SOME ENVIRONMENTAL ASPECTS OF NUCLEAR POWER

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Of all the possible environmental consequences of nuclear power, the disposal of radioactive wastes has achieved the most regular publicity. The United Kingdom has 25 years of experience of the utilisation of nuclear energy, and has been using it to generate electricity for more than half this time. Throughout this period, considerable care has been taken in the management of radioactive wastes and the first decade's experience was used as the basis of government policy and the associated legislation. The government policy, published some 12 years ago, included two basic principles. The first was to ensure, irrespective of cost, that exposure of individual members of the public remained within the dose limits recommended by the International Commission on Radiological Protection, and that the genetic dose from waste disposal remained below a limit of 1 rem per person in 30 years. The second principle was to do what was reasonably practicable, now taking due account of cost, to reduce doses far below these levels.

Dose Limits

The dose limits for members of the public recommended by ICRP are derived by that body from their recommendations for maximum permissible doses for workers. These, in turn, have been obtained partly by a historical process of reviewing of earlier recommendations and partly by direct comparison with the now substantial amount of human data on the effects of high doses of radiation delivered in short periods. The process of extrapolating this high dose information down to the levels recommended for exposure of members of the public is one requiring considerable judgement, and at present it is usual to make the cautious assumption that the risk of deleterious effects is directly proportional to the dose over the whole of this extrapolated dose range, and is also independent of changes in dose rate or protraction of the dose over many decades. There are sound biological reasons for believing that these assumptions substantially overestimate the risks at the low doses implicit in the control of radioactive wastes. The Commission itself says of these assumptions, they may often "suffice to assess what is considered to be an upper limit of hazard against which the benefit of a practice or the hazard of an alternative practice, not involving radiation exposure, may be based." They add, however, that "in the choice of alternative practices, radiation risk estimates should be used only with great caution, and with explicit recognition of the possibility that the actual risk at low doses may be much lower than that implied by deliberately cautious assumptions."

These views have achieved world-wide and almost unanimous acceptance. Nevertheless, there are a few workers who claim that an even more pessimistic interpretation of the facts is possible and claim, as a result, that the dose limits should be reduced. Detailed studies of these suggestions have not indicated that they are well-founded but, nevertheless, it would be wrong to ignore them. This emphasises the importance of a further recommendation of ICRP to the effect that all exposures should be kept as low as is readily achievable, social and economic aspects being taken into account. This recommendations has an effect very similar to the second principle used in the control of radioactive wastes in Britain, the principle of doing what is reasonably practicable to reduce doses far below the dose limits.

Waste Management

The practical application of the waste management principles in Britain requires two distinct procedures. The first is a scientific procedure aimed at forecasting the radiation doses which would result from any proposed release of waste to the environment. The second procedure is a process of discussion aimed at deciding how far the discharges can be reduced by methods which can legitimately be described as "reasonably practicable". When both these procedures are complete, the statutory limits for that particular release can be specified.

The scientific sutdies have been based, since the late 1940's, on the now well-known method of the critical pathway, and the experience gained allows even major releases to be assessed by very simple methods. For most environments, a simple but plausible model can be postulated to describe the dispersion mechanisms and enough information is available to superimpose on this the effects of reconcentration processes. The results are quite adequate for planning purposes and, if necessary, can be refined by further studies before and during the initial discharges. For the more common situations where only small amounts of radioactivity are released in waste, these methods show that the resulting doses to man will be literally trivial. Even in these cases, however, the second procedure has also been applied, and releases have not been permitted if they could reasonably have been eliminated or reduced. In assessing what is reasonable in the circumstances, the government inspectors take account of the economic and technical feasibility of achieving reductions and also of the expected level of dose and the magnitude of the available reductions of dose, in relation to the dose limits recommended by ICRP.

It has sometimes been suggested that these qualitative concepts should be converted to numerical guidance. However, it is part of their strength that they allow the statutory controls to be adjusted to a very wide range of situations. Phrases like "reasonably practicable" and "the best practicable means" occur widely in British Statutory Instruments relating to safety, and attempts to qualify them would be generally disadvantageous.

The final stage is the granting of a statutory authorisation, without which any disposal of radioactive waste is illegal. The government departments issuing these authorisations in England are the Department of the Environment and the Ministry of Agriculture, Fisheries and Food.

The Present Position

As the slide shows, most of the nuclear sites in Britain are on the coast and their liquid wastes are discharged to coastal or estuarine waters. Of the nuclear power stations, only Trawsfynydd in North Wales discharges to fresh water.

The next slide shows how effective these procedures have been in practice. The doses, expressed as percentages of the dose limits, are those to small critical groups between 10 and 100 people each, and are the result of discharges of liquid wastes. Gaseous wastes make no appreciable contribution. Most of the power stations give rise to doses of less than 1/10 of 1% of the dose limits, while Bradwell and Hinkley Point, which are on estuaries, and Trawsfynydd on a freshwater lake, give doses around 1% of the dose limits. The fuel from all these power stations is reprocessed at Windscale, where the doses are held at around 10% of the dose limit. It is not difficult to make an approximate assessment of the total dose in man-rems to the people in the critical group. For power stations the figure is only a fraction of a man-rem/year per station.

There will also be some contribution from the integral of the very small dose rates over larger numbers of people outside the critical group. This contribution is small but its actual magnitude depends very much on the integration procedures - especially on the lower limit of dose rate at which the integration is stopped.

The Future

The present situation is satisfactory, but it is important to see whether it will remain satisfactory as nuclear power in Britain increases by a factor of 10, or even 30, over the next few decades. There will be no difficulty in limiting the doses from the wastes from nuclear power stations. The critical groups are small in size and the interaction even of adjacent power stations will be only marginal in its effect on their doses. The total genetic dose will also remain far below the figure specified in government policy. At the same time, the increasing throughput at the existing factories concerned with the fuel cycle will be accompanied by improved arrangements for gas cleaning and for segregation and treatment of liquid wastes, and by extensions of present arrangements for burying low-activity solid wastes. As a result, radiation doses from most types of waste will remain at around their present levels.

However, our review has identified several types of waste to which increased attention should be paid in the future. The next slide shows the annual arisings of fission products at the time of reprocessing. This curve rises more rapidly than the power curve because of the shorter fuel cycle of the fast reactor programme. At present, all but traces of these fission products are stored in cooled tanks in an acid aqueous solution. These waste facilities at Windscale contain at present some 250 MCi of fission products, releasing a decay heat of about 1.5 MW. They occupy a ground area of less than 0.2 of a hectare. The system is well able to cope with future expansion and, provided that spare tank capacity is kept available, the plant can deal adequately and safely with the arisings of the next few decades. The system requires a simple form of chemical engineering maintenance for several hundred years. Thereafter, the low-activity residues can be sealed in their concrete enclosures or pumped out for disposal as low-activity liquid waste.

An alternative method is to achieve at an early stage the conversion of the liquid to a glass of high resistance to leaching. The choice of a geological location for permanent disposal is then not difficult and only a watchkeeping surveillance is needed on the site in the long term. A suitable glassification system has been developed in Britain to the large-scale pilot plant level. An initial period of liquid storage would still be necessary to reduce the amount of fission product heating and the glass-making process would require very effective and reliable gas-cleaning methods to keep gaseous wastes down to an acceptable level. Although there is in fact no decisive safety reason for solidification, there is little doubt that it is easier to demonstrate in public the safety of the storage arrangements if the fission products are in solid rather than liquid form.

The next slide shows how the annual production of the noble gas, ^{85}Kr, is expected to increase over the next few decades. The curve tends to flatten in later years because of the increased dependence on fast reactors, in which the krypton production is rather less. The annual arisings of tritium will be about a factor of 10 lower than those for krypton. The genetic doses from the world's production of krypton will be less than 1/1000 of natural background in the last decade of the century, and skin doses to the critical group near the UK reprocessing plant only about 1% of the relevant dose limit. Nevertheless, consideration will be given to methods of reducing krypton releases from plants coming on stream late in the century, and such methods will be applied if it is concluded that they are reasonably practicable, taking into account technical and economic feasibility and also their effectiveness in terms of the overall reduction in doses. Tritium will be no problem at a coastal reprocessing plant provided that, as now, the bulk of the tritium appears in aqueous streams.

With the increasing amounts of plutonium as a fuel, the problem of solid wastes containing traces of plutonium becomes increasingly important. Shallow burial is acceptable only if the plutonium content of the wastes is low, and man-made storage of higher activity waste must be regarded as a temporary expedient, since it cannot be expected to last the half-million years or so required to reduce the plutonium activity to trivial levels. Temporary storage is appropriate for wastes which also contain short-lived nuclides, for example, for the cladding from irradiated fast reactor fuel, but is an admission of defeat for wastes which are as easy to handle now as they will be in the future. Permanent disposal can be considered in areas of considerable natural isolation, such as salt formations. Disposal on the deep ocean floor is also a satisfactory permanent solution, because this environment provides a high degree of natural isolation together with a considerable capacity to accept safely traces of activity leached from the solid wastes. In order to limit the amounts of plutonium going to either of these disposal systems, it may well be necessary to apply plutonium recovery processes to an extent which would not normally be regarded as economically practicable, and thus to keep more of the plutonium within the fuel cycle.

The sea has widely been used as a recipient for small and moderate amounts of radioactive waste, either by direct injection from pipelines, indirect transfer through rivers, or by disposing of packaged solid waste from ships. Like other forms of waste disposal, these procedures need very careful evaluation, and their safety depends partly on the amount of radioactivity disposed of and partly on the care with which the operations are conducted. Generally speaking, sea disposal of packaged waste is more expensive than other methods of disposal and, despite its environmental advantages, it has been used to only a limited extent. The amounts of radioactivity involved have been smaller than those entering the marine environment from other forms of waste disposal and the points of injection have been very much further away from areas where radioactivity might significantly enter the biological food chains. Indeed, the problem of disposal of packaged wastes is not the entry of radioactivity into the biosphere; it is easy to show that the amounts involved are small and will give rise to radiation doses to marine organisms and to man which are trivial in comparison with the natural radiation levels. The most important feature of the planning of these disposals is the need to ensure that undamaged or partially damaged packages are not recovered while they still contain the radioactivity. For this reason, it is necessary to select disposal areas on the deep ocean floor, free of under-sea cables and at depths sufficient to prevent fishing by methods such as trawling. Having selected the area, it is then important to enforce procedures which ensure that the waste is properly disposed of in these areas. This requires close attention to navigation and a thorough control of the design and manufacture of the packages, so that their contents will be carried reliably to the ocean floor. When these precautions are applied effectively and when the total amounts of radioactivity are properly limited, sea disposal is a very satisfactory way of dealing with many kinds of solid radioactive waste. It will never be a cheap procedure, but its environmental advantages will often justify its use in preference to other cheaper procedures.

In summary, our experience has confirmed that the waste disposal policies developed in the 1940's and 1950's can be extended satisfactorily to deal with the expansion of nuclear power over the next few decades. Comparatively simple developments of existing techniques will deal with most of the wastes and the only major changes likely before the end of the century are the introduction of processes for the solidification of the main fission product wastes and possibly for the reduction of the discharges of ^{85}Kr. Special attention will also be needed to deal with the solid wastes containing significant amounts of plutonium.

Accidental releases

In addition to the problems of the disposal of radioactive wastes, there is the possibility of large accidental releases of radioactive material into the environment. No human activity is entirely free from risk and it would be foolish to suppose that accidental releases cannot occur. The emphasis by designers and operators is to keep the probability and the severity of these releases as low as they can. Reliability analysis plays a major part in identifying sensitive aspects of design and operation and in estimating the probability of releases of various magnitudes. For accidents producing only small amounts of radioactivity, perhaps a few hundred curies, the main pressure on the designer is that of availability of the generating plant. The environmental consequences are comparatively minor. Larger releases begin to have environmental consequences and may call for the operation of emergency plans and counter measures to protect people in the immediate vicinity. Accidents of this magnitude must clearly be rare and figures in the region of one accident per 1000 reactor-years have been mentioned as upper limits. The possibility of very large accidents is expressed in varying ways, depending largely on personal attitudes. Sometimes these are said to be incredible, because they can only occur with combinations of circumstances which no one believes can happen, but more often now they are described as being very highly unlikely, with probabilities in the range of 10^{-5} or 10^{-6} per year. Accidents as rare as this are normally regarded by the man in the street as non-existent.

Environmental benefits

While these conclusions are important, they are essentially negative, in that they indicate only an absence of environmental damage. Nuclear power, however, offers a much more positive contribution to our approach to the environment. Certainly in areas other than nuclear power we have damaged our environment by the unwise disposal of waste products, but a much more important form of damage may well be the ill-considered consumption of world resources. In this connection, it has become fashionable to talk about the earth as a spacecraft, implying that both the availability of resources and the capacity to dispose of wastes are strictly limited. The analogy tends to be inadequate, however, because there is a very much higher ratio of earth to people than there is of spacecraft to crew. This means in particular that there is an enormous annual income of energy, both solar and gravitational, and this represents a steady input of resources. However, the spacecraft analogy does emphasise that, with the exception of the equivalence of mass and energy, material on earth is conserved in total although man's intervention often reduces it wastefully from a useful product, such as coal or oil, to the useless or even toxic byproducts of combustion. We clearly ought to be working towards a world strategy, by which we make the optimum use of molecular compounds which are difficult to make other than by slow natural processes, for example, fuel oil and food protein, while treating simpler chemicals and elements as materials to be continuously recycled. In order to achieve some degree of social justice, we clearly have to achieve a substantial increase in the amount of many useful materials currently in play, but certainly we are not forced to regard chemical elements, or simple chemical compounds such as water, as waste mateials. As soon as they go out of service they can be reprocessed as the raw materials for the next cycle.

One feature of a strategy of this kind would be a substantial increase in the demand for energy. Almost all the energy sources we now use involve the consumption of indigenous resources. However, nuclear and, later perhaps, thermonuclear, generation consume these resources at a very slow rate compared with the available pool. I suggest, therefore, that the main ecological aspect of nuclear power is that it provides the basis for solving our ecological problems and thus avoiding, or at least minimising, the ecological disaster of which everyone speaks so freely these days.

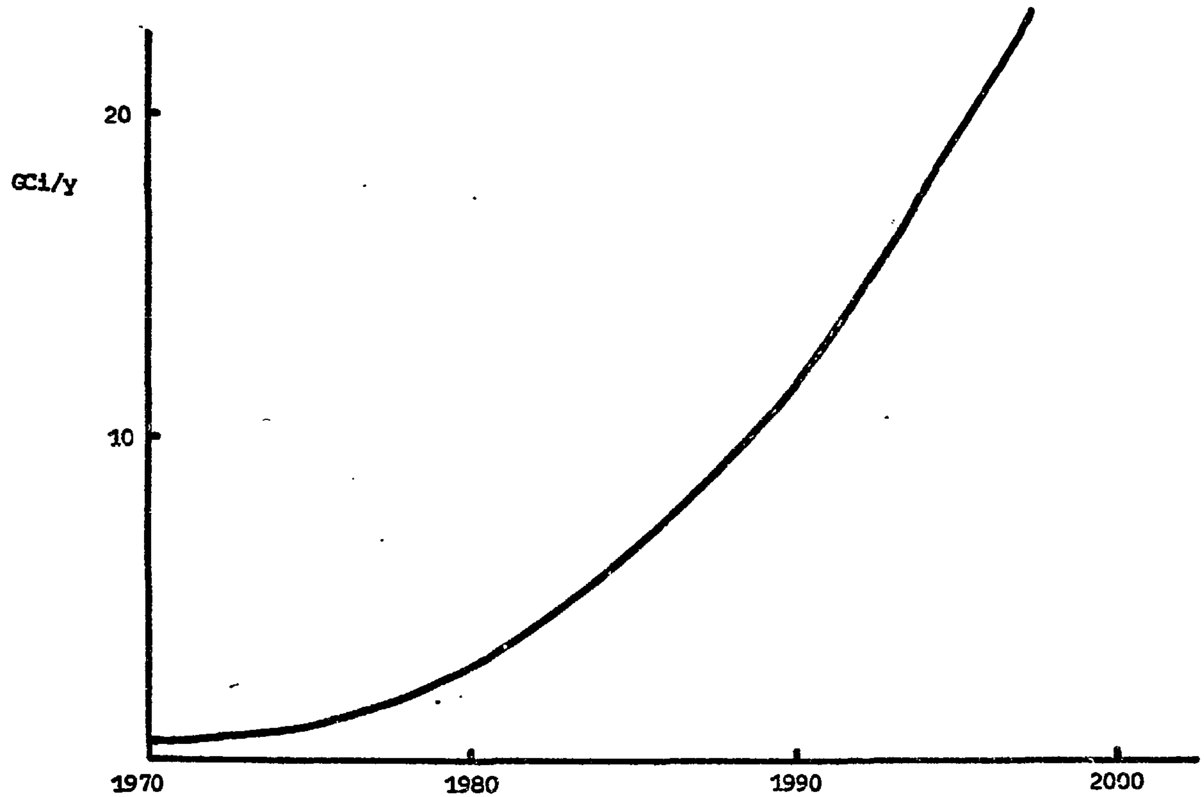
This is a view which contrasts sharply with the more widespread attitudes towards nuclear power, and there have been many attempts to explain why there should have been so much and such passionate opposition to nuclear power projects in many parts of the world. The most convincing explanation seems to be a combination of two factors. Man has always been a predator but he has only recently become a self-conscious predator. Some of the more sensitive of our species now see us not merely changing our environment for our own benefit but rather destroying that environment for our own greed. These people, who in earlier periods would have organised crusades, or fought for the abolition of slavery, or even started new political parties, are now directing their efforts towards the defence of the environment. In the confusion of the struggle it is often difficult to tell friend from foe and it is just the bad luck of nuclear energy that it arrives panting on the scene, anxious to help in the defence of the environment, only to be cut to pieces in the crossfire.

The other factor has I think been contributed by nuclear energy itself. The whole subject was oversold in the early stages of development and the public began to expect immediate, perhaps even revolutionary, benefits. The timescale has been longer than expected and the public have been disappointed. An account of long-term benefits is less interesting, and therefore legitimately less newsworthy, than accounts of sharp political and scientific disagreements. There is thus an inevitable and self-perpetuating imbalance in the public's understanding of the problems and benefits of nuclear power. I do not think it is helpful for the supporters of nuclear power to berrate the news media for their part in this imbalance, but nor is it helpful for reporters or critics of nuclear power to take the line that a man cannot be trusted to tell the truth if his salary is paid by an atomic energy organisation. Accidents are news, not because the press emphasise them, but because the public as a general rule are a bloodthirsty lot and like accidents. The implications, and sometimes the open allegations, of bad faith are perhaps more worrying, but are not a new feature of controversy in science. They are, however, very damaging. The public sees scientists in this controversy reaching diametrically opposed conclusions, apparently from the same basic facts. What can they conclude but that some, or indeed all, scientists are either corrupt or incompetent? No doubt we possess our share of both weaknesses but I do not believe either is the cause of the present disagreement. I suggest this disagreement is the result of building a logical structure of deductions on a single false premise. I think the argument runs something like this. Industrial development is harmful to the ecology. The production of nuclear power is now in the forefront of industrial development and is therefore particularly harmful to the environment. There is to be an enormous expansion in the production of nuclear power and therefore the effect on the environment will be catastrophic. The basic error lies in the assumption that the generation of nuclear power is harmful to the environment. Apart perhaps from questions of the aesthetics of the appearance of nuclear power stations, or any other type of generating station, and of transmission lines, there is not a scrap of evidence of ecological damage done by nuclear power. Scientists are thus taking hypotheses about possible mechanisms of damage not yet demonstrable and using these hypotheses to forecast the future. The extreme pessimists reach one conclusion, the optimists another, and there is a spectrum of conclusions in between. It is then a matter of judgement and not of fact, to select the most probable forecast and use this as the basis for action.

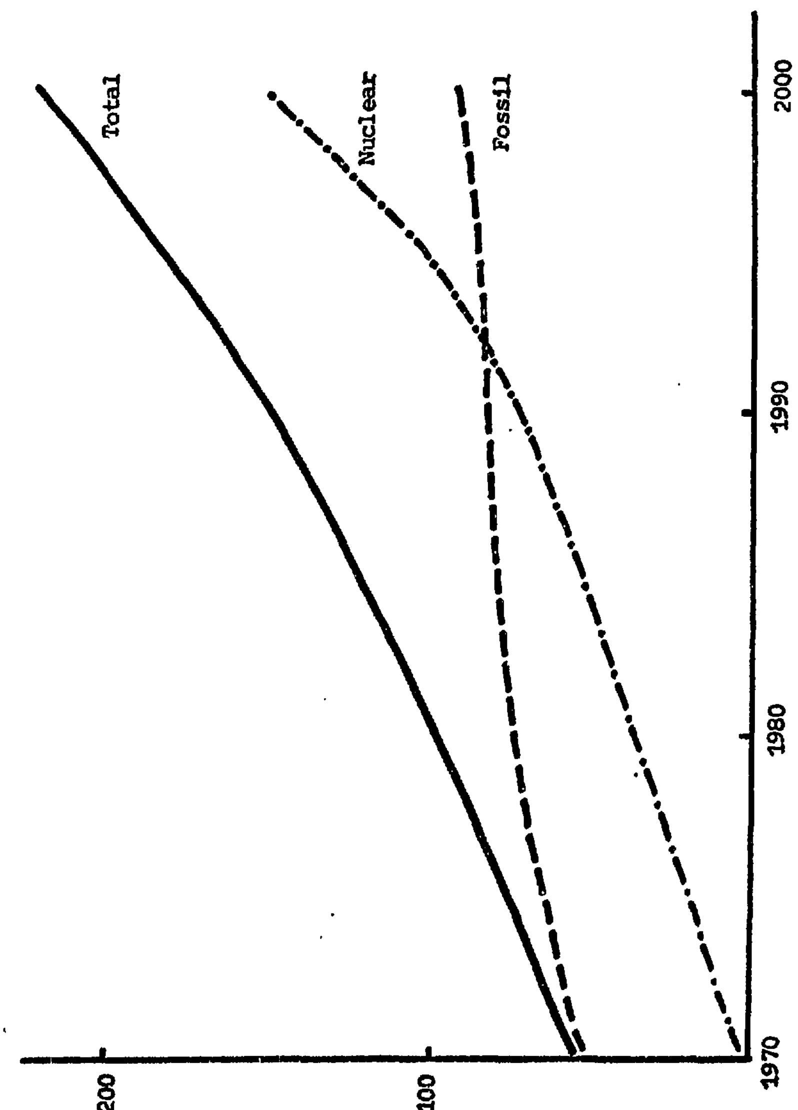
It has often been suggested that this action should take the form of a nuclear moratorium for, say, 10 years. Apart from being a very expensive decision in terms of hard cash, it would also be an unwise one on at least two counts. In the first place, the nuclear power industry is highly technological and a moratorium would break the continuity of development. On restarting, the industry would be inexperienced and fragmented, its design philosophy would be naive, its operating teams would be relearning their jobs and the industry would be less efficient and less safe than at present. Secondly, the demand for power would have to be met from other sources during the moratorium and this would be more damaging to the environment than nuclear generation, both directly and by consuming dwindling resources. This detriment would apply, not merely over the period of the moratorium but over the whole working life of the plants.

In the International Maritime Signalling Code, the signal letter "U" stands for "You are standing into danger" and it is entirely appropriate for the environmentalists to hoist this signal as a warning to the nuclear power industry. The severity, even the very existence, of the danger is uncertain but the warning is timely. The correct response, again in nautical terms, is not "Stop both" but rather "Slow ahead together". I shall now abandon this rather laboured marine jargon and revert to plain English.

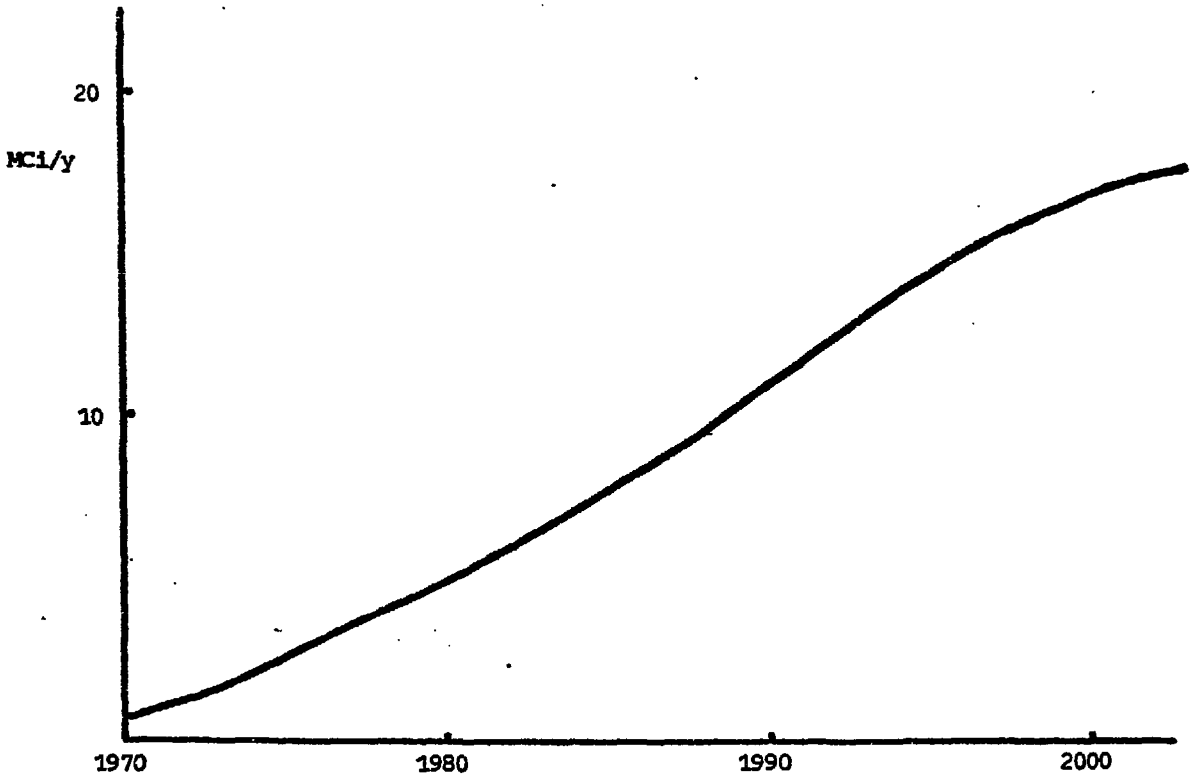
Lacking incontrovertible evidence of the absence of ecological damage, we must undertake scientific studies and spend a good deal of money to improve our understanding of the ecological problems concerned and to keep watch for any signs of deterioration. The atomic energy industry and the governments that have sponsored it, can fairly claim that they have adopted this policy right from the start and have been very, perhaps uniquely, successful. The problem facing scientists in this field now is to convince their colleagues so that together they can convince the public. The present series of confrontations is not particularly edifying and discussions on a more rational level would certainly be welcome. Perhaps the first small step should be an attempt to get agreement that everyone concerned has the same long-term objective, that of achieving an ecological balance on this planet that permits mankind, all of mankind, to reap the benefits of technology without handing on intolerable burdens to future generations.



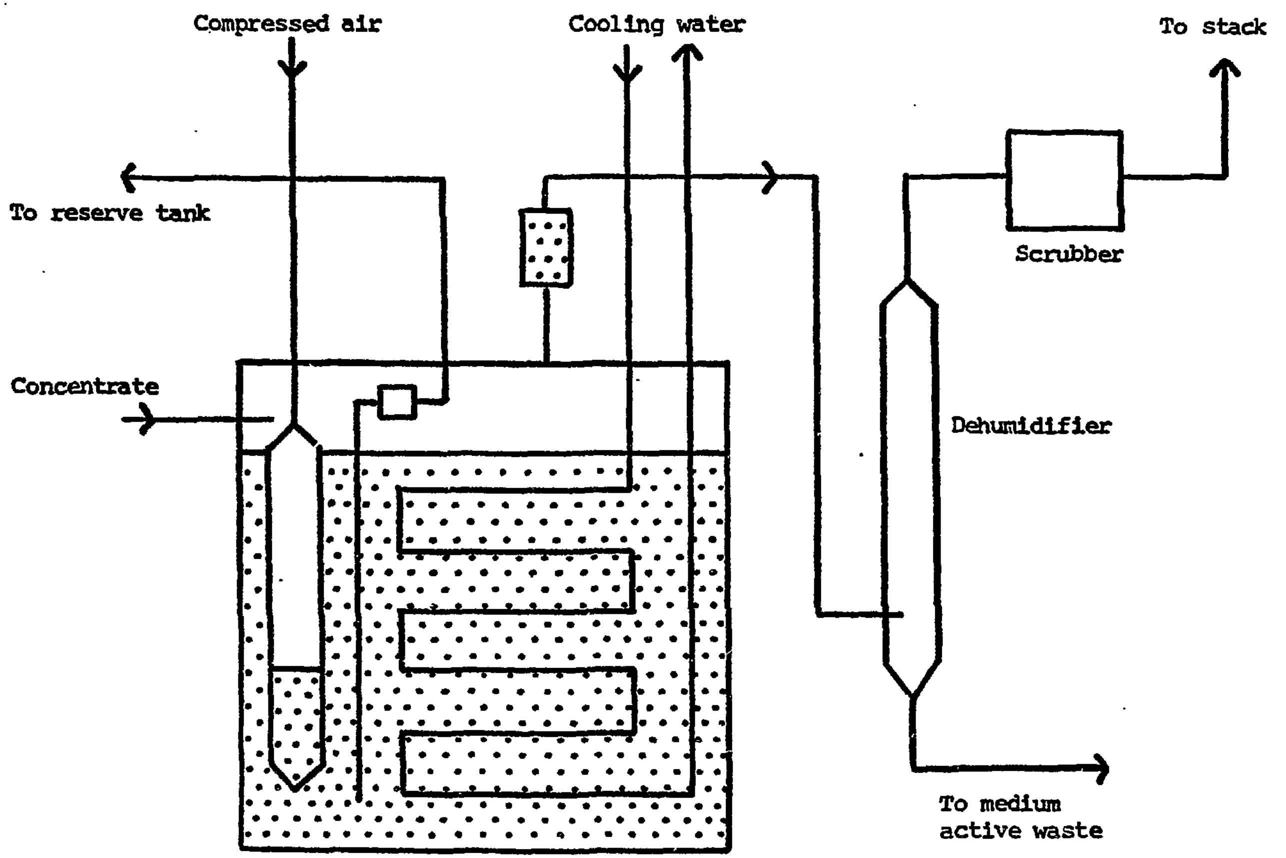
Annual throughput of fission products in UK reprocessing plants



UK Generating Capacity

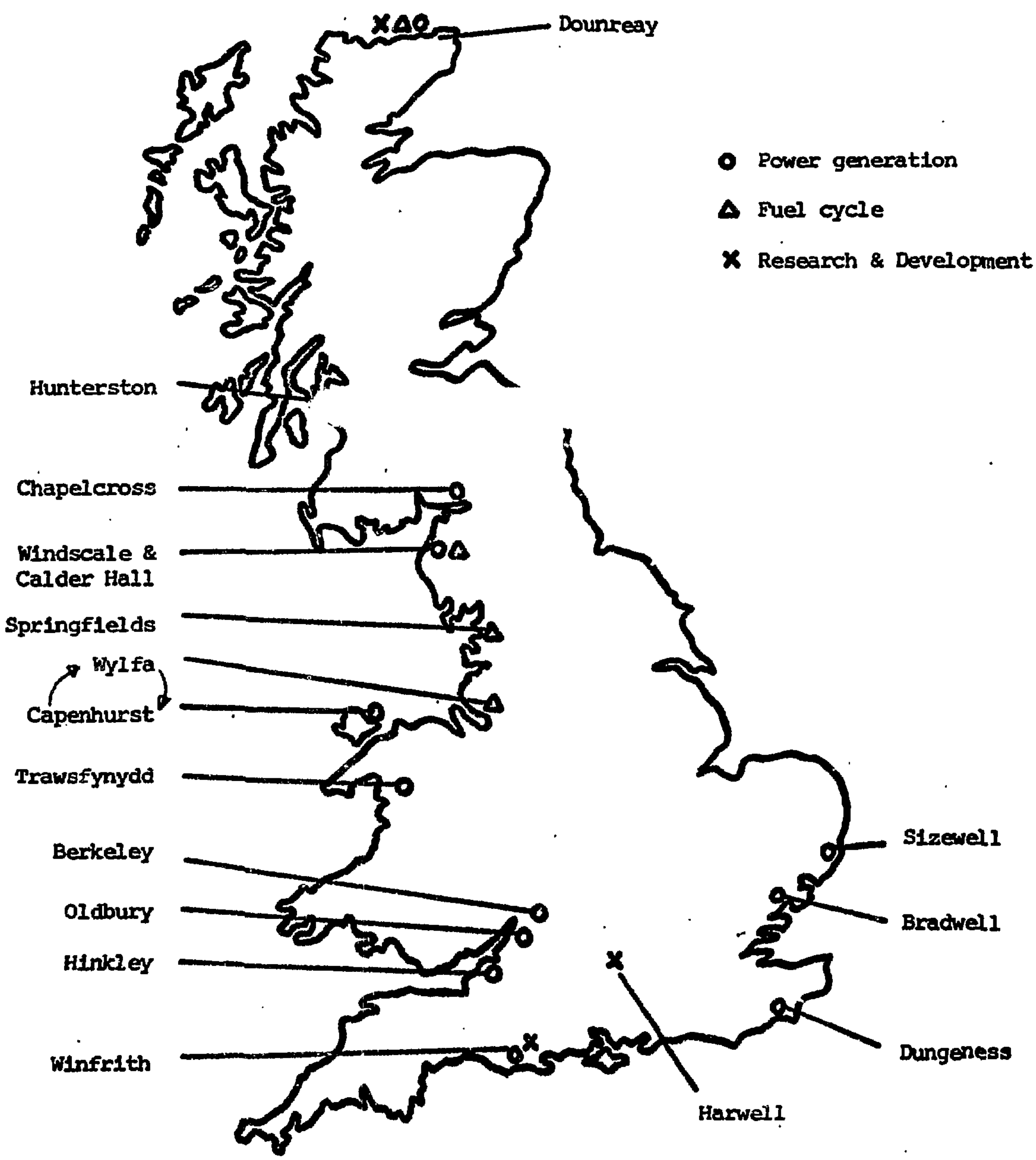


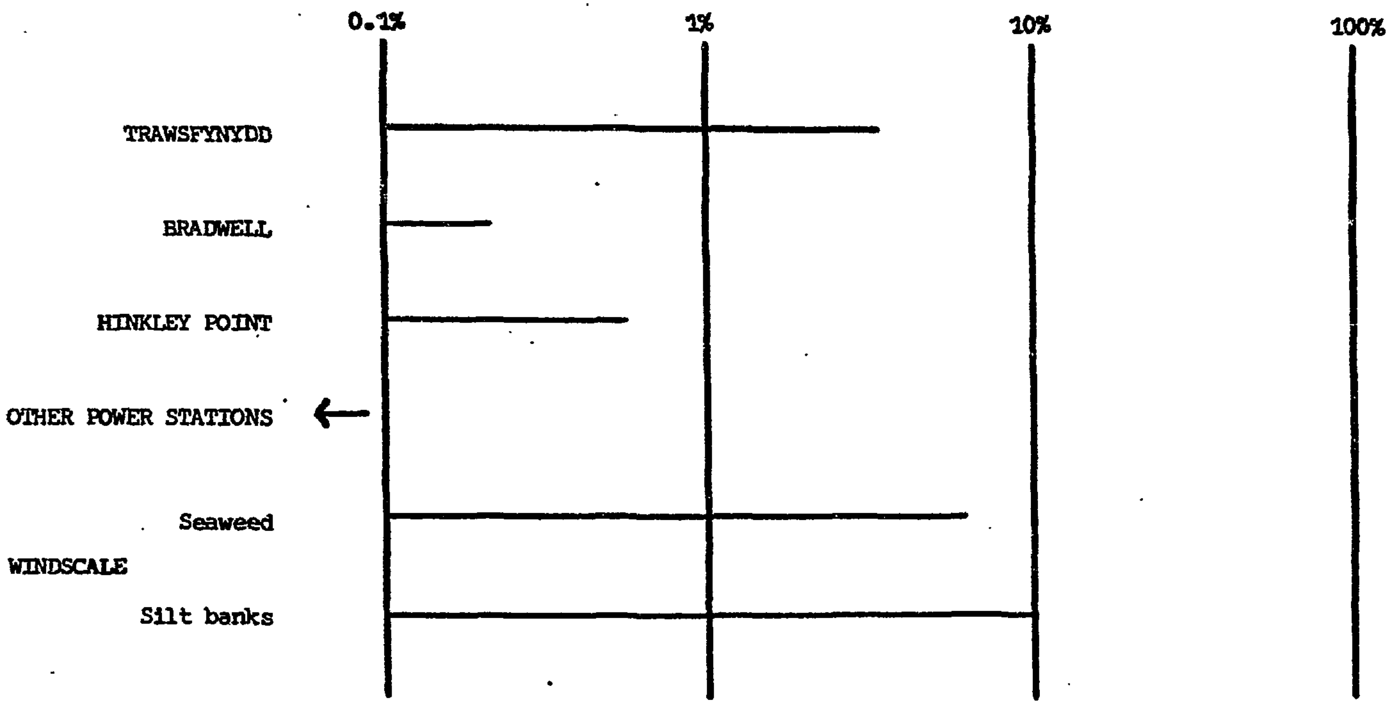
Annual arisings of ^{85}Kr (UK)



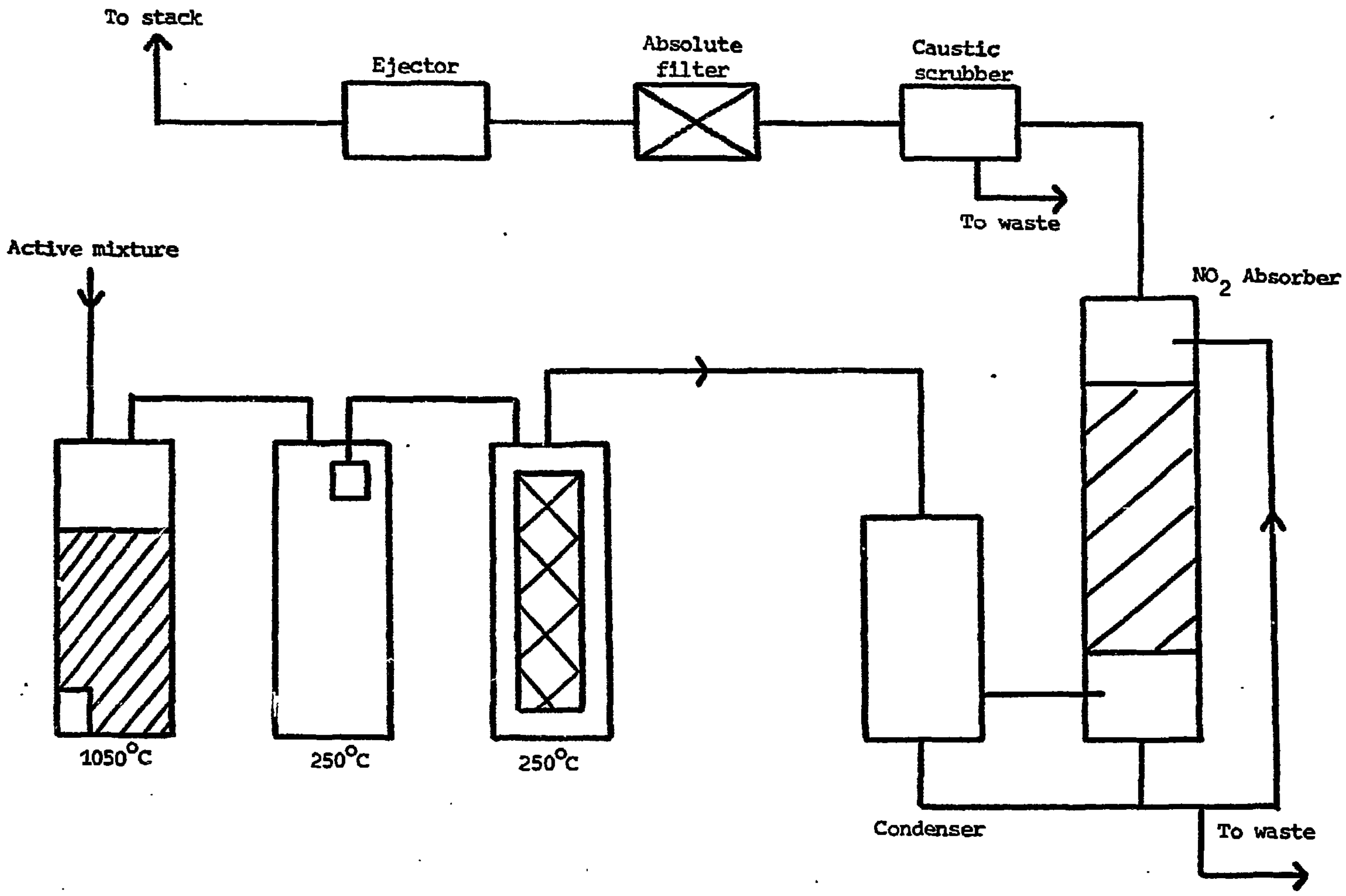
Simplified diagram of storage tank

Sites in the UK Nuclear Power Programme





Percentage of Dose Limits received by Critical Groups in the UK



Simplified diagram of FINGAL