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COMMUNITY PROGRAMMES ON RADIOACTIVE WASTE MANAGEMENT AND STORAGE

The increasing use of nuclear energy has begun to cause anxiety among the citizens of the European Community; they fear that nuclear power presents hazards to their safety and their environment which existing methods of protection are not adequate to control. Radioactive waste constitutes one such potential hazard and it has become the subject of considerable controversy and heated debate.

The research programmes of the European Communities have always reflected the Commission's concern to promote the harmonious development of nuclear power in the Community and a ceaseless drive to solve any problems engendered by this new source of energy. This issue of "Information R&D" describes the steps taken by the Commission to help solve the difficulties entailed in the management and storage of radioactive waste.

1. What is radioactive waste?

"Radioactive waste" means any solid, liquid or gaseous radioactive material (whether or not mixed with non-radioactive materials) which is either provisionally or permanently unusable) and which presents a level of radioactivity or physical properties which make dispersal in the environment unacceptable. In cases where dispersal is permissible, the term used is "radioactive effluent".

The first point to be made is that radioactive waste occurs in a wide variety of forms which do not all pose the same management and storage problems. Certain characteristics of radioactive waste are independent of their level of activity, such as their initial physical state (gas, liquid, sludge or solid), their treated state (concrete, bitumen, resin, glass, ceramics), their chemical composition and their volume.

However, their most significant parameters are those relating to their radioactivity. First, there is the type of radioactive product contained in the waste, which may emit varying particles or rays (alpha, beta or gamma rays, or neutrons); then there is the level of activity expressed in curies per source or per container; finally, there is the period required for the activity in curies to diminish by half. Another very important point is toxicity, i.e., whether the ionizing radiations emitted by the waste could, if the necessary protective measures were not taken, give rise to biological damage in man; such damage may be somatic (triggering of cancer, for instance) or genetic.

Various radionuclides are formed during the fission of a uranium isotope (uranium-235) in the core of a nuclear reactor. First, there are the fission products formed by the splitting of the uranium; these are highly radioactive bodies, with half-lives averaging some tens of years. Then there are the activation products, mainly the fuel element cladding metals, which become radioactive after they have been in the reactor core; their half-life is generally short. Finally, there are the transmutation products, also called actinides, which are formed from, and are heavier than, the uranium; their activity is fairly low but their half-life is extremely long (7 000 years for americium-243 and 24 000 years for plutonium-239).

For waste management purposes, three main categories of waste are distinguished:

- low-activity waste, i.e., waste having an activity of the order of one curie per m^3, containing no long-lived radioactive elements, nor actinides, but produced in fairly large quantities;

- low or medium-activity waste, containing long-lived radionuclides, especially fairly large quantities of plutonium or other actinides; the radioactivity of this waste (excluding the activity of the long-lived elements) would be about 1 000 Ci/m^3, which is substantially higher than that of the first category;

- high-activity waste, produced in fairly small quantities, but containing almost all the radioactivity produced in the reactors.

2. <u>Where is radioactive waste produced?</u>

Most waste is produced during the fuel cycle, including during the time the fuel stays in the reactor. To take the case of a 1 000 MW(e) pressurized-water reactor, the capacity of which is representative of the reactors being built at the present time, the annual arisings produced in the fuel cycle are as follows:

(a) 8 kg of natural uranium is required to produce 1 kg of enriched uranium containing 3.5% of uranium-235; in order to operate a reactor, one third of the fuel in the reactor core must be changed each year, which represents 30 tonnes of enriched uranium. Consequently, 240 tonnes of natural uranium must be prepared each year from a total of 100 000 tonnes of ore assaying at 2.5%. Almost all the arisings of radium-226, the commonest natural isotope of uranium, will be contained as waste in the mining spoil, the remainder being evacuated through the ore-processing effluent.

(b) The uranium extracted from the ore must be refined to obtain a product of very high purity to give a good fission yield, then converted into uranium hexafluoride to be enriched in the isotope uranium-235. The hexafluoride is transformed into uranium oxide, which is finally shaped and clad in metal in the fuel element fabrication plants. All these operations produce small quantities of waste which is generally of very low activity.

(c) Irradiation of the fuel elements in the nuclear steam supply system should not, theoretically, release waste because the fuel is enclosed in a leak-tight casing called the "cladding". But the primary coolant is always active and contains activation products resulting from the corrosion of the circuits, the fission products that have escaped through an accidental crack in the clad or radionuclides produced by its own irradiation. Most of these products are trapped in filters or concentrated (iodine trap, ion-exchanger resins, evaporator concentrates), the rest being discharged, after appropriate dilution, in the form of short-lived gaseous effluent with a total activity of about ten thousand curies (xenon-133, krypton-85) or very low-activity liquid effluent (tritium). Solid waste represents about 100 m^3 with a total activity of about 8 000 curies.

(d) After being withdrawn from the core of the nuclear reactor, the spent fuel elements can be regarded as waste and stored as such in specific facilities. The immersion of the spent fuel elements in a cooling pond for several months reduces their radioactivity by more than 98%, as a result of the decay of the short-lived radionuclides.

At the present time, there is a preference for reprocessing them, i.e., removing the irradiated fuel after a protracted stay in the cooling pond and separating the useful byproducts, such as unburnt uranium-235 and the plutonium that has formed, from the useless byproducts. Out of the 30 tonnes of uranium placed as fuel elements in the reactor core and withdrawn after three years, about 1 500 kg of uranium-238 and fairly similar quantities of uranium-235 will be found to have been consumed: the spent fuel contains, on average, one tonne of fission products, half a tonne of unburnt uranium-235 and plutonium isotopes in equal quantities, 140 kg of uranium-236 and 30 kg of neptunium, americium and curium.

Reprocessing involves first the mechanical separation of the clads in order to dissolve the uranium and plutonium and separate them from the fission products by successive extractions in organic solvents. The highly active clads (around one million curies) make up a volume of about 10 m^3 and contain about 0.5% of the plutonium that was in the fuel. Fission product solutions have the highest radioactivity (more than 150 million curies for a volume of about 15 m^3); in most cases they contain very long-lived highly-toxic actinides. Almost all the radioactivity originally contained in the nuclear fuels turns up again in those solutions.

The other waste arising in the course of reprocessing is solid low-activity waste, mainly originating from the concentrates and residues of low- and intermediate-activity liquid waste processing; it has a volume of 13 m^3 and contains about 45 000 Ci of fission or activation products and 0.2% of the plutonium produced. The gaseous or liquid effluent produced is of the same type as the effluent arising during reactor operation.

To sum up, if we disregard the considerable quantities of effluent and the 200–300 m^3 of low-activity waste, whose radiotoxicity will have decayed after a few years because of the short half-lives of the constituent radionuclides, the volume of waste produced each year in the fuel cycle of a power reactor will represent only about 30 m^3 of high-activity liquid or solid waste and about 15 m^3 of low- or intermediate-activity solid waste, mixed with small quantities of very long-lived actinides. Thus, the quantities involved are very low and the activity – which was formidable to begin with – will have virtually disappeared in a few hundred years as a result of fission product decay. Only the – very small amount of – activity arising from the long-lived radionuclides will persist.

3. What should be done with the waste?

The purpose of radioactive waste management is to prevent such waste harming man or his environment, either now or in the long term:

(a) low or medium-level radioactive waste poses few problems: after being isolated in bitumen, concrete or metal, the waste is stored below ground in block form in specially engineered vaults or trenches, which are monitored until its activity has decayed to a level acceptable for the environment.

(b) This is not the case with fission product solutions, which are the most dangerous because they have the highest level of activity. They are first stored on site in cooled double-walled stainless steel tanks for several years, during which their radioactivity gradually decays. These devices have been used in Europe for several years and have so far given excellent results; no incident likely to cause problems outside the storage sites has ever occurred, but constant monitoring is required. Consequently, preference is now given to solidifying such waste as rapidly as possible by evaporation of the solutions, followed by calcination of the residue and immobilization of the ash in large blocks of glass, similar to Pyrex glass, to isolate them more efficiently from the environment.

(c) The blocks of glass are then stored in safe places. Such storage must ensure that no radioactivity can leak into the biosphere in quantities which might lead to radiation exposure beyond the permissible doses for man and other forms of life. It must also ensure that there is no hazard to future generations, i.e., that there will be no need for continual monitoring and surveillance and no preclusion of the use of natural resources by future generations: current thinking is that the only feasible solution in the present state of the art and knowledge is storage in stable geological formations. This method of storage involves placing a number of barriers between the radioactivity and the biosphere, particularly the immobilizing material and the geological formation itself.

At present, waste disposal in geological formations is only experimental. It is being tried out at Asse, near Hanover, in Germany. The chosen site is a salt formation, but disposal in clay or crystalline formations may come about during the next decade.

(d) Solution of the problem of waste containing long-lived elements without resorting to geological storage would be facilitated, if the actinides could be isolated from the other elements and transmuted, i.e., recycled and burned in reactors to become short-lived radioactive waste. This is what is at present being done with plutonium, which, if it were not recycled in breeder or light-water reactors, would have to be regarded entirely as waste.

The transmutation process is being studied: it is known to work for some of the abovementioned radionuclides, but the separation efficiency needs to be increased and our understanding of nuclear reactions improved.

4. Is there a radioactive waste problem?

At the moment, there are no major problems besetting the management of existing radioactive waste: the technical solutions are available and are being used, in compliance with the radiological protection standards laid down by the international health authorities. But some difficulties could arise in the future because of the expected increase in electricity generation by nuclear processes; this would be accompanied by a corresponding growth in the quantities of waste produced. It is estimated that about 20 000 m^3 of solidified high-activity waste and 1 000 000 m^3 of treated low-activity waste will have accumulated in the Community before the end of the century. Consequently, all the pilot processes being used at the moment will have to be adapted to application on an industrial scale.

As regards very long-term isolation of waste, new experimental schemes for waste disposal in geological formations should be launched as soon as possible so that the practical experience essential to such operations can be acquired in good time.

The first disposal experiments will inevitably have to be on a reversible basis: the sites must be designed not only to store the waste long enough for their radiotoxicity to be eliminated but also to enable the waste to be recovered if some of the initial assumptions are found to be not entirely correct; lengthy experimental checks will be needed before final decisions can be taken in this field.

In the case of liquid and gaseous effluents, the present policy is to discharge them into the environment within the limits laid down by the international health protection and radiological protection authorities. Naturally, when the total quantity of low-activity liquid or gaseous waste reaches a certain level, it will be impossible to dilute it in enough air or water to comply with the permissible concentrations of activity. No time must be lost, therefore, in working out ways of trapping and storing such waste: some studies have already been started, more particularly on iodine-129, krypton-85, tritium and other long-live products.

Finally, the problems of improving proven technologies and adapting them to application on an industrial scale must not be dissociated from the legal, administrative, financial and political problems. The appropriate non-technical arrangements must be made gradually to harmonize and standardize international practices concerning the quality and properties of the treated waste and the conditions for its long-term disposal in compliance with the relevant safety and protection standards.

5. Measures taken by the European Community in this field

The Commission's constant interest in the radioactive waste problem is reflected in specific steps taken over a number of years. As early as 1965, it granted considerable financial aid towards the construction of a vault for experimental waste storage in the salt mine at Asse.

But it was not until 1973 that the major Community programmes were launched. These have been implemented in the form of "direct action", i.e., directly by the Community's Joint Research Centre (JRC), whose work is entirely financed by the Commission, or in the form of "indirect action", i.e., through a series of shared-cost contracts between the Commission and public or private bodies in the Member countries.

The first multiannual programme of direct action on radioactive waste, costing 6.9 million u.a., was set in train in 1973 and completed in December 1976. Most of the studies were carried out at the Ispra Establishment, being concerned in particularly with the determination of the long-term hazards presented by wastes and the separation and transmutation of actinides. The second programme, costing 21.06 million u.a., is at present in hand as part of the JRC's multiannual programme for 1977-1980. The work represents an extension of the studies begun earlier, with emphasis on the assessment of long-term risks.

In June 1975, the Council of Ministers of the Community adopted the first multiannual programme of indirect action, providing for a Community contribution of 19.16 million u.a. for the period 1975-1979. This contribution represents about 40% of the total cost of the programme, amounting to approximately 50 million u.a. Work will be principally concerned with the treatment of radioactive waste, disposal of such waste in geological formations and the solution of administrative, legal and financial problems of waste management.

The management structure required for these two programmes had to be flexible to take account of the widely differing characteristics of the participants and unified to ensure efficiency. The programmes are therefore implemented under the Commission's responsibility with the assistance of an Advisory Committee on Programme Management (ACPM), which serves both programmes and is made up of Commission officials and national experts. Furthermore, standing working parties, comprising national officials with direct responsibility for research, follow the progress of the work and discuss it with Commission representatives so as to ensure a supply of up-to-date information to the laboratories and effective coordination.

These programmes are ambitious but not unreasonably so. They form a coherent entity, backed by substantial funds and involving research facilities and personnel both in the Member States and in the competent departments of the Commission. This is probably one of the ingredients of their success; it also provides the general public with a Community-level guarantee that the less favourable aspects of nuclear power are not being treated lightly.

ANNEX

1. The direct-action programme

This programme comprises desk studies and experimental work. Emphasis is placed on three topics:

(a) first, chemical separation and nuclear transmutation, in order to gain a better understanding of these new radioactive waste management techniques based on the recycle of elements presenting long-term hazards. The following work is involved:

- research on chemical separation of actinides by means of ion exchange or solvent extraction;

- evaluation of actinide production and burning in nuclear reactors, in order to detail as factually as possible the feasibility of the method, which is regarded as an advanced strategy theoretically capable of solving the problems of long-lived waste storage. The feasibility of actinide recycle for transmutation in fast reactors has been demonstrated from the point of view of neutron physics; what remains to be demonstrated is that such sophisticated reactors can be operated on a sound basis and that the associated fuel cycle is practicable;

- measurements to find out more about the nuclear cross-sections of actinides.

(b) second, evaluation of the long-term hazards of radioactive waste storage, in order to assess and define the long-term safety of ultimate disposal in suitable geological formations. The following work is involved:

- analysis of the hazards of waste storage and the various options and possible strategies, in order to arrive at the optimum choice of sites; the methodology (fault tree) required in order to evaluate the risks of disposal in geological formations is already established and will be applied to models of disposal in different formations;

- research on the leakage of actinides to the environment as a result of a fault in the geological barrier;

- study of the long-term behaviour of wastes immobilized in bitumen or glass;

- study of methods for detecting and measuring actinides contained in solid wastes.

(c) third, the decontamination of reactor components. The following work is involved:

- study of the contamination mechanism in high-temperature water circuits;

- definition of the nature of contaminated surface layers;

- study of the mechanism of action of decontaminants on surface layers and on the constituent materials of the components.

This research should provide useful information for power plant operators on this very specific category of radioactive waste.

2. The indirect-action programme

The indirect-action programme lays equal emphasis on projects to solve some of the technological problems inherent in waste treatment, storage and disposal and on measures to establish a general framework.

(a) Research aimed at developing radioactive waste treatment processes which will increase the safe handling of certain critical waste categories and transport to the storage sites, and at permitting or facilitating the use of safe long-term storage techniques.

The following work is involved:

- study of the incorporation of medium-activity solid waste in plastic resins rather than in bitumen, thereby achieving a substantial reduction in volume oompared with waste immobilized by other methods;

- study of the decontamination and treatment of irradiated fuel-element claddings and high-activity solid waste with a view to replacing the present method of interim storage under water by a safe long-term storage method;

- study of the immobilization of the calcined residues of high-activity reprocessing wastes in a metal matrix rather than in glass, whose resistance to radiation is difficult to assess in the long-term and which is a poor conductor of radioactive decay heat, thus making storage problems more complicated;

- study of a process for incinerating alpha-contaminated solid wastes to permit appropriate treatment of the ash for long-term storage;

- comparative study of the properties of various materials under consideration for the immobilization of solidified high-activity waste.

(b) Work on the storage and disposal of high-activity and/or long-lived waste is the key factor of a Community project on protection of the environment against radioactive waste. The following work is involved:

- exchanges of information and comparisons of projects for interim storage in engineered structures, and study of the weight to be assigned to such storage in an overall waste management strategy;

- work on the disposal of radioactive waste in geological formations, including the listing (or mapping) by specialist bodies in the Community of geological formations in the territories of the Community countries and the determination by such bodies of a type suitable for ultimate disposal;

- selection of certain sites (if possible of different geological types) which the national authorities would be willing to accept as experimental sites for ultimate disposal and studies concerning experimental storage; this project is at present the linchpin of the Community programme and more than two-thirds of the available funds are being devoted to it;

- a project on the specific problem of gaseous waste storage;

- study of an advanced management model to assess the state of the art as regards the separation of actinides from radioactive waste and the changes they subsequently undergo as a result of nuclear reactions (transmutation).

(c) Measures to help establish general arrangements for waste storage and disposal operations.

This includes reviewing all the radioactive waste management problems for which no solution is to be found in existing international legal, administrative and financial provisions, and proposing solutions so that a first set of guiding principles on high-activity and long-lived waste management can be laid down.

(d) The Commission is also studying the problems raised by the decommissioning of power reactors. This study is being carried out with the assistance of a group of national experts under the Programme of Action on the Environment, adopted by the Council in December 1976. It should serve as a basis for mapping out a programme of indirect R&D action and laying down guiding principles to govern decommissioning.