nuclear power stations: environmental surveillance of radioactivity

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It will soon be twenty years since the commissioning of the first power station using nuclear energy.

In 1970, more than fifty facilities located all over the world represented a total capacity of 22 000 megawatts, and present estimates anticipate a capacity of 4000 gigawatts by the year 2000.

Contrary to what the uninformed public sometimes seem to think, the nuclear power industry is thus no longer in the experimental stage. After some adjustments during its youth, which are inevitable with any new technique, it has recently come of age and, during the last five years, has in fact taken its place among the sources of power upon which advanced countries rely. Thanks to the increasing importance which it will undoubtedly assume in the future, it will in due course replace most of the alternative energy sources.

It was thanks to nuclear power alone that a major European country, recently paralysed by a coal-miners' strike, was able for nearly two weeks to maintain its vital power supplies and in particular to keep its hospital services functioning. Could one conceive of a more encouraging confirmation of utility?

Simultaneously with progress in the design of the reactors themselves, appreciable development, of which the public at large is still less aware, has taken place in numerous areas which are inseparably associated with nuclear power.

We have seen how, during the last two decades of experience and after some inevitable groping in the dark, there have emerged in clear-cut form the basic legal principles relating to liability for operation of facilities, practical radiological protection standards, rules governing preliminary siting studies and correct interpretation of monitoring results, and procedures for efficient organization of surveillance.

At the same time, the techniques of low-level radiation measurement, fine radiation analysis, decontamination of effluents and handling of radioactive wastes have been perfected. These techniques are now quite different from what they were ten years ago.

A precise knowledge of the various factors that have gone into this important process of development and of the stages it has now reached is essential for a proper understanding of the present organization of environmental surveillance at nuclear power stations.

Basic principles of rational surveillance

Let us first recall the principles on which safety standards are based. We can then proceed clearly to define responsibilities – those of the public health authorities and of the operators of nuclear power stations.

A: **Safety standards** – These have been laid down by the International Commission on Radiological Protection (ICRP) with a view to preventing any harmful biological effect of irradiation and radioactive contamination either on individuals (somatic effects) or on their progeny (genetic effects). ICRP has thus determined safety limits which have been embodied in numerous international recommendations and national regulations in the form of "maximum permissible dose equivalents". On the basis of these limits and considering the average daily consumption of the "standard man", ICRP has calculated, inter alia, "maximum permissible concentrations" in air and water for various radionuclides as a function of their inherent radiotoxicity. These maximum permissible concentrations have been calculated basically for workers exposed to radiations. For the population as a whole, ICRP recommends that an additional safety factor of 1/10 (MPCP) should be added to the maximum permissible concentration for workers (MPCW), since exposed workers, in accordance with the regulations, are subjected to much more thorough surveillance than can be arranged for a large population.

The exceptionally useful nature of the work carried out by ICRP for more than 25 years past must be emphasised. No other hazard has ever been the subject of such thorough research or of so much joint effort by research workers, public health experts and jurists in all countries and in all disciplines. The reason is that the hazard is a new one, recently appearing in a world which has already made great technological progress. Thus, research workers and public health experts have had placed at their disposal facilities never before available for combatting conventional kinds of pollution, which are often more extensive and more dangerous, but which have, alas, long been firmly entrenched in the environment... and in public habits and public acceptance.

The ICRP standards are extremely strict, certainly the most strict, hazard for hazard, of all safety standards relating to harmful effects. Had measures similar to those now being taken against radiations and radioactive contamination been taken against other hazards at the outset, no one would be talking about problems of environmental pollution today.

The ICRP standards, it is true, have in practice to be interpreted and adapted for each type of nuclear power station in each particular environment. This work, as we shall see, is the responsibility of the competent public health services in each country.

Despite the local peculiarities of the regulations and a certain degree of latitude in the way in which they are applied, we nevertheless have in every case the essential principles of efficient and practical control; these are now well known, well defined and common to all the countries concerned, thanks above all to the work of the international organizations.

B: **Responsibility of the public health authorities** – The purpose of any public health operation is to safeguard the health of individuals. It is thus the specialized medical services of public health departments, consisting primarily of doctors trained in radiobiology, which are responsible for determining the conditions to be imposed upon the nuclear industry in order to ensure that the standards are complied with and that no harm accrues to the health of man.

Since, however, irradiation and radioactive contamination can affect man through more or less complex pathways in his environment (possible diffusion in the atmosphere, water, soil and food chain), the doctors of the public health services naturally require to take their decisions in consultation with experts in various disciplines such as ecology, geology, meteorology and nuclear technology – to mention only the most important ones. Safeguarding the environment here, as in other fields, is therefore a prerequisite to safeguarding man.

Nevertheless, one must never at any time lose sight of the basic principle that the ultimate responsibility is of a medical nature. This is a fundamental concept in protecting the health of both the general public and workers in nuclear industry, and its vital importance is stressed in particular by ICRP, the World Health Organization, the International Atomic Energy Agency, the United Nations Scientific Committee on the Effects of Atomic Radiation and, in their turn, by the countries possessing an advanced nuclear industry.

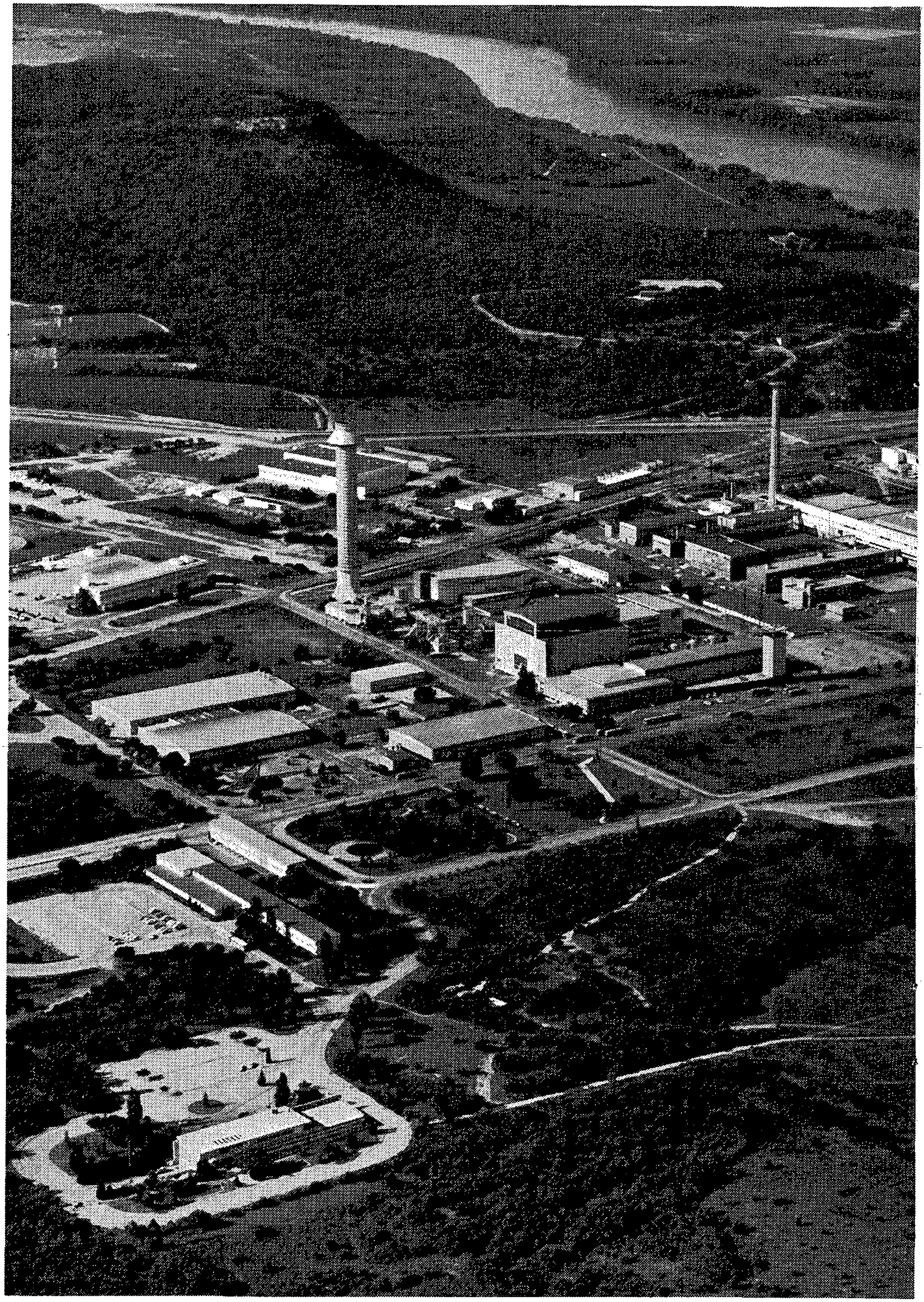
It is for this reason that the public health authorities in all countries now play the decisive role in regard to the surveillance of nuclear power stations.

C: **Responsibilities of the operators of nuclear power stations** – The liability of the operator of a nuclear power station is no different from that of any other citizen in regard to the very general principle of law by which no one, wilfully or otherwise, may by his actions cause damage to the health or property of others. The construction of a nuclear power station in a particular area introduces a new factor into an already existing balance. It can be permitted only if it does not upset this balance, especially where the health of man and the integrity of the environment in which he lives are concerned.

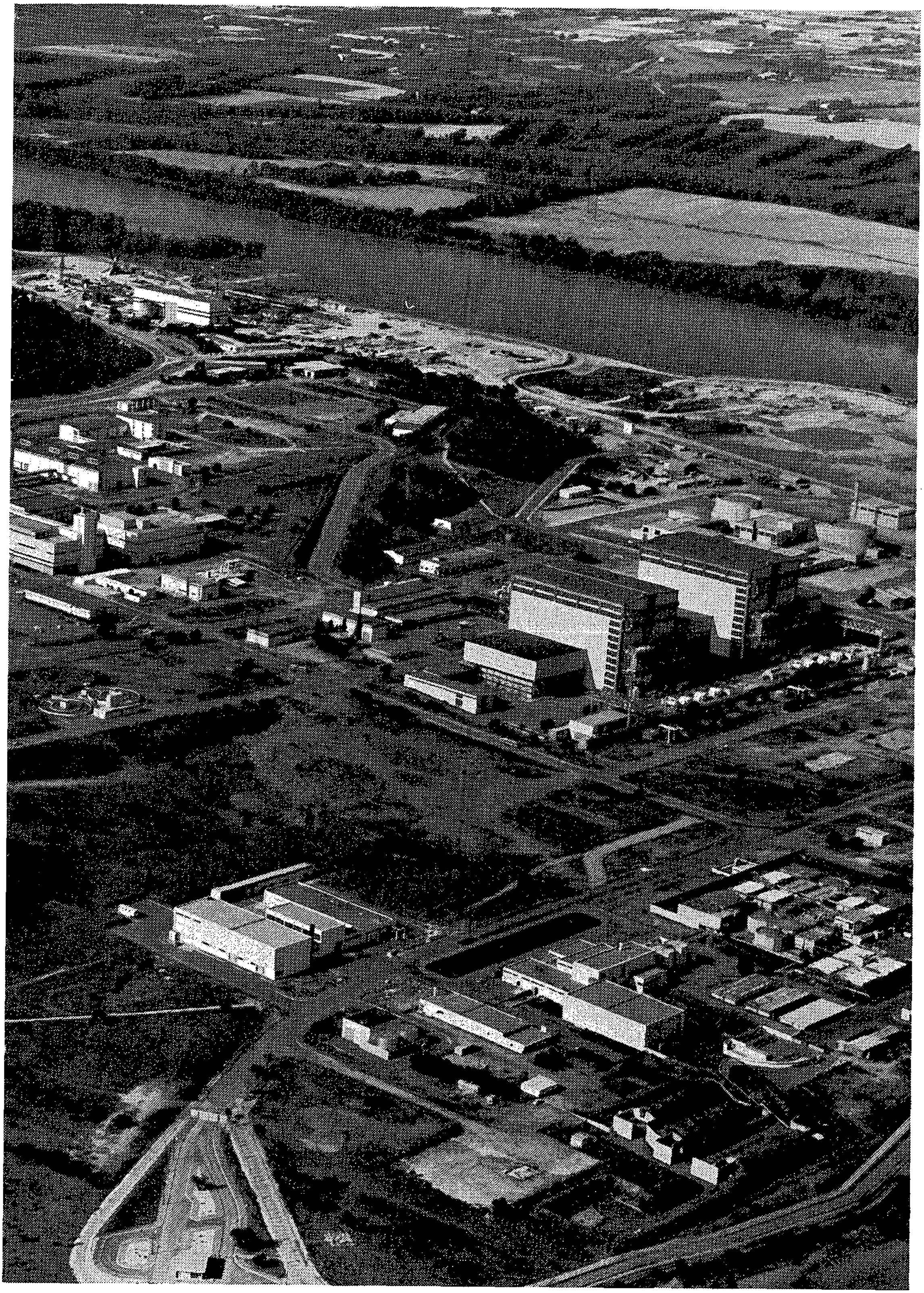
The aspects considered to be negative – and we shall see that they are in general of very minor importance – are of course not the only ones to be taken into consideration in connection with the new balance. Account must also be taken of the numerous economic benefits accruing from construction of the station, the better living and health standards which will result, the elimination of the much more dangerous types of pollution associated with thermal power generation, the avoidance of spectacular problems associated with the displacement of populations sometimes called for by the building of dams and so on. These aspects, however, more particularly concern the governmental authorities who have to take the decision on construction with full knowledge of the various factors involved.

The operator, who usually takes the iniative in the project, has to submit to the controlling authorities a preliminary study on the consequences of operation of the power station, especially the consequences of waste disposal to the environment, and must prove that the fauna and flora as well as the health of the population living in the neighbourhood will suffer no damage.

The public health authorities carry out a thorough critical examination of these studies and, where appropriate, carry out certain checks of their own. They can, if they deem it necessary,



An aerial view of the Marcoule Centre, France. Photo: Pierre Jahan



call upon the operator to make fresh preliminary studies or modify his waste disposal plans.

If construction of the power station is authorized, and when the latter is commissioned, the operator must have available on the spot all the facilities that will enable him to verify, from the outset, that releases of waste in all circumstances actually comply with the limits laid down by the public health authorities. It is in fact essential that he continuously check the consequences of his disposal operations and that he should be fully aware of their exact scope, so that he can at any time take the measures needed to keep them within the limits laid down. A detailed inventory of the waste material released and of its composition must be kept permanently up to date and be available to the public health authorities, to whom the operator must periodically report on this activities. Naturally he cannot be a judge in his own case, especially in regard to the population concerned; and although he is, in any case, obliged to carry out the checks whose principle has been defined above, the results thereof can be authenticated only by the public health services, who compare them with the checks they carry out themselves.

In all cases the operator must take steps to spread out the release of liquid and gaseous wastes from the power station in order to ensure the greatest dilution. The maximum concentrations laid down should, in fact, be considered to be the extreme limit and the actual concentrations should always be kept as far below this limit as possible.

Lastly, if during the environmental checks which he is required to perform the operator found that the limits laid down were likely to be exceeded or that the population in the neighbourhood was liable to be exposed to abnormal dose equivalents, he would obviously be seriously at fault were he to fail immediately to bring the matter to the notice of the public health authorities and to take instant action to remedy the situation.

Practical organization of surveillance

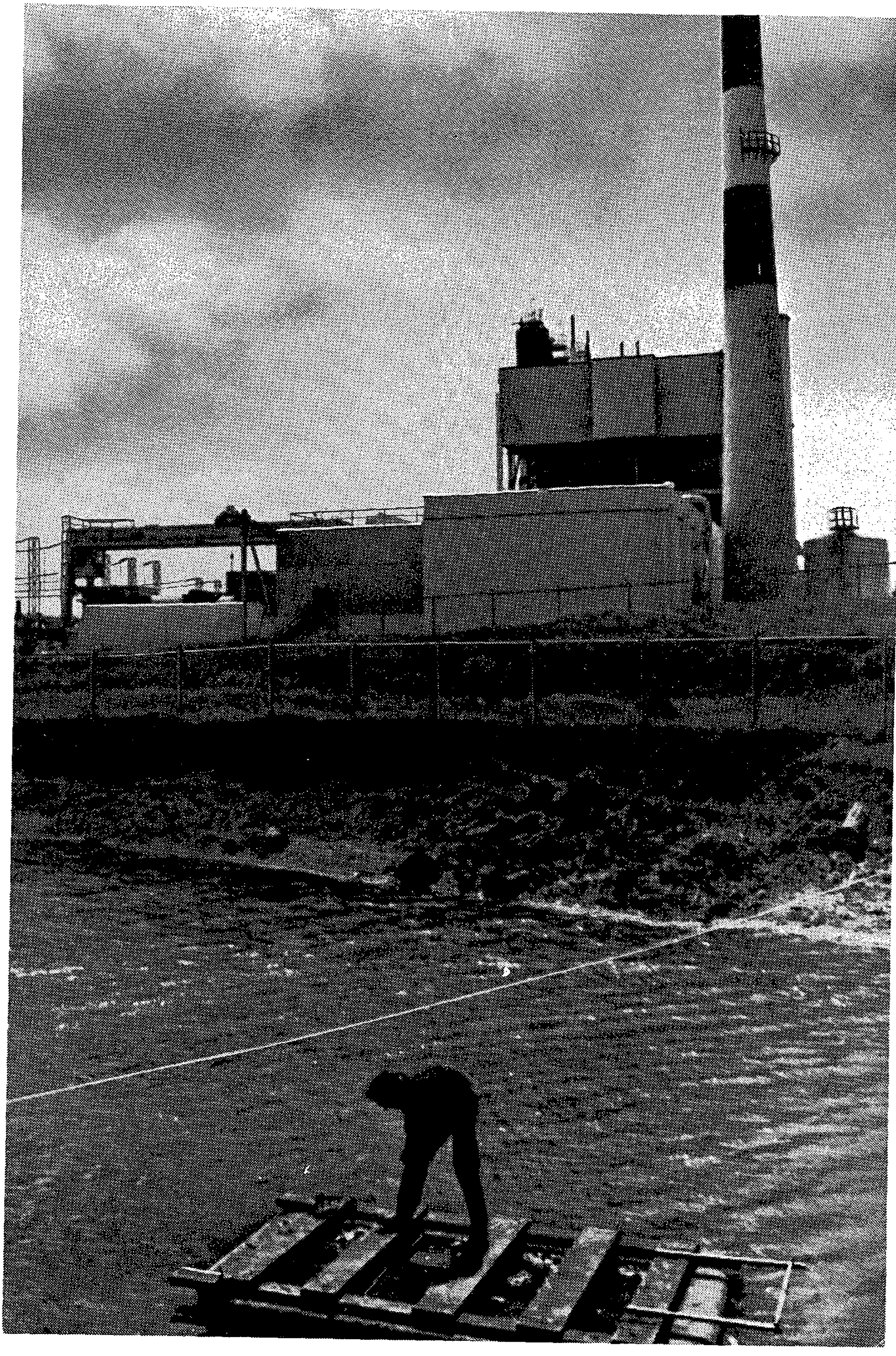
Nuclear power stations discharge practically no chemical or biological pollutants to the environment. They are, however, liable to release small quantities of radioactive effluents and slightly greater quantities of heat than thermal power stations of equivalent electrical capacity.

We shall, therefore, now study the first of these two types of pollution from the standpoint of rational organization of methods of surveying it.

A: Evaluation of the limiting radiological capacity of the receiving medium — This involves determination of the maximum quantity of radioactive contamination which the receiving medium can tolerate. The determination is based on the quantities of radioactive wastes discharged to the environment which would deliver to individuals the maximum permissible dose equivalent as defined above. In the context of the present brief account, the essential nature of the problems to be solved can be better appreciated by reference to a specific example. We shall, therefore, confine ourselves to the study of the limiting radiological capacity of a river basin.

Let us consider a river with an average discharge of 1200 m^3 per second, which corresponds to some 40 000 million m^3 per year. The MPCP laid down by ICRP for a mixture of α, β and γ emitters of totally unknown composition is 10 pico-curies per litre. The river can, therefore, accept a maximum of 400 curies per year of a mixture of totally unknown radionuclides.

A research worker studies the growth of oysters in the discharge canal of the Humboldt Bay nuclear installation, in the US. Preliminary results indicate that the warmed water helps the oysters to grow faster, and that their uptake of radioisotopes contained in the discharge water presents no health hazard — even if a person were to eat only oysters from the canal during his entire lifetime. Photo: Pacific Gas and Electric Company



This standard is rigorous in the extreme because, for obvious reasons of safety, ICRP consider that this mixture of unknown radionuclides may consist entirely of the most dangerous radionuclide of all, radium-226. The standards applicable to other radionuclides are much less rigorous (some by a factor of 1000), but of course they can be applied only if the activity of each radionuclide in the mixture is measured separately.

However, detailed radiation analyses of this kind sometimes take very long to perform, a situation which could lead to delays incompatible both with efficient monitoring of the medium and with rational operation of the facility. The analysis is therefore confined in most cases to the separate determination of the most dangerous elements (radium-226, plutonium-239, strontium-90 etc.) or the most ubiquitous element (tritium).

Thus, on the basis of a separate determination of tritium, which has an MPCP of 3 microcuries per litre of water, the river we have taken as an example will tolerate as much as 100 megacuries (of tritium) per year! At all events, for practical purposes the maximum radiological capacity would be some 400 curies for all the other radionuclides, which it would not be necessary to analyse in detail in routine monitoring.

Bearing in mind the processing to which its effluents is subjected, a pressurized-water reactor with a power of 1000 megawatts electrical (MW(e)) does not release more than 20 curies per year of α, β, and γ emitters, tritium being counted separately and representing a maximum of 5000 curies per year. The river under consideration, from the standpoint of radioactive effluents alone could therefore theoretically support 20 facilities of the same type with a total capacity of 20 000 MW(e).

The above evaluation, let us remember, is by far the most conservative since it is based on the most rigorous standard, and detailed radiation analysis of the effluents would permit much higher MPCPs for individual elements.

With 20 000 MW(e), however, the region of maximum cooling capacity of the river is reached at about the same time. 1000 MW(e) of nuclear power correspond approximately to the heating through one degree of 2000 m^3 of water per second, and a stretch of some twenty kilometres of the river is regarded as necessary for dissipating the resulting heat. Thus, even if a two- or three-degree rise in the river water temperature were to be tolerated for each facility, it would be difficult in practice to install more than 3000 MW(e) every 30 or 40 km.

This example indicates that it is necessary to plan the distribution of capacities over a given river basin from the standpoint of limiting radioactive pollution. Under such a plan, a precise fraction of the total radiological capacity, as laid down by the public health authorities for the basin in question, will be allotted to each of the nuclear power stations located therein.

Technological progress may, of course, make it possible in the future to install higher capacities on a river of the same flow rate by lowering the radioactivity of the wastes during processing and by reducing the heating effect (improvement in efficiency, possible addition of atmospheric refrigerants, etc.).

At all events, the capacity of the basins which can profitably be used is far from unlimited, and this is ultimately bound to lead to the construction of power stations on the sea coast, since the water of the oceans offers greater possibilities for cooling and dilution compatible with the public health regulations.

B: Practical implementation of surveillance — The different stages of environmental surveillance during the life of a nuclear power station are well known and relate first to site selection and then to the period of industrial-scale operation. The latter phase (industrial operation)

Measurement of the uptake of radioisotopes by aquatic life: here, aquarium studies of the effects of plutonium contamination of the marine environment, at the Laboratory of Marine Radioecology, La Hague. Photo: Pierre Jahan

will obviously be much longer, since it is the very purpose of the project. Nuclear power stations are at present built to last for 20 to 30 years on an average.

1. *Preliminary siting study prior to construction* — This study should show how, within the allotted fraction of the radiological capacity of the basin, the facility can be best adapted to the public health regulations, and should also determine the natural radioactivity of the site before any pollution occurs in order to permit the identification of any contamination added subsequently.

The type of nuclear facility (gas-cooled, pressurized-water or boiling-water reactor) governs the composition of the waste material to be released, subject of course to the limits stated earlier. The actual technical features of the reactor can affect the composition of the wastes, and it is interesting to note, for example, that the use in water-cooled reactors of Zircaloy instead of steel for fuel element cladding results in a reduction of tritium release by a factor of about 100, since the tritium combines with the alloy right at the place where it is produced.

Permission to construct and commission the power station cannot, of course be granted by the public health authorities unless the preliminary study confirms that the facility will be correctly adapted to the site.

2. *Surveillance during the period of industrial operation* — This relates to verification of the proper application by the operator of the measures to ensure compliance with the authorized limits.

Gaseous effluents may be released only if the outlet channels are provided with the appropriate measuring facilities and there is also provision for recording standard meteorological parameters during each release.

In the case of liquid effluents, it is essential to carry out a preliminary determination of the physico-chemical composition, volumes and activities of the material to be released, and to monitor emissions during each release. The river mud should also be monitored periodically.

Regarding solid wastes of intermediate activity, these may be stored at the site provided that there is every guarantee that they will not contaminate either the soil or the ground water, even in the case of high water in the receiving river.

This continuous monitoring should be supplemented with periodic monitoring of elements in the food chain (especially milk).

These provisions as a whole should be embodied in agreements governing application to be concluded between the operator and the responsible public health authorities. The latter should have access to the facilities at all times. They should, independently of their routine verifications, proceed to carry out spot checks whose results, should they be in any way unusual, may entail the conduct of more thorough analyses and, if necessary a revision of the operating conditions authorized for the station.

Conclusions

Because of the radiations they emit, radioactive substances can be detected, identified and measured at extremely low concentrations — the corresponding masses are lower by a factor ranging from 1000 to 10 000 than those that can be measured by any other chemical or physical method, however precise, applied to non-radioactive substances.

Radioisotopes can therefore be detected in the environment at levels much lower than those at which genuine public health problems begin to arise. Unfortunately, we cannot say the same of numerous non-radioactive pollutants, which can be measured only at concentrations very close to, or even exceeding, the toxicity threshold.

In the mind of the uninformed public confusion seems quite frequently to reign as between the detection threshold and the toxicity threshold. This undoubtedly explains the following situation which is, to say the least, paradoxical: people are afraid of the hypothetical effects of radioactivity at ridiculously low levels, whereas nobody is alarmed at the fact that the toxicity limits for a very large number of non-radioactive, but very real pollutants are being exceeded almost continuously. The sum of all artificial irradiations does not exceed the normal fluctuations of natural irradiation, and if the genetic effects of very low radiation doses were truly cumulative, the natural radiation to which we are all exposed and which is by far the highest would by itself have eliminated every trace of life on earth long ago.

Lastly, let us not forget that merely the use of X-rays in medicine, particularly in radiodiagnosis, represents an additional average artificial irradiation of the population amounting to double the natural radiation (100 millirem per year). This is about 100 times the irradiation which would accrue from nuclear industry even according to the most pessimistic estimate.

We have seen that the measures described above will make it genuinely possible to maintain environmental radioactivity in all circumstances at a level which is perfectly compatible with public health regulations.

Far from constituting a hazard to the public, nuclear facilites can, by virtue of the strictness of the controls to which they are subjected, serve as a model for combatting numerous unacceptable conventional pollutants of the environment, the most alarming of which, indeed, nuclear power will undoubtedly cause to disappear in the long run.

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