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Acceptable Nuclear Risk: Some Examples from Europe

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ACCEPTABLE NUCLEAR RISK: SOME EXAMPLES FROM EUROPE

By

Greg KASER

SUMMARY

The paper examines the construction of the concept of acceptable risk by comparing the approach to regulating nuclear power plant safety at international and national levels in Europe. It focuses on the European Community and two of its member states, Italy and the UK, and Hungary. Their approaches to regulation are related to developments in the scientific community concerning the meaning of safety. Two themes are pursued, namely the socially determined and the probabilistic nature of safety. In particular the method examined is that of cost-benefit analysis. It is argued that the different tests applied to establish safe standards either explicitly or implicitly make a judgement as to the acceptability of risk. Safety is modelled as the product of trade-offs between risk and social and economic factors. The decision-aiding tools of probabilistic safety analysis and cost-benefit analysis provide means, albeit flawed in respect of the political nature of the values involved, to measure the two dimensions of acceptable risk. Their use however enables choices concerning the acceptability of risk to be transferred back from the experts to citizens and workers and into the political process.

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INTRODUCTION

Overview

Two themes are examined in this paper. Controversy surrounding the regulation of nuclear power plant safety has sharpened and clarified certain issues which have much wider implications for public policy. To the public demand that nuclear power be safe regulators and the industry's leaders have developed the concept of "acceptable risk", that is, nuclear power plants are safe because the degree of hazard they pose is one generally accepted by society. Hazard assessment techniques are used to demonstrate the degree of risk. The very notion of safety, it is argued here, has been changed from its meaning of a state free from risk or worry. Its new meaning results from two processes. One involves the implicit or explicit social judgements that underlie the standards of safety set by regulatory scientists. The other is the shift from deterministic to probabilistic methods for defining hazard. If a hazard is defined in terms of probabilities those facing it cannot consider themselves absolutely secure from harm.

The focus of this paper is upon the approach and methods used by regulators at the international and national levels. Specifically a comparison is made between the European Community (Euratom) and the national authorities of Hungary, Italy and the United Kingdom. Their approaches to regulation are related to developments in the nuclear scientific and engineering community concerning the meaning of safety. The method examined is cost-benefit analysis.

Chernobyl has demonstrated that nuclear safety is a matter of international concern. Radioactive contamination spread world wide respecting no frontiers. In fact international regulation in this area has a relatively long history and Euratom is an example both of this and of an international organisation with powers to prescribe as well as to advise. As comparators at national level Italy and the UK were chosen as each are member states of the European Community. Since the exercise involved a study of nuclear power plant safety regulation there was an element of self-selection, with the requirement that the countries chosen have a nuclear programme. The UK has invested heavily in nuclear power, whereas Italy's nuclear programme has played a more minor role in its national life. Indeed Italy is probably going to give up the option of nuclear power. So the countries represent each end of a spectrum of involvement with this technology. For further comparison a non-European Community country was chosen. Although Sweden would have been an obvious, and relevant choice, Hungary is a nation of the socialist commonwealth and, importantly for a researcher, accessible and open.

Why safety is regulated

The nuclear industry shares with many other economic activities the capacity to cause harm. A nuclear reaction involves the use of materials (for example, uranium) whose innate natural radioactivity has been enhanced and produces both heat and substances (for example, plutonium) which may remain highly radioactive for extremely long periods - sometimes for timescales beyond the experience of any literate society. Certain chemical processes may also, of course, create novel substances or compounds in forms which are, say, toxic or carcinogenic forever. As an industrial hazard a source of ionising radiations is of concern since these radiations can affect essential components of the body. Current medical thinking considers that any exposure to ionising radiations causes irreversible harm.

At the heart of regulatory policy concerning nuclear safety is the concept of "acceptable risk". There is a widespread consensus that "health and safety are not absolutes that can be defined in a quantitative sense" (Starr, 1985, p97) and that "a thing is safe if its risks are judged to be acceptable" (Lowrance, 1976, p8). Achieving safety in its absolute sense is seen as impracticable.

It can be argued, quite apart from any set of social values which makes the community responsible for guaranteeing individuals the rights to life - as do socialist aims that people should live free from want and flourish under conditions of social peace - or of moral systems based upon religion, that markets do not operate optimally in this area. Modern industrial societies have through health and safety or product liability legislation generally sought to end the sort of situation (described by Lowrance) which prevailed in the USA around 1900 where "workers laboured under their own peril" and caveat emptor [let the buyer beware] "strictly governs the market" (Lowrance, 1976, p76). In such circumstances workers and consumers can only obtain compensation for irreversible harm if the labour and insurance markets are not undermined by people, perhaps through desperation, willing to take higher risks. Moreover the dead, the unborn and others not in paid economic activity cannot directly affect the market.

As a result few dissent from applying regulations to ensure that practices are carried out as safely as is acceptable to society. In the case of radiation the risk of harm is based upon the relationship of exposure with effect, that is damage to health. Having established the exposure-effect relationship it is possible to control the radiation source to ensure that the dose received represents an acceptable risk of harm. An upper control limit is set for the dose, well below the no detectable adverse effect level. Such an exercise relies upon the modelling of the exposure-effect relationship. There is disagreement within the medical and scientific community over the interpretation of data and the shape of the exposure-effect relationship: hence conflicting assessments of what constitutes a 'safe' level of exposure. If it is assumed that there is no threshold below which a dose cannot cause harm, it follows that an undetectable amount of harm will inevitably occur. On the basis of the no-threashold assumption there is thus a further requirement to optimize radiation protection, that is "balancing protection costs and [the detriment of] residual levels of exposure" (Webb and Lochard, 1984, p5-6).

The rest of this paper follows these issues in their practical setting.

ACCEPTABLE RISK

What if it doesn't work?

In great secrecy the first atomic reactor was activated in December 1942. The research team at Chicago was led by Enrico Fermi. Their atomic pile of graphite, uranium and uranium oxide had three independent sets of control rods. In addition Fermi instituted a number of other safety features. There was an emergency safety rod which was to be released in case the automatic rods failed. On top of the pile, researchers stood ready with buckets of cadmium salt solution to flood the pile should something unexpected happen (Stadie, 1985). Thus the very first nuclear reactor was protected through the practice of defence-in-depth - in this case, by the installation of backup shut-down systems to nullify the consequences of malfunction.

A safety system can be imagined as a series of barriers. The reactor's fission products are sealed from the environment by several independent barriers, avoiding undue reliance upon any single safety provision. Some barriers are physical: the fuel's cladding, the reactor core, the pressure vessel and the containment building. Others may be engineered systems, such as backups to be brought into action if necessary or the extent to which the reactor is designed to achieve inherently safe behaviour. The barriers can also be thought of as including social arrangements, such as quality assurance and quality control in plant design, construction and operation, and siting criteria. Emergency planning or preparedness is not always considered to be part of defence-in-depth since plant owners and operators are expected to reduce the risks to acceptable levels without the help of such procedures.

In asking the question "what if it doesn't work?" a regulator can probe the extent of defence-in-depth. A designer can include features to avoid predetermined consequences of failures. Provided there is sufficient assurance against the worst case accident, a licence can be granted to operate the plant. Clearly, such an approach relies upon the capacity of designers and safety engineers to foresee the possibility and consequences of failures.

"Engineering judgement" is the term used to describe the process whereby engineers decide upon a design that has a negligible probability of failure. A structure might be designed to withstand specific but unusual events, for instance, a freak wave or storm experienced only once in a century. Safety margins are calculated for load-bearing structures or stressed materials. Case histories are analysed and average failure rates or rules of thumb used to establish a standard of good practice.

Such an approach is called deterministic and underlies, as will be shown, the regulation of safety as it is practically applied. It can be criticized on a number of grounds. Firstly, the risk of failure is not fully quantified. There is a spread of, say, stresses or strengths in a structure and thus a range of chances of failure. Designing on the basis of an average or rule of thumb cannot take into account the distribution of probabilities, including those for events with a low chance of occurrence. Secondly, there is a hidden judgement concerning those risks that are acceptable or negligible. Thirdly, an engineering philososphy relying upon the extension of past practice and case histories inadequately handles novel situations, for instance those arising from advances in technology. Finally, the issue of how safe plant should be is open-ended. The question "what if it doesn't work ?" can be repeated endlessly, a potential for bidding up of safety levels by regulators (see The Royal Society, 1983, p26-27; Rimington, 1987, p10).

Probabilistic safety analysis systematically examines expected performance and failure to obtain estimates of the risk and consequence of a hazard. This perspective allows for the quantification of the spread of possible events according to the probability of their occurrence. Whether the risk is acceptable or not can be assessed independently of the designer's judgement: it opens up the design to scrutiny. Potentially probabilities can be assigned to events that have not yet happened, and, moreover, such estimates may be questioned or altered, perhaps being described as " conservative assumptions". Risks between different plants or between industrial and social activities can be compared on a similar basis and a decision on what constitutes an acceptable risk might be made as a result. This defines the ultimate level of safety with which a regulator may be satisfied.

To be sure, probabilistic safety assessment remains only a decision-aiding tool. Its proponents advocate its usage as a means whereby hazards are subjected to systematic evaluation: possible sources of danger, fault conditions or a sequence of failures leading to accidents should not be overlooked if every part of the engineered system is examined. In its quantified form of probabilistic risk assessment, an event tree (or fault tree) can be constructed. Each component can be assigned a probability of failure together with an anticipated consequence. In principle human failure can be treated in the same way.

Such estimates of probability are only as good as the reliability data upon which they are based. Professor Allan Mazur cited his own experience as a reliability engineer in the aerospace industry, calling probabilistic risk assessment "an exercise in science fiction" in view of the lack of failure data (Mazur, 1980). Indeed at the same international workshop it was agreed that risk assessment research was an immature field "characterised ... by fragmentation, lack of coherent knowledge and consensus of researchers, and little evidence of the establishment of a stable and qualified community". Johnston also particularly pointed to probability analysis and toxicology, for instance in the latter's reliance upon exposure-effect correlations, as being able to "provide only the most tentative of guidance" (Johnston, 1980). A later assessment could merely claim that probabilistic risk assessment "has made significant strides towards maturity" over the last two decades (Speis and Jahns, 1985, p185).

Furthermore, some have argued that such risk assessments "in part serve to legitimate decisions and actions ... rather than being outcomes or expressions of rational search processes. Tragic choices by organizations do not have to be optimal or even solve the problem demanding attention, but they do have to be legitimated to those who will bear the cost of those choices" (Clarke, 1988, p30). Despite the protestations of (regulatory) scientists that risk assessment is a scientific issue while risk acceptability is a political one, the technique itself is both the product of social forces - the outcome of disputes within the scientific community and organisations or of political factors - and value loaded, by incorporating assumptions that individuals can choose between risks they face or that trade-offs are possible. It is an example of a "trans-scientific" issue (see Weinberg, 1974).

Although probabilistic methods for assessing safety are being employed more frequently, see Appendix A, they remain complements to regulatory and licensing procedures. The latter are still based upon deterministic approaches. That is, based upon "a set of requirements for normal operation and of a pre-determined set of accidents, the so-called 'design basis accidents', considered to lie within a sufficiently low range of probability of occurrence and to be the extreme cases of certain types of accident" (CEC, 1987, p2). Yet there is a shift underway to probabilistic methods which could have major implications for how hazards are judged to be acceptable. The shift is being championed by scientist regulators associated with the International Commission on Radiological Protection.

Acceptable risk from radiation

Despite the common belief that standards for protection from the harmful effects of radiation are derived through the application of scientific method, their origin lies in a social judgement. This can be seen from the way the International Commission on Radiological Protection (ICRP) - a non-governmental organisation that effectively sets the regulations world-wide - formulates its recommendations. An analysis and history of the ICRP's part in formulating the concept of acceptable risk is to be found in Fagnani and Nicolon (1979). This organisation's pivotal role in setting a set of world-wide safety standards cannot be seen in isolation from the dominant position that the USA has held in the industrialised and scientific worlds since the 1940s (Fagnani and Nicolon, 1979, p481). It is however the substance of its recommendations that concern us here rather than how or why the ICRP has been so influential.

The current limit for occupational exposure is 50 mSv per year. [A sievert (Sv) is a measure of exposure.] It is equivalent to that adopted by the ICRP thirty years ago: 5 rem per year for a whole body dose (ICRP, 1959). This "maximum permissible dose" was defined as "that dose ... which in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities".

The argument then, as now, crucially revolves around the idea of acceptable risk (see Ilari, 1986, p4). In 1959, provided that the regulations were adhered to, risk of severe harm from exposure was "negligible" and, of harm generally, "not unacceptable". It is however a social judgement going under the guise of a scientific statement. The basis upon which the judgement is made is not stated explicitly; for "negligible" begs the questions "compared to what?" and "to whom?". By 1977, when the ICRP revised their recommendations significantly by dropping the maximum permissible limit and adopting a three-fold system of dose protection (see next section), there was greater clarity: "In recommending appropriate limits for any occupational or other exposure to radiation, it is obviously desirable to estimate the types and frequencies of harmful effects that may result from any given radiation exposure. Moreover, in assessing the safety of an occupation involving such exposure and comparing it with the safety of other occupations, it is important to compare the total harm that may be caused by the radiation, both in those exposed and in their descendants, with the total harm involved in other occupations, whether by fatal or minor injury, occupational disease, or the effects of mutagens in the environment" (ICRP, 1977b, p1).

In the ICRP's view the risk to all radiation workers at the exposure level of 50 mSv/year is " equivalent to an occupation with a fatal accident rate of 340×10^{-6}/year, comparable with that in construction work or coal-mining in many countries" (ICRP, 1977b, p22). The risks to the public were also considered comparable in kind to the risks of immediate deaths in other industries (Webb and Dunster, 1985, p307).

The relationship between an individual's exposure and risk of harm is shown in Figures 1 and 2. At the higher levels of exposure - in the range 3-5 Sv/year - early death is very likely. At the equivalent of about 4 Sv/year half an exposed population will die: this is the LD50 [meaning the lethal dose for 50%]. Much lower levels of exposure carry a lower risk of severe harm, for example the induction of a fatal cancer. Nevertheless in any one year, exposure at the upper control limit of 50 mSv implies that the individual worker faces a lifetime risk of between 1 in 1 000 and 1 in 10 000 (about 5×10^{-3}). Even at the lower level of exposure of 15 mSv, which is the usual "investigation or trigger level", that is the point at which a more rigorous justification for further exposure is required, the risk exceeds 1 in 10 000. In practice most radiation workers face a risk of between 1 in 10 000 and 1 in 40 000 (HSE, 1988, p23). The upper control limit for the public of 5 mSv lies in the same range (about 5×10^{-4}). Whilst the limit for all doses for the public over a lifetime, recommended as being 1 mSv/year, is a risk of 1 in 100 000.

By way of comparison, the fallout from almost 500 atomic bombs exploded above ground will by the end of this century deliver a dose of about 1 mSv to everyone on the planet (Caufield, 1989, p30). The contamination resulting from the world's worst nuclear accident at Chernobyl-4 necessitated the evacuation of 135 000 people from a 30 km zone as exposure levels climbed over 100 mSv per person. In terms of its fallout, the total dose for an average adult over 50 years is between 6.5 and 30.5 mSv in the European part of the USSR - dependant upon assumptions made about the intake of radionucleides in food - and about 1, 0.4 and 0.27 mSv in Hungary, northern Italy and Wales respectively (see CEC, 1986a, p10; EC ESC 1987a, pp8 and 11; Sztanyik, 1985, p164).

There has been much debate both within the scientific and medical community, and in the public arena, as to whether the ICRP's calculations of the risk values attached to harm are valid (see for example Bertell, 1985, pp49-63). In a candid aside a member of the ICRP, John Dunster, has admitted: "I think that most of the information we describe as data in the radiation protection and nuclear safety sense is not data at all. It is invention. We pretend we know the dose-effect relationship. It is a convincing story [but] it rests on fairly shaky bases" (NEA/OECD, 1985, p315). A review is in hand by the ICRP, taking into account re-evaluations of data relating to the survivors of the atomic explosions over Hiroshima and Nagasaki amongst other things, which is expected to result in a revised set of recommendations in 1990.

Much less attention has however been devoted to the relationship of the dose limits themselves and the concept of acceptable risk. These limits are not simply the upper control limits, set at a level prejudged to carry an acceptable risk, but are intended to be set for each different practice through a process of optimization. This further component in setting acceptable risk is analysed next.

Cost-benefit analysis and the morality of optimization

At an international seminar the director of the UK's National Radiological Protection Board, John Dunster, made the remark that optimization of safety was necessary because " if you have a residual risk you have a moral duty to remove risks which are easily removable" (NEA/OECD, 1985, p74). He was expressing the philosophy which underpins the system of radiological protection advocated by the ICRP and arguing for its wider application to nuclear power plant hazards. In this section we examine the ICRP system.

The main features of the ICRP's system of dose limitation are:

> "(a) no practice shall be adopted unless its introduction produces a net benefit;
>
> (b) all exposures shall be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account;
>
> (c) the dose equivalent to the individual shall not exceed the limits recommended for the appropriate circumstances by the Commission" (ICRP,1977a).

Operating these three principles - justification of practice, optimization of protection and individual dose limitation - in conjunction with one another, throws up decision-making problems of considerable complexity. This stems from the fact that the harm threatened by the hazard cannot be determined for sure.

For instance, the extent of protection provided to a radiation worker is not to be determined by reference to the risks the worker is prepared to bear. Even if the individual explicitly accepted the risk itself the ALARA principle requires that the costs of additional protection be weighed against the benefit of a reduced risk of harm. Two arguments can be advanced to justify this position. Firstly, there are possible mutagenic and teratogenic effects which because they involve the health of future generations are the responsibility of society as a whole, not merely the individual. Secondly, there is some definite expectation of harm to the whole exposed population from all doses. "If this harm can be reduced at reasonable efforts, why should this not be done? If we fail to do the reasonable thing, we can hardly call the situation acceptable" (Beninson and Lindell, 1985, p24).

Echoes of a deterministic approach are found in the third element of the system, that of individual dose limits. The risk of harm is assumed to be proportional to the dose, exposure to which can be estimated with certainty. Exposure can be planned through dose control, that is through measures which regulate the source of radiation and the distribution of the collective dose amongst those exposed. In day to day operations the ICRP individual dose limits act as upper bounds to planned exposure. The individual's risk of harm can be calculated from the dose actually committed (received). But clearly each exposure carries a further increment of risk and, at any one time, future exposures are uncertain. Under the previous system of maximum permissible doses this uncertainty was not acknowledged. ICRP now recognise that the distribution of doses amongst those exposed and over time is a factor in radiation protection. The way that this uncertainty factor can be incorporated into the system of radiation protection is under discussion within the ICRP and the scientific and regulatory community (see González and Webb, 1988). It is likely that annual individual dose limits for workers will be recommended: if these were established at 0.5 or 1 mSv/year there would be "consistency" with the existing limit for members of the public.

Yet the nature of the exposure-effect relationship is probabilistic, except at lethal levels of exposure of greater than the equivalent of 5 Sv. Even if individuals face a negligible risk from their own exposure, society could face a situation where a large number of small doses amount to a high overall expectation of harm. Attempting to use the ICRP's own principles of justification and optimization is in practice fraught with difficulty.

Nevertheless the ICRP recommend the use of cost-benefit analysis to evaluate principles of both justification and optimization. "Ideally the acceptability of a proposed operation or practice involving exposure to radiation should be determined by cost-benefit analysis, the purpose of which is to ensure that the total detriment should be appropriately small in relation to the benefit resulting from the introduction of the proposed activity" (ICRP, 1977a, para.69). Although work is under way to develop multi-attribute utility analysis to aid decision-making in the optimization process - to include criteria which are difficult to quantify in monetary terms - the system of optimization relies upon cost-benefit analysis wherever quantification is attempted in practice.

The costs of radiation protection in a workplace may include shielding and ventilation, use of remote handling equipment or robots, bringing more people in to do the task (to reduce the size of doses to each individual) or mock-up training (to speed the actual operation). Benefits relate to the value put on life. For any unit of exposure - measured in sieverts - there is a risk of fatality. Thus dividing the value of life by the risk can give a value for a unit of exposure in $/person Sv.

Where the dose committed is certain, practice in the radiation protection field relates harm to the size of the dose (which may be a collective or individual dose). So-called "objective health detriment" is measured therefore in terms of the dose (more properly the effective dose equivalent) in sieverts. Multiplying the dose(s) by the reference $ value for a sievert gives the benefit of avoiding that dose in monetary terms. It is possible to so value the collective dose to give greater weight to high individual doses - implying risk aversion to larger doses - thus taking into account the distribution of risk amongst those exposed (so-called "subjective health detriment").

The ICRP advise that optimization is achieved when "the increase in the cost of protection per unit dose equivalent balances the reduction in detriment per unit dose equivalent"

(ICRP, 1977a, para.74). The balance is attained when the sum of the cost of protection and the cost of dose detriment is minimized or their marginal costs equated. This is illustrated in Figure 3.

Figure 3 shows the cost of the collective dose - and therefore the cost put on risk of harm - rising linearly: the cost of harm is proportionate to the degree of risk. As risk becomes more remote, the value put on avoiding harm is assumed to be smaller. Alternative models can be postulated, for instance an exponentially rising curve, where the cost put on harm rises at a greater rate than the degree of risk. It can also be argued that the value of avoiding harm should be invariant with regard to the degree of risk, in other words, that D is constant (it would be drawn parallel to the x axis in Figure 3). It cannot be deduced from the fact that since remote risks are often ignored - perhaps because individuals are only dimly aware of them - that they should be valued (dis)proportionately lower. Even remote risks of harm add to the total risk already faced by everybody in society. The imposition of many additional small risks could sum to a significantly large total risk from all sources. "If a low price of risk α were accepted for these, safety measures would be shifted considerably away from the optimum" (Babaev and others, 1986, p475).

Also shown in Figure 3 is the typical range of protection costs which might be incurred through the application of the best practicable technology. The cost of protection curve (P) implies that technology is available to achieve - at varying costs - certain levels of protection. 'Best practicable technology' is usually taken to refer to protection technology that is commercially available, in a tested design and at a cost that is not exorbitant: it reflects above average industrial practice (Crouch and Wilson, 1982, pp92-93 and Rowe, 1988, p78). Were protection to be organised according to best practicable technology, a higher level of safety could be provided than would be the case if the ICRP system was followed. As a method of controlling risk, however, it makes no attempt to evaluate the harm threatened.

Defenders of the ICRP system frequently argue that it does not attempt to put a value on human life. One suggests that "no economic valuation is directly attributed to human life, and, in fact, there is no limit on the cost of protection needed to keep the exposure of individuals within the recommended dose limits. On the other hand, if further reduction of the collective radiological impact of a source must be pursued ... there is a need to ensure the optimum use of resources available to society by aiming at a level of protection which is the highest achievable without conflicting with other legitimate needs of the society for these resources" (Ilari, 1986, p8).

The same point is made by the UK National Radiological Protection Board (NRPB) and the French Centre d'études sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN): "if the efforts of the authorities are not to result in all of the available resources eventually being pressed to spend on safety related measures then either those who are being pressed to spend the money must resist - which is out of touch with the present day ethos - or the system which applies the pressure should have some built in checks and balances of its own" (Webb and Lochard, 1984, p13). It is a view shared also by the Vatican's Pontifical Academy of Sciences who call it "a device for conserving lives" (Pontifical Academy of Sciences, 1985).

A distinction is sometimes drawn between "statistical deaths" where victims are not identifiable and, presumably, the reality (for someone) of dying before your time (Rowe, 1988, p365). Others talk of the value of statistical lifesaving from risk reduction (Lakey and Lewins, 1987, p35) or of the price of risk (Babaev and others, 1986). These arguments are examples of casuistry since, as will be shown, in practice the $ reference value for a sievert can only be based on making an estimate of the value of life.

INTERNATIONAL REGULATION IN EUROPE

Setting basic safety standards

Nuclear matters have commanded a large measure of attention from international organisations. This section examines the role of the European Community (EC) in regulating nuclear power and also briefly refers to the work of the International Atomic Energy Agency (IAEA). Both are involved in setting basic safety standards but do so in rather different ways.

One can define a number of levels of regulation in respect of industrial safety. Table 1 provides such a format. At the international level only basic safety standards are likely to be set. They are basic because they are usually the result of consensus around a fairly low common denominator reflecting currently adopted "good practice". In addition countries have the right to choose to set higher standards . However they are also basic in the sense that they set out those principles and practices that are generally considered to be fundamentally necessary towards ensuring safety.

Both for reasons of national sovereignty and responsibility to their own citizens most states are unwilling to allow international organisations rights of licensing or inspection. Nevertheless it is evident that the role of international organisations in setting basic safety standards is a powerful legitimating factor in respect of national levels of safety. This is particularly true in areas where technical competence is thought to provide an objective basis for safety standards. It is surely reassuring to know that experts worldwide are agreed on the efficacy of particular standards or measures. For the Community's nearly one million workers who are regularly checked for exposure to radiation there is in theory one system of protection, offering equality in treatment in safety matters according to accepted Science (CEC, 1986c, p1). The arguments which developed within the EC as a result of differing national standards being applied to contaminated agricultural produce due to fallout from Chernobyl only serves to underline how the absence of internationally agreed measures called into question the competence of Science itself.

The European Community: responsibilities

Within the European Community, regulation of radiation exposure has been established under the terms of the Euratom Treaty. Article 2b of the 1957 Treaty specifies that the Commission shall "establish uniform safety standards to protect the health of workers and of the general public and ensure that they are applied" (CEC, 1978). The motive, it seems, for creating uniform standards was that differing national health and safety standards could affect the mobility of labour and production costs, thus undermining the effectiveness of the nuclear common market (Droutman, 1973, p53). Chapter III of the Treaty sets out the duties and powers of the Commission in the field of health and safety and the rights and obligations of Member States.

These provisions stipulate that the Commission shall draw up basic standards after obtaining the opinion of a group of experts appointed by the Scientific and Technical Committee and of the Economic and Social Committee. In the Treaty the basic safety standards are defined as being the maximum permissible doses compatible with adequate safety, the maximum permissible levels of exposure and contamination and the fundamental principles governing the health surveillance of workers. Member States are obliged to comply with the basic safety standards and the Commission is required to make appropriate recommendations for the purpose of harmonizing the provisions. Member States have to demonstrate their compliance with the standards by providing the Commission with the results of monitoring, which the latter has the right to verify through access to monitoring facilities. The Commission may also issue directives in cases of urgency requiring action by a Member State to take all necessary measures to prevent infringement of the standards.

Virtually all the Commission's activity in the field of nuclear safety can be traced back to its powers to set basic safety standards. The powers however are lacking in the area of enforcement. Except in situations where dangerous experiments or the disposal of radioactive waste could affect another Member State, Member States are answerable only to their own citizens as regards their peaceful use of the atom. Nor does the Commission play any role in licensing or inspection of nuclear power plants.

The Commission does have further powers in the field of scientific research and environmental protection. Under Article 2a of the Euratom Treaty the Commission shall "promote research and ensure the dissemination of technical information". This provision together with Annex I-VI of the Treaty which foresees the "study of the harmful effects of radiation on living organisms" form the basis for the Commission's radiation protection programme.

It is not yet clear how the provisions of the Single European Act will affect the EC's activity in the field of nuclear safety. Article 25 of the Single European Act specifies that "action by the Community relating to the environment shall have the ... objectives to preserve, protect and improve the quality of the environment [and] to contribute towards protecting human health" (Bulletin, Supplement 2/86). Directives laying down minimum requirements for the health and safety of workers are permitted by Article 21 "having regard to the conditions and technical rules obtaining in each of the Member States" and provided that these do not "hold back the creation and development of small and medium-sized undertakings".

The provisions of the Euratom Treaty also structure the Commission's own bureaucracy. Hence the work defined by Article 2b and Chapter III is undertaken by Directorate-General XI for Environment, Consumer Protection and Nuclear Safety. Until 1988 nuclear safety was part of D-G V (Employment, Social Affairs and Education) responsibility, with only a small section of staff in D-G XI involved in co-ordination. Work under Article 2a is the responsibility of D-G XII for Science, Research and Development. Quite separate again is the work of D-G XVII for Energy dealing with energy policy. Within D-G XI its competence in the area of nuclear environmental impact continues to be linked closely with the Euratom Treaty, despite the wider role the Commission now has in environmental policy and planning.

Differing national perceptions of the Commission's role, the growth of the nuclear industry since the 1950s into a significant industrial sector of both public and private enterprises and diverging energy policies of Member States have all conspired to force the Commission to restrict its activities even under the terms of the Euratom Treaty. It sees its role as limited to setting safety objectives and providing uniform radiation protection standards (EC EP, 1988c, p54).

The European Community: practice

Without general powers in respect of nuclear safety the Commission's activities are specifically geared to research and development, harmonization of standards and radiological protection. These are examined in turn.

The Commission's Joint Research Centre is involved in several aspects of risk management, both nuclear and non-nuclear (see Amendola, 1988). It is undertaking, for instance, an assessment of methods and procedures for probabilistic safety analysis to establish a common awareness of the advantages, cost-effectiveness and state of the art of such models and procedures. This included the MARIA project started in 1982 (Methods for Assessing the Radiological Impact of Accidents - see CEC, 1985). A programme is underway to establish a commonly agreed state of the art procedure throughout Europe. The Major Accident Reporting System (MARS) set up for chemical incidents under the Seveso Directive and the European Reliability Data System which collects and harmonizes component reliability, incident and plant availability data from nuclear power plants in Europe aim to improve data acquisition. A European Safety and Reliability Association has been sponsored and the EC is involved in steps to create a Master's Degree in Reliability (interview with Brian Tolley, D-G XII.E.1 on 13 October 1988). Such moves aid the discipline of risk management's progress towards maturity and builds up the data bases, so that uncertainty in carrying out probabilistic risk assessment is reduced. Of itself, however, such activity does not address the problem that in the capitalist world much performance data is owned by private companies who are protected in many cases from having to disclose data by laws permitting the confidentiality of commercially sensitive information.

Aiding the harmonization of reactor safety requirements was added to the Commission's responsibilities by a Council Resolution of 22 July 1975 (Official Journal C185/1, 14.08.75). This authorised "the progressive harmonization of safety requirements and criteria in order to provide an equivalent and satisfactory degree of protection of the population and of the environment against the risks of radiation resulting from nuclear activities and at the same time to assist the development of trade". It also requested the Member States to seek common positions and co-ordination in respect of safety harmonization and research being dealt with by international organisations.

In the Commission's view the benefit of such work comes from the analysis and diverse scrutiny of differing approaches which "tends to consolidate the confidence in each others' approach and to ensure that potentially severe sequences of accidents have not been overlooked". It will "promote convergence to an equivalent assurance of safety throughout the Community" (CEC,1987, p3-4). Two types of nuclear power plant were chosen, the Light Water Reactor (LWR) which is the most common technology in Europe and the Liquid Metal Fast Breeder Reactor (LMFBR), the next generation of reactors using plutonium. Work on the harmonization of LWR safety proceeded slowly because of complexities introduced by reviews of nuclear safety policies following the accident at Three Mile Island (TMI-2) in 1979 and because most national regulatory organisations were "reluctant to envisage a central role of the Community on regulatory matters" and unable to achieve consensus amongst themselves (CEC, 1987, p12). Nevertheless the Commission issued its basic safety principles for LWR nuclear power plants which are a reference for judgements made in the safety evaluation process at national and lower levels (see CEC, 1981). Appendix B sets out these basic safety principles. This activity whilst a significant move towards harmonization of safety standards, fell far short of constituting a Community Nuclear Safety Code of uniform standards binding upon Member States, a proposal advocated by the EC Economic and Social Committee (EC ESC, 1977).

Basic safety standards for radiological protection have been regularly updated by the EC following those first issued in 1959. At first a principle of minimization of exposure was adopted, but this was revised to the ALARA principle in 1976 (see Bischof, 1984, p59). The Council of Ministers' current Directive was adopted on 15 July 1980 and amended slightly on 3 September 1984 (see Official Journal Nos. L246/1 [80/836/Euratom] and L265 [84/467/Euratom]). It reads as follows:

> "The limitation of individual and collective doses resulting from controllable exposures shall be based on the following general principles:

(a) the various types of activity resulting in an exposure to ionizing radiation shall have been justified in advance by the advantages they produce;

(b) all exposures shall be kept as low as reasonably achievable;

(c) without prejudice to Article 11 [planned special exposures], the sum of the doses and committed doses received shall not exceed the dose limits laid down in this Title for exposed workers, apprentices and students and members of the public."

In a Communication the Commission has set out a commentary on these principles. "The justification (ie. the first principle) of any type of activity is the duty of competent authority in Member States. Compliance with this principle is adequately demonstrated in respect of a type of activity by the existence or the laying down of regulations specifically concerning the type of activity. The second principle (optimization) requires that exposures shall be kept as low as reasonably achievable below the prescribed limits, economic and social factors being taken into account. Generally, in routine activities, optimization need not involve complex calculations.

"It is implicit in this requirement that scientific considerations should be supplemented by economic and social factors. The techniques for judging the need for further reductions in exposure in the light of what is reasonable are very diverse. They include for instance formal aids to decision-making, such as cost-benefit analysis, etc. but they are more usually based on simple common-sense practice. If an improvement is easy to make and commits only few resources, it is sensible, and therefore reasonable, to make the improvement. If the improvement requires the major commitment of resources and produces only small reductions of exposure, it is likely to be unreasonable and therefore inappropriate. Because the procedures involve a combination of scientific, economic and social judgements, it is helpful to link them with decision-making procedures used in the Member States" (Official Journal No. C347 1985).

In effect this means that the Commission assumes that the presence of regulatory procedures in the Member States is a sufficient condition for demonstrating the existence of net benefit from activities resulting in radiation exposure. One could argue that the Commission consider that positive net benefits do indeed exist from the operation of and investment in nuclear power plants. The Commission's Illustrative Nuclear Programme indicates nuclear energy production targets based on considerations of energy strategy and diversification of sources (CEC, 1985b). It also advocates the use of cost-benefit analysis and , furthermore, the use of probabilistic safety assessment as tools for rational decision-making (CEC, 1986a, p26). But such considerations play no part in the

Commission's monitoring of Member States' compliance with its basic safety standards.

This is despite the opinion of the Economic and Social Committee that the advantages required for the principle of justification "must take full account of the social as well economic considerations" (Official Journal No. C128 1979). An explanation for the Commission's reticence may lie in the fact that the Council is polarised as regards the advantages of nuclear power and has adopted a compromise position of agreeing with the Commission's analysis of the role of nuclear energy in the Community's overall energy strategy on the understanding that it is for each Member State to make its own decisions. On the issue of cost-benefit analysis the social partners on the Economic and Social Committee are divided. The European Trade Union Confederation (ETUC) has reservations with respect to cost-benefit analysis' "strictly economic approach" (CEC, 1984, p487). In general, the ETUC advocates the establishment of environmental standards according to the state of the art, constantly adapted to the best available technologies (ETUC, 1988).

On the related issue of occupational health protection from chemical, physical and biological agents, including those with carcinogenic effects, the Committee rejects the Commission and Council's reliance (in Directive 80/1107/EEC and its amendments) upon reducing exposure "to as low a level as is reasonably practicable" in favour of "an exposure level which takes account of the state of the art [in protection technology], as far as possible" (EC ESC, 1987, p18). This protection philosophy is combined with the principle that "priority must be given to protecting the health of workers [...] though economic interests should suffer as little as possible as a result" (EC ESC, 1979, p6 and EC ESC, 1987, p3). Below the maximum permissible values for carcinogen concentrations in the working atmosphere "employers should be required, using available technology and ... work organisation, to reduce exposure as far as possible" (EC ESC, 1988a, p7).

This approach is also adopted by the European Parliament's Committee on the Environment, Public Health and Consumer Protection. In submitting its amendments to the Commission's draft Framework Directive on measures to encourage improvements in the safety and health of workers, issued under the terms of the Single European Act, the Committee put forward a quite different point of view to that of the Commission. It considered that "safety and hygiene at work and the mental and physical health of workers constitute a fundamental right which cannot be subordinated to economic considerations" (EC EP, 1988a, p13). While the Directive repeats the formula of "the maximum degree of protection which is reasonably practicable to achieve", the Parliament's Committee proposes that "technologically feasible safety standards must be observed" (EC EP, 1988b, p14).

These criteria, being technology-led - workers are in essence entitled to the best available technology to reduce risk - avoid optimizing protection on the basis of net costs (or benefits) altogether. In fact the European Parliament's Committee considers that since health is a supreme and inalienable good "there is no place for cost-benefit analysis" (EC EP, 1987a, p16).

The consensus rather than regulatory approach to safety policy-making can also be seen in the Commission's relationship to the scientific community. In addition to the requirement of the Euratom Treaty to seek the opinion of a group of scientific experts, including public health experts - the Article 31 Group - on the basic safety standards, the Commission has organised wider discussion within the scientific and radiological protection technical community. Three European scientific seminars have been held. The first, on 3-5 October 1979 in Luxembourg, facilitated discussion of the standards in advance of their acceptance. That of 8-9 November 1983, also in Luxembourg, provided the forum for discussion of the standards' practical implementation and meaning since some concepts were not widely understood. The Madrid seminar of 12-14 September 1988 allowed experience of the usage of optimization to be exchanged and highlighted the need to go beyond the use of cost-benefit analysis to developing multi-attribute utility analysis and outranking analysis as complements. (Interview with Jaak Sinnaeve, D-G XII.F.1 on 13 October 1988.) These are active measures designed to explain, enlighten and engage, unlike consultation processes which rely only upon the submission of written views. A handbook on optimization is being produced and there is an intention to publish a communication on the assurance of nuclear safety on the basis of consensus within the Community (interview with Jean-Paul Pele, D-G XII.D.1 on 12 October 1988).

The European Community: the future

Although it is the aim of the Single European Act to create a large barrier-free internal market based on greater economic and social cohesion and geared towards rectifying imbalances between countries, regions, production sectors and economic groups, it is not clear that it will encourage improvements in the sphere of nuclear safety. The pressures of competition to reduce costs could erode margins of safety. A west European electricity grid (the UCPTE network) already stretches from Scandinavia to the Mediterranean, carrying 1300 TWh per year (EC ESC, 1988b, p8). Encouragement of trade in electricity using the grid (currently about 10% of the EC's total power production), the harmonization of tariffs to consumers and the competition from non-EC coal may result in downward pressure on electricity prices in the middle 1990s. Whether this would adversely affect safety standards in nuclear power plants depends also on the extent to which intra-EC coal trade is liberalised and on the harmonization of environmental protection controls for fossil-fuel power stations. Continued protection of Member States' own coal industries and high environmental protection standards for emissions would cushion the nuclear industry's exposure to competition from lower cost power producers.

Within the Commission's bureaucracy, nuclear safety and environmental impact issues are treated separately from its general policy stance towards public and occupational safety, risk management and environmental protection; this despite the integration of the nuclear safety section within D-G XI. The development of a comprehensive and common policy in these areas could be based on the existing similarities in approach. In the area of worker protection from chemical and other harmful substances there is a distinct equivalence between "as low as is reasonably practicable" and nuclear's ALARA. The emphasis placed by the Commission on "state of the art" methods and "best available technology" in determining environmental protection standards has a parallel in the recognition that with "appropriate provisions" doses from discharges can be kept very low, though ALARA remains the aim (see CEC, 1981, p5 and CEC, 1986b, p31). However a consensus approach to to regulation tends to involve the use of the principle of the lowest common denominator. Moreover the EC's history in regulating hazardous chemicals is that "its programmes more effectively remove or prevent trade barriers than guarantee the citizens of member countries equal protection from harm" (Brickman, Jasanoff and Ilgen, 1985, p289). Unless there are specific pressures to improve nuclear safety standards there is a distinct possibility that a common safety and environmental protection policy would merely maintain the current situation, or even allow it to be undermined by the forces of competition. Such pressures might have been expected after the Chernobyl disaster.

Following the tragedy at the Chernobyl-4 RBMK in 1986 the extent of the Community's role and the adequacy of existing powers and activities were reviewed. (More detailed appraisals can be found in Leroy, 1986, Johnson and Corcelle, 1987 and Vercellino, 1986.) Calls from the European Parliament for the establishment of a Community Inspection Force for monitoring the application of common Community safety standards for nuclear installations according to the most up-to-date technical norms were referred to a "group of national representatives" (see EC EP, 1987b, p6 and CEC, 1986c, p12). This group concluded that such a force would achieve little more than duplication of national inspectorates and, without being very large in number, would not materially assist in the prevention of accidents. However the Commission would review the setting of emission standards, a controversy highlighted in the dispute between France and its neighbours over the frontier-based Cattenom nuclear power plants.

To examine problems of safety standards and emergency reference levels a committee of "high-level independent" scientists was established. This committee recommended further research in a variety of fields, the issue of guidelines by the Commission on accident counter-measures and planning and studies of public opinion (CEC, 1988b). In these actions the Commission was acting in a similar way to another international agency, the Organisation for Economic Co-operation and Development (OECD), which commissioned a report by a "group of experts" (NEA/OECD, 1987). This method allows governments to pass responsibility for drawing up the agenda for action to people already highly involved in the nuclear industry. Undoubtedly also international bodies need to be more prudent than even national governments in their selection of the eminent, and to avoid controversial selections.

Despite the transboundary nature of the radioactive cloud released from the burning reactor and the European-wide concern aroused, the role of the EC is not to be enlarged. Against certain non-nuclear nations, such as Ireland, which has called for the closure of the Sellafield plant across the Irish Sea, demanding greater assurance to be provided by the EC in respect of the safety of their neighbours' nuclear power plants are ranged France and the UK. These maintain that the correct level for responsibility for safety is that of the plant owner/operator, licensed by the national authority. Whilst the desirability of common basic safety standards is widely acknowledged the preferred forum for developing these is the IAEA, with the exception of the field of radiation protection. Thus a larger role for the EC in regulating nuclear safety is most unlikely to come to pass. In the next section the role of the IAEA is briefly examined.

The International Atomic Energy Agency

The IAEA is an agency of the United Nations Organisation, which was established in 1957 with the principal objective to "accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Its work has included the issue of basic safety standards for all aspects of nuclear power operations. In principle these standards are only applicable to the activities of the IAEA itself or to bilateral or multilateral ageements between it and Member States. They are nonetheless widely accepted.

Under its Nuclear Safety Standards programme (NUSS) the IAEA has issued a number of safety guides and codes of practice, covering, for instance, design and operation for safety of nuclear power plants. It has organised operational safety inspection teams (OSART) since the accident at TMI-2 to advise nuclear power plant management with a view to increasing operational safety. Following Chernobyl the Director-General, Hans Blix, proposed that the IAEA basic standards be converted into binding norms to be incorporated in national legislation and hoped for agreement on basic safety principles (quoted in EC EP, 1987c, p13).

In the field of radiation protection the Agency first issued basic safety standards in 1962. A major review was undertaken along with the International Labour Office and the World Health Organization after the publication of the ICRP's proposals of 1976. Largely based upon the ICRP's recommendations the revised basic safety standard was published in 1982, under the joint sponsorship of the other UN agencies and the OECD.

These specify that the system of dose limitation must include justification of the practice, optimization of radiation protection and annual dose equivalent limits. Specifically the standards say that "in order to prevent unnecessary exposure, no practice involving exposure to ionizing radiation shall be authorized by the relevant competent authorities unless the introduction of the practice produces a positive net benefit. The design, plan and subsequent use and operation of sources and practices shall be performed in a manner to ensure that exposures are as low as reasonably achievable, economic and social factors being taken into account" (IAEA, 1982, p4).

An annex offers practical guidance. "Ideally" it suggests, "cost-benefit analysis could be used" in authorising the introduction of a practice involving exposure to radiation, that is in determining justification. With respect to optimization, "the aim of the quantitative analysis should be to assess how far exposures may be reduced before further reduction would not justify the incremental cost required to accomplish it. This assessment may be made by a differential cost-benefit analysis" (IAEA, 1982, pp144-145).

The system recommended does not provide any values for human life or as the IAEA put it "the valuation of the change in life expectancy of unknown individuals" (IAEA, 1985). However to reduce the problems arising from the use of different values by national authorities the IAEA has put forward its calculation for justifying transboundary pollution from routine emissions. On the basis of ICRP risk factors for the induction of fatal cancer (1.25×10^{-2} Sv^{-1}) and for induction of severe hereditary harm in all generations (8×10^{-3} Sv^{-1}), the IAEA calculated the expected loss of healthy life attributable to a radiation dose of 1 person Sv. Applying these risk factors to averages for loss of life from one case of radiation-induced lethal cancer and for loss of life from one case of a hereditary disease of 15 and 30 years respectively, the IAEA suggest that 0.4 person years is lost for each dose of 1 person Sv.

Assigning a minimum reference value for "objective health detriment" is achieved by multiplying 0.4 by Gross National Product per head and adding the cost of additional health care. Since standards of living differ between countries, giving in this case a range of values between $200 per person Sv (parts of Asia) and $5 000 per person Sv (USA), the IAEA recommended a minimum reference value of $3 000 per person Sv with the anticipation that regulators from affluent countries would choose higher values (IAEA, 1985, pp5-7). At the risk factors quoted, the value implied for human life by the IAEA's minimum figure is about $150 000 [$3 000/0.0205].

This is the only example of an international organisation going further than simply recommending the principle of cost-benefit analysis. Whilst forming part of its basic safety standards the fact that the document is the product of an advisory group drawn from the OECD, WHO and national regulatory bodies demonstrates the essentially consensus approach adopted by the Agency. It is also important to note that the IAEA minimum figure makes no attempt to value the ICRP's so-called subjective health detriment. In the subsequent section we can see how the UK has attempted to operationalize the ICRP system in a full way.

REGULATION IN THE UNITED KINGDOM

Background

The United Kingdom has a capitalist market economy, developed over two centuries of industrial growth. With a relatively well-organised trade union movement since the end of the 19th century and a history of liberal social reform, industrial safety has long been an area of policy-making. Nuclear power was introduced relatively soon after its potential as a source of power was recognised. As one of the permanent members of the UN Security Council and with the pretensions of being a world power stemming from its history as an old imperialist nation the UK armed itself with nuclear weapons in the early 1950s. The first reactors (Magnox GCRs) built in the 1950s and 1960s were dual-purpose, to produce weapons-grade plutonium as well as electrical power, or having the potential to do so.

For strategic reasons the government funded its own reactor designs until the early 1980s. The place of nuclear power in the UK's energy situation is shown in Table 2. As a result of a shift in the main electricity producer's thinking and the election of a Conservative government less willing to support British designed and manufactured nuclear plant, the Energy Minister gave approval to the construction of a PWR at Sizewell in 1987. This followed a major public inquiry held under site planning procedures (IEA, 1987, p429). Two further PWRs are to be installed before 2000. A significant movement against nuclear power has emerged, without which the public inquiries into the establishment of the Sellafield reprocessing plant for AGR fuel (THORP) and the the PWRs at Sizewell and Hinkley Point would not have become important areas of political debate.

Notwithstanding the nationalism which underpinned many of the decisions regarding the development of nuclear power, those leading the industry traditionally play a significant role internationally. The ICRP itself has had a strong British presence in its ranks. It will be argued that British regulations are the clearest example of the ICRP system in operation.

Safety regulation

One of the earliest control philosophies was the principle of best practicable means, introduced to curb air pollution in 1863. When this legislation was updated in 1956 best practicable means was defined in terms of financial implications and the current state of technical knowledge (Webb, 1987, p7). During the late 1960s and early 1970s Labour and Conservative governments comprehensively reviewed occupational and public safety, leading to the passing of the Health and Safety at Work etc Act of 1974. This established a tripartite Health and Safety Commission, made up of three equal groups, employers, trade unions and others drawn from local government authorities. The Commission is responsible to the Department of Employment for the administration of the Act which places a primary obligation upon employers "to ensure, so far as is reasonably practicable, the health, safety and welfare" of workers and the public (Bischof, 1984, p83). The Health and Safety Executive (HSE) is appointed by the Commission and is the licensing and inspecting authority for most industries.

A particular feature of the Commission's approach is the stress upon consensus decision-making. Its origins lie partly in the history of the Commission's establishment. The report commissioned by the government on safety and health at work was drawn up in an atmosphere "where looking after people was the primary aim and the question of finding the resources to do it was given much less weight" (Singleton, 1983, p158). Moreover it maintained that there was "a greater natural identity of interest between 'the two sides' [that is, employers and trade unions] in relation to safety and health problems than on most other matters" (Robens, 1972, p21). On the Commission itself, local authority and trade union representatives agreed only to proceed with regulations with the approval of the employers: giving the latter an effective veto (Wilson, 1986, p293). In terms of enforcement strategy, inspectors seek to to persuade rather than coerce employers and much relies on their interpretation of what is reasonably practicable.

The principle of so far as reasonably practicable (ALARP) has been tested in the English courts, where a long standing interpretation still holds good. "It is a narrower term than 'physically possible' and implies that a computation must be made in which the quantum of risk is placed in one scale and the sacrifice, whether in money time or trouble, involved in the measures necessary to avert the risk is placed in the other: and that if it be shown that there is a gross disproportion between them, the risk being insignificant in relation to the sacrifice, the person on whom the duty is laid discharges the burden of proving that compliance was not reasonably practicable" (Webb, 1987, pp7-8).

It follows from this principle of UK safety law that there is a stiffer test to be applied than the ICRP's ALARA supported by the balancing of costs and benefits. The test is one of gross disproportion that, in the Health and Safety Executive's words, "err on the side of safety" (HSE, 1988, p5). This is not an insignificant distinction, despite the clear similarity of meaning between the words achievable, feasible and practicable. In the HSE's opinion ALARA and ALARP are "broadly equivalent provided that the interpretation of ALARA [is] consistent with the philosophy that radiation risks should be reduced below the balance point ... [with] the imbalance ... expected to increase as the level of individual risk increases" (Harbison and Winyard, 1987, p27).

After the promulgation of the EC's Council Directive of 1980, the UK revised its Ionising Radiations Regulations, issued by the HSE. In their current form these state that "the responsible person shall, in relation to the work with ionising radiation which he undertakes, take all reasonably practicable steps to restrict the extent to which all persons are exposed to radiation" (HSE, 1985). The ALARP formula is also found in the HSE's fundamental principles relating to radiation protection:

"(1) No person shall receive doses in excess of the appropriate dose equivalent limit as a result of normal operation;

(2) The exposure of persons shall be kept as low as is reasonably practicable;

(3) Having regard to principle (2), the collective dose equivalent to operators and to the general public as a result of operation of the nuclear installation shall be kept as low as is reasonably practicable;

(4) All reasonably practicable steps shall be taken to prevent accidents;

(5) All reasonably practicable steps shall be taken to minimise the radiological consequences of any accident" (HSE, 1982).

It will be recalled that the EC deems that the principle of justification of a practice is satisfied by the existence of regulations licensing activity involving radiation. The UK's Health and Safety Executive is the competent authority for regulating nuclear installations. Its Director-General explained the HSE's role in deciding whether or not to have nuclear power: "It is not for us to propose nuclear power; it is for others to come to us saying they want to contruct a reactor. Our function is to examine the risks involved, as estimated by experts, and to consider whether what is proposed can be improved and to what extent it is worth doing" (Rimington, 1988, p3). In his position he does not "have to have an opinion on nuclear power" (interview with John Rimington 15 December 1988). "Only the political organs of the state are capable of determining what, and which, risks are tolerable" (Rimington, 1987, p26). Such an approach does not rule out banning a dangerous activity, but the test is not overall net benefit but the cost of further risk reduction.

Although the HSC/HSE has the leading role in regulating nuclear power plants, two ministries are involved in prescribing standards of protection. The Department of the Environment and the Ministry of Agriculture, Fisheries and Food set and monitor emission limits and food contamination standards. One actor is missing: the Department of Health plays no direct part in nuclear power plant safety regulation, but is limited to advising government on the health impact of the industry. Nor is there any regulatory requirement for or oversight of professional standards in occupational health services set up by employers (Gevers, 1985, p220).

Case study: the Sizewell B PWR and cost-benefit analysis

The proposal by the Central Electricity Generating Board (CEGB) to construct Britain's first Pressurised Water Reactor at Sizewell illustrates the methods employed by the designers and regulators to assess and assure safety. As the plant owner and operator the CEGB laid down its Design Safety Criteria to be followed by the designers, Westinghouse Electric Corporation and the Bechtel Corporation who had designed the SNUPPS version of the PWR built for several US utilities. These included design targets for exposure. For occupational exposure two targets were set: an annual target for the effective dose equivalent for individuals of 10 mSv and an annual target for the station collective effective dose equivalent of 2 person mSv per MW(e) installed capacity (equating to 2.4 person Sv per year). Both these targets were set at more stringent levels than was being achieved on average by existing nuclear power plants (GCRs). There were also targets set for emissions affecting the public to meet regulatory requirements (Pepper and Dutton, 1984, p262-264). For instance, under the HSE Nuclear Installations Inspectorate's Principles for Safety Assessment design basis accidents carrying a risk of 3×10^{-3} per year have a maximum consequence of exposure of 100 mSv per event to people nearby (Cave, 1988, p12).

The CEGB put forward its initial design approach to the HSE in 1982. However the HSE asked the CEGB to demonstrate that it had made reasonable attempts to quantify its ALARP judgements by the use of cost-benefit analysis along the lines recommended by the ICRP (Harbison and Winyard, 1986, p162). This put the CEGB in a quandary since ICRP have not valued the benefit of risk reduction (the value of life) and there was a need to reach agreement on the relationship of ALARA to ALARP. In the end HSE agreed to accept figures which the CEGB based upon a discussion document issued by the National Radiological Protection Board (NRPB).

Operator and regulator also agreed to apply cost-benefit analysis only to design features aimed at reducing exposures during normal operation. This excluded a cost-benefit analysis of the overall design - which was a standard US one, the SNUPPS - or to major accidents (Harbison and Winyard, 1986, p164-165). Agreement was not reached on the starting point: the predicted occupational exposure. The CEGB were predicting 2.3 person Sv per year in line with their target. HSE's more cautious estimate took into account that such a figure would put the Sizewell plant amongst the best 10% of operating PWRs in the USA (Harbison and Winyard, 1986, p167). Nevertheless the exercise was the most comprehensive ever undertaken in the UK.

In the operator's view the design was based "on the application of good engineering practice" with many of the design features involving "a capital expenditure ... up to 10 times higher than would be justified on the basis of balancing detriment and cost. ... Compliance with the criteria and design guidelines results in a design which is to a much higher standard than would be justified by a cost-benefit balance ... [of] more than a thousand times" for some features (Pugh and others, 1987, p61).In other words the CEGB had demonstrated that their design targets already passed the test of gross disproportion. Yet this , of course begs the question of whether the NRPB's values for life were appropriate.

The value of life

The National Radiological Protection Board (NRPB) is responsible for carrying out research and development and providing information, advice and services to organisations using radioactive sources and materials. It is required by the government to give advice whenever recommendations are made by the ICRP. There is indeed an overlap of membership between the ICRP and the NRPB.

In 1980 the NRPB began a programme to offer advice on the application of a quantitative framework to the optimization of radiation protection. This programme is ongoing with the aim of extending the advice already given from day to day operational situations to ones involving major accidents. The Board first issued a consultation document on the application of cost-benefit analysis to protecting the public from radiation (NRPB, 1980). A provisional framework was then proposed followed by another consultation document, this time on occupational exposure (NRPB, 1981b and NRPB, 1982). The two frameworks have since been brought together in NRPB (1986), but will be revised due to changes in the ICRP risk factors assumed following re-evaluations of the doses received by the survivors of Hiroshima and Nagasaki.

NRPB argue that it is necessary to establish a minimum reference value of the cost to society from health detriment (a unit of harm from radiation exposure). This is the only cost assigned to very low doses. For reasons of "equity, risk aversion and legislative requirements" progressively higher costs are assigned to higher doses (NRPB, 1981b). By this they mean that those most exposed should receive greater protection, which can be encouraged if the benefits from that (costlier) protection are commensurately larger. It is also consistent with English law's test of gross disproportionality (ALARP). In the earlier framework this was achieved by a system of bands for levels of exposure, but the latest version employs a curve to multiply reference values according to risk. For ease of exposition this paper will use the bands.

The NRPB estimated the value of life according to what it termed the "human capital" approach. A worker is viewed as an asset, whose use adds value to output. Essentially this approach involves costing the net loss of future output from radiation victims and adding the cost of health care for such individuals. This has been the approach traditionally used by UK government departments, pioneered by the Department of Transport's valuations of the costs of road accidents.

Many theoretical and practical objections can be levelled at this approach. A dead person neither produces nor consumes, but at the time the decision about investment is being made the potential victim is alive and should be valued as such. To a firm a worker's value added is measured by net output, that is offsetting the wage paid against the value of the work. But from society's point of view the loss of a person's consumption (or spending power) is also material. Thus, it can be argued, the potential victim should be valued in terms of gross, not net, output. Valuing the contribution made to society by people not in paid work is likely to be arbitrary and contentious: the NRPB valued the output of housewives at the average annual wage of employed women and set the value of childrens' and pensioners' output at zero (NRPB, 1980, p43). As a way of valuing life it is flawed, since it actually based on valuing the output of paid work. Despite this, it is a method which gives results: it is calculable.

Welfare economists argue that it is people's willingness to pay for investment in benefits or compensation to those who incur costs (harm) that should determine the value of life. However both revealed preference studies (deriving implicit values from actual circumstances) and contingent value studies (using questioning to elicit preferences from hypothetical situations) give values differing by several orders of magnitude. The fault, if fault it is, appears to lie in the perception of risk. Whether workers or any other agents actually have a full appreciation of the risks they face is a moot question, whilst their behaviour often results from being in a position of price-taker. Decisions on paying for health or life insurance are affected both by perceptions as to the significance and consequence of the threat being insured against and the individual's ability to pay the premium. It is also difficult to understand measures of risk, especially where only small changes are involved and the situation is patently unreal. Results displaying a willingness to pay very high amounts in respect of nuclear hazards perhaps reflect an attitude of "nuclear power? not at any price". Willingness to pay methods for valuing life are income/wealth and perception biased and, perhaps not surprisingly, show wide variations when measurement is attempted.

Whatever these objections it can at least be said that the NRPB's method was consistent with that employed by other government departments, and, it will be seen, arriving at much the same value. This answers the point made by Dobbs (1985) that the consistency principle requires that independent decision-makers should agree to use a common shadow price of a single good or agree to reduce the extent of their shadow price inconsistencies in situations where resource allocation is dominated by budget constraints. One significant area of difference however is the NRPB's use of a 3% discount rate rather than the 5% employed by the public sector generally. Due to the inter-generational nature of harm caused by radiation the Treasury gave the NRPB special dispensation to use the lower figure. Using a positive rate of discount is in itself a controversial matter, since, even at low rates the cost of harm to succeeding generations is valued at almost zero.

Applying the ICRP's risk factors (see page 25), the NRPB proposed the following costs of unit collective dose equivalent:

Individual dose equivalent dose band (mSv)		Cost of unit collective (£/person Sv)
< 0.05	for	2 000
0.05-0.5	members of	10 000
0.5 - 5	the public	50 000
< 5	for	4 000
5 - 15	radiation	20 000
15-50	workers	100 000

Costs are in 1980 prices, based on using a 3% discount rate.

At the ICRP risk factors for somatic and genetic harm, the minimum value of life implied is £100 000 (£2 000/0.0205). A re-evaluation of these risk factors by the NRPB and taking into account price inflation has led the NRPB to increase their minimum value to £10 000/person Sv or, as can be calculated, nearly £250 000 per life (£10 000/0.045) (see NRPB, 1988, p13-15). However the NRPB claim to now be using a value for life of £500 000 (interview with Tony Wrixon, NRPB on 22 December 1988). The discrepancy apparently arises because the NRPB are using the old risk factors (summing to 0.0205); hence £10 000/0.02 = £500 000. Were they to be consistent the minimum reference value per person Sv would have to be about £23 000 (£23 000/0.045 = £500 000). The fact is that until the ICRP has completed its review the NRPB's advice is called interim and its valuation on life obscured.

Changes in the NRPB's advice is not to be seen in isolation from developments in government departments and the HSE. For some years the Department of Transport used a value of life figure of under £250 000 (Davies, 1988, p41). This figure was criticised by proponents of the willingness to pay approach and differences between government departments were exploited by objectors at the Sizewell B Public Inquiry. Following a review of the literature by the Department's Economic Adviser, a new figure of £500 000 was announced (interview with Neil Davies, HSE Economic Adviser on 20 January 1989). The HSE has not recommended a figure for the value of life because the Commission is divided, with trade union representatives strongly opposed to the use of cost-benefit analysis in safety policy making. Nevertheless the HSE is required by the government's Enterprise and Deregulation Unit to justify all proposals for regulatory controls with a structured assessment of their likely economic impacts, particularly on businesses (Davies, 1988, p35-36). This compliance cost assessment now uses similar values for life as those of the Department of Transport, although at the Sizewell Inquiry the HSE revealed it had been using a figure of £150 000 multiplied by so-called aversion factors of up to 10. Thus the NRPB's figures have been kept in close alignment with those of the HSE.

The UK therefore has a well developed system of cost-benefit analysis for assessing safety measures, including those in the nuclear industry. This has been achieved at the expense of social consensus however, with workers' representatives and pressure groups often fundamentally opposed to this approach and revealing widely differing perceptions about risk. Furthermore, this breakdown of consensus has taken place at a time when several state functions have been privatised and the influence of trade unions on tripartite bodies diminished or eliminated, for instance in the field of vocational education and training. HSC's consensual approach to regulation appears already damaged and vulnerable to the pressures from the "enterprise culture" promoted by the ruling Conservative Party.

REGULATION IN ITALY

Background

Italy has a capitalist market economy lacking indigenous energy resources. Although it was one of the first European countries to adopt nuclear power in the early 1960s - in 1963 Italy was the world's third largest producer of nuclear energy with three nuclear power plants - this early development was not followed up until 1970, when a new nuclear power plant project, Caorso, was begun (see IEA, 1987, p248; Ippolito, 1980, p25 and Renzetti, 1979). This BWR was followed by two further BWRs at Montalto di Castro, due for commissioning by 1991/2. Under the 1985 National Energy Plan a further five twin PWR plants, based on a standard design - Progretto Unificato Nucleare (PUN) - were to be introduced, and work was begun at Trino Vercellese (already the site of an existing PWR commissioned in 1964).

Environmental concerns developed during the 1970s, led by local authorities [comune] opposed to the siting of plants in their area, but nuclear power remained a relatively minor political issue. The mood of public opinion was substantially altered by the explosion at Chernobyl-4 and a campaign was mounted to halt the use of nuclear power. This was achieved in 1987, when in a referendum over 80% of voters gave Parliament the responsibility for overriding the decisions of communes and regions on the siting of new power stations, and depriving a ministerial committee (CIPE) of its power to intervene in the siting procedures. A parliamentary resolution in 1986 had already resulted in a moratorium in the nuclear programme, and as a result of the referendum and the need to form a majority government all nuclear power plants remained shut down following safety evaluation reviews and future plans abandoned (see IEA, 1988, p257 and Ceri, 1988, p79).

Despite the effective abandonment of nuclear power in Italy, it is instructive to examine the approach taken towards acceptable risk in the period preceeding 1987. There are differences in the system of regulation to that found in the UK. Nuclear science, and indeed publicly-funded scientific endeavour, has been dominated by theoretical physicists, whilst radiation protection and the biological effects of radiation have not held as important a place - there have in fact been no Italian members of the ICRP in recent times (Green, 1984). In addition Italy has always imported its nuclear technology from abroad, largely from the USA. The position of nuclear power in the Italian energy scene is shown in Table 2. Italy also imports nuclear generated electricity from France, some of whose nuclear power plants, the complex of PWRs at Bugey and the fast reactor at Creys-Malville for example, are sited on the other side of the Alps.

Safety regulation

Italian citizens have, under the 1948 Constitution, a fundamental right to health (Article 32). The establishment of a national health service in 1979, the Servizio Sanitario Nazionale (SSN), based on the principles of prevention, planning and participation, made local health units, Unità Sanitarie Locali (USL), responsible for enforcing safety legislation (Berlinguer and Biocca, 1987, p462 and de Leonardis, 1983, p152). For radiation protection, a number of USLs in an area are organised into joint units [Presidi Multizonali di Prevenzione (PMP)] which undertake environmental monitoring and general health protection. These, during the Chernobyl emergency, especially in the north of Italy, were active in controlling the distribution of contaminated food. A single set of regulations adopted under the act setting up the SSN (Act No. 833 of 23 December 1978) governs general work and production standards with a view to preventing occupational injuries and diseases (ILO, 1979, p180).

Regulation of nuclear safety does not fully reside with the SSN or the Ministry of Health. Until 1979 the SSN's Higher Institute for Health [Istituto Superiore di Sanita (ISS)] was charged with protecting the health of the population and workers from radiation, including the setting of emission standards. However, on the grounds of overlapping responsibilities with another agency (ENEA-DISP), this area of competence was removed (Liberatore, 1988, p16). Operating permits for hazardous or polluting industrial plants are issued by the commune and usually require "best practicable means" to be employed to control risk or emissions (OECD, 1987, p49). But in this area too, nuclear power plants are the responsibility of ENEA-DISP not the local authority. There are no statutory provisions regarding the use of specialist occupational health services, but a number of northern regions -the "red regions" - have issued guidelines on standards and functions (Gevers, 1985, p220; IRS, 1988, p8).

As regards radiation protection, much earlier regulations still apply. Italy has not yet revised its regulations in line with the EC Directive of 1980, although in practice the organisations operating nuclear power plants and other facilities have adopted the standards established by the ICRP (Eletti, 1983, p672). Since 1981 the National Energy Plan [Piano Energetico Nazionale (PEN)] has made direct reference to compliance with the Directive. The relevant legislation is that of 1964 (Presidential Decree No. 185) which governs matters of nuclear safety and health protection. Article 1 states that all activities should be carried out "in the most effective way calculated to ensure that the health of workers and the general population is protected against the dangers of ionizing radiation" (Bischof, 1984, p71).

This wording implies some absolute level of safety, since protection means to keep safe or secure from danger or harm. However Article 66 qualifies this level of safety by stating that "employers must take all appropriate safety and protective measures to reduce the exposure of workers, bearing in mind what is technically feasible" (Bischof, 1984, p72). Thus the test in Italian law is one of effectiveness and as low as technically feasible, a test moreover frequently advocated by critics of ALARA.

The difficulty with a test such as "as low as technically feasible" is that the total elimination of radioactive discharges from a nuclear plant is impossible but the technology exists to reduce emissions to virtually zero. The regulator has no quantifiable point at which to say that a satisfactory reduction has been achieved. It is therefore said, certainly by the nuclear industry, to be an unenforceable test (see, for instance, Webb, 1987, p8). However in conjunction with a test of effectiveness some limits can be applied. A good definition of effectiveness is that of the World Health Organization: "the effect of the activity and the end results, outcomes or benefits for the population achieved in relation to the stated objectives" (WHO, 1971). Therefore the point at which protection can be said to be satisfactory is when the impact of reduced emissions meets stated health objectives. Such a point can be expressed in terms of target exposure levels, given that sieverts relate to risk of harm.

Authorisation of nuclear power plants is given by the Ministry of Industry, Commerce and Crafts (MICA) but its licensing and inspection responsibilities are in fact devolved. Responsibility for regulatory procedures in the field of nuclear safety lies with the Comitato Nazionale per la Ricerca e lo Sviluppo dell'Energia Nucleare e delle Energie Alternative (ENEA) [National Commission for Research and Development in Nuclear and Alternative Energy Sources]. Since 1982 a separate division in fact has this responsibility, known as the Central Directorate for Nuclear Safety and Radiological Protection (DISP). Although it is an autonomous body of ENEA - which had had the responsibility of promoting nuclear power, an objective in potential conflict with its regulatory duties - ENEA-DISP remains accountable to the Ministry of Industry. ENEA-DISP has published a series of technical guides for nuclear operators, although these are not binding but issued to provide better understanding of the controls exercised in matters of health and safety (NEA/OECD, 1986, p57).

Regulation in practice

Italian safety philosophy is complicated by the fact that the country has imported its nuclear technology. In fact the first nuclear power plants were constructed in advance of any legislation being passed to ensure radiation protection or siting criteria. Even the later Caorso BWR was ordered on a turn-key contract. Thus all licensing was based upon reference to codes and standards of the country of origin, rather than on any national standards (Naschi, 1980, p16). In practice this meant that the safety criteria and guides of the US Nuclear Regulatory Commission and the manufacturers' specifications were used. Since these are deterministic standards there was no way of ensuring equivalent safety objectives for different nuclear power plants. Nor has legislation addressed the problem that what is technically feasible is constrained by the practice of purchasing nuclear power plants designed by the Westinghouse Corporation or General Electric.

When defining safety goals or objectives, it is necessary to employ probabilistic methods of safety assessment. A goal is translatable into the design or operation of the nuclear power plant if margins of reliability and safety can be calculated, and this is only possible using probabilistic techniques. Although safety goals are employed by the US regulatory authority they are only used as an adjunct to the licensing procedure. However, as we should recall, the test for safety under Italian law is well suited to the adoption of safety goals as a means of ensuring protection.

Under the PUN project, the design objective for operational conditions was established at an individual dose for members of the public of 0.1 mSv for one site containing installed capacity of 2 000 MW(e), that is two big nuclear power plants. For accidental events with a risk of 1 in 10 000, including all design basis accidents but not severe accidents like a core melt-down, the design objective was 100 mSv per event (Benassai, Frittelli and Piermattei, 1986, p53). The objective for severe accidents was set at an overall limit of less than 1 in 100 000 per year. Within these design objectives further improvements could be made provided these "entailed reasonable burdens". This optimization procedure did not involve cost-benefit analysis, although the cost of protection and uncertainties associated with the models used were taken into account. As a result exemption levels were proposed in the order of 0.001 mSv (10 µSv) for individuals (Benassai, Frittelli and Piermattei, 1986, pp54-55).

For occupational exposures, the PUN project set a design objective for individual workers of 5 mSv per year on average and a collective dose target of 4 person Sv per year (Benassai, Frittelli and Piermattei, 1986, p55). All these design objectives were set on the basis of Italian experience, albeit largely from BWRs, and the available technology. The Italian safety philosophy rejects the setting of a reference value to a person Sv as any monetary value is deceptive given the margins of error involved in undertaking a full cost-benefit analysis (see Benassai and Bramati, 1984, p251, Eletti, 1983, p675 and Naschi, 1980, p16).

In consequence the process of optimization of protection is technically led. As the director of ENEA-DISP outlined, "a perhaps more correct ... approach to the problem [of reducing risk but balancing costs and benefits is] by looking for approximate solutions. ... In a technological field, a method that is both valid and capable of giving progressively better approximations of the goal of the "risk as low as reasonably achievable" can ... be done through recourse to the best utilization of the available experimental technology, when a significant experimental basis is available" (Naschi, 1980, p16).

This same approach can be seen to be applied in respect of the existing nuclear power plants, constructed by reference to country of origin standards. Backfitting is the term used to describe the post-construction implementation of additional safety features. The philosophy adopted by ENEA-DISP was to use the new regulations as a reference to be "met as far as practically achievable ... related to good engineering judgement" (Eletti, 1983, p675). Thus designs imported from the USA and designed according to seismic hazard criteria applicable for North America had to be reassessed to cope with those likely to be found in the Mediterranean region. As a result the Latina CGR was modified and the Garigliano BWR shut down.

Although cost-benefit analysis is not carried out to assess the efficiency of radiation protection in advance, specific improvements have been costed out in terms to give a value per person sievert. A shield wall at Caorso constructed to reduce lifetime occupational exposure from 2.6 to 0.6 person Sv per year cost about $20 000/person Sv (Benassai and Bramati, 184, p255-256). At the risk factors prevailing at that time this implies a value for life of nearly $1 million ($20 000/0.0205).

The Italian approach to nuclear safety regulation has placed little reliance upon the use of cost-benefit analysis as a means of justification or optimization. Until the early 1980s there was little political or social pressure on the nuclear industry to justify the use of nuclear power, particularly on a quantifiable basis, with, for instance, trade unions relatively quiesecent on the safety issue and favouring nuclear power. Instead there has been a development of the philosophy of safety goals, themselves requiring the use of probabilistic risk assessment. The motives behind this approach lie in the need to avoid the problems caused by adopting the country of origin methodology. Despite its own acknowledged problems, probabilistic risk assessment was employed to evaluate the Caorso (for backfitting) and Montalto nuclear power plants, and was to be used in the licensing procedures for the PUN project (Eletti, 1983).

Of course the goals themselves are nothing more than risk targets, but set according to, largely engineering, judgements as to what is technologically feasible. Nonetheless, through probabilistic risk assessment, they are goals and judgements open to scrutiny. An increasing polarisation of views on nuclear power in the 1980s also provides a backdrop to reliance upon the criteria of "as low as technically feasible", since this test appears to bypass the need for justification of risk on the basis of a trade-off between economic factors. Lack of social consensus on the merits of placing a value upon saving life from the hazards of a technology rejected by a significant proportion of citizens clearly invalidates the effectiveness of cost-benefit analysis as a method of legitimation.

REGULATION IN HUNGARY

Background

Hungary has a socialist planned economy, though a determined effort has been under way to introduce markets into many sectors. Electrification was seen as a priority by economic planners, and a major programme was embarked upon to raise its contribution from its 1950 share of 21% of total energy consumption. Until 1960 coal provided nearly 100% of electrical power (Szili and others, 1977, p34). Through the Council for Mutual Economic Assistance (CMEA) and multilateral agreements, Hungary came to rely upon energy imports from the Soviet Union. The Druzhba [Friendship] oil pipeline and the Mir [Peace] electric power grid, both completed in the 1960s, and the Bratstvo [Brotherhood] gas network in the 1970s provided the infrastructure for energy transfers.

In 1965-66 the USSR concluded agreements with a number of CMEA countries to provide technical assistance and fuel for their own nuclear power programmes. Though these agreements were not put in hand at the time, Hungary and the USSR resurrected the project to install four VVER-440 MW(e) nuclear power plants in the 1970s, by which time the first such reactor was operating at Novovoronezh. This followed the 1971 CMEA agreement on a Complex Programme to develop socialist economic integration, thus moving from a regime of co-operation to planned industrial specialisation (Kramer, 1986; Sobell, 1984, pp16-18 and 145). As Table 2 shows, Hungary remains highly dependent upon imported electricity, largely from nuclear power plants located in the Ukraine. A sharp rise in the price charged for Soviet oil and gas in 1973 hit the Hungarian economy hard. Economic reformers have pointed to the constraints imposed upon growth by a large energy import bill (Antal and others, 1988, p13). Under severe fiscal pressure state subsidies are being cut in the energy sector. But priority is being given to the expansion of the nuclear power and lignite-fuelled power station programmes, with closures of deep-mined coal capacity (FT Business Information, 1988, 257 and 269).

Preparations for construction of the country's first nuclear power plant began in 1973. It was decided to create a nuclear park at Paks, where all nuclear power plants would be built (Szili and others, 1977, p35). The local population was not informed of the risks involved until after construction had started in 1978 and special efforts had to be made by the authorities to explain the safety system and calm fears (interview with Bêla Horváth, Deputy Head of SzOT Safety Department on 18 November 1988). Further expansion of the site is planned with contracts signed with the USSR's Atomenergoexport for two VVER-1000 MW(e) plants, to enter service in 1994 and 1996 respectively (Ravasz, 1988).

Safety regulation

Under the 1972 Constitution - indeed since 1949 - the "working class is the leading class of society" and safety has been seen as an absolute goal under the control of the working class. Until 1984 responsibility for occupational safety was exercised by the trade unions, organised in the Central Council of Trade Unions (SzOT). Slogans, such as " human life cannot be measured in forints", were the order of the day (interview with Gyözö Wiegand, General Manager, Technical Inspection, ÁEEF on 17 November 1988). Much has been changing in the 1980s, including the possibility of removing the "leading role" clause, but without this background it is not possible to understand the Hungarian system of regulation of nuclear safety.

Legislation covering nuclear safety was promulgated in 1980, well before Paks-1 went critical at the end of 1982; although radiation protection had been necessary in uranium mines, hospitals and laboratories well before. The Atomic Energy Act of 5 April 1980 states:

(a) "In the Hungarian People's Republic, the applications of nuclear energy, the related research and development shall serve the interests of the society as a whole. Nuclear energy may only be used in a way that does not result in any damage to human life, to the health and living conditions of present and future generations, to man's environment and material goods."

(b) "Within the permitted dose-limits, radiation exposure shall be reduced to a level as low as reasonably achievable."

(c) "Exposure of workers employed in nuclear energy applications and of the population to all sources of radiation must not result in annual doses exceeding the dose-limits permitted by the relevant regulations [laid down by the Ministry of Health] on the basis of the current level of knowledge and the recommendations of competent national and international advisory bodies" (Sztanyik and Bojtor, 1982, p606).

As Sztanyik has pointed out this law includes two of the ICRP's principles, but excludes that of justification of practice (Sztanyik and Bojtor, 1982, p606). It proved to be impossible to introduce the concept of acceptable risk into Hungarian law and instead maximum safety has to be guaranteed (interview with Dr. Lászlo B. Sztanyik, Director, National Research Institute for Radiobiology and Radiohygiene on 17 November 1988).

Under the Labour Code, employers are obliged to "take every available measure for the prevention of any danger threatening the health and safety of workers employed" (Sztanyik and Bojtor, 1982, pp606-607). It also confers on enterprise trade union bodies the right "to raise objections if they observe that any action taken by the enterprise is in violation of the regulations respecting working conditions or that the treatment of workers offends socialist morality" (quoted in ILO, 1984, p67). Trade unions have the right, infrequently used, to interupt work where there is a probable hazard and to receive compensation for the time they strike (ILO, 1985 and interview cited above).

Until 1984 trade unions had a dual function of both enforcing safety regulations and protecting the interests of their members. By a Decree of the Council of Ministers (No. 1010/1984/III.31) a national Occupational Safety Inspection Unit was established, taking over the work of the SzOT Labour Safety Affairs Department (ILO, 1985 and Noti, 1987, p83). The Ministry of Health and Social Welfare was given responsibility for developing a national plan for occupational health protection and operates through the County Sanitary Epidemiological Inspectorates (ILO, 1985 and interview with Sztanyik cited above). The change in control by the trade unions is described as moving from authoritative to social control.

Such social control is now backed by an increased role in enterprise planning, including the right to form union committees for safety and social policy, to participate in enterprise safety precaution reviews and to approve programmes relating to working and living conditions at a general meeting of all members (ILO, 1983, p332; Marton, 1987 and interview with Horváth cited above). The right to strike however is not guaranteed by the Constitution, which indeed specifies (in Article 65) that trade unions exist "for the protection of order and achievement of socialism, for increased participation in socialist construction work ... [and] for the implementation of the rights and obligations of the people" (quoted in ILO, 1984, p38). A mixed agenda, which, as will be seen in the next section, makes for a participatory rather than an adversarial role in industrial relations.

With the removal of occupational safety enforcement from the trade unions to state bodies, Hungarian regulatory institutions formally resemble those in most OECD countries. A decentralised system of regulatory authorities was established in 1979. The National Supervisory Authority of Energetics and Energy Safety (ÁEEF), which is accountable to the Ministry of Heavy Industry, has the responsibility for approving the preliminary safety analysis report submitted by the nuclear power plant owner and licensing operation (Nyerges, 1986 and Szönyi and Nyerges, 1988). Its general tasks involve also the elaboration of codes and guides for safe construction and operation, aiding the qualification of organisations and the training of the utility's inspection staff, and participation in the standardisation work of the CMEA.

Notwithstanding its delegated powers from the Ministry of Heavy Industry, the ÁEEF has to report to the State Commissioning Committee (AIB) which exists to "ensure the necessary consensus among the authorities at the main stages of the licensing procedure" (Szönyi and Nyerges, 1988). Essentially this ensures close political control over the introduction of nuclear power plants. The Committee includes representatives from the trade unions, consumer protection groups and county and municipal authorities.

As for environmental protection generally, Article 57 of the Constitution establishes the right to an environment "worthy of human beings". Detailed regulation on several fields is in hand under the terms of the Protection of the Human Environment Act of 1976, with radioactive emission limits fixed for air and water and monitoring of concentrations in the environment and agricultural produce by appropriate ministries. Under the Act "adequate measures" must be taken to prevent pollution (Sztanyik, 1985, p160; Wright, 1982).

Regulation in practice

Starting late in development of nuclear power the Hungarian regulatory authorities were able to benefit from the experience gained elsewhere. Their starting point was to apply international standards to the Paks project, described as "western standards" while taking into account Soviet regulations (interview with Györö Wiegand, General Manager Technical Inspection, ÁEEF on 17 November 1988). This was made easier as the USSR had supplied a similar LWR to Finland, but the Soviet safety philosophy and design was subject to considerable modification. The design basis accident was changed from a medium size loss of coolant accident to a more severe melt down. Special emergency core cooling systems and a containment and containment cooling system were included (Vöröss, 1984, pp3-6).

The ÁEEF developed codes and standards for use in the design, manufacture and construction of the nuclear power plants. These included a quality assurance code and general and specific technical safety codes, based on Soviet specifications and IAEA NUSS publications (Nyerges, Szönyi and Czoch, 1985, p39). Some 30% of the plant was manufactured in the USSR, including the primary and secondary circuits and the complete control and instrumentation system. Czechoslovak manufacturers supplied the reactor pressure vessel and certain other major components while Hungarian industry took about 40% of the work (Vöröss, 1984, p4). Although ÁEEF were satisfied with the quality control exercised in Czechoslovakia, manufacturing problems were encountered in the USSR for which they compensated by insisting upon undertaking extensive testing of all components (interview with Pál Nyerges, Chief Nuclear Inspector, ÁEEF on 17 November 1988).

The nature of the difficulties encountered by ÁEEF in the Soviet Union are illuminated by Valeri Legasov's testament, made before he committed suicide in April 1988. Legasov had headed the investigation into the Chernobyl disaster and in a taped memoir levelled criticism at the Soviet nuclear power industry. Amongst the charges he made was that the industry's scientific design and construction organisations do not co-ordinate sufficiently, leading to shortcomings in plant quality and violations of essential station design (FT Business Information, 1988, 265). Safety culture in socialist countries has also led to problems. Traditional practice has been to avoid admitting that industrial practices carry a risk. Strict prescriptions are therefore laid down, but are violated in order to maintain ouput. Thus when accidents happen culprits need to identified and blamed. In consequence failures are hidden and defects go unreported (interview with Wiegand and Gusztav Jancsik, Deputy Manager ÁEEF on 17 November 1988). That this is a widespread problem affecting quality and permitted by the fact that in the CMEA countries a sellers' market dominates is also the conclusion of Pécsi (1981, p27-28).

Such a safety culture, or lack of it, poses significant difficulties for the development of probabilistic safety analysis. In Hungary these techniques have been under development at the Institute for Electrical Power Research (VEIKI) since 1982. In order to obtain reliability data from the operations at Paks a computer system was established for recording technical data and unusual events (Szabados and Vöröss, 1986, pp4-5). However this is still not functioning six years after Paks-1 was commissioned through lack of training of site personnel and possible reluctance to report failures. Nor is Soviet reliability data available to VEIKI and the CMEA's joint data bank is not yet functioning despite three reorganisations of the Permanent Commission for the Use of Atomic Energy for Peaceful Purposes aimed to achieve this, since no country appears willing to share failure data.

Despite these problems the Hungarian authorities intend to apply probabilistic safety analysis to the licensing of Paks-5 and 6. In the meantime a probabilistic risk assessment was made in respect of a loss of coolant accident in the Paks VVER-440 plants using the MARCH 2 computer code developed by Battelle and LWR data available from the IAEA (Szabados and Vöröss,1986, p5 and Téchy and others, 1988). Not surprisingly the use of failure rates from mainly Westinghouse designed PWRs led to similar risk assessments to those of PWRs - a case of junk in, junk out.

Probabilistic safety analysis is viewed as one method of determining the optimal allocation of resources available for risk reduction over different energy sources (Vöröss, 1984, p9) but absence of the use of cost-benefit analysis makes it hard to see this occurring in the near future. In the context of Hungarian safety law the valuation of a person seivert is impossible and so explicit cost-benefit analysis is not employed. As in Italy exposure targets are set, based upon ICRP recommendations and IAEA basic safety standards. For the public, the annual dose must not exceed 0.25 mSv per 1000 MW(e) of installed nuclear power plant capacity for day to day operations (Sztanyik, 1985, p160).

For occupational exposures a trigger or checking level of 0.2 mSv per day is used with a reporting level of 1 mSv, the latter requiring special permission for it to occur and a medical examination for the individual and investigation if an unplanned dose is received. Radiation protection regulations required the approval of the trade unions and, at the workplace, company safety rules are similarly approved. A five year plan for investment and improvements in work safety has to have, like all investment and enterprise plans, the approval of the company trade union committee. The relationship between management and unions at the Paks Atomic Power Plant Company (PAV) was described by a senior manager as like a marriage, with both parties having to live together day by day (interviews with Janos Márton, Project Manager and Józsefef Katz , Chair of the TU Work Safety Committee on 16 November 1988). Both company and union saw a common interest in minimizing radiation exposure and conflicts over the application of resources had to be settled by consensus at company level or higher. Each accepted the regulations issued by the Ministry of Health.

Despite a legal obligation to cause no harm, in practice the Hungarian system of regulation is little different from that in Italy or the UK. Its distinguishing feature is that the optimizing of the level of risk is formally a matter of joint decision between the workforce and management. However the non-adversarial role of the trade union movement means that responsibility for resource allocation is shared unequally, since the unions are not in a realistic way able to affect the overall resources available to the enterprise except through sacrificing wages. An underdeveloped democracy also has difficulty in validating citizen acceptance of the risks created by nuclear power plants.

COMPARISONS AND CONTRASTS

General

The examples of regulatory approaches from the EC, Hungary, Italy and the UK illustrate differing attempts at deciding acceptable risk. That of the EC reflects its attempt to achieve consensus between Member States and the social partners by means of deference to Science - the wisdom of the ICRP in this instance. The Community prescribes a process (the rules of the game) whereby acceptability can be arrived at, leaving Member States to determine for themselves the nature and degree of risk to be accepted by their populations. In recognition at least of the need to strengthen dialogue between the social partners themselves and with the Commission and the Council, the Community has, in 1987, included radiation protection within the terms of reference of the tripartite Advisory Committee on Safety, Hygiene and Health Protection, but large differences remain on the principles for health protection and the appropriateness of nuclear power.

In Hungary the safety standards adopted are those agreed internationally (also those of the ICRP) but with an explicit rejection that a value can be placed upon human life. This leaves the way open for actual safety levels to be determined through the political process, until now by means of achieving social consensus between government agencies, management and trade unions - the top echelons of each being under the influence of the Hungarian Socialist Workers' Party (MSzMP).

Recognition of the lack of social consensus in placing a value upon human life has in Italy contributed to a reliance upon safety goals, themselves subject to review by the regulatory authorities under pressure of technical progress and other social pressures. Despite the history of relative harmony between employers and trade union representatives on the HSC, a breakdown of social consensus in the UK has provided the opportunity for the rapid adoption by government and regulatory authorities of the value of life approach to augment the longstanding principle that risk must be reduced by whatever means are reasonably practicable. The potential conflict in approaches of the regulatory authorities and trade unions has not yet become manifest in the area of radiation protection.

Trade-off

Another feature of the case studies is the approach taken towards the idea of a trade-off between harm and social benefit. For the EC the trade-off is explicitly accepted in principle as being both necessary and, in conditions lacking an abundance of goods and resources, desirable. In Hungary the trade-off is hidden and its desirability denied. Italian regulators recognise the need for trade-off but by defining targets according to technical criteria disguise its operation in economic terms. Whilst in the UK a trade-off is accepted as necessary but applied selectively to different industrial sectors, with the nuclear industry investing heavily in safety precautions.

Nonetheless these examples also display several common features. Perhaps this is on the face of it unsurprising given the pervasive influence of the ICRP. However an analysis of the way this institution operates or its degree of influence is beyond the scope of this paper. It remains the case that in each of the examples considered, the principle of optimization of protection from harm finds support, that is, the regulation of risk includes a rational procedure for risk reduction. Each accepts the principle of ALARA though in practice they all set safety goals which are subject to social and economic assessment to varying degrees. Furthermore the decision-aiding technique of probabilistic safety analysis is used in the task of risk reduction.

Thinking about acceptable risk

This section seeks to present the analysis in a general form. The relationships underlying the construct "acceptable risk" are presented graphically. The aim of this analysis is to bring together the two strands pursued thus far in this paper: the socially determined and the probabilistic nature of safety. Two forms of safety are illustrated. The chance of an individual being harmed by an industrial activity is termed "individual risk" in the literature. "Societal risk" by contrast represents the chance of substantial harm suffered by a whole population or community. The diagrams are adaptions from British, Dutch, US and Soviet literature. They have been modified to display the results of risk assessment for a small selection of advanced technological systems in an illustrative rather than mathematically precise manner.

Since the focus of this paper is upon acceptable risk and the role played by cost-benefit analysis in its determination, the environmental impact or social or psychological consequences of nuclear power plants (and other advanced technological systems) are not considered here. Clearly such considerations form an important part in defining the acceptability of such systems, and the narrower focus adopted here should be seen as only one of a set of factors at work.

In the UK the policy debate concerning acceptable risk has moved towards adopting a less value-loaded term "tolerability" rather than "acceptability", following recommendations made in the Layfield Report of the public inquiry into the siting of a PWR at Sizewell (Layfield, 1987). It is also a term employed by Perrow (1984), as is suggested by the title of his book "Normal accidents: living with high risk technologies". However the approach to risk management adopted in the Netherlands continues to use the term maximum acceptable risk (van Kuijen, 1988). The distinction is a fine one, particularly since in the British definition tolerability "refers to a willingness to live with a risk so as to secure certain benefits and in the confidence that it is being properly controlled. To tolerate a risk means we do not regard it as negligible ... but rather something we need to keep under review and reduce still further if and as we can" (HSE, 1988, p1).

There is however a shift of emphasis from the assumption of positive choice implicit in the term acceptable risk. Or, to put the argument more strongly "if it is organisations, not individuals, that set the definition of acceptable risk and the terms of a cost-benefit payoff, then what is weighed in risk analysis may be, as Perrow says, 'not risk, but power'" (Clarke, 1988, p31).

Even so, changing the word used to define the boundary between those risks that are to be eliminated and those which should be minimized does not seem to advance the debate significantly. After all, arguments against the concept of acceptable risk based upon demonstrating the public's lack of choice, or on their (mis)perceptions of the "true" nature of risk, do not invalidate the political proposition that citizens are entitled to make choices concerning the acceptability of risk from technological systems, or that the availability of information is a form of empowerment. If risks cannot be wholly eliminated from life, then at least there must be mechanisms whereby society can decide as to their acceptability. Thus the paper will continue to use the term "acceptable risk".

<u>Individual risk</u>

The relationship between the maximum acceptable individual risk and the process of optimization is illustrated in figure 4. The form of figure 4 is derived from work undertaken by the HSE and the I V Kurchatov Institute of Atomic Energy (see HSE, 1988, p9 and p24 and Babaev and others, 1986, p481). A comparison is made with a similar exposition of risk criteria for the policy on external safety in the Netherlands (van Kuijen, 1988, p55). Reference is also made to the work of Rowe in the USA.

The starting point for this exposition is the normal death rate. The overall level of the risk of death in industrially developed countries is about 1 in 100 per year (10^{-2} per year). The lowest risk is for children aged between 5 or 10 and 15 years: that is 1 in 10 000 (10^{-4}) per year.

The government of the Netherlands has decided that a new location- specific industrial activity will not be allowed if it imposes an additional risk of more than 1 in 1 000 000 - 1% of 10^{-4} (van Kuijen, 1988, p46). This risk refers to members of the public living outside the industrial plant and not to the workers in the plant. In principle it is the same as HSE's view that for people living near a nuclear installation a risk of between 1 in 1 000 000 and 1 in 100 000 is "just tolerable" (HSE, 1988, p24). A risk below 1 in 1 000 000 is "usually" accepted without much difficulty in the HSE's opinion. A Soviet proposal sets a similar limit at 1 in 500 000 (midway between 10^{-6} and 10^{-5}) per year (Babaev and others, 1986, p481).

Since this level of risk is also one below which only normal safety precautions need be taken, figure 4 sets the boundary for negligible risk between 1 in 10 000 000 and 1 in 1 000 000 (10^{-7} to 10^{-6}) per year. By contrast the Dutch target value for negligible risk is 1 in 100 000 000 (10^{-8}) per year. This is a particularly strict criterion and is considered unrealistically low by, for instance, the HSE (interview with Dr Adrian Cohen and John Rimington, HSE on 15 December 1988). William Rowe, a risk assessment specialist, suggests that without net benefit an unacceptable risk is 1 in 10 000 000 (10^{-7}) and with benefits up to a maximum of 1 in 1000 (10^{-3}) (Rowe, 1988, p374).

There is agreement between the British and Soviet regulatory approaches to maximum acceptable risk for workers as being under 1 in 1 000 (10^{-3}) per year. Nevertheless this is a high level of risk, being borne by, for instance, deep sea fishermen. Heavy manufacturing and mining carry a risk of about 1 in 10 000 (10^{-4}) per year (HSE, 1988, p23). The range between the maximum acceptable individual risks for workers and the public and negligible levels of risk define the zone for optimization of safety measures. Indeed the Soviet proposals specifically state that for large risks, implicitly those above 1 in 1 000, "the unwillingness of an individual to incur involuntary risk should become absolute" (Babaev and others, 1986, p473). Beyond this level using the concept 'the value of life' is "inadmissible". (In this context involuntary risk should be thought of as including occupational risk, since both capitalist and socialist societies make paid work a condition for full participation in social life. A voluntary risk could be one borne through participation in a challenging or dangerous sport.)

In the zone where a reduction in risk is desired there is scope for using cost-benefit analysis as the method for optimization. But it is also possible, though less explicit, to achieve the same ends by setting safety goals that become progressively tougher as economic enrichment progresses. According to the UK's regulatory approach, emissions from a nuclear power station (over 1 000 MW(e)) must not carry a risk greater than 1 in 100 000 to members of the public living nearby during normal operation and should be lowered as far as is reasonably practicable. The equivalent Italian target of 0.1 mSv/year for each 2 000 MW(e) of capacity implies a risk of about 1 in 1 000 000. Hungary's target of 0.25 mSv/year for each 1 000 MW(e) of capacity means that an individual close to the power plant faces a risk of 1 in 500 000. A similar analysis could be undertaken for workers' exposure.

Societal risk

A relationship between the maximum acceptable risk and the process of optimizing risk reduction can be illustrated for societal risk as well as for individual risk. An attempt is shown in figures 5 and 6. The diagrams' origins lie in the relationship between the frequency of accidents (f) and their consequences (C) developed by Farmer and Kinchin of the UK Atomic Energy Authority and Coppola and Hall of the US Nuclear Regulatory Commission (see The Royal Society, 1983, p36). In the literature these are either referred to as fC lines or FN curves, the latter standing for frequency of events (F) compared to the number of deaths/numbers (N) harmed. Such curves are the subject of considerable doubt due to the inadequacies of the data for plant failure, non-quantification of human error and modelling difficulties, such as the basis for extrapolating exposure-effect relationships to low doses and statistical confidence limits and margins of error. Nevertheless, for the purposes of this presentation, it is not necessary to do more than indicate on the map the societal risks concerned. Thus no attempt has been made to plot FN curves for specific advanced technological systems.

The starting point of the boundaries between unacceptable-acceptable-negligible risk zones are the same as those pertaining to individual risk. The risk of one person's death is taken to be equivalent to the risk faced by any one individual. The slope of the boundaries is a matter for debate. Should it take into account an increasing aversion to ever larger numbers of deaths or provide for an equality of misery? The particular slope chosen here reflects the recommendation of an HSE Advisory Committee that the chance of a serious accident of >10 deaths involving any one major non-nuclear plant should be less than 1 in 10 000 per year (HSE Advisory Committeee on Major Hazards, 1976). This figure remains one which the HSE would normally accept (interview with Dr Cohen and Mr Rimington, HSE on 15 December 1988). It does however imply a willingness to accept the consequences of very large disasters, albeit at remote chances of occurrence.

In Rowe's scheme - involving a method of balancing gains and losses, the degree of control and the cost-effectiveness of risk-management - the zone of acceptable risk extends up to 1 in 10 000 (10^{-4}) but down to 1 in 100 000 000 000 (10^{-11}). In fact to be considered acceptable an involuntary risk of >10 deaths per event is likely to be below 1 in 100 000 000 (10^{-8}) (Rowe, 1988, pp327-388). It is not possible to illustrate this in figure 5 however as the scheme involves calculating specific numbers (termed risk referents) against which actual technological systems are compared: no lines can be plotted on the map. Whilst the scheme is complicated and uses some arbitrary factors to asses the balancing of gains and losses, it supports the premise that a zone exists below 10^{-4} for optimizing precautions.

The map has been further divided, to be sure arbitrarily, into zones above and below 1 000 deaths. The zone above this number of deaths is designated "catastrophic events"; that below "tragic events". The boundary for negligible risk is taken to be parallel to that of the maximum acceptable risk. Clearly such labelling is subjective. Rowe, for instance, designates ten or more deaths as the border between a large event and a catastrophe (1988, p154). Yet, in terms of the horror of their impact upon us, there are differences between Bhopal (2500 killed) or Chernobyl (5 to 10 000 early deaths) and Flixborough (28 killed) or Seveso (no immediate deaths) (HSE, 1989; Weir, 1987, pp189-194). Adjusting the boundary for catastrophic events downwards to 100 deaths would not significantly affect the argument below.

In the Netherlands a maximum acceptable group risk for >10 deaths in one incident has been set at a maximum chance of 1 in 10 000 (10^{-4}) per year. But "a heavier weight is assigned to the larger consequences of accidents. It has been decided in this connection that a consequence n times greater must correspond to a chance n^2 smaller, as it appears from literature that the seriousness of the societal consequence of an incident is judged to increase with the square of the number of people killed" (van Kuijen, 1988, p46). In fact the slope of this line means that the chance of 1 000 deaths is 1 in 100 000 000 (10^{-8}) and it can be seen from figure 5 that introducing a "catastrophic event zone" could have much the same effect in making a distinction between sizes of disasters. A chance of 1 in 10 000 000 per year with <10 deaths is taken as posing a negligible group risk in the Dutch scheme.

It can be seen from figure 5 that relating the "physical" factors of chance and deaths is by itself insufficient to model acceptable risk. Nuclear power plants are well within the boundaries for acceptable risk while chemical and petroleum plants lie in the zone of unacceptable risk. Aviation is included on the map because it is arguable whether all passengers freely choose to fly - business travellers or longhaul passengers have little practical alternative. Demonstrably, experience shows that aviation and chemical industries are considered socially acceptable risks, notwithstanding pressures to improve safety.

Our apparent conundrum is fairly easily solved, of course, once one adds the economic dimension. This is done in figure 6, which takes the cost of providing an alternative to the advanced technological system as one (y) dimension. This map is derived from Perrow (1984, p349) but is significantly different in its treatment of the second (x) dimension. In Perrow, the cost of alternatives is plotted against net catastrophic potential, giving nuclear power a high rating on the latter score. Figure 6, by contrast, plots the chance of a catastrophic number of deaths, namely >1 000 per year from a single event. Adopting this dimension shows nuclear power plants with a low score - there being only a small chance of a large accident according to probabilistic risk assessment.

Since we can assume that the scales of each dimension of figure 6 measure increasing satisfaction - a remote risk or a lower penalty for switching to an alternative is preferred -

social indifference curves could potentially be drawn convex to the origin and downward sloping. Gains in utility can be supposed to exist through changing the mix of society's technology. Additional safety features for chemical plants would alter the form of technology while substituting fossil fuel power stations for nuclear power plants represents a change in mix. Different forms of technology carry with them, or embody, different risks.

By taking the midpoint of the (notional) index for the cost of alternatives and the maximum acceptable risk in respect of 1 000 deaths (about 1 in 500 000 on the bottom axis), one can divide the map into quadrants. Each quadrant may be assigned a policy objective. Where the technology carries a high risk of catastrophe but a low penalty for its removal, a gain in social welfare could be achieved by following a goal of reject or abandon. With high risk but indispensable technologies, gains could be achieved only through risk reduction measures a goal of control and improve. Technologies where risks are remote but costs of alternatives high, would not offer large prospects for social welfare gains - thus a policy goal of acceptance. Finally, a technology posing a remote risk but with a low penalty for removal could be the subject of a gain in social welfare by folowing a goal of avoidance.

It would be possible to substitute a y axis measuring the cost of harm for that shown in figure 6 (the cost of alternatives). However this would merely replicate the y axis of figure 5, but in monetary rather than physical units. In any case, the method of valuing life by reference to the cost of death or suffering to society as a whole (that is the loss of output plus cost of treatment) is of little help in determining society-wide decisions concerning the acceptability of risk. The values of life in such calculations reflect the prevailing form and mix of technology.

Thus the value of life is not appropriate as far as the trade-off between societal risk and benefit is concerned. The relevant benefit (or cost) measure lies in the ability of society to switch technologies in meeting equivalent needs and demands. The advantage of figures 5 and 6 are that accident consequences are measured in physical units and cost/benefits in, at least in principle, ascertainable money terms, achievable through costing of engineering or of preferences for goods and services. Furthermore the maps focus concern upon society's capacity to control technology. Nevertheless it is admitted that marginalizing the monetary valuation of the social and economic losses from major accidents in modelling what constitutes an acceptable societal risk is clearly controversial.

The models drawn here delineate the concept of acceptable risk according to two sets of dimensions: dimensions that measure social and economic factors and dimensions of risk (the chance of adverse consequences). Safety is revealed as their product. The next section argues that these measurable dimensions -

measurable through the use of cost-benefit analysis and probabilistic safety analysis - are required if decisions concerning safety standards are to be made by society.

Who sets the standards?

On 15 September 1979 the members of the US President's Commission on the accident at Three Mile Island - the Kemeny Commission - discussed the question of acceptable risk. Charles Perrow describes how the Commission arrived at its conclusion through an examination of the transcript (Perrow, 1984, pp335-338). From their visit to the plant the Commission members inferred that industrial safety standards were much the same anywhere and that the plant appeared as well managed as any of the best: what could be more acceptable? However the potential consequences of a major accident clearly made nuclear power plants special. If this was the case should they not recommend far tighter management, along the lines of the US Navy, operating nuclear-powered submarines? Yet the prospect of imposing military-style discipline on civilian activity was clearly worrying. "But Professor Pigford," a former employee of a nuclear vendor and currently professor in nuclear engineering "would not let up. 'There is no such thing as no accidents', he said. 'So we have got to bite the bullet and realise that we are not going to be able to determine what is acceptable'. This became the majority view".

Whilst it is commonplace for the leaders of the nuclear industry, and indeed regulators, to point out that society accepts many activities, industrial or not, voluntary or involuntary, carrying far greater risks than those posed by the day to day operations of nuclear power plants, most are unwilling to take responsibility for saying what constitutes an acceptable risk. "Everyone takes it as normal that out of a population of ten million with one million cars there should be 2 000 accidents a year. But there would be panic if five died at Paks... Glasnost in the newspapers is a positive thing but there are some negative consequences: it is absurd for the press to suggest that there is such a thing as no risk... This [no risk] philosophy leads to growing risk in society - there are resources to lower risk but they are wasted on places where there is a small risk" (interview with Győző Wiegand, General Manager Technical Inspection, ÁEEF, on 17 November 1988).

The conclusion is that the public must be involved, but, suggests Perrow, only on the risk assessors' terms. "This is done by 'closing the gap between the expert and the public' (that is, them and us); but the gap almost always is to be closed in one direction only - by bringing the public over to the experts' side through education" (Perrow, 1984, p315). In the meantime nuclear power plants are planned, designed, constructed, licensed and operated. No-one wants to set a standard for acceptable risk - least of all politicians, who prefer to promote projects that are safe - but someone always will. In the case of nuclear power plants that decision is taken by engineers working within budget constraints.

It is possible to view the question of acceptable risk as a series of transfers of risks, benefits and responsibilities. Nuclear power plants pose risks that have a transboundary dimension : in space and time. Italians may have voted against nuclear power but the risks they face are those determined by the safety standards of Hungary or France. It may well be the case that half the postulated mutagenic effects of radiation will be revealed within two generations, but to conclude, as the ICRP does, that because the first generation is mainly concerned with its children and grandchildren no account need be taken of the latters' descendants is unwarranted (ICRP, 1977b). Nor are the benefits spread fairly. Those rejecting nuclear power may still benefit from its use, such as electricity consumers in Italy who are supplied with cheaper French power. Those who suffer in the future may only bear the cost of nuclear waste and decommissioned reactors.

Responsibilities are transferred from the political process to technical experts, when they are asked to give an opinion on whether nuclear power plants are safe. 'Trans-scientific issues' concern "answers to questions which can be asked of science and yet which cannot be answered by science" (Weinberg, 1972). It has been argued that scientists and engineers are particularly ill-qualified to make such discretionary, or value, judgements as a result of their training which encourages them to seek a positive (or negative) result, or answer, from an analysis or experiment (see Marcus, 1988, p149).

But it is not just the 'big' questions of what constitutes safety that are transferred to technical experts. It is the job of a design engineer to make engineering judgements concerning safety margins. These are routine questions not generally open to validation except through the complexities of the licensing procedure. It will be recalled that most licensing is carried out on the basis of a deterministic approach, that is, an analysis aimed at ascertaining whether the design achieves the criteria for 'design basis accidents'. The discipline of probabilistic safety analysis is not yet mature enough to used as more than an adjunct to existing licensing procedures. Nevertheless these show (refer to figure 5) that the margins of safety in nuclear engineering far exceed those of other industries. Probabilistic safety analysis is an extension of rationality into engineering judgement, it unmasks the pseudo-certainties of safety margins based on averages or rule of thumb and facilitates the comparison of engineered systems.

In the area of radiation protection safety standards are based upon levels of risk which are considered by the ICRP to be acceptable. The ICRP's comparators are other occupational hazards, with public exposure levels set an order of magnitude lower. Yet the ICRP have in fact developed a system to validate technical judgements through the application of optimization of protection according to the principle of ALARA.

Critics of ALARA and of the use of cost-benefit analysis, often from the Left but, as this paper has shown, commanding a good degree of consensus in representative forums such as the European Parliament and the Community's Economic and Social Committee, tend to offer technology-led criteria as a substitute. As methods of pollution control, rules requiring the use of best available technology or the state of the art, or designed to keep hazards as low as technically feasible, are quite popular. To a greater or lesser extent they are used in the environmental or safety regulation of the EC, Hungary, Italy and the UK. The nuclear industry however is not regulated according to such criteria.

Although in principle based on the practice of ALARA, investment in protection in the nuclear sector appears to be even higher than would be warranted by cost-benefit analysis. This paper's analysis of those examples where cost-benefit analysis has been carried out, of LWRs in Italy and the UK, bears out the comments made by a senior manager at Babcock Woodall-Duckham Limited, a power engineering company, to a professional symposium on ALARA. "Is the disparity between ALARA costing and the cost arising from applying nuclear industry design standards mainly due to the exceptionally high standards used in the nuclear field in comparison with those in general engineering..? In setting the safety margins ... extremely low risk probabilities are used - 10^{-6} to 10^{-7}; this is disproportionate to normal safety standards as applied to the general engineering field, where levels of 10^{-3} to 10^{-4} might be considered reasonable... If one applied safety levels to the nuclear industry more consistent with engineering practice, you would then find that ALARA would be ... much more significant. I am not suggesting that we should go for those safety levels, but that surely is why that disparity exists" (Lakey and Lewins, 1987, p80).

It is perhaps ironic that the nuclear industry which of nearly all advanced technological systems has come closest in practice to applying the best available technology should have been the most heavily criticised on safety grounds. In response the industry's leaders developed the concept of acceptable risk and the application of cost-benefit analysis and probabilistic safety analysis to measure safety performance. These tools open up the hitherto closed world of engineering judgement. The analysis presented in this paper has shown these tools to be flawed, but to reject them in favour of reliance upon technology-led criteria would be to hand back the choice on acceptable risk to the engineers and professional risk managers.

In particular, the flaws identified concern the calculation of the value of life and the need to assess the trade-offs for societal risks in a manner that accounts for catastrophic risks and the capacity to switch technologies. The latter case calls into question society's ability to control technology. In capitalist societies that control is weakened by private property rights. Under existing socialism the capacity of citizens to validate industrial decisions is underdeveloped.

Turning to the former issue, the methods used to calculate the value of life are income/wealth and risk perception biased. Many would wish to avoid making reference to 'the value of life' for just such reasons. However to use the term should remind us that lives are being weighed in the cost-benefit trade-off. The fact that measures of the value of life are arbitrary and problematic suggests that setting its value is part of the political process.

This is equally the case as regards occupational risk, where the value put on a worker's life has to involve those affected; being a part therefore of the industrial relations process.

Thus the flawed nature of the tools for assessment of what constitutes an acceptable risk require not further expertise on the part of technical specialists, but input from the public and workers, in general from those who face the risks - and in the case of nuclear power plants, everyone is involved. The environmental movement and the developing concern over public and occupational health have introduced new values into what were until recently seen as technical questions. Fagnani and Nicolon put the issue well: "Do [these non-technical values] in practice open up a field of intervention in the process [of setting safety and environmental norms] simply to new forms of expertise as has previously been the case, or do they constitute a space where new forms of collective decision-making can be tried out, opening the way progressively from a system of delegated power to a system of participation?" (1979, p483).

Addressing this challenge cannot be a simple matter. Green and environmentalist opposition to nuclear power has aimed at a strategy of shut-down as soon as possible. But, however viable this strategy is within the context of national politics, it cannot deal with the transboundary nature of the risks if other nations opt to continue with nuclear power or embark on new programmes. Nor does it take into account the risks that remain after shut-down, risks faced by workers in decommissioning operations for example. There may also be inconsistencies in treatment where other hazardous technologies are involved, unless it is argued that these are to be closed down too. Thus it seems necessary to adopt a strategy that takes account of those factors which are avoided if the political approach remains aimed at securing a no risk society through shut-down.

Cost-benefit analysis and probabilistic safety analysis are decision-aiding tools for assessing the trade-offs underlying the concept of acceptable risk. Their use makes possible the transfer of responsibility for safety back from the expert and manager to the citizen and the worker.

CONCLUSION

Engineers design and build nuclear power plants, employing engineering judgement in the process. Safety is assured by the application of the principle of defence-in-depth. Regulators can assess the effectiveness of defence-in-depth by deterministic methods, but increasingly probabilistic safety analysis is employed. Use of probabilistic risk assessment allows the validation of safety goals, which may be expressed as radiation exposure targets. At such levels of radiation exposure, the harm threatened cannot be known for sure. The system of radiological protection therefore prescribes dose limits and a requirement to optimize the level of safety in order to keep exposure as low as reasonably achievable, economic and social factors being taken into account. Cost-benefit analysis is often proposed as the method by which this optimization is to be achieved.

Judging the acceptability of risk from a hazardous industrial technology involves making a trade-off between the potential for harm and the social benefits accruing. At the European level of safety regulation, such trade-offs are viewed as necessary and national regulators are encouraged by the European Community to employ cost-benefit analysis in this task. Such a system is in place in the UK, where cost-benefit analysis and probabilistic safety analysis have been used to validate the extent to which new nuclear power plants have sufficient defence-in-depth to meet the requirements of English law. In order to use cost-benefit analysis to assess investments in safety it is necessary to place a value on life. Such an exercise is likely to be at the expense of social consensus.

In Italy and Hungary no values are calculated for life as part of their regulatory processes and cost-benefit analysis is not used to justify safety standards. Instead safety goals are set which are subject to validation by probabilistic safety analysis in Italy, and, it is intended, in Hungary. Safety standards are set in Italy by reference to the need to keep exposures as low as technically feasible, provided that this is effective and entails reasonable burdens. Hungarian safety standards require the consensus of organised social groups with the aim that nuclear energy serves the interests of society as a whole.

Such exposure targets and dose limits disguise the prior judgement made on the acceptability of risk. While overtly set according to engineering judgement or to maximum use of available technology, the state of the art or best practicable means, any safety standard implies the existence of some risk; it can therefore be said to represent an implicit view of acceptable risk. Yet even when the trade-off is explicitly made, as in cases where cost-benefit analysis is used, it is necessary to define clearly the terms of the trade-off.

For individual risk, it is suggested that a trade-off between the risk and the value of life is appropriate, although calculating the latter is a political not a technical issue. In the case of societal risk it is proposed that the trade-off exists between catastrophic risk and the cost of switching to an alternative technology. This is also a political matter involving, as it does, society as a whole. Safety is modelled as the product of trade-offs between risk and measures of social and economic factors. These are measurable by application of cost-benefit analysis and probabilistic safety analysis.

The nuclear industry and its regulators have developed some powerful decision-aiding tools for risk management in their efforts to satisfy public demands that nuclear power plants be safe. In this enterprise the notion of safety has been changed to one of acceptable risk. But in so doing the door has been opened on the previously closed world of engineering and expert judgement. The challenge faced by citizens and workers is whether to seek to employ these decision-aiding tools or to leave them in the hands of a new cadre of experts.

APPENDIX A
HISTORY OF PROBABILISTIC RISK ASSESSMENT FOR NUCLEAR POWER

Since the 1970s probabilistic risk assessment techniques have been applied to nuclear power technology.(See for example the seminal article by Chauncey Starr, former head of the Atomic Division of North American Aviation and subsequently president of the Electric Power Research Institute (Starr, 1969).) Developed from their application in defence and aerospace, patially encouraged by Robert McNamara's emphasis upon cost-benefit analysis in respect of procurement of weapons systems during his tenure at the US Defence Department, techniques such as event tree analysis were employed by the US Nuclear Regulatory Commission to examine reactor safety, most notably in its 'Rasmussen Report' (US NRC, 1975). The team of 150 analysts, including a dozen Boeing Corporation engineers, tried to assess the probability of reactor core melt-down and the effects of such a catastrophe on the health of the surrounding population. Eighty-two event trees were analysed for a General Electric BWR and a Westinghouse PWR. Comparisons were made with other societal risks, though none from alternative means of energy supply.

The official evaluation of that study by the Lewis Committee recommended that the regulatory process explicitly incorporate more rational and cohesive methods, such as probabilistic risk assessment, for decision making (Lewis, 1978). Use of probabilistic risk assessment was further encouraged by the Kemeny Commission, established to review nuclear safety after the accident at Three Mile Island-2 on 28 March 1979 (Kemeny, 1979). For the US Nuclear Regulatory Commission the lesson of TMI-2 was that although the health risks from severe reactor accidents were very small, the political and economic risks were not. Requiring the plant operator to undertake probabilistic risk assessment for beyond design basis accidents is intended to identify 'pronounced vulnerabilities' to severe accidents (Birkhofer and others, 1985, p54). The US NRC began to make use of probabilistic risk assessment in reactor regulation. Several studies using such techniques were carried out as a result, for instance by General Electric (see Speis and Jahns, 1985).

In Europe, the German risk study (Bayer and others, 1982) was undertaken to give an assessment of the accidental risks posed by nuclear power plants and to gain experience of applying this method. Whilst not part of the regulatory or licensing process, the Federal Parliament used its comparison of an existing PWR with a proposed fast reactor (SNR-300) to reject a petition to stop the latter's construction (CEC,1985). As part of its evidence to the public inquiry in the UK to contruct a PWR at Sizewell the plant operator put forward risk predictions of the risk from degraded core accidents based on the existing (but unfinalised) design (HSE, 1989).

APPENDIX B
FUNDAMENTAL SAFETY PRINCIPLES FOR NUCLEAR POWER PLANTS

The following objectives for light water reactor nuclear power plants are intended by the Commission of the European Communities to form a framework which can be used as a reference for judgements made in the safety evaluation process to enable a consistent and uniform approach to be adopted (CEC, 1981).

1. Nuclear power plants shall be sited, designed, constructed, tested, operated and decommissioned so as to provide reasonable assurance there is no undue risk to the workers, the general public and the environment.

2. Measures shall be taken to ensure that radioactive materials which are present in the installations are confined in an appropriate manner.

3. The release of radioactive materials shall be as low as reasonably achievable.

4. Adequate steps shall be taken in the design, operation and decommissioning of the plant to ensure that all exposures to ionising radiations are as low as reasonably achievable.

5. Individual doses shall always be kept within prescribed limits. In addition individual and collective doses to both site personnel and the general public shall be kept as low as reasonably achievable in all operational states of the nuclear power plant.

6. All reasonably practicable steps shall be taken to prevent accidents.

7. All reasonably practicable steps shall be taken to minimize the radiological consequences to the general public of any accident, should it occur.

8. All reasonably practicable steps shall be taken to minimize the radiological consequences to site personnel of any accident, should it occur.

9. The more serious the potential consequences of an accident, the smaller should be the probability of its occurrence.

10. Provisions shall be made to prevent the exposure of site personnel reaching levels which hamper the actions necessary to mitigate the consequences of an accident.

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GLOSSARY

ÁEEF Állami Energetikai és Energiabiztonságtechnikai Felügyelet - National Supervisory Authority of Energetics and Energy Safety (H).

AIB State Commissioning Committee (H).

ALARA An acronym for "as low as reasonably achievable, economic and social factors being taken into account". It was used for the first time in radiation protection in the ICRP's recommendations of 1965 in the slightly different form of "as low as readily achievable, economic and social factors being taken into account".

ALARP An acronym for "as low as reasonably practicable".

Backfit To apply new requirements to previously approved reactors to bring them up to the same degree of compliance with the new regulations and new interpretations and guidance as state of the art reactors.

BWR Boiling Water Reactor; a LWR (USA).

Carcinogenic processes give rise to malignant tumours in cells (cancer).

CBI Confederation of British Industry (UK).

CEC Commission of the European Communities.

CEGB Central Electricity Generating Board (UK).

CIPE Comitato Interministeriale per la Programmazione Economica - Inter-ministerial Committee for Economic Planning (I).

Committed dose equivalent is the dose to an organ or a tissue over a period of 50 years.

CMEA Council for Mutual Economic Assistance.

Cost-benefit analysis A decision-aiding technique of applied welfare economics, which is used to throw light on the social desirability of undertaking a project. The positive and negative effects of the project are usually evaluated in money terms, despite the difficulties in assigning values to individual preferences or to "goods" and "bads" not traded on a market. If the net benefit is positive it is implied that those who gain from the project would be able to compensate those who lose and still remain better off. Such compensating variations are income biased and problems of distributional equity exist.

Design basis accident A fault or fault sequence is said to be within the design basis if it is one which has been taken into account in the design and for which it has been demonstrated by virtue of the safeguard system provided that neither a loss of coolable geometry nor release of radioactivity exceeding off-site exposure limits to the environment would result.

DISP Direzione Centrale Siccurezza Nucleare e Protezione Sanitaria - Directorate of Nuclear Safety and Health Protection (I).

EC European Community.

Effective dose equivalent is the sum of the weighted average dose equivalent in the various organs or tissues. It is measured in **sieverts**.

ENEA Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative - National Commission for Research and Development in Nuclear and Alternative Energy Sources (I).

ETUC The European Trade Union Confederation.

Euratom The European Atomic Energy Community.

European Community Directives, et cetera. When acting under the Rome Treaties the Council of Ministers and the Commission of the European Communities issue:

> **Regulations** of general application; these are binding in their entirety and applicable in all Member States;
>
> **Directives** are binding on Member States to which they are addressed as regards the results to be achieved, but leave the form and methods of achieving them to the discretion of the national authorities;
>
> **Decisions** may be addressed to a government, or to an enterprise or to a private individual; they are binding in their entirety on those to whom they are addressed;
>
> **Recommendations** and **Opinions** are not binding.

Factors of magnitude The standard set of prefixes used in science include:

Factor	Prefix	Abbreviation
1-millionth part	micro	μ (10^{-6})
1-thousandth part	milli	m (10^{-3})
thousand times	kilo	k (10^{3})
million times	mega	M (10^{6})
thousand million times	giga	G (10^{9})
million million times	tera	T (10^{12})

GCR Gas-cooled Reactor.

Genetic effects caused by radiation involve harm to the descendants of the exposed individual.

Harm is the loss of **health** to a person.

Hazard is the situation that in particular circumstances could lead to **harm**.

Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (**WHO** Constitution).

HSC and HSE The Health and Safety Commission and Executive respectively (UK).

IAEA The International Atomic Energy Agency.

ICRP The International Commission on Radiological Protection.

Ionising radiations produce ionisation in matter - the process by which a neutral atom or molecule acquires an electric charge.

ISS Istituto Superiore di Sanitá - Supervisory Institute of Health (I).

LD50 The median lethal dose to an exposed population.

LWR Light water reactor; a nuclear reactor that uses water as both a moderator and a coolant.

MICA Ministerio dell'Industria del Commercio e dell'Artigianato - Ministry of Industry, Commerce and Crafts (I).

MSzMP Magyar Szocialisztai Munkai Part - Hungarian Socialist Workers' Party.

Multi-attribute utility analysis A decision-aiding technique of decision theory (or decision analysis) concerned with how to evaluate options where there are conflicting objectives. It uses a scoring system (or a utility function) for the relevant factors (the attributes) with the property that if the score (or utility) is the same for two options there is no preference for one or the other, but if scores differ then the option with the higher score is preferred. Generally the best outcome or lowest adverse consequence for each factor j is assigned a utility U_j of 1 and the worst consequence a utility of 0. Each option i has various sub-scores associated with it and assuming that these are independent of each other they can be summed to give a total utility for each option U_i. The utility function need not be linear and can be expressed in an additive form. Optimization using this technique requires that the factors be commensurable and that it is acceptable for factors to be traded-off against one another. Assigning the score or weights to the relevant factors is problematic.

Mutagenic effects involve changes in the genetic material of somatic or germ cells whereby their successors differ in a permanent and heritable way from their predecessors.

NRPB The National Radiological Protection Board (UK).

Occupational health should aim at the promotion and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations; the prevention among workers of departures from health caused by their working conditions; the protection of workers in their employment from risks resulting from factors adverse to health; the placing and maintenance of workers in an occupational environment adapted to their physical and psychological equipment; and, to summarise, the adaption of work to the person and of each person to their job (based on **WHO** statement).

OECD The Organisation for Economic Co-operation and Development.

OSART An Operational Safety Review Team of the **IAEA**.

PAV Paksi Atomerömu Vállalat - Paks Atomic Power Plant Company (H).

PEN Piano Energetico Nazionale - National Energy Plan (I).

Probabilistic Risk Assessment is the act of quantifying an expected average **risk** based on observed and calculated component and human failure rates in engineered systems and the anticipated consequences associated with these failures.

Probabilistic Safety Analysis systematically examines expected performance and failure to obtain estimates of the **risk** and consequence of a **hazard**. It is more general than **Probabilistic Risk Assessment** and involves normative evaluations of, for instance, benefit/detriment and the equity of risk distribution.

PUN Progretto Unificato Nucleare - Standardised Nuclear Programme (I).

PWR Pressurised-Water Reactor; a **LWR** (USA).

Risk The likelihood of a particular undesired event occurring within a specified period or in specific circumstances. Risks exist when objectively known probabilities can be attached to a range of possible outcomes. Risk is the product of the probability of occurrence and the magnitude of the consequences (severity) of the event, should it happen.

RBMK Reaktory Bolshoi Moshchnosti Kanalnye - High-power pressure-tube reactor; like a LWR but with a graphite moderator (USSR).

Sievert (Sv) A unit of radiation dose which incorporates adjustments to take account of the different characteristics of various radiations and the different sensitivities of body tissues.

SNUPPS Standardised Nuclear Power Plant System (USA).

Somatic effects caused by radiation involve harm to the individual exposed. The ICRP divides these into non-stochastic effects (which occur only if a substantial threashold dose is exceeded) and stochastic effects (where only the induction of a malignant disease is likely to be significant).

SSN Servizio Sanitario Nazionale - National Health Service (I).

SzOT Szakszervezetek Országos Tanácsa - Central Council of Trade Unions (H).

Teratogenic effects involve damage to the embryo (that is, after fertilisation) causing congenital malfunction or organ malfunction.

THORP Thermal Oxide Reprocessing Plant, at Sellafield (UK).

TMI Three Mile Island (USA).

TUC Trades Union Congress (UK).

Uncertainty exists when there is more than one possible outcome to a particular course of action; the form of each possible outcome (state of the world) is known but the chance or probability of getting one particular outcome is not known

USL Unità Sanitarie Locali - Local Health Units of the SSN (I).

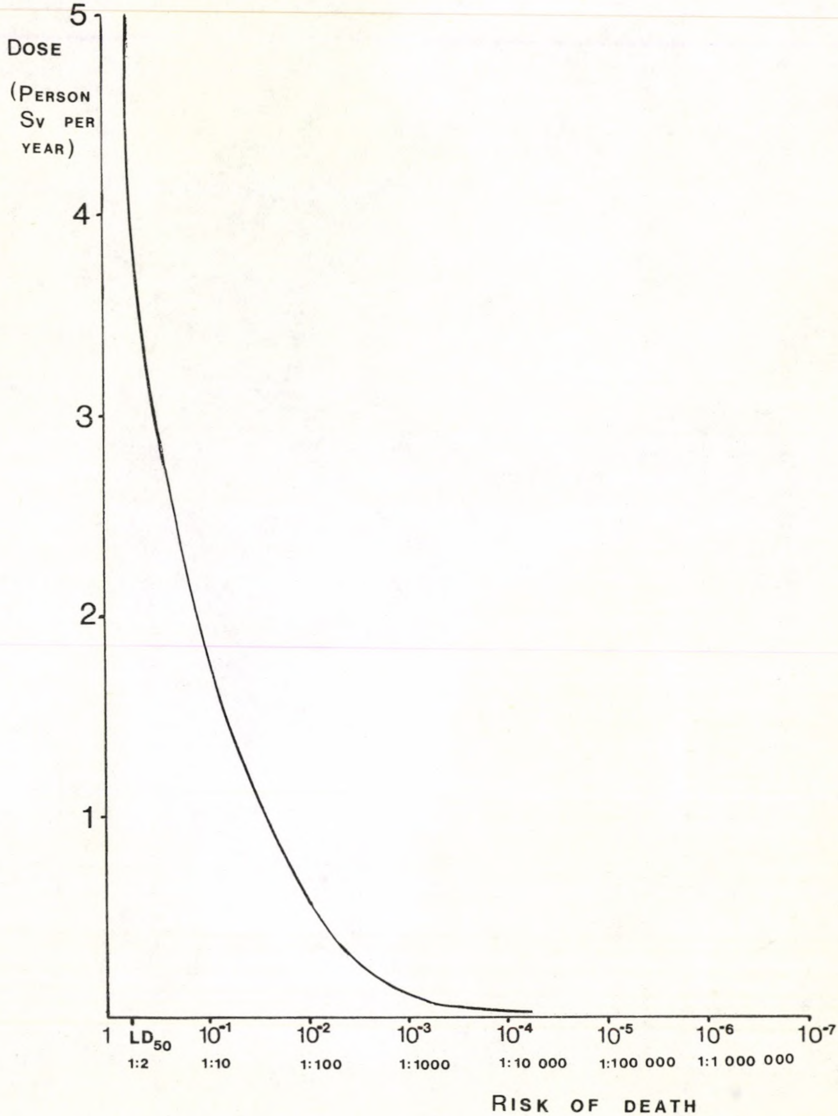
VEIKI Institute for Electrical Power Research (H).

VVER Vodo-vodiannyi Energetichesky Reaktor - Pressurised water and moderated reactor; a LWR (USSR).

Watt A measure of power or the rate of energy flow.

WHO World Health Organization.

figure 1



INDIVIDUAL RISK FROM EXPOSURE TO RADIATION figure 2 INDIVIDUAL RISK FROM EXPOSURE TO RADIATION

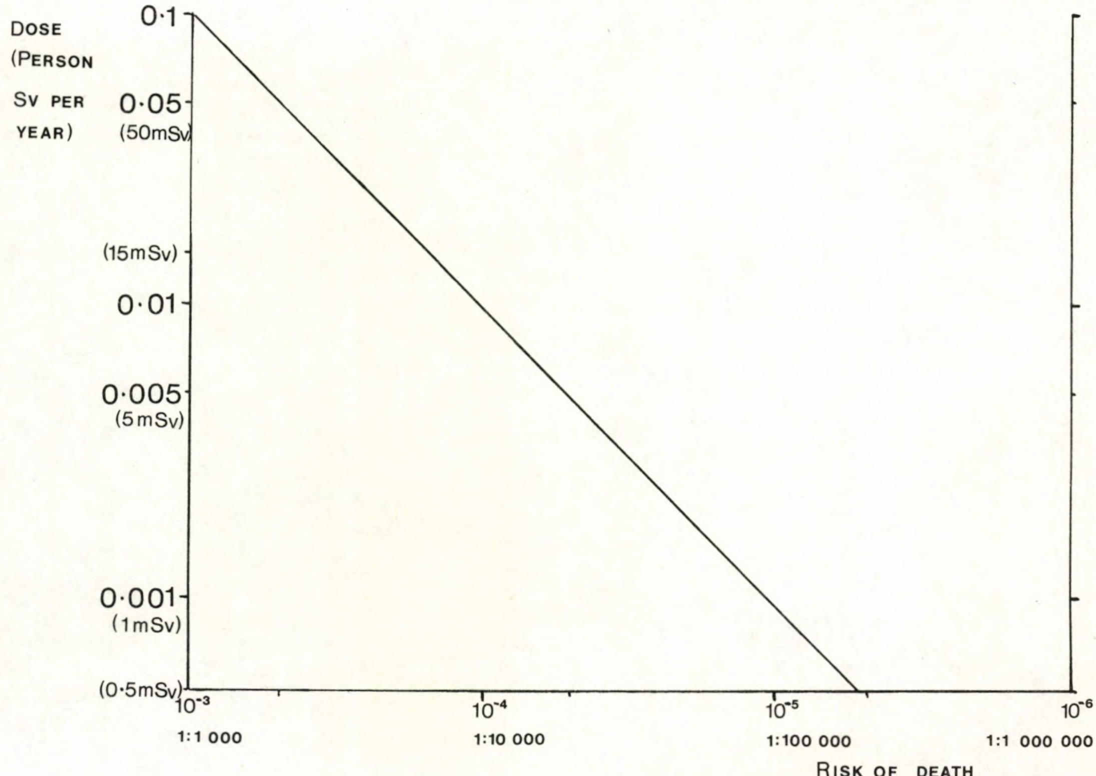
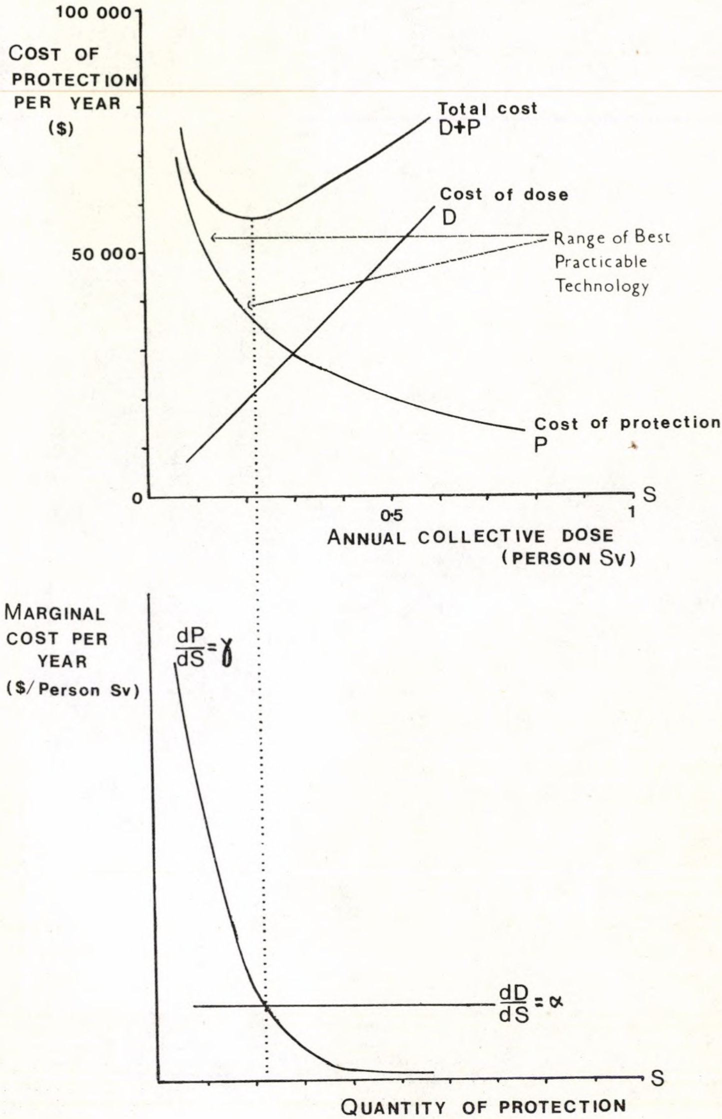


figure 3



ILLUSTRATIVE EXAMPLE OF THE APPLICATION OF COST-BENEFIT ANALYSIS TO RADIATION PROTECTION

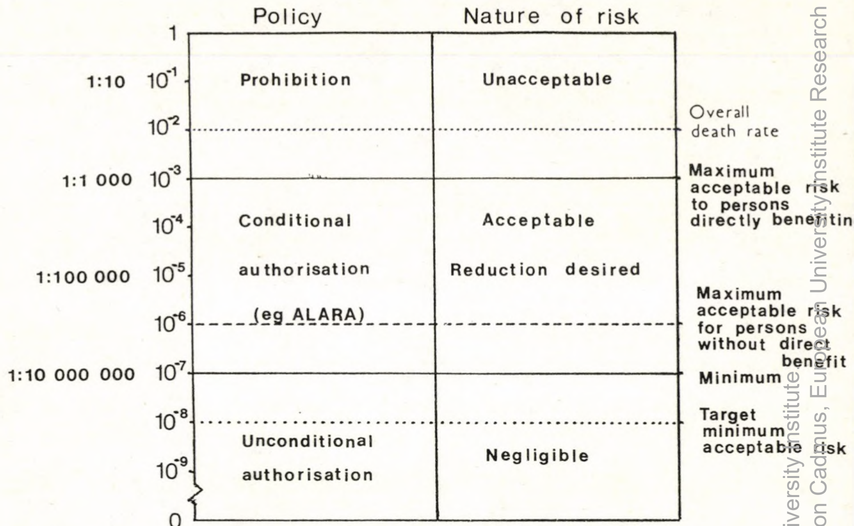


figure 4 INDIVIDUAL RISK

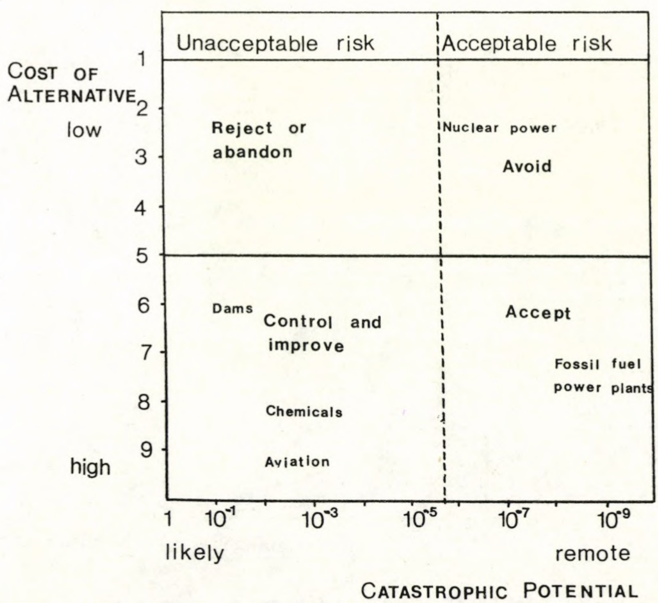
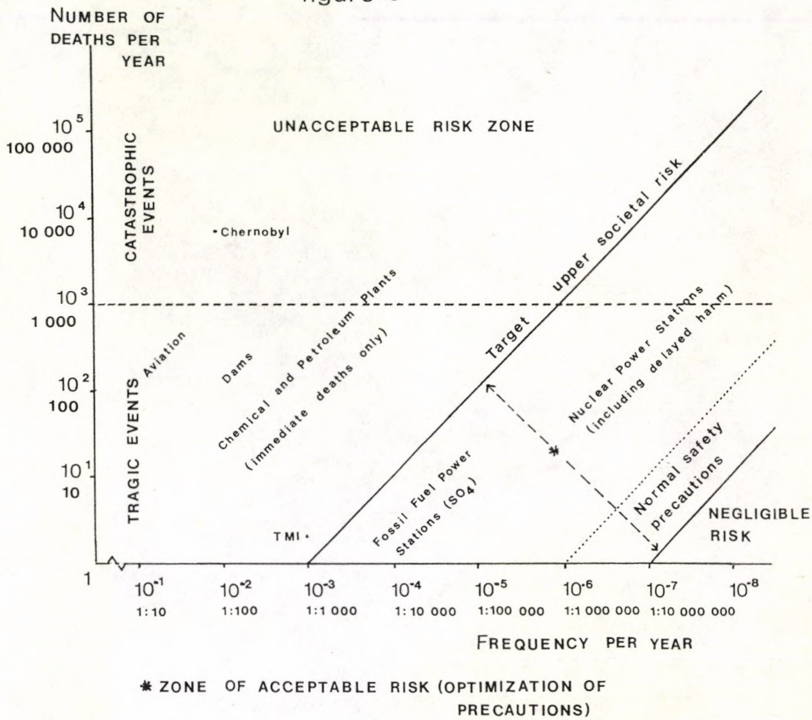


figure 6 CATASTROPHIC SOCIETAL RISK

figure 5



AN ILLUSTRATIVE APPROACH TO SOCIETAL RISK FROM ADVANCED TECHNOLOGICAL SYSTEMS

TABLE 1: A FRAMEWORK FOR SAFETY AND HEALTH REGULATION

LEVEL OF REGULATION	ACTIVITY	METHOD	MAJOR ACTORS	MAIN LINES OF ACCOUNTABILITY
International	Setting basic safety standards	Treaties Recommendations International law	UN specialist agencies Inter-governmental bodies	National governments Non-governmental organisations Multi-national representative forums World scientific community
National	Setting safety standards Approval of industrial development Monitoring of safety compliance	Law Codes of practice Operator licenses Accident investigation Health surveillance	Government and quasi-governmental bodies Law courts Expert advisory committees	Citizens Political parties National scientific community National pressure groups
Local/Regional	Approval of industrial development Monitoring of compliance	Planning approval for siting/operation Public health programmes	Local/Regional governments and health authorities	Local electors Political parties Local pressure groups
Corporate	Establishing company safety policy or philosophy Investment decisions Community liaison	Company safety policy statement Public relations	Board of Directors Top executives Strategic planners Communication managers	Owners/Shareholders Regulatory agencies Workers' representatives Consumers Insurer

TABLE 1: CONTINUED

LEVEL OF REGULATION	ACTIVITY	METHOD	MAJOR ACTORS	MAIN LINES OF ACCOUNTABILITY
Project	Design of plant and facilities Quality assurance Procurement specification Risk management	Collection of data on failure rates, reliability and in-service experience Quality control and testing Probabilistic safety analysis	Designers/Architects Project engineers QA management and inspectors Accountants and procurement managers Specialist consultants	Top executives Client (if sub-contract) Professional institutions
Plant	Operational plant management Safety audit Maintenance and inspection Labour relations Training	Work schedules Permits to work Operating logs Segregation/isolation of facilities Surveillance and analysis of hazard exposure levels and accident rates	Plant managers Safety and quality inspectors Maintenance engineers Personnel managers Occupational health staff	Top executives Workers' representatives Professional institutions
Workplace	Work planning Supervision of performance Control of exposure to hazard	Permits to work Verbal instruction and guidance by notices and signs	Line managers	Operational plant management Workers' representatives Safety inspectors Workforce

TABLE 2: THE PLACE OF NUCLEAR POWER IN ELECTRICITY GENERATION AND IN TOTAL ENERGY CONSUMPTION (1986)

		ITALY	HUNGARY	UNITED KINGDOM
Electricity production	GWh	192 330	27 730	301 085
of which Nuclear	GWh	8 758	7 424	59 079
	%	4.6	26.8	19.6
Imports	GWh	23 928	11 863	4 444
Exports	GWh	1 814	1 346	189
Domestic supply	GWh	214 444	38 247	305 340
Net maximum capacity	MW(e)	56 205	6 244	69 053
of which Nuclear	MW(e)	1 273	1 230	9 685
	%	2.3	19.7	14.0
comprising:				
GCR	MW(e)	153	-	4 135
AGR	MW(e)	-	-	5 223
LWR	MW(e)	1 120	1 230	-
FR	MW(e)	-	-	234
Others	MW(e)	-	-	93
Nuclear energy as percentage of Gross consumption of primary energy (physical input)	%	3.1 (1985)	2.2	2.5

Sources: Eurostat (1988a); Eurostat (1988b); IEA (1988b); UN ECE (1987); UN ECE (1988).

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