NUCLEAR ENERGY'S SOLUTION TO AIR POLLUTION PROBLEMS by J.K. Basson, Atomic Energy Board, Pelindaba.

The steadily increasing demand for energy is being solved, in principle, by nuclear energy in its two practically important forms, viz. nuclear fission and nuclear fusion. Nuclear fission, which already appears to be the technological solution to the problem of primary energy reserves, has been used almost exclusively for the commercial generation of electric power, which at present accounts for about 25% of the total demand. As opposed to a modest contribution of less than 2% in 1970, nuclear electricity generation in the world is expected to contribute over 50% by the turn of the century.

Nuclear reactors are inherently only practical in large units such as for base-load electricity generation and, to a lesser extent, ship propulsion, desalination, etc. However, the conditions in the other energy areas which are dominated by fossil fuels, are already changing to an increasing substitution by synthetic hydrocarbons. This transition to non-fossil fuels should lead to an increased contribution by nuclear power in the form of process heat supplied by high-temperature reactors.

Although the question of primary energy reserves may have been solved, additional technological and sociological problems are posed by the various interactions of nuclear pollutants with the biosphere. As in the case of conventional effluents, solid and liquid wastes can, in principle - but with due regard to the costs! - be accumulated and analysed before treatment so as to present the minimum insult to the environment, or even be stored permanently. Gaseous pollutants can, in general, only be retained or removed to a much smaller extent and, consequently, are continuously released to the atmosphere. Recent developments have, however, led to an appreciable reduction of the radioactive release levels by means of absorption and gas liquifaction, with subsequent radioactive decay in storage tanks - so-called "zero-release systems".

In this paper, further consideration will concentrate on the airborne radioactive releases from a nuclear installation and their impact on the environment.

Nuclear Waste Products

In a nuclear reactor the fission process, which is sustained by the neutron flux, not only produces a large amount of energy but also leads to a large inventory of radioactive fission products in the reactor core. More than 200 different radionuclides are formed, but are well-contained by the carefully designed fuel cladding. Furthermore, activation products, which may be released by corrosion, etc., are produced by neutron interaction with the structural materials. However, under normal operating conditions all the radioactive products are extremely efficiently contained by the reactor and only a very small fraction of the total radioactive inventory is released to the environment. The total effluent from a nuclear power station is therefore very small in comparison with fossil-fired power stations, but its toxic nature results from the radioactive properties.

Fuel reprocessing plants, in which the fission products are separated from the remaining fuel, do produce highly radioactive wastes; however, suitable processing methods have already been developed and these wastes have been shown to present an insignificant hazard to the environment. Furthermore, the number of reprocessing plants is expected to be limited to less than one per 30 000 MWe installed nuclear generating capacity, i.e. by 1980 there will probably not be more than 10 sizeable reprocessing plants in the world. The possibility of siting these plants in remote areas is a further advantage of nuclear energy.

Radioactivity is the property of unstable atomic nuclei to disintegrate, with the emission of characteristic nuclear radiation. Such radioactive decay takes place with a characteristic half-life and cannot be influenced by heat, chemical reactions, etc. The radiation is usually energetic and penetrating and can therefore cause biological damage, especially if the radionuclide is taken up internally by the organism concerned. Such metabolism is, however, not influenced by the nature of the radio-activity but is dependent only on the normal biochemical properties of the element of which the nuclide is a radioisotope(1).

As the radiation only decreases as a result of radioactive decay, radioactive wastes can be treated only

(i) by dilution to acceptable concentrations, or
(ii) by concentration (e.g. chemical processing, evaporation) and subsequent storage.

Health Physics

Although mankind has always been exposed to a background of natural radiations, and furthermore though ionising radiations in the form of X-rays and radium have, since the turn of the century, been in widespread use, especially by the medical profession, the hazards associated with nuclear energy burst on the public with the bombings at Hiroshima and Nagasaki. However, the norms for radiation protection were already well established by the International Commission on Radiological Protection (ICRP) which was constituted in 1928 by the International Congress of Radiology and was accepted throughout the world. It may safely be stated that more is known about the effects of radiation on the human being than of any other toxic agent(2).

Exposure to ionizing radiation can result in injuries that manifest themselves in the exposed individual and in his descendants: these are called somatic and genetic injuries, respectively. Late somatic injuries include leukaemia and other malignant diseases, impaired fertility, cataracts and curtailment of life. Genetic injuries manifest themselves in the offspring of irradiated individuals, and may not be apparent for many generations. Their detrimental effect can spread throughout a population by the mating of exposed individuals with other members of the population. The objectives of radiation protection are to prevent or minimize somatic injuries, and to minimize the deterioration of the genetic constitution of the population.

Taking into consideration all available biostatistical evidence on human population groups exposed to radiation, as well as data from experiments with animals, recommended Dose Limits for humans have been devised by the ICRP(3). These are not based primarily on short-term clinical injuries but on long-term effects that could be detectable only by statistical methods applied to large groups (e.g. incidence of lung cancer in uranium miners(4)). Consequently, overexposure cannot normally be determined by medical examination but requires physical dosimetry and hence health physics.

Furthermore, these Dose Limits for radiation exposure are not based on the assumption of a threshold for radiation injury - although the absence of such a threshold dose has by no means been proven. (This is in contradiction to the Threshold Limit Values accepted for conventional contaminants on the basis of acute effects). The philosophy of benefit versus risk has therefore been introduced, with the Dose Limits representing the maximum acceptable risk in relation to the normal risks of living, but with the overriding recommendation that the actual exposures to radiation should be as low as practicable.

Although these Dose Limits to the various organs represent the fundamental ICRP recommendations, derived working limits e.g. maximum permissible concentrations in air and water for each radionuclide, may be obtained. No international dose limits exist for life other than human beings but, because of the length of their life cycle and the fact that higher forms of life are more sensitive to radiation, these limits are the most restrictive. The exposure of an individual is a function not only of the levels of radiation and radioactivity in his environment, but also of the individual's use of that environment and of his personal habits. Thus, in most situations in which radioactive materials are introduced to man's environment, there will be numerous and complex pathways by which each of the released nuclides may ultimately cause radiation exposure to man. However, a comprehensive and detailed study of all such pathways will not be needed, as experience has shown that a study of the situation will indicate that certain nuclides and certain exposure pathways are much more important than others. These nuclides and pathways are designated "critical".

Environmental Criteria for Nuclear Installations

Under normal operating conditions a combination of leakage of fission products through the fuel cladding into the primary coolant, and activation of materials outside the fuel, make the primary coolant the principal source of liquid and gaseous wastes. However, leakage of primary coolant into other systems, as well as various plant operations, causes the sources to be numerous. Measurements of concentrations of specific radionuclides present in gaseous and liquid wastes are not generally available from nuclear power plants. Airborne-waste discharges are usually categorized as being either halogens and particulates, or activation and noble gases.

External exposure from gaseous releases is due almost entirely to isotopes of the noble gases of xenon and krypton. In deriving the release rate limits before reactor startup, the annual average meteorology is determined, based on site data, and a total dilution factor is derived so as to limit the annual average exposure at the site boundary.

Internal exposure from airborne materials that may enter terrestrial food chains is dominated by the "critical" Halogens (primarily radioiodine) and particulates with a half-life greater than about eight days. These materials are released in such small amounts that they contribute very little to external exposure or to exposure by inhalation. However, the food chain "air-pasture-cow-milk-human" has been shown to be the critical pathway(5).

Accidental releases may conceivably result in a wide range of airborne activities to the environment. However, it is remarkable that, during more than 1 000 reactor years of operating experience, there has not been a single incident involving accidental release of harmful amounts of radioactivity from a power reactor to its surroundings. It is generally agreed that the isotopes of iodine, and particularly ^{131}I, carry a greater threat to health than any of the other radioactive fission products that might be released in a reactor accident - due to the concentration of iodine by the thyroid gland and the resulting risk of cancer.

No engineering plant or structure is entirely risk-free and the building of a nuclear reactor certainly implies the acceptance of some finite degree of risk(6). In establishing an acceptable risk level, a comparison must be made with the large number of risks to which society is continuously exposed. A wide-ranging analysis, extending from abnormal births and motor vehicle accidents to death by lightning, indicates that a risk of mortality of 1×10^{-6} per person per year could at present be deemed acceptable. Consequently it has been proposed that, in fixing an acceptable risk level for a nuclear installation - the so-called "environmental dose commitment" - a safety factor of 10^{-2} be incorporated to reduce the risk level to 10^{-8} per individual per year for the accident potential of the installation(7).

A pre-operational safety analysis of each nuclear installation is performed, making use of all available information on postulated accidents and occurrences, with consequent release (iodine-131) to the environment. The probabilities associated with exposure levels to the population can then be derived and a restrictive probability/consequence curve be laid down(8). Nuclear power can thus be made as safe as anyone could really want it to be - at a cost! Whereas nuclear power sites were originally selected for their remoteness from population centres, the probability approach, using the best available techniques for fault-free and reliability analysis, plus stringent quality assurance during construction, commissioning and subsequent operation, has made siting within a few kilometres of population centres possible. (Recent events e.g. the refusal of permission for ISCOR to build a new steelworks in Pretoria, have also indicated the advantages of separating conventional industry from residential areas.)

A number of studies have attempted to compare the radioactive and chemical pollutants released per unit of electricity generated from fossil-fuelled and from nuclear power plants. Such comparison is complicated by the different types of reactors, variations in composition of the fuels, the efficiency of the ash-collection equipment for fossil-fuelled plants, differing waste-treatment systems, and adjustments for biological activity and the half-lives of the nuclides released. However, it is concluded that the airborne emissions from a nuclear power station are substantially less dangerous to human health(9). (For example, in the most conservative comparison considered, a pressurized-water reactor appears to offer 18 000 times less health risk than a coal-burning plant.)

It therefore appears that not only does the normal operation of a nuclear power station lead to considerably less environmental pollution, but that nuclear safety technology is giving a lead to conventional accident analysis. These techniques, which allow a quantification of the total accident hazard from complex process systems, have already been applied at petrochemical installations in Britain. The question has even been asked as to whether the nuclear safety knowhow of the UK Atomic Energy Authority could have saved the tragic explosion at the Nypro caprolactam plant at Flixborough?

Nuclear Installations in South Africa

In South Africa the Nuclear Installations (Licensing and Security) Act (No. 43, 1963, and subsequent amendments) provides for "the licensing of sites used for certain installations capable of causing nuclear damage, to regulate the liability for such damage in certain circumstances, to compel certain persons liable for such damage to provide security for the fulfilment of such liability, and to provide for matters incidental thereto". A special Licensing Branch of the Atomic Energy Board is responsible for determining radiation standards, evaluation of each design and inspection during construction. Much thought has gone into the underlying philosophy and, as a guide to potential licensees, a curve has been prepared illustrating the upper limits of acceptability for the magnitude and frequency of occurrence of accidental releases of iodone-131 for a typical site. As a further guide a Table has been prepared which specifies the maximum permissible doses to persons associated with the operation and maintenance of the installation, and limits for the exposure of the population at large have been laid down.

Natural radioactivity is always present in the biosphere and, consequently, any increase due to the operation of a nuclear installation has to be determined above the existing background. Surveys of the environmental radioactivity of the National Nuclear Research Centre, Pelindaba, have therefore been carried out since 1963, well in advance of the date, 18 March 1965, when the research reactor, SAFARI-1, went critical(10). Initially a wide range of media were analyzed meticulously for individual radionuclides and their seasonal variations. An appreciably curtailed programme was, however, introduced during 1970, which places the emphasis on the monitoring of only those materials which, due to their properties of concentration of hazardous nuclides and their use and/or consumption by the population, would be the principal routes, i.e. critical path, through which human beings would be exposed(11).

The original permissible releases of airborne radioactivity for normal reactor operating conditions from the 70 m high stack at Pelindaba, were calculated before any meteorological, dispersion or reconcentration data for the site were available. Since 1968, however, data concerning wind speed, wind direction and the vertical temperature profile have been continuously recorded on site and have been used to compute the expected incidence of three categories of atmospheric stability in each of eight directional sectors around the site. Experimental determinations of atmospheric dispersion were made for each of these stability categories(12). The expected incidence of the different stability categories in each direction and the accompanying dispersion data were used to determine the resultant dilution of continuous releases for each sector. The distances at which uniform dispersion is expected to prevail in each sector were calculated and contours of expected equidilution were mapped.

Information regarding the possible levels of exposure of human beings due to the inhalation and ingestion of radioactive materials was gained from studies of the routes through food chains of radioactive nuclides present in nuclear bomb fallout(5). The food chain "air-pasture-cow-milk-human" proved to be far more restrictive than direct inhalation, and was accepted as being the critical path of exposure due to continuous releases of airborne radioactive effluent. Safe levels of radioactivity in air and milk were calculated and the permissible annual releases of certain critical nuclides, viz. ^{131}I, ^{90}Sr and ^{137}Cs, to the atmosphere were derived for the Pelindaba site(13).

The experience gained at Pelindaba is also being put to use at the site of South Africa's first nuclear power station, Koeberg A, which is to be erected by the Electricity Supply Commission at Duynefontein, on the coast 28 km north of Cape Town. The proposed commissioning date for the first 1 000 MWe reactor is 1982; a second will follow within a year or two. However, as early as 1969 ESCOM formed several working groups to examine the suitability of the site and to advise on the likely impact of the station on its surroundings. The AEB Isotopes and Radiation Division has been primarily responsible for determining the capacity of the Duynefontein environment for the safe discharge of radioactive effluent. Such investigation has already provided reasonable estimates of the capacity of the marine environment for specified radionuclides.

Studies of the dispersion factors for atmospheric release under varying mesometeorological conditions at this complex land/sea interface are a prerequisite for critical-pathway investigation of airborne radioactive releases. Initially, the incidence of the various mesometeorological conditions prevailing at Duynefontein was reported by the Air Pollution Research Group of the CSIR. Particular attention was given to the path of low-speed winds over the ocean and in the general direction of Cape Town. The conclusions emphasize the unreliability of predicting long-range trajectories, under stable atmospheric conditions, from surface-wind data at the point of release only - especially at this particular land/sea interface. Consequently, the following various techniques, aimed at measuring long-range trajectories, especially over the ocean where additional measurement of meteorological parameters is difficult, have been investigated:

(1) Smoke plumes released from a stack and their development studied by aerial photography.

(2) Trajectories of constant-level balloons, prepared to fly at heights below 300 m and tracked with mobile radar up to distances of tens of kilometres.

(3) Mathematical-model studies (in collaboration with the University of Natal) using basic meteorological parameters as well as topographical features.

(4) Dispersion measurements, to be made at Duynefontein with a nuclear technique developed at Pelindaba(12), involving the release of aerosols of inactive elements which do not readily occur in nature, viz. indium, gold, lanthanum. Filter samples collected at selected points, are measured by neutron activation analysis and are used to determine dispersion factors. (Such field tests have also been carried out at Richard's Bay to determine conventional air pollution.)

Practical experience in regulating the entry of nuclear-powered vessels into South African ports has already been acquired with the visits of the nuclear submarine HMS Dreadnought and the ore-carrier Otto Hahn. Licensing requirements included environmental surveys to determine any increase in radiation levels. No releases of radioactive effluent were detected; this was to be expected inasmuch as the assurance was given that there would be no measurable increase above the natural background.

Conclusions

1. It is clear that energy from the atomic nucleus will continue to play an ever-increasing role in the production of electricity and, eventually, of process heat. Nuclear safety has, however, on account of its association with nuclear warfare, been under the severest scrutiny by the public since World War II. This may be con-

tributory reason for its unsurpassed safety record.

2. The health hazards from atmospheric releases arising from the normal operation of a nuclear power plant have been proven to be appreciably less than those from a coal-fired station.

3. The study of a nuclear installation's design, the pre-operational investigation of the capacity of the proposed environment, as well as the post-operational monitoring of the critical pathways of radioactive effluent, serve as an example to conventional industry in which the environmental aspects are as often as not left in abeyance until the plant is in operation, at which stage curtailment of atmospheric releases can only be effected at great inconvenience and cost. The comparison of such pre-operational and post-operational environmental surveys should provide conclusive evidence of the pollution caused by the establishment of an undertaking.

4. Nuclear techniques for tracing airborne releases, and hence for determining atmospheric dispersion, could also be of great value for conventional air pollution studies.

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