MEDICAL RESPONSE TO EFFECTS OF IONISING RADIATION

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Preface

In 1987 an incident occurred in Goiânia (Brazil) which spotlighted the role which the medical community needs to play in coping with the effects of ionising radiation. A medical radioactive source was accidentally exposed and many people received varying doses, some fatal, of radiation. This accident, like the Chernobyl reactor accident, placed unprecedented demands on the local medical and emergency services, and it is with the response to such demands that this conference is concerned.

The conference sets out various scenarios and then considers laboratory and clinical aspects of medical effects upon the individual. Then the responsibilities, plans and resources for coping with an event are covered. Finally the long-term effects of radiation, including epidemiological studies, are presented.

Some prominent authors signalled their intention to use the conference as a platform for presenting new findings, and the speakers and chairmen were chosen for the authority which they bring to bear on these important topics.

The conference is aimed at a general audience, and the papers are presented in a readily understood manner. It will be of interest to general medical practitioners, accident and emergency personnel, environmental health officers, environmental planning officers, community physicians, safety engineers, environmental scientists, epidemiologists and officials from both government and industry. It will also be of particular value to news and media personnel.

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THE MEDICAL IMPLICATIONS OF NUCLEAR POWER PLANT ACCIDENTS

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ABSTRACT

This paper examines the UK position regarding the potential for an accident at a nuclear power plant, the safeguards in place to prevent such an accident occurring and the emergency procedures designed to cope with the consequences should one occur. It focuses on the role of the medical services and examines previous accidents to suggest the nature and likely scale of response that may need to be provided.

It is apparent that designs of UK nuclear power stations are robust and that the likelihood of a significant accident occurring is extremely remote. Emergency arrangements are, however, in place to deal with the eventuality should it arise and these incorporate sufficient flexibility to accommodate a wide range of accidents. Analysis of previous nuclear accidents at Windscale, Three Mile Island and Chernobyl provide a limited but valuable insight into the diversity and potential scale of response that may be required. It is concluded that above all, the response must be flexible to enable medical services to deal with the wide range of effects that may arise.

INTRODUCTION

Recent accidents including those at Goiania and Chernobyl have highlighted the importance of an effective medical response in dealing with accidents involving radioactive materials. Although the chance of such accidents is extremely small, they have the potential to give rise to a number of unique features including radiation exposures, contamination and psychological stress. These features justify detailed consideration and the preparation of procedures to mitigate their consequences.

The first section of the paper examines the philosophy and procedures behind the design and operation of nuclear power plant for ensuring that the likelihood of an accident is kept as low as reasonably practicable. This theme is developed in the second section which reviews the emergency procedures which are nevertheless available in case a severe accident actually develops. Section 3 examines experience gained from major accidents at Windscale, Three Mile Island and Chernobyl and considers the medical effects and the load placed on medical services. The final section builds on this experience and speculates on the likelihood of such a demand being made in the UK, the magnitude of the consequences and the scale of response that might be required.

Although the paper is primarily concerned with the position in the UK, and in particular with that concerning nuclear power reactors, it is necessary to examine the international arena for experience of nuclear incidents and their medical response.

NUCLEAR POWER PLANT SAFETY

Commercial nuclear power was born out of the wartime development of the atomic bomb and from the outset the potential hazards involved in working with significant quantities of radioactive material were well recognised. Safety and the need to prevent accidental release of radioactive material has therefore been of prime concern at all stages of the design and operation of nuclear plant. The responsibility for this lies clearly with the operator, who works within a strict regulatory framework. It is this combination of operator responsibility and regulatory control that provides the basis for nuclear safety within the UK.

Legislative Framework

The primary legislation governing Health and Safety standards at civil nuclear installations in the UK is the Health and Safety at Work, etc, Act 1974 plus the associated provisions made under the Nuclear Installations Acts of 1965 and 1969. National legislation is, however, subject to guidance from the international arena. The International Commission for Radiological Protection (ICRP) made a number of recommendations in their Publication 26 in 1977 and some of these formed the basis for a Euratom directive. As signatories of the Euratom Treaty, the UK is bound to introduce legislation to at least the standard of the directive, which it did by the introduction of the Ionising Radiations Regulations in 1985.

Commercial nuclear facilities including power reactors must not be constructed or operated without a nuclear site licence granted by the Health and Safety Executive (HSE). The HSE delegates its licensing and regulatory functions to the Nuclear Installations Inspectorate (NII) and they in turn ensure that all necessary arrangements for monitoring safety are made by the licensees.

In addition to the HSE/NII, the nuclear industry is also subject to regulation by the Department of the Environment (DoE) and the Ministry of Agriculture, Fisheries and Food (MAFF). The DoE is responsible for granting authorisations for the storage and disposal of solid radioactive waste and also for the discharge of materials to atmosphere. Whilst MAFF are also involved in these activities, their main interests are in the authorisation of liquid discharges to rivers or sea and the impact of all discharges on the environment.

The Nuclear Site Licence

The issue of a nuclear site licence is dependent upon the satisfactory outcome of an NII review of proposals made by a prospective licensee. These proposals set out the safety principles on which the design of the nuclear plant is based and demonstrates how they can be met by the reference design. The NII must be satisfied from its examination of these proposals that the facility can be built and operated to the required standard of safety before recommending that a nuclear site licence be granted by the HSE (Ref 1).

A nuclear site licence is generally accompanied by a series of licence conditions attached by the HSE as considered necessary in the interests of safety. The conditions are far-reaching and influence many areas including design, construction, operation, modification and maintenance of the facility in addition to the radiological protection of personnel both on and off site. They may be added to, amended or revoked at any time during the period when a licence is in force and this provides a very flexible regime of safety control.

The NII Safety Assessment Principles

The fundamental principle applied in the UK to the regulation of industrial risks is the so-called As Low As Reasonably Practicable (ALARP) principle (Ref 2). This requires that operators take all reasonably practicable steps to reduce risks bearing in mind the cost of further reductions. Detailed guidance on how this principle is to be implemented for nuclear facilities is provided by both regulators and designers.

In order to guide its assessors, the NII have developed a set of Safety Assessment Principles (Ref 3) to ensure consistency in the assessment of nuclear power plants of different designs. They include both limits and assessment levels which provide guidance as to whether all reasonably practicable steps have been taken to prevent accidents and, should they occur, to minimise their radiological consequences.

The principles can be broadly divided into 3 categories; the first category provides a set of fundamental principles for radiological protection. The second category lays down basic principles for the limitation of the radiological consequences of operation for both normal and accident conditions and the third category is mainly concerned with engineering features of the plant. The semi-quantitative guidance provided by the NII, detailing the relationship between radiation dose to the public and accident frequency, is illustrated in Figure 1.

Safety by Design

The primary objective of nuclear plant designers is to establish a good, safe design which fulfils the general plant performance specification. This specification includes details of the duty of the plant and, importantly, the requirement to meet the safety objectives and safety principles discussed previously. To this end, reactors tend to be conservatively designed with wide margins of safety and based on proven technology backed up by extensive testing and experience.

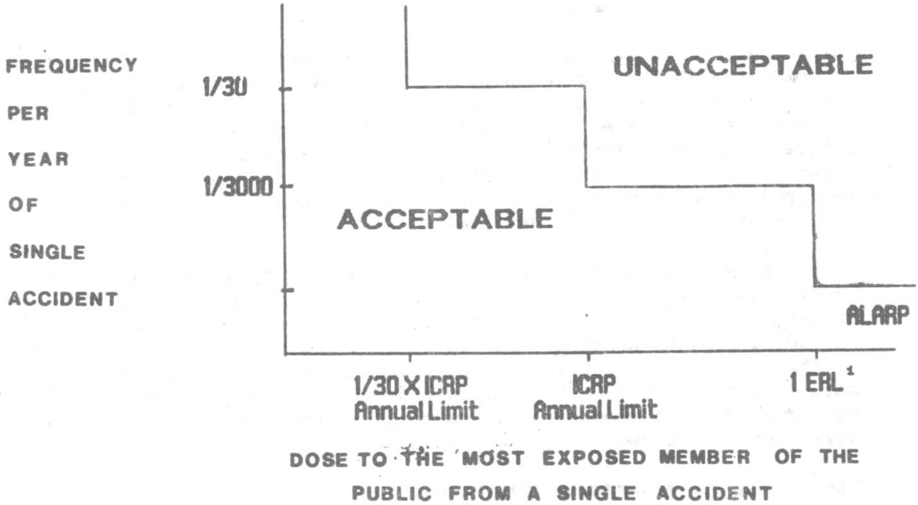

Figure 1. NII safety assessment principles

Defence in Depth - Multi-Barrier Principles

One of the most important techniques employed by designers to ensure a satisfactory standard of safety is that of providing defence in depth. This provides the basic framework for most nuclear power plant safety and has been refined and strengthened through many years of application.

The defence in depth concept compensates for both human and mechanical vulnerability and is centred on several levels of protection preventing the release of radioactive material to the environment. This multi-layer principle is based primarily on a series of barriers which would need to be breached in turn before harm could occur to people or the environment. These are physical barriers providing containment of radioactive material at successive levels. They may serve both operational and safety purposes, or safety purposes only.

The reliability of physical barriers is enhanced by applying the defence in depth methodology to each of them in turn and by protecting each of them by a series of measures. Each physical barrier is designed conservatively, its quality is checked to ensure that the margins against failure are acceptable and all plant processes capable of affecting it are controlled and monitored in operation.

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[1] ERL: An Emergency Reference Level (ERL) is the radiation dose below which countermeasures to protect the public are unlikely to be justified. The National Radiological Protection Board (NRPB) is the UK body with responsibility for advising on this level, which is presently set at, for example, 100 mSv whole body dose equivalent for evacuation. See Section 2.

A number of human aspects of defence in depth are also used to protect the integrity of the barriers. These include quality assurance, control procedures, safety reviews and other administrative areas within the general safety culture.

Engineered Safety Features

Wherever practicable passive safety features are incorporated into the design of nuclear power plant. In addition, engineered systems are provided to shut down the reactor, maintain cooling and limit any release of fission products that may occur should there be a fuel failure. Both the initiation and operation of these engineered safety features are highly reliable. This is achieved by the appropriate use of fail-safe design and by independence between safety systems and plant process systems.

Systems are designed to ensure that failure of a single component does not cause the entire safety feature to fail (the single failure criterion). To guard against this, redundancy is built into systems to ensure that sufficient back-up is available in the event of a component failure. In addition, diversity is built into the design to ensure that safety mechanisms can be operated by alternative means should the primary means fail. Diversity is also important in ensuring that safety systems are not disabled by common mode failure conditions.

Design Guidelines

To assist in the practical application of these principles, the Central Electricity Generating Board (CEGB) publish design safety criteria (Ref 4) which apply to the design of all their nuclear power reactors. These are accompanied by a set of Design Safety Guidelines (Ref 5) which expand and interpret these criteria for the new generation of Pressurised Water Reactors (PWR) to be introduced in the 1990's. They are similar to the NII Safety Assessment Principles but in some cases they are more stringent. Thus the CEGB state that accidents giving rise to doses of 1/10 ERL should not exceed 10^{-4} per reactor year compared with the NII figure of 1 in 3000 reactor years. The CEGB's design guidance is illustrated in Figure 2.

Accidents which would give rise to high off-site doses are covered by a target total frequency of 10^{-6} per year for all accidents giving a 'large uncontrolled release', with a maximum contribution of 10^{-7} from any single accident sequence. Some latitude is allowed for 'uncontrolled releases' at levels between 1 ERL and 10 ERL to have probabilities somewhat higher than 10^{-6}.

Safety in Operation

The way in which a plant is operated is dictated by the conditions attached to the nuclear site licence. These conditions ensure that all steps are taken by the licensees to protect both workers and members of the public from risks associated with the operation of nuclear reactors. These plants are regularly inspected by the NII to ensure that the conditions of the site licence are being complied with.

Nuclear plant operating staff are of a high professional standing and are well qualified by both experience and training. Automatic systems ensure that plants operate within well defined safe limits and are designed such that any breach of these limits results in the plant shutting down. Reactor shutdown and other immediate emergency actions, are fully automatic on modern reactors and no input is required from the operator for about half an hour after they have shut down. This avoids the need for rushed decisions and enables the operator to take advantage of a pre-arranged formal system of technical advice. The training and re-training of operators on simulators to deal with such situations is required by the NII and is a standard part of operational procedure.

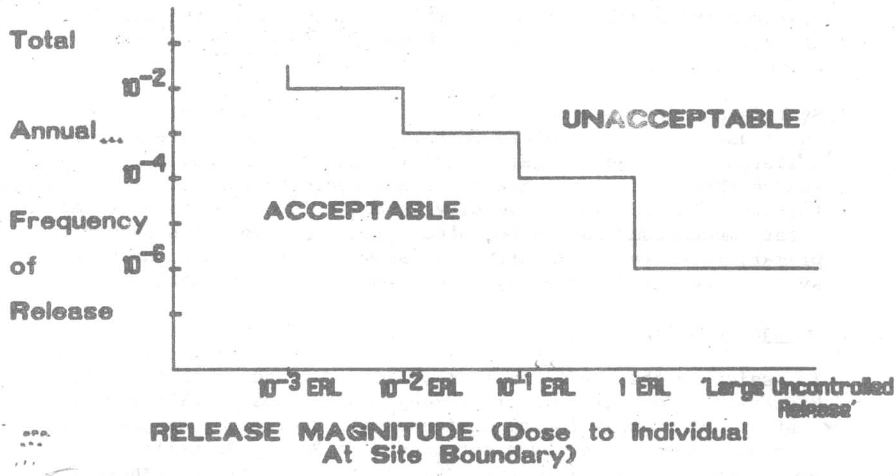

Figure 2. CEGB design safety criteria

Operational safety is also improved by incorporating lessons learned from incidents and experiences at other plants. Guidance on these matters will come from within the industry, from the HSE/NII, who must be informed of all incidents or potential incidents at nuclear installations in the UK, or from one of the internationally established agencies. These include:

The International Atomic Energy Agency (IAEA) who investigate all serious radiological accidents and produce a detailed account from which all States may learn and hence avoid similar consequences (Ref 6).

The International Nuclear Safety Advisory Group (INSAG) who advise on the safety of nuclear power plants. This body (established by the IAEA) serves as an international forum for the exchange of information on nuclear safety issues, and assists in the formulation of common safety concepts where appropriate (Ref 7).

The Organisation for Economic Co-operation and Development, Nuclear Energy Agency (OECD/NEA). This organisation maintains an Incident Recording System (IRS) which can be used to provide information on particular operational experiences and incident events.

The World Association of Nuclear Operators (WANO) which is also being established to disseminate information and to enable experience to be made more widely available to nuclear operators throughout the world.

EMERGENCY PROCEDURES

Despite all reasonably practicable steps taken to design and operate nuclear plant to the highest levels of safety, there can be no absolute guarantee that accidents will never happen. It is therefore necessary to have emergency arrangements to deal with any accident that might occur. We are all too aware of the demands made on emergency services in recent years in responding to major non-nuclear accidents at Bradford City Football Club, Manchester Airport, Kings Cross Station, Clapham Junction, Lockerbie and Kegworth. The responses to these accidents have demonstrated that civil Emergency Plans exist and that the emergency and medical response capabilities are in place to deal with large scale accidents.

The response to such accidents is planned at Local Authority level and is based on arrangements involving the Police and other emergency services. These plans need to be sufficiently flexible to cope with a wide variety of potential incidents. Despite the fact that nuclear accidents could give rise to a number of unique characteristics, the response required to protect the public is not vastly dissimilar to that required for other civil emergencies. Consequently, nuclear plant emergency arrangements are integrated with existing County Emergency Plans to ensure that, where possible, there is commonality in the response required by organisations which have a role to play.

Nuclear Emergency Planning

It is a requirement of a nuclear site licence that the operator must have an emergency plan approved by the NII. Such a plan will provide a general framework with detailed arrangements focused on a reference accident. These plans are published and are available for public scrutiny. They are regularly exercised in the presence of the NII, to ensure their continued effectiveness in providing the necessary action, both on and off site, to protect members of the public.

There is no single emergency plan which provides a universal optimum solution; each site will develop its own which will be subject to scrutiny by the NII. If the plant is new, emergency plans will have to be in place before the plant is commissioned. They are generally based on a tiered structure of alert:

Building Emergency : Where the effects of an incident are confined within a building.

Site Emergency : Where there are no off-site effects.

District Emergency : Where the incident gives rise to effects off site.

The plans must be able to cope with a wide variety of accidents, ranging from those with potential for a release of little more than the routine radioactive discharge to those with potentially far reaching off-site consequences, possibly involving fire and injury to operating staff.

The operator is at all times responsible for the on-site control of the incident irrespective of whether it has off-site consequences or not. The emergency plan for the affected site should contain a wide range of response capabilities which could be drawn upon to assist in the control of an incident.

Off-site action involves the local emergency services and other authorities which may be called upon to implement measures to protect the public. As with any other type of civil emergency, the main responsibility for interaction with the public lies with the Police. The importance of the Police role and their experience in dealing with a variety of emergency situations cannot be too strongly emphasised.

Accident Consequences

The consequences of an accident for operating staff and other workers at the plant could be severe, dependent upon its detailed nature and speed of development. If a serious accident did occur, it is likely to result in the release of volatile radioactive species including caesium, radioactive noble gases, and the radio-iodines both in gaseous and particulate forms. This radioactive material would be transported by the wind from the affected plant and behave similarly to a plume of smoke, dispersing into the atmosphere and depositing some of its contents on the ground.

The activity contained within the plume could give rise to radiation exposures to the public in a number of ways. The first consideration is the external dose from the airborne plume itself, material deposited on the ground and possibly on the skin and clothing of people in its path. The second, and possibly most significant route of exposure, is via the inhalation of material suspended in the plume. Finally and on a longer timescale, there are exposures arising from the consumption of contaminated food and water.

The release of radioactivity resulting from a serious reactor accident should not cause any immediate health effects to the public but there are a number of countermeasures which could be appropriately taken to minimise longer term effects. These include:

(a) Sheltering - The normal constructional materials used in houses and other buildings provide some protection from the effects of radioactive materials released to the atmosphere, up to a factor of ten dose reduction being obtained in favourable circumstances.

(b) Potassium Iodate Tablets - If taken early enough, the thyroid can be blocked with stable iodine and this limits the absorption of radioactive iodine which may be present in the radioactive plume.

(c) Evacuation - If it is practicable to evacuate personnel from the effected areas, doses arising from exposure to the plume itself and from activity deposited on the ground could be reduced.

Furthermore, following the incident, checks would be made on foodstuffs and MAFF may consider it necessary to introduce restrictions on agricultural produce and dairy products. These countermeasures should reduce exposures and help ensure that the public are not exposed to significant risks to health.

The Police, the Local Authority, MAFF and the Local Health Authority would all be involved in the emergency response. It is the responsibility of the Local Health Authority to ensure that the health of the public is considered at all times during the control of the incident particularly with regard to countermeasures. Upon being informed of the incident, representatives from all organisations with a role to play would proceed to the local Operational Support Centre (OSC). Once established, the OSC becomes the focal point for liaison activities and the co-ordination of advice to all outside organisations. Upon declaration of an emergency a Government representative would be dispatched to the OSC to act as Government Technical Adviser (GTA). His principal task is to preside over all off-site developments and to ensure that consistent advice is given to all interested and involved parties including Government departments and the media.

Medical Aspects

There are many important aspects which must be considered for an emergency plan to work effectively. The arrangements must include procedures for clarifying responsibilities, ensuring that effective teams can be readily mobilised, providing robust communications facilities, manning of control, support and media briefing centres, etc, etc. We are primarily concerned, however, with the medical implications of accidents and therefore attention is focused on these.

The Medical Response for On-Site Personnel

Nuclear establishments are generally well drilled in their response to accidents/emergencies. Each establishment will have its own emergency instructions, exercised on a scheduled basis and personnel working in affected areas should follow these instructions. Dependent on the type of emergency these may require staff to stay indoors (shelter) or possibly to evacuate to a local assembly point. Any monitoring and decontamination of personnel that may be required can be arranged on site since facilities are available for showering, change of clothes and health physics monitoring.

In the event of a major accident it is possible that workers or personnel involved with bringing the incident under control may require medical treatment. Most nuclear establishments have on-site medical services which are geared to deal with emergencies including those requiring decontamination procedures. Medical staff are on call at every site and if conventional injuries allow, the medical centres would be used to receive, decontaminate and sort casualties prior to transfer to hospital.