment two panels are planned for 1980, a small one to decide on the comparison methodology and a second expanded panel to make the comparative assessments. The IAEA has participated in all panels held so far and actively co-operated in the preparation of the report on the environmental impacts of nuclear energy Ref. [1]. The IAEA will also seek to participate in both panels on comparative assessments.

The environmental impacts of the nuclear power industry are generally similar in nature to those of the fossil fuel power industry. However, a dominant concern in the nuclear power industry is with radioactive releases and their effects on the biosphere, especially on human health. As a consequence, the UNEP study concentrated mainly on the health detriments of nuclear power production.

ENVIRONMENTAL IMPACTS

In order to assess the environmental impacts of nuclear energy, the UNEP document considers the various operations involved in the nuclear power industry. These operations are the mining and milling of uranium, enrichment, fabrication of fuel elements, reactor operation, reprocessing of irradiated fuels (in the case of the recycle option), the management of radioactive wastes produced in all steps of the nuclear fuel cycle, decommissioning of nuclear facilities, and transport of radioactive materials. The environmental impacts of the various operations have been normalized to the net production of one gigawatt-year (GWy).

Dr. Ahmed and Dr. Daw are staff members in the Division of Nuclear Safety and Environmental Protection, IAEA.

Mining of Uranium Ores

Radiobiological impacts of uranium mining are due to exposure to radon and radon daughter products which are given off from uranium ores. Following inhalation of radon and its daughter products, the tissues of the lung and respiratory tract are irradiated with alpha particles, thus increasing the possibility of contracting lung cancer. In some uranium mines, whole-body exposure to gamma radiation can also be significant.

Milling of Uranium Ores

In the milling operation, the ore is processed mechanically and chemically to extract the bulk of the uranium and produce a concentrate of uranium oxides, called "yellow cake". Radiological impacts in milling operations result from the release of dusts containing uranium and uranium daughter products (thorium-226 and thorium-230), radon and radon daughters, etc. Radon is released from the leach tank vents, ore piles, tailings retention system and the ore crushing and grinding ventilation system. Most of the radium in the ore is insoluble and remains in the tailings solids; a small portion, about 1 per cent or less, is dissolved. The waste solutions contain radium-226, thorium-230, uranium and small concentrations or radon decay products.

Uranium Hexafluoride Production

The concentrate of uranium oxides (U_3O_8) from the mill must be purified and converted to a volatile compound, uranium hexafluoride (UF_6), in order to be suitable as a feed for enrichment plants. Radiological impacts from this operation result from the release of radionuclides into the environment both to the atmosphere and water bodies.

Uranium Enrichment

Enrichment of uranium (increasing the concentration of the uranium-235 isotope) is necessary to provide fuel for light-water reactors (LWR) and advanced gas-cooled reactors. The concentration of uranium-235 in natural uranium is about 0.7% and the enriched uranium content of present day LWR fuel is 2—4%. Large-scale enrichment technologies are based on gaseous diffusion or centrifugation of uranium isotopes in the form of UF_6.

Radiological impacts at this stage arise from the release of isotopes of uranium into the environment. It should be noted that the UNEP study attributes increased occupational hazards to the large quantities of electricity used in the gaseous diffusion enrichment process. Assuming that two-thirds of the electricity is provided by coal-fired power stations, then electricity use in the gaseous diffusion enrichment process will result in another 0.01 to 0.1 deaths per GWy since the hazard from coal-fired plants is much higher than for nuclear. This risk is decreased in gas centrifuge plants which require about 1/10 of the electricity needed by diffusion plants.

Fuel Fabrication

In a fuel fabrication plant, enriched UF_6 is converted into uranium dioxide (UO_2) powder which is then formed into pellets and sintered to achieve a solid of the desired density. Finished pellets are loaded into zirconium alloy tubes, and end caps are welded on to form sealed fuel pins. The completed fuel pins are assembled in fixed arrays called

fuel elements The radiological impacts from fuel fabrication may arise from the release of uranium isotopes and thorium-234.

Nuclear Power Plant Operation

During the operation of nuclear power reactors, radionuclides are formed by fission of the nuclear fuel and by neutron activation of structural materials, corrosion products, and impurities in reactor coolant water. Most of the fission products remain in the fuel elements, but a fraction can escape into the coolant through defective fuel cladding. Most of the radioactive isotopes released into the coolant or moderator are removed by gaseous and liquid water processing systems. Nonetheless, part of the radioactive material may eventually be released into the environment.

Of the many radioactive fission and activation products generated during reactor operation, emphasis has been given to the environmental impacts of tritium, carbon-14, and radionuclides in particulate forms released to the atmosphere and water bodies. Special consideration is given to tritium and krypton-85, as both radionuclides are long-lived and distribute themselves worldwide. In particular, krypton-85 deserves special attention because of the inherent difficulty in controlling it and its essentially unreactive and mobile nature in the environment. Because of the long half-life or carbon-14, the radiation exposure commitments resulting from its build-up in the environment are considerably larger than those from noble gases and tritium. Several radionuclides, particularly iodine-131, are radiologically significant in the local environs. Iodine-129 is also significant globally. Noble gases, tritium in the form of tritiated water vapour, carbon-14, and iodine enter into the environment as airborne effluents. Aerosols containing fission and activation products as well as the decay products of noble gases may also be released as airborne effluents.

The detriment to human health arising from nuclear power generation is mainly due to occupational exposure to gamma rays from fission and activation products. The population exposure arises from the release of radionuclides into the environment. Radionuclides released into the environment as airborne or liquid effluents during reactor operation undergo a series of complex physical, chemical and biological processes before reaching man. Such processes depend on the location of the reactor, meteorological conditions, and the different exposure pathways.

Radionuclides discharged in liquid effluents may result in doses to man through the pathways of drinking water and fish consumption for releases to fresh water, and of ocean fish and shellfish consumption for releases to salt water. A portion of the population may also be exposed on shorelines to external irradiation from radioactive sediments.

Reprocessing

The spent fuel elements from light-water reactors contain unburnt uranium, plutonium, some higher actinides and highly radioactive fission products. Uranium and plutonium in this spent fuel are valuable energy resources and may be re-used by separating them from the fission products. The uranium may be re-enriched and formed into new reactor fuel elements, or it may be used as the basis of "mixed oxide" fuel in which an appropriate amount of separated plutonium is added.

There are three options for LWRs: no recycle, recycle of uranium only and plutonium-uranium recycle. The three options raise a number of techno-economic, health, safety and environmental considerations that require different solutions. The recycling of plutonium and uranium introduces a traffic in purified plutonium, which will require safeguards in addition to those in effect. Recycled plutonium is essential for the development of breeder reactors.

In the spent fuel elements of LWRs, essentially all the radioactive fission gases are trapped physically or chemically in the zirconium cladding, in the fuel matrix itself, and in the fission gas plenum at the end of each fuel pin. These gases are released in the early stages of reprocessing, usually during chopping of the fuel elements or dissolution of the fuel. The gaseous effluents contain krypton-85, iodine-129, some tritium and carbon-14. Techniques for removing each of these elements from the off-gas stream have been developed.

In order to estimate the environmental impacts of reprocessing, the Thermal Oxide Fuel Reprocessing Plant (THORP) to be constructed at Windscale, UK, is taken as an example. THORP has a designed maximum through-put of 1200 tonnes of irradiated uranium per year (equivalent to about 40 GWy). Table 1 shows the predicted risk to the world population from THORP's operation.

Table 1. Predicted Risk to World Population from THORP Operation

Group at risk	Nature of effect	Risk* (for each year of operation)	Comment
World population (including THORP work-force)	Death from radiation – induced cancer	2 (in entire world population)	Death from spontaneous cancers (all causes) are estimated to be 8 million
World population (including THORP work-force)	Serious genetic defect	1 (in entire world population)	Applies to total of all subsequent generations

* Risk based on integration of dose, over a total period of 100 years, arising from one year of operation at design capacity (1200 t/y which is equivalent to 40 GWy).

Radioactive Waste Management

Radioactive wastes are generated in practically all areas of the nuclear industry and accumulate as either liquids, solids or gases with varying radiation levels. The bulk of the wastes occur at the front end of the nuclear fuel cycle which includes mining and

milling, while the more radioactive wastes occur at the back end of the cycle which includes reactor operation and fuel reprocessing (in the case of the recycling option). In the case of no recycle and recycle of uranium only, plutonium is not recovered, hence it is considered as transuranic waste.

Radioactive wastes are categorized as low, intermediate, high-level and wastes contaminated with transuranic elements. Such wastes may be dealt with as follows: (a) Immediate disposal as they may arise, which applies to low-level gaseous and solid wastes; (b) Intermediate-level wastes which may require conditioning and storage prior to disposal; (c) High-level and transuranic wastes which will require conditioning and extended storage prior to disposal. Safe and acceptable methods of disposal have been demonstrated for the first two categories of waste.

The management of solid wastes contaminated with transuranic elements requires various treatment steps before shipment to the waste repository or disposal site. Solidified high-level wastes will generally be held in interim storage before shipment to the repository or disposal site.

Several possibilities are being investigated as future alternatives for disposal of radioactive wastes on earth, namely, sea-bed isolation, ice sheet isolation and deep continental geological isolation. Several concepts have been advanced for each of these alternatives, which are made specific by choice of site, waste form, and emplacement medium and method. Of these, deep continental geological isolation is considered to be a promising alternative.

Decommissioning of Nuclear Facilities

Decommissioning of a nuclear facility can be defined as the measures taken at the end of the facility's lifetime to assure the continued protection of the public from the residual radioactivity and other potential hazards in the retired facility. Two basic approaches are generally considered in this regard, one being immediate dismantling and the other, safe storage with or without deferred dismantling. Methods for decommissioning nuclear facilities range from minimal removal and fixation of residual radioactivity with maintenance and surveillance, to extensive clean-up, decontamination and entombment. Each of these methods of safe storage requires surveillance and care during the holding period which may vary in length from a few years to decades. Each method ends with the deferred dismantling of the nuclear facility.

Transport of Radioactive Materials

In the transport of radioactive material, the actual quantities involved are small in comparison to the enormous transportation requirements for coal-fired stations, which in fact account for a major environmental impact of such stations. It is only the radioactivity that raises public concern over the environmental impacts of the transport of radioactive material. The volume of radioactive material being transported has grown and will continue to increase with the growth of the nuclear power industry. Radioactive materials arising in the nuclear fuel cycle are generally transported by truck, and to a lesser extent, by rail or sea.

SUMMARY

The inferred cancer mortality as a result of the nuclear industry per GWy for workers and for the public has been summarized as follows (Table 2), considering no recycle option.

Table 2. Inferred Cancer Mortality to Workers and the Public from LWR Fuel Cycle (no-recycle) per GWy

Fuel Cycle Component	Workers	Public
	Inferred Cancer Mortality	Inferred Cancer Mortality
Mining	0.03–0.1	0.02–0.04
Milling	0.036	0.005–0.04
UF_6 conversion	0.0004	0.001
Enrichment	0.0005	negligible
UO_2 fuel fabrication	0.01	negligible
LWR Power generation	0.13	0.06
Decommissioning (immediate)	0.004	negligible
Waste management (including storage of irradiated fuel)	4×10^{-5}	negligible
Transport	4×10^{-5}	1×10^{-5}
Industry total	0.28	0.14

The detriments resulting from the nuclear power industry form a small fraction of the detriment to the world population from exposure to natural radiation and other sources of radiation, as shown in Table 3.

Table 3. *Global Dose Commitments from Various Radiation Sources (from Ref.[2] p.16)*

Source of exposure	Global Dose Commitment (days)**
One-year exposure to natural sources	365
One-year of commercial air travel	0.4
Use of one year's production of phosphate fertilizers at the present production rate	0.04
One-year global production of electric energy by coal-fired power plants at the present global installed capacity (1000 GWe)	0.02
One-year exposure to radiation-emitting consumer products	3
One-year production of nuclear power at the present global installed capacity (111 GWe)	0.83
One-year of nuclear explosions averaged over the period 1951–1976	30
One year's use of radiation in medical diagnosis	70

** The global dose commitment for each of these radiation sources is expressed as the duration of exposure of the world population to natural radiation which would cause the same dose commitment The occupational contribution is included.

References

[1] The Environmental Impacts of Production and Use of Energy: Part II — Nuclear Energy, UNEP Energy Report Series, UNEP, Nairobi (Sept.1979).

[2] Sources and Effects of Ionizing Radiation, 1977 Report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) to the General Assembly, United Nations, New York (1977).