Nuclear power, man, and the environment

by A. Hagen*

Despite conservation efforts and more efficient usage, energy demand continues to increase in the world. The choice of energy systems is one of national policy involving the resolution of sometimes conflicting values and the balancing of economic, technical, social, institutional and environmental factors. Those values placing a high importance on a country's development and economic growth and those values placing a high importance on maintaining or preserving a high-quality environment often clash. Judgements also need to be made on how much risk society should be subject to. Public perception of risk, regardless of how it is derived, is as important for decision-making as analyses by experts, although the term "public" applies to many different groups who may perceive the risks of a particular situation very differently. Environmental protection is one goal which needs to be considered and balanced with others. The weight given to any one goal will vary according to national values, needs, and objectives.

All man's activities, including the use of energy, are likely to affect the environment in which he lives. Energy systems pose no unique problems which set them apart from other sources of risk. All methods of supplying energy for industrialized societies carry certain environmental, health and societal costs.

In collaboration with the World Health Organization the International Atomic Energy is shortly to publish a book** which will be an up-to-date review of the environmental issues related to nuclear power. The booklet will describe the nuclear fuel cycle, the health and radiobiological effects of radiation, radiation protection criteria, nuclear safety, and waste disposal.

The environmental aspects of nuclear power plants and the facilities of the associated fuel cycle are not very different from any other large-scale industrial activity. However, the radioactive materials that are part of the various fuel cycle operations, particularly those radioactive materials generated during the operation of nuclear reactors, have to be strictly controlled. Many factors are considered when assessing the environmental and public health consequences of any industrial activity. These include the expected risk to workers and to the public outside the facilities; the kind and extent of environmental pollution; the kind, amount and toxicity of wastes to be handled and isolated from the environment; the rational use of natural resources, including land and water and secondary requirements, such as transport needs; the potential for accidents with serious consequences.

It is very difficult to compare energy sources, and even more difficult to quantify some factors to provide a firm guideline in decision-making, but such comparisons must be made. Thus, judgements are involved which have to be viewed in the context of the general background of benefits and risks a society is willing to accept.

Environmental protection philosophy

One can outline a three-part environmental protection philosophy: the first concerns the *conservation of resources;* the second the maintenance of an *ecological status quo;* and the third *protection of human health.* Such philosophies can be given effect by the setting of standards and criteria. However, it is often impossible to integrate and satisfy frequently qualitative and conflicting environmental goals.

Conservation of natural resources does not mean merely setting aside parks and wilderness areas, or managing and exploiting natural resources such as timber, minerals, and energy supplies, but also takes into account the use of land, water, and air.

Maintenance of an ecological *status quo* as an environmental philosophy concerns itself with the biological or living parts of the environment. All man's activities disturb or change the fragile biosphere in which he lives. The arguments revolve around how much change or disturbance should be permitted.

The concept of protection of human health is nothing new. Radiation protection standards and criteria have been in existence since the very early days of the nuclear power industry. The goals in this area revolve around

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how much risk society can tolerate. However, in the area of radiation protection, there are internationally agreed standards and criteria. The basis of all forms of radiation protection is the limitation of radiation doses which requires that each source of exposure be justified in relation to its benefits or those of any available alternative; that any necessary exposure be kept as low as reasonably achievable; and that dose-equivalents to individuals do not exceed specified limits. The limit recommended by the International Commission on Radiological Protection (ICRP) for radiation protection of workers is that the effective dose should not exceed 50 mSv to any worker in any year. The observance of this limit, and of the requirements noted above, generally ensures that the average annual dose is considerably lower than this limit, often by a factor of ten. The dose limit does not include exposures from natural sources or from medical treatment.

The corresponding limit recommended for members of the public is that an annual dose of 5 mSv shall not be exceeded in any year, exposure from natural sources and medicine again being excluded. Moreover, in circumstances in which a member of the public might be exposed *annually* for prolonged periods, the average annual dose should not exceed 1 mSv. The observance of these limits is considered likely to result in average doses of much less than 0.5 mSv per year.

Various kinds of authorized limits are set by national authorities on the basis of the system of dose limitation recommended by the ICRP. The use of such authorized limits ensures that actual radiation exposures are kept well below the values quoted in the previous paragraphs. The effluent from nuclear facilities is monitored to verify that authorized release limits are not exceeded and to detect and to identify unplanned releases. Off-site environmental monitoring is used to assess the exposure and detect any long-term trends.

Some global environmental issues

After consultation, deliberation, and debate, policy-makers can set acceptable levels of risks for specific activities. Although individual exposures can be calculated over a period long enough to encompass significant rates of dose, it is more difficult to calculate population exposure because estimates of future population sizes are uncertain, resulting in very large population doses as very small doses are integrated over very long periods of time. The significance of this may be seen only by comparison to a reference exposure over the same period of time, such as exposure to natural background radiation. This leads to an unanswered and perhaps unanswerable question: what dose to a future population is deemed acceptable? Answers could be given in terms of present standards (e.g. 0.05 mSv/generation); a certain per cent above background radiation; a level likely to result in unobservable biological effects (i.e. greater than 5 mSv); or even levels which are now known to result in long-term chronic effects.

In normal operation, the major environmental impact of the nuclear power industry arises from the radioactive wastes produced during the nuclear fuel cycle. There are essentially three principles governing the management of radioactive wastes. Wastes which lose their radioactivity in a relatively short period of time are often stored (delay) until the levels of radioactivity have reached "innocuous" levels. Wastes containing significant amounts of long-lived radionuclides are concentrated and contained. Gaseous and liquid wastes in amounts below authorized limits, based on radiological protection criteria, are released directly to the environment (air, water) where they are rapidly dispersed and diluted (see Box). These categories should not be viewed as mutually exclusive, since with some wastes, such as low-level waste disposed into the deep sea, both the philosophies of containment and dispersion are used. In that example, the material is contained to ensure safe arrival at the sea-bed, at which point no allowance is made for the integrity of the container and the assumption is that the material will disperse.

A more realistic assessment and analysis of hazards from any waste isolation facility or medium must take into account the effectiveness of the many barriers that isolate the waste from the biosphere – physical phenomena, such as insolubility, ion-exchange properties, adsorption and slow migration potential, can minimize the estimated hazard from such toxic radionuclides as plutonium. The extent to which any transport from the point of disposal back to the biosphere is acceptable will depend upon the performance criteria and standards.

In terms of high-level waste management, long-term barriers to release include immobilization of waste in borosilicate glass, and the technology exists for retrievable storage. Long-term isolation can be achieved by geologic emplacement – as long as a suitable site is chosen that would ensure a low probability that erosion, volcanism, meteorite impact and other natural events would breach the repository. The possibility of inadvertent intrusion by man can also be limited. The most important mechanism for potential transfer of radionuclides from a geologic repository to the biosphere is hydrogeologic transport. Therefore site selection must take hydrogeology into account. The ability to model a system and to determine which are the sensitive parameters and assumptions, including estimates of the dose to man, should assist in site suitability and in the determination of the period over which isolation is required.

The dominant gaseous effluents which affect long-term public exposure are ^{14}C, ^{85}Kr, ^{3}H and ^{129}I. Such nuclides could be dispersed around the globe and their control will require international agreement.

Radium hazards from uranium mining and milling could contribute more to population exposures than plutonium, and for regional population exposures, uranium mill tailings are at least as important as the

Radioactive waste management

Source of waste	Type of waste radioactivity	Form of waste	Typical isotopes	Treatment & disposal
Mining & milling of uranium ores	Natural activity	Solids	U-238 Radium-226 Thorium-230	Contain & open controlled pit
		Liquids	Radium-226	Treat & dilute
		Airborne	Radon-222	Ventilate & disperse
Uranium fuel fabrication plants	Natural activity	Solids		Decontaminate or contain
		Liquids	U-235 & -238	Concentrate & contain
		Airborne		Filter & disperse
Reactor operations	Activation & fission product activity	Solids	Cobalt-58 & -60, Fe-59 Manganese-59	Concentrate & contain
		Liquids	Cerium-144, Caesium-137 Tritium, Strontium-90	Treat & dilute
		Airborne	Argon-41, Sulphur-33 Iodine-131, Xenon-133	Delay & disperse
Fuel reprocessing plants	Fission product activity and transuranics	Solids	Americium-241, Strontium-90	
		Liquids	Caesium-137, Americium-241 Plutonium, Cerium-144 Tritium & Zirconium-99	Concentrate & contain
		Airborne	Iodine-131 & -129 Krypton-85 & Tritium	Dilute & disperse or contain
Production use of isotopes	Activation product activity and transuranics	Solids	Cobalt-60, Strontium-90 Caesium-137, Plutonium	Concentrate & contain
		Liquids	Tritium, Carbon-14 Phosphorus-32 Cerium-144	Treat & dilute
		Airborne	Iodine-131	Dilute & disperse or contain

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activities in high-level waste because of the relative accessibility of mill tailings as opposed to the isolation of high-level and actinide wastes.

The possibility of disposing of low-level radioactive wastes in the seas is receiving broad attention. An international convention currently prohibits the disposal of high-level waste into the oceans, and a few countries are disposing of packaged low-level waste into the very deep oceans (depths greater than 4000 metres). Like the atmosphere, the oceans are global and dumping waste there unlike land-based disposal affects not only the nation doing the disposing, but a potentially large part of the global population also. International policies on environmental assessments, pollution prevention and avoidance of interferences with other uses will require the agreement of a wide number of countries with different interests and different expectations of benefits from the use of either the atmosphere or the ocean as a disposal media.

Governmental decisions are made difficult by the inability to quantify political, social, and ethical attitudes which have to be balanced with those aspects more easy to quantify, i.e. the economics of optimal resource allocation. Available data is often inadequate and disagreements as to methodologies to be used also complicate decision-making. The awareness of environmental protection issues has grown since the 1970s and national laws, regulations, standards, and bilateral, multilateral and international agreements and conventions have proliferated since. Those conflicting values systems, i.e. economic and technical values vs. risk and ecological consequences, which often come into conflict and are difficult to resolve on a national level, can be even more problematical internationally.