Countermeasures:

Radioecological and social impacts

Factors to be considered before the implementation of radioactive countermeasures following a nuclear accident

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Mastering Events of the Past

In the past, the decision to apply countermeasures following a nuclear accident has been based primarily on their effectiveness at reducing doses to man. However, experience, particularly over the last few years, has shown that the successful implementation of countermeasures requires a much wider range of issues to be considered in addition to normally considered factors of cost effectiveness and cost benefit.

These issues include:
the reasons for introducing the countermeasure, the time scale over which they will be used, their effectiveness and their practicability.

The latter includes consideration of factors such as technical limitations, capacity, exposure pathways during implementation, potential environmental impacts, cost and acceptability, both social and ethical, as well as a number of site specific issues.

The attitudes and likely interactions of a variety of different groups, including retailers, farmers, consumer groups and food distributors have to be kept in mind when implementing countermeasures and the ways in which information is given out to them. In addition, application of a set of countermeasures developed for one scenario to another cannot be performed without detailed consideration of the portability of the countermeasures.

A range of countermeasures has been examined using these criteria and a spreadsheet information system has been prepared highlighting relevant factors that need consideration before the implementation of each countermeasure. Generally applicable (i.e. not isotope specific) countermeasures and those specific to iodine, strontium and caesium radioisotopes are given for intensive and extensive agriculture, aquatic systems, forests and direct actions by affected populations.

A number of these aspects need further research to achieve their full potential, including ethical issues, clarification of the dose thresholds and methodologies for the analysis of cost benefit and cost effectiveness. A number of other issues also need to be studied if they are to become useful tools in the countermeasure decision making process. These include problems of spatial and temporal variability, integrated catchment management and prediction of soil sorption properties and soil – plant transfer based on soil characteristics.

The database presented here could form the basis of a Computer Expert System for Optimisation of Countermeasures where IUR could provide an effective forum for the collection and curation of this database.

Over the period from 1990 to 1996 a number of publications reviewed the effectiveness of countermeasures, particularly those used post-Chernobyl. They concentrated mainly, but not exclusively, on agricultural and semi-natural systems. The most notable of these include the REACT proceedings (Howard and Desmet, 1993) the IAEA handbook of countermeasures (IAEA, 1994) and reviews arising from the EC Chernobyl projects (Karaoglou et al., 1996, Howard and Desmet, 1998).

However, in recent years it has been recognised that the choice of countermeasures should be a balance between the potential benefits and negative consequences. As a result there has been a re-evaluation of countermeasures incorporating factors such as long-term considerations, secondary effects, socio-economic interactions and the difference between a theoretically applicable countermeasure and its usefulness in a real situation (Nisbet, 1995). However, a comprehensive evaluation of these factors for all potential countermeasures is not available. It is now time to re-evaluate these countermeasures in the light of the new understanding. The IUR has therefore drawn on the expertise of its members to provide an updated collation and summary of counter-measures in electronic format, which represents the first attempt to take these factors into account, and which can be easily distributed for use by decision-makers.

There are three major parts to this work:

- A check list of generic questions which need to be considered in the choice of an appropriate countermeasure in a specific situation including a discussion of the important aspects which arise as a result of a re-evaluation of counter-measures, such as the applicability of “Chernobyl” experience.
- An electronic information system of potentially available countermeasures, which is intended to be easily accessible and understandable to decision-makers rather than “experts”.
- Conclusions and recommendations of issues for consideration in future research programmes.

The electronic information system provides information on countermeasures for different ecosystems and environments: intensive agriculture, extensive agriculture, aquatic systems, forests and direct actions which can be carried out by affected populations (excluding urban countermeasures). Although a few countermeasures are generic in application and are effectively applicable to all isotopes, the effectiveness of most of the countermeasures considered depends on a specific property of one isotope and they are therefore useful only for that isotope. At the present stage the information system has been restricted to cover generic countermeasures and those specifically for iodine, strontium and caesium isotopes, since most data relate to these isotopes and they generally constitute the major contribution to dose after an accidental release to the environment.

The requirement for a countermeasure will in most cases be indicated following a dose assessment and corresponding risk assessment. However, it may also result from either experience of the short term effects following an accident, from an emergency decision support system or from an expectation that the public need to be reassured over some perceived risk, e.g. potable water supply or contaminated food supply.

At present a range of recommendations on intervention limits have been published by different institutions such as the IAEA, the ICRP or national authorities about the action levels which trigger the implementation of countermeasures after accidental situations in order to protect the public. Because the recommendations are stated in different terms (doses or intervention levels) confusion has arisen in some cases when politicians have applied them. For intervention situations the ICRP recommendations (ICRP 60 and 63) emphasise the principles of justification (do no more good than harm) and optimisation (maximise the net benefit), and also note the need to take both radiological and social factors into account. In some instances, however, countermeasure strategies have often been developed barely on radiological considerations, with no evaluation of broader practical and social issues. Such assessments would be based only on a) whether or not the expected benefit outweigh the cost, and b) which of the possible actions offers the most cost effective dose reduction.

In the CIS countries the limit of 1 mSv annual dose is applied since the Chernobyl accident in practise, but has been questioned because the 1 mSv y^{-1} maximum effective dose for the protection of the public during a normal operating „practice“ is not necessarily a relevant criterion to use in a decision on whether countermeasures should be implemented after an accident. In the European Union, the recommendations of the ICRP resulting in food activity concentrations levels not exceeding 1250 Bq kg^{-1} (for ^{137}Cs) in major food items have been accepted as intervention limits and being adopted to regulate trade (EC, 1995). These values are at the lower end of the range recommended by ICRP within which intervention could be considered (ICRP 60 and 63).

Some countermeasures are more appropriate than others over certain response time scales (IAEA, 1994; ICRP 63). A range of time period definitions appears in the literature. Typically four time periods must be considered, and we will use the following:

- Before the deposition of radioactivity.
- In the short term (< 6 weeks) following an accident (acute).
- In the mid term (6 weeks to 2 years)
- In the long term. (> 2years).

In this report, countermeasures that could be implemented during radioactive deposition are discussed in the section „before the deposition of radioactivity". However, they will automatically include some countermeasures that are also relevant in the short term. Although some countermeasures are generic, others are only applicable over certain time scales. This will constrain the number of useful countermeasures available in a given situation.

Most radiological countermeasures have been developed in response to specific contamination events, for example the Chernobyl accident. The particular sources of radiation dose and dose pathways change with time after an accident. As a result, the relative importance given to different countermeasures varies at different times after an accident. In the short term after the Windscale and Chernobyl accidents, most of the dose was derived from short-lived radionuclides, in particular ^{131}I. Countermeasures applied in this short term are likely to be focused on aversion of dose from external irradiation, inhalation and consumption of short-lived radionuclides. Thus, after Windscale, a ban on the consumption of milk was implemented in order to avert the ingestion dose from ^{131}I. It is believed that this countermeasure alone averted between 55% and 75% of the potential maximum ^{131}I dose to a child's thyroid (Jackson and Jones 1991) in the area covered by the ban. During the first few weeks after fallout, in the highly contaminated (> 5 Ci/km^2) areas around Chernobyl initial doses to the thyroid from ^{131}I were up to 3 mSv, mostly by ingestion of contaminated milk and fresh vegetables (Tsyb et al. 1996, Drozdovitch et al., 1997). After this initial period, dose rates dropped rapidly, primarily as a result of decay of short-lived radionuclides. Hence, there is a need to consider the nature of the fallout, particularly the presence of short-lived radionuclides. Under these circumstances average doses tend to reduce rapidly in the short term as a result of the decay of the short-lived isotopes, which leaves Cs and Sr to form the major contribution to the dose in the medium to long term. Although countermeasures specific to Cs and Sr may be most effectively applied in the early stages after fallout, their objective is usually medium to long term dose reduction and focus on remediation of contaminated environments.

In general, radiation doses tend to decline over time after fallout is deposited as a result of environmental processes as well as radioactive decay. For example, after both weapons test fallout and the Chernobyl accident, radiocaesium activity concentrations in drinking water and foodstuffs declined over a period of about 5 years after deposition as a result of slow fixation to the soil (Muck, 1997; Smith et al., 1999). Therefore, decisions on the application of countermeasures must take into account the effects of such environmental 'self-cleaning' processes on potential averted dose. It may be most effective to focus countermeasure effort on those environments which have a low 'self-cleaning' capacity (e.g. low soil fixation ability) and are likely to give rise to food products above the intervention limits in the much longer term (time scale decades) after fallout. However, it should not always be assumed that internal doses will decrease with time after deposition. For example ^{90}Sr activity concentrations in vegetation increased with time after Chernobyl due to weathering of hot particles (Kashparov et al, 1999.)

The need for countermeasures in the short term, when doses are high, is obvious and can clearly be justified in terms by the size of the averted dose. However, in the medium and long term, countermeasures often result in only a relatively small additional aversion of dose. The receipt of a high radiation dose by a registered worker would strengthen the case for subsequent countermeasures for the worker. However, in the Former Soviet Union following the Chernobyl accident, a question arose concerning the justification of the application of countermeasures in the medium and long term for sections of the population who had already received a large dose. In other words, if people have already received a large dose what is the point of avoiding a small, later dose using countermeasures? However, from an ethical perspective, the decision to use a countermeasure should be based purely on the future benefit achievable rather than on dose history, since alternative approaches would clearly result in a disadvantaged group being further disadvantaged.

In the medium/long term, if activity concentrations in products persist above intervention limits then the case for countermeasures is clear. As a consequence, it may be necessary to reduce contamination levels below a legal intervention limit even though the actual reduction in doses from moving from just above the limit to just below it may be very small and not justified on a cost benefit analysis of the dose reduction. However, even if the limits are below intervention there may still be a case for applying low-cost countermeasures or for supplying information to the public about ways in which they may further reduce their dose if they are concerned and wish to do so. It is important to remember that, in addition to dose reduction, countermeasures can have benefits, such as increasing the confidence of the population in the relevant authorities managing the situation. This approach represents a new line of thinking, and one that has been gaining support for a number of years in management practice (e.g. Frech and Greber, 1995; Lochard et al., 1998). A typical example of such an approach is the provision of leaflets and information on the relative uptake of radiocaesium by different species of mushroom and their identifying features which was distributed in some areas of the Chernobyl affected CIS countries to allow people to reduce their own dose (Beresford and Wright, 1999, Beresford et al., 1999). Another example may be the provision of free counting facilities and interpretation services to allow the public to check the radiation levels in their own foods.

General Criteria

There is clearly no point in considering a countermeasure if it will not be effective under the environmental conditions in which it is intended to operate. However, the identification of a potentially effective countermeasure is only the first step in any decision on whether it should be implemented. The overall applicability of a countermeasure depends equally on both the effectiveness and practicability. Information on effectiveness of many countermeasures is widely available from the scientific literature. Complementary data on countermeasure practicability is much scarcer.

Both the effectiveness and the practicability of any countermeasure option will vary on a country-by-country and a site-by-site basis and will depend on the scale and timing of an accident. Practicability comprises six main factors that need to be considered before an optimum countermeasure strategy can be selected:

- Technical requirements and limitations
- Capacity (e.g. limitations due to equipment availability, logistics)
- Exposure pathways during implementation to the operators
- Potential environmental impact
- Economic aspects
- Social and ethical acceptability

These criteria have previously been used in the selection of options for managing foodstuffs contaminated as a result of a nuclear accident (Woodman and Nisbet, 1999) and for managing Chernobyl-restricted areas in England and Wales (Nisbet and Woodman, 1999) and are used here for the re-evaluation of a range of countermeasures given in the electronic information system.

Site specific considerations

Post Chernobyl studies highlighted the importance of local conditions which may alter dose rates compared to generic model scenarios. Considerations include:

- The chemical form (speciation) of the deposition must be considered in any dose assessment. This was a major discovery following the Chernobyl accident, where a significant proportion of the deposition in the 30 km zone was in an insoluble, particulate form and was immobile, at least over the medium time scale (years). After this time the particles broke down, resulting in increasing radionuclide mobility and doses began to rise above those actually measured in the mid-term. Most calculations in dose assessments assuming complete mobility in the early stages resulted in recommendations to introduce countermeasures when they were, in fact, unnecessary in some instances and, in others, resulted in rushed decisions and ineffective implementation of countermeasures which wasted resources and money (e.g. examples in Voitsekhovitch et al., 1997).

- Timing of the deposition relative to harvest time. - Agricultural production is highly seasonal and dependent on climatic conditions. As a result, the radiological consequences of an accidental release of radioactivity and the subsequent selection of countermeasures, particularly those designed to reduce doses from the food chain, are heavily dependent on the time of year at which deposition occurs. Hence, the most applicable set of countermeasures for accidents occurring during the winter, when many livestock are housed and most crops are at an early stage of development, will be quite different to those selected for accidents occurring at other times of the year. In aquatic ecosystems, seasonal effects are of less importance.

• Variation in rates of fallout levels with distance from the source (near zone / far zone) - Different radionuclides tended to be more important at different distances from the Chernobyl plant. Iodine and strontium dominated doses in the near to medium field whereas caesium was the major isotope at larger distances.

• Climate – Radionuclides tend to be more environmentally mobile in the environment in rainy climates than in warm dry climates. Deposition of radioactivity onto snow can cause very large peaks of radioactivity to pass through the environment during snow melt.

• Fluxes - it is important to consider the total amount of radioactivity transmitted to man (flux) by a crop rather than concentrating solely on the activity concentrations in the crop. The total flux is the product of activity concentration in the crop and production or harvesting rates, i.e. it may be more appropriate to apply a countermeasure to a crop with a high production but medium or low activity concentration, rather than to a crop with a low production but high activity concentration.

• Local critical group and average diets. – Local eating habits can be very important. For example in the former Soviet Union mushrooms and forest products are regularly used as free food and are important in the diet of country people particularly. The same would be true for some countries in Western Europe, but would not be the case for all.

• Psychology of affected population/ stakeholders – This is a major factor in the acceptance of any introduced countermeasures (or not introduced). For example older people are more likely to accept an increased radiation risk and stay in their own homes, whereas families with young children are more likely to wish to move to reduce doses.

• Different social/ political/ economic structures – For example, a clear result from the post-Chernobyl studies was the large difference in effectiveness of countermeasures between collective (government organised) and private farms.

Radiological Effectiveness

Data on effectiveness is available for many countermeasures in terms of the percentage reduction of a parameter which influences dose, e.g. soil to plant transfer factor. However, experience has shown that the effectiveness of most countermeasures is site specific and consideration should be given to the similarities and differences between the test sites and the site of application. For example, because the fertility of soils around the Chernobyl plant is low the effectiveness of countermeasures is much greater than in soils with higher levels of fertility (Nisbet, 1995).

Technical requirements and limitations

An alternative title is technical feasibility. A wide range of countermeasures is available for most situations but they may not be useable in a particular situation because of one or more technical limitations. The type of considerations which need to be considered include:

· Is special equipment or chemicals needed (e.g. skim and burial ploughs)?
· Is specially trained personnel required?
· Is the countermeasure applicable to the particular soil (e.g. although there is a range of different ploughing options they may not be useable in certain soils (for instance deep ploughs cannot be used in shallow soils))?
· Is the farm management practice or the ecosystem appropriate (e.g. daily dosing of binders to animals may be effective, but not possible for free ranging animals)?

Capacity

Is there enough of the equipment/ chemical(s) available in the appropriate time scale to carry out the countermeasure effectively. For example, the application of stable iodine tablets to cows may be a potential countermeasure to reduce the transfer of radioiodine to milk, but sufficient stable iodine in a suitable form must be available in a realistic time scale. Similarly if two skim and burial ploughs are required to carry out the required countermeasure in a given time scale and only one is available then the capacity limitation rules out the countermeasure.

Exposure pathways during implementation

A countermeasure may significantly reduce the dose to the general population or a specifically susceptible sub-group of the population. However, the dose to the individual operator(s) who have to carry out the countermeasure may be unacceptably large and the countermeasure may be unacceptable without either greater protection for the operators or some acceptable inducement to offset the extra risk.

Potential environmental or side effects

In simple terms the question is „will the countermeasure used to reduce doses have an unacceptable effect on the environment/ ecosystem?“. In the worst case situation it may even result in the destruction of the environment/ ecosystem itself. On the other hand some countermeasures may have unexpected beneficial environmental effects. Information on secondary effects has been drawn from current research undertaken within the 4th Framework Nuclear Fission Safety Programme of the EC (CESER, FORECO and TEMAS projects) as well as expert judgement by the participants.

In general ecosystems are rather resilient but it is important to ask if any effects are reversible or irreversible. For example, fertilisation of soils will increase eutrophication of lakes in the catchment or estuaries downstream of rivers. Even in the worst cases, this effect is reversible over the time scale of one or two decades so that the countermeasure is still useable. Conversely, fertilisation of a low fertility ecosystem will not be reversible over a realistic time scale and may therefore be ecologically unacceptable. In the latter case, the existence of similar, uncontaminated sites nearby might make the use of the countermeasure more acceptable. However, if the habitat/ ecosystem has special conservation status then the continued existence of the habitat carries an even higher weighting.

Countermeasures may have a wide range of impacts on the abiotic as well biotic environment ranging from changes in the quality of soil, water and air to changes in biodiversity and landscape (Desmet et al. 1989). A few examples are given to illustrate these in the following:

Physical measures designed to dilute or bury radionuclides involve soil disturbance which may lead to erosion and losses of nutrients and organic matter. The direction and degree of impact depends greatly on the nature of the soil brought to the surface as well as the post countermeasure management. Deep ploughing is predicted to reduce phosphorus losses due to the lower P status of sub soils in general (Bärlund et al., 1998), however, crop yields are likely to decrease. Tillage of grasslands and other permanent vegetation leads to particularly high losses of soil, organic matter and nutrients (Whitmore, et al., 1992). Depending on transport processes within a catchment, sedimentation and eutrophication of water bodies may occur (Tunney et al., 1997) resulting in reduced value for fishing, drinking water abstraction etc.

Chemical treatments of soil such as liming or application of potassium may lead to deficiencies or toxicities in plants and animals through a nutrient imbalance in the soil. Dale et al. (1997) were able to demonstrate enhanced losses of magnesium from upland soils under grassland in response to K treatment. K application alone is unlikely to change plant species composition of permanent vegetation (Dale, personal communication.; Jones, 1967), compared to liming or application of NPK. The latter are also more likely to stimulate biomass production. These types of soil treatment only remain effective if applied regularly, i.e. every 1-2 years, due to leaching or fixation. Ecosystem recovery will set in once they cease, however, if the measure has been applied for many years this could take decades.

In animal production systems the feeding of binding agents/competing ions as well as modifications to the feeding regime may interfere with animal health (NCR, 1980). Potential negative impacts on water and air quality may occur where the period of housing or the level of concentrate feeding are increased. The longer the housing period the more manure has to be spread on land with the risk of leaching and runoff of nutrients. Ammonia emissions are elevated during housing (Sommer & Hutchings, 1997). Increased concentrate feeding gives a higher nitrogen and phosphorus content in faeces increasing the potential for nutrients to enter water bodies or volatilise (Smits et al., 1997).

Drastic measures such as afforestation or cessation of production (fallow) have many beneficial effects on the environment, particularly in previously intensively managed systems. Nutrient inputs and long term erosion are greatly reduced. Soil organic matter will build up over time. Biodiversity may increase or decrease depending on pre and post countermeasure management and the communities present. Such changes in land use will also modify the character of the landscape and may not be readily reversible particularly when areas of high conservation status are affected.

It is difficult to make generalised predictions about the direction and magnitude of secondary effect since the response of a given system to a countermeasure very much depends on local environmental conditions and agricultural management practices. Therefore the entries into the spreadsheet database can only give a rough guide regarding the potential impacts. Decision makers are advised to assess secondary effects at regional or local level. The CESER project has developed a methodology which allows countermeasures to be selected based on minimising side-effects taking into account the users preferences (Salt et al., 1999). An additional problem, which complicates any evaluation of the effects of a countermeasure is the multiplicity of roles played by a particular environment in society, ecology, hydrology, economy etc. The local people are not the only people with a stake in the affected environment. A fundamental point is the recognition that a change in an environment has impacts on many levels and, as a result, a “secondary effect” can mean different things to different people or groups.

An issue that is frequently overlooked in evaluating the practicability of countermeasures is the quantity and type of waste produced as a result of implementing a particular option. For example, removal of contaminated soils and/or vegetation can generate thousands of tonnes of waste from relatively small areas. The biodegradable nature of vegetation, in particular, causes problems for its subsequent management. However, many other types of countermeasure also produce contaminated waste from less obvious pathways e.g. by-products from the food processing industry, manure from the housing of animals normally at pasture, waste from crops grown for non-food uses and energy, water and sewage treatment sludges. Whilst it is outside the scope of this report to evaluate the impact and management of waste production from each countermeasure, the database does indicate those options considered to pose a potential environmental problem in this respect. More detail on this aspect can be obtained from the TEMAS project, which directly addresses this problem (Vasquez at al., 1999). The generation and disposal of waste originating from application of countermeasures is in addition to environmental impacts also an important economic and social/ ethical issue.

Economic aspects

The immediate or direct costs of a countermeasure are those connected with the practical application of the measure. These may include labour, transport, equipment, and consumable such as fertilisers or binding agents. In addition farmers may lose or gain profits if product yield or product quality changes. In situations where the original product is replaced with a new one, incomes will depend on availability of markets. This also presupposes that expertise is available to switch production. In the European Union farm incomes are heavily dependent on subsidies. In the event of a nuclear accident it is feasible that payment structures would be modified to reflect changes in production.

The secondary effects of countermeasures on the environment can be valued in economic terms using methods such as contingent valuation or travel cost models (Hanley et al. 1997). For instance, the CESER project used contingent valuation to place a monetary value on changes in landscape quality due to pasture improvement and afforestation (Hanley et al., submitted).

Different approaches have been taken to quantifying the benefits of countermeasures. They may be expressed as the value of the food saved from disposal due to application of countermeasures (Strand et al 1990). Alternatively the benefit to human health may be expressed as the collective dose averted applying a monetary value to a person Sievert (e.g. Brynhildsen et al. 1996; ICRP 63) and assuming a linear relationship between dose and effect. The estimates of the monetary value applied in the literature vary widely.

Decision-makers should be aware of all these economic factors in assessing the cost-benefit or cost-effectiveness of a given countermeasure. However, it is ultimately the choice of decision-makers as to which costs are deemed politically and socially acceptable, relative to the benefits.

Social / Ethical acceptability

Even though a countermeasure may be very effective it may not be socially or ethically acceptable. Evaluation of radiation risks needs to take account of other factors in addition to the size of the dose. It is well established that the public's acceptance of risk will depend upon a number of questions. These include environmental and farming issues such as: animal welfare; environmental impact; and waste disposal, which have only recently been included in radiation protection and countermeasure assessment. Furthermore, a wide variety of studies have shown that social and ethical factors have a significant influence on the public's perception of risk (Oughton, 1996, 1999; Slovic 1987, 1996).

Radiation exposures and the countermeasures implemented to reduce dose often pose difficult questions with respect to temporal and spatial distribution of risks and benefits. Inequities can arise between industry, workers and the public, and between regions, countries, age groups and generations. It is both unfair and unreasonable to expect one group of people to accept a risk of harm when another group reaps the benefits. Inequities in distribution can be redressed to some extent by making sure that people have given consent to the risk, are informed and have control over the risk and are compensated for the risk imposition. Furthermore, a wide variety of studies have shown that lack of individual control and failure to provide people with information about risks can be both psychologically and physically harmful to health. In practice, this means that authorities should promote policies that ensure that the public is involved in decision-making processes, and is properly informed about both the size of risks and possible actions that might reduce exposures.

Non-accident situations introducing enhanced levels of natural radioactivity into the environment.

In the present document emphasis has been predominantly on managing situations contaminated by a nuclear accident involving man-made radionuclides. However, a large number of sites exist which are contaminated with enhanced levels of naturally occurring radionuclides (NOR). In some instances the level of contamination may be of concern for the public. Countermeasures in this type of scenario are different from countermeasures following a nuclear accident since generally the surface involved is of a smaller scale and physical and chemical remediation options are more likely to be applied.

A number of important industries can be identified involving the extraction and processing of materials which contain enhanced levels of NORs. Of these, the most contaminating and widely distributed industries are uranium mining and milling (where exposure is mainly due to atmospheric exposure from ^{230}Th and ^{222}Rn in the vicinity of the tailings and exposure to ^{226}Ra through aquatic pathways), metal mining and smelting (where the main exposures result from ^{210}Pb and ^{210}Po in the vicinity of smelters and ^{232}Th inhalation in the vicinity of the deposit) and the phosphate industry, where radon and ^{226}Ra are the main radioactive pollutants.

As well as the radioactive materials, there are also a number of non-radiological contaminants which may occur in materials containing NOR and which can be mobilised under processing conditions (e.g. low pH) and appear in seepage water. They include heavy metals, rare earth metals, salts and nutrients. As a result any countermeasure which is introduced should also reduce exposure to these materials. As a general rule, the migration of both radionuclides and toxic chemicals into the environment from ore piles, tailings and sludges should be controlled (Vandenhove et al., 1998).

Social and Ethical Values

A radiation protection policy that fails to recognise the importance of fundamental social and moral norms will be both difficult to defend ethically and hard to implement in practice. For intervention situations, ICRP recommendations emphasise the principles of justification („do more good than harm") and optimisation („maximise the net benefit") taking into account also social aspects in addition to the radiological aspects. The need to consider social costs of intervention is stressed under the ALARA principle (as low as reasonably achievable). However, what exactly the social and ethical values represent and how they might be incorporated into radiation protection policy is less clear. The major issues for countermeasure evaluation, however, have to include equity, stakeholder involvement and uncertainty.

Equity and the distribution of risks and benefits

A simple cost-benefit analysis of a countermeasure asks whether the action will result in a net benefit, namely, are the costs of intervention outweighed by the averted collected dose. However, ethical evaluation should also consider the distribution of risks and benefits. A small dose reduction to a large population (large collective dose reduction) might only be possible at the expense of high doses to a small group (e.g. clean-up workers, liquidators or operators). Similarly, intervention to control the activity concentrations of radionuclides in human foodstuffs might result in social hardship to minorities, such as the threat to the Sami culture posed by high ^{137}Cs levels in reindeer meat. Countermeasures that carry risks of environmental damage might harm populations or future generations that have no direct benefit from dose reduction. The issue here is not to veto all actions having an inequitable distribution of risks and benefits, but rather to ask if there are ways in which inequity might be redressed, for example compensation for operators, and to stress a thorough evaluation of the possible alternatives. In Norway, consideration of the livelihood of reindeer herders played a significant role in the decision to permit a small increase in dose to the population from raising the intervention level for ^{137}Cs in reindeer meat (Strand et al., 1990). Finally, equal dose does not necessarily mean equal risks across a population; in this respect, countermeasures that reduce doses to children can be particularly relevant.

In terms of the information needed to evaluate such variations, it is important that scientists provide data on the variability of doses and exposures, and take care not to average doses and risks indiscriminately across heterogenous populations (collective doses).

Personal control, consent and stakeholder involvement

Radiation doses to a population immediately after an accident are almost always imposed rather than voluntary. However, the degree to which the public can exert personal control over their exposures can vary considerably, depending among other things on the exposure pathway and availability of information. Likewise, some countermeasures, such as state intervention and control of food stuffs might provoke helplessness; while others, like advice on diet and food preparation, can increase personal control. In addition to the established psychological benefits of control and choice, the right of individuals to participate in decisions that affect their personal well-being is considered one of the pillars of ethics. Since many countermeasures carry a risk of negative side-effects, it is important that persons affected by these actions are involved in the decision-making process. In practice, this can mean promotion of „self-help“ countermeasures (e.g. provision of counting facilities), access to information on risks and ways of reducing exposures, and ensuring that representatives of affected stakeholders (e.g. farmers, food producers) have a say in matters of policy. Liquidators and clean-up workers need to be volunteers, after the norm of giving free informed consent to any increased personal risk. Self-help countermeasures have the added bonus that the operators are also directly benefiting from the action.

The incorporation of uncertainty into the decision making process

An understanding of how to incorporate uncertainty into decision making is required in a number of dimensions. In the first place radionuclide deposition tends to be very patchy making it extremely difficult to make dose estimates and designate restricted or other areas where countermeasures are to be applied. This spatial uncertainty fuels uncertainty in the public understanding of the management problem and can result in a lack of trust in the administration responsible for managing the problem. An example is the post Chernobyl situation where the combination of changing dose thresholds and improved mapping of the deposition as time progressed resulted in complete distrust of the authorities by the population.

It is easier to predict the consequences of some countermeasures than others. Unfortunately, many cost-benefit analyses do not take proper account of uncertainties when evaluating actions, focusing more on the relative size of the costs and the benefits than the certainty with which those figures can be calculated. For example, the effectiveness and environmental consequences of feeding animals with AFCF boli are quite well tested, hence the cost effectiveness of the countermeasure could be predicted with a reasonable accuracy. On the other hand, the removal and burial of top soil might be highly effective as a method of dose reduction, however, the possible environmental effects would be harder to predict. Even if the latter option gave the greater expected net benefit on paper, because of the uncertainties and severe consequences of our environmental assessment being wrong (soil erosion/ ground water contamination) one might be justified in opting for a less cost effective, „safer“ option.

Decision-making under uncertainty is a topic of some debate in Environmental Ethics (Shrader-Frechette, 1991; 1993). The Rio Declaration on Environment and Development (Agenda 21- Agenda for change) discussed the applicability of the Precautionary Principle, under risks of severe ecosystem damage, i.e. if the risks are unknown, err on the side of caution. The question is when can one justify foregoing societal benefits (like dose reduction) on the grounds of a possible risk to the environment? A simple cost-benefit analysis is rarely sufficient grounds on which to base such decisions, and ethical evaluation can be a valuable tool in highlighting the significance of factors like alternatives, burden of proof and catastrophic consequences. From both an ethical and a scientific point of view it is important that uncertainties are evaluated and considered in the decision making process, and that one is open about these uncertainties in predicted consequences of countermeasures. Of course, the question of site-specificity and the applicability of available knowledge will be central to the evaluation. Ethically and pragmatically, the choice of the right action is determined by the available alternatives. This, in turn, stresses the need for authorities to be properly informed about the possible available options. The present consensus suggests that in order to obtain the most positive reaction of the population to countermeasures, the best information available, including the level of uncertainty in any predictions must be freely available to the general population.

Spatial variability on different scales

In many cases following a nuclear accident, environmental observations and model predictions are spatially distributed. ‘Events’ are associated with a location which may be defined precisely in terms of a co-ordinate system (e.g. latitude and longitude) or, more often, in a more general way, such as a political district, an ecological sub-area (e.g. a forest), a cultivated field, or even a plant or leaf. Thus the resolution or spatial scale may vary widely from local, to regional, to global. At each level of spatial resolution, there is variation in the measurement, and a major challenge in environmental analysis is to understand the causes of the sample variation in space and account for the variation over appropriate spatial scales.

Three aspects of spatial scale must be considered: the extent of the study area, the size of the sampling unit, and the sample intensity (spacing). The context and purpose of a study generally defines both the spatial extent (area) and the population for which inferences have to be drawn. A relevant sample area could be a single lobster, e.g. the location of hot particles, or extend over the whole of Europe, e.g. mapping Chernobyl fallout. Governments often set sample area boundaries, but political boundaries are often not normally related to any physical, chemical or biological distribution processes.

The unit size of samples (e.g. a single soil core or a bulked sample comprising 20 cores from one field, bulked) is also context dependent and should be chosen to average out uninformative small-scale variation whilst remaining meaningful at the scale of the information to be mapped. Samples, which are too specific, e.g. the radionuclide content of single mineral grains from different sites, can hide meaningful spatial patterns in noise. Large samples, which smooth information too much, may hide meaningful variation. Sampling intensity, which (in a spatial context often means the distance between samples) is usually a compromise between a statistically optimal value and a practical constraint on time and effort. For example, during a nuclear incident a compromise must be reached between the ideal sample coverage to give a statistically accurate picture of land contamination, and the need to use rapid survey methods to identify the most contaminated areas or critical population groups as fast as possible.

The design of spatial surveys and analysis of the resulting data are complicated by spatial variation and spatial correlation (i.e. near observations are more likely to be similar than distant observations). Tools such as Geographic Information Systems (GIS) aid both processes. Modern GIS provides the means for both rapid mapping and the exploration of relationships between many spatially varying attributes, e.g. soil maps and land use. When used in combination with geostatistical methods, uncertainties associated with spatial data can be estimated resulting in the development of better sampling strategies. GIS and geostatistics are extremely helpful both in testing the likely effect of applying different countermeasures to areas of contaminated land and also in highlighting secondary effects on the affected ecosystem resulting from the applied countermeasures.

Integrated catchment / environment management

Significant accidental releases usually spread radioactivity over large areas of the countryside. As a result it is generally most effective to consider the management of the problem at an environmental or catchment level. On this scale, it may be appropriate to sacrifice some highly contaminated habitats/ ecosystems in one part of a catchment while restoring or enlarging that habitat or ecosystem in another, less contaminated part of the catchment. The catchment approach is even more relevant when rivers run through the contaminated region. As a general rule, radioactive contamination does not move rapidly through the terrestrial environment, once it is deposited onto soil a major mechanism for transporting radioactivity through a region becomes the river systems. Under these conditions, the effect(s) of the application (or not) of a countermeasure must consider the whole catchment, including the estuary and the coastal region near the river discharge. For example, in the mid term, following the Chernobyl accident, increases in radiostrontium activity concentrations in the river Dnieper reservoir chain have had their greatest effect several hundred miles from the Kiev reservoir (the first in the chain after the most highly contaminated area). This is because lower down the Dnieper many of the crops require irrigation, whereas in the northern part of the catchment this is not the case.

The prediction of soil sorption properties

A major factor influencing our ability to predict both the importance of applying a countermeasure and the likely effectiveness of any countermeasure is our inability to predict, with any reasonable accuracy, the sorption coefficient (K_d) of any radionuclide on any soil. This is particularly the case with Cs, where „frayed edge sites“ (Cremers, 1988) are known to describe the K_d but are not easily related to other, normally measured properties of the soil. As a result it is hardly possible to predict soil to plant, and hence, plant to animal transfer factors to the level of accuracy which is needed. In recent years more information and a better description on the parameters involved, such as among others the Radiocaesium Interception Potential (RIP), has become available for different soil types; this should be taken into account when evaluating the potential effect of soil based countermeasures. Also laboratory pilot studies before application of highly expensive techniques therefore are advisable before field implementation.

Which dose thresholds are appropriate?

After the Chernobyl accident, attempts to reduce exposures and control contaminated foodstuff resulted in inconsistency and misunderstanding. Some people suggested that the confusion arose because authorities erroneously assumed that the dose limit used to control public exposure from normal operating practices were applicable in the intervention situation (Emmerson, 1988; Waight, 1990). As identified earlier, there is still considerable confusion as to which dose thresholds are appropriate under which conditions. More work is required to clarify these trigger levels in emergency situations.

Cost benefit and cost effectiveness analysis

An important outcome of studies of the application of countermeasures following the Chernobyl accident (Voitsekhovitch et al., 1997) was the recognition that countermeasures are very expensive and only those which can be justified economically should, as a general rule, be applied. Two different economic tools can be helpful in accident situations – cost benefit analysis and cost-effectiveness analysis.

Cost benefit analysis (ICRP 37) is a useful aid to decision making when trying to assess whether the benefits of a particular operation outweigh the negative consequences. Using this approach an attempt is made to put a monetary value on the positive and negative outcomes. For example how much is a reduction in dose of a certain amount worth compared with the value of a certain landscape which will be destroyed by the countermeasure. The former is often estimated by either hospital costs and lost income or by trying to put a „value" on a life. The latter has been estimated by "willingness to pay" or „willingness to accept" surveys (contingent valuation) or by contingent ranking surveys.

Cost effectiveness (ICRP 55) is a tool for deciding which countermeasure to use, based on the relative costs of different approaches. For example, once a decision has been made that the dose to a certain population must be reduced, which of the methods of achieving that objective has the least cost per man-Sievert reduced.

The two methods are complimentary but the use of economic tools like this for environmental decisions is in its infancy and more work is required improve the application of the techniques to countermeasure choice.

An expert system for optimisation of countermeasures

The database presented here could form the basis of a Computer Expert System for Optimisation of Countermeasures (CESOC). This system should develop a measure of „total efficiency", which includes radiological efficiency and socio-economic efficiency on the one hand, and on the other hand, implementation costs and the consequences and costs of side effects of applied countermeasures. The total efficiency could be generalised as risk factor, which would require fine-tuning when applied to a specified country or region. For this purpose it will be necessary a) to collate all data on the application of countermeasures in different countries. Their efficiency, costs, practicability, time-scale, side-effects etc., i.e. creation of a data bases valid for each country; b) to derive principles, which allow a generalisation of the main criteria affecting total efficiency over a variety of ecosystems and regions; c) further monitoring of countermeasure regimes to update the system. The IUR could provide an effective forum for the collection and maintenance of this database.

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Table heading descriptions in the Electronic information system. - Appendix I

General comments - Except in a few clear cases, no recommendations have been made. The appropriate choice will only be possible after considering, in the light of local conditions, all the questions posed in the accompanying paper. The system will identify when a radioactive waste is generated but no consideration will be given to the disposal of waste.

Radionuclide - Although a few generic countermeasures, applicable to many isotopes have been included, the majority of the entries refer to I, Sr and Cs. This is because these elements tend to be the major causes of dose exposure to man. The main exceptions are specific releases or very near field where transuranics can dominate but specific countermeasures for these elements are rarely required.

Specific countermeasure - name of countermeasure.

Area of action - targeted ecosystem component

Contamination pathways - pathways via which exposure occurs.

Application time - period in which countermeasure can be used.

Radiological effectiveness - averted dose to public or consumer. Reduction of activity concentration in foodstuffs, soil, water, etc.

Technical requirements and limitations - constraints on application due to technical limitations.

Exposure pathways - exposure to operator (contractor or farmer), and public whilst the countermeasure is being applied.

Environmental effects - possible effect on ecosystem status and function.

Economic aspects - identification of direct and indirect economic costs.

Social and ethical acceptability - identification of social and ethical factors that will influence acceptability of the countermeasure,

State of the art - extent of relevant information whether the countermeasure has been used, tested experimentally or is only theoretical.

Key references - Where available appropriate reviews have been recorded. Where these are not available the most relevant references for a specific countermeasure have been listed. These can be used as initial search inputs for a more detailed study of the literature.

Comments - addition relevant information not covered above.