RESEARCH TO KEEP NUCLEAR POWER SAFE: THE EXPERIENCE OF A MAJOR INDUSTRY

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Abstract

The nationalised electricity industry of England and Wales is a single utility with a present installed capacity of 54 GW of which 3 GW is in nuclear stations. The Central Electricity Generating Board (CEGB) is responsible to the national Parliament for operating its system safely and economically. It necessarily maintains a large research department to assist in obtaining or interpreting the data needed for planning, specifying and operating its plant. Much of the research work is directed to environmental studies, particularly in atmospheric dispersion and hydroecology. In the nuclear field much of the work is concerned with the safety of structures and materials, and so affects radiological safety indirectly. Some of the work, the subject of this paper, is directly concerned with radiological safety and will be described under the headings of Fundamental, Applied and Operational research.

It is concluded that CEGB experience has shown it to be essential for a major utility company to maintain a vigorous health physics research programme.

1. Introduction

The nationalised electricity industry of England and Wales consists of a Central Electricity Generating Board (CEGB), and a number of Area Boards. The CEGB is responsible to the national parliament for generating and transmitting power safely and economically. It has an installed capacity of 54 GW of which 3 GW is in nuclear stations, and sells power to the Area Boards who distribute it for sale to consumers. The CEGB operations are managed on a largely autonomous regional basis with a central headquarters organisation providing major services and some necessary co-ordination. Each Region has a Scientific Services Department, whose efforts are integrated with the headquarters Research Department consisting of three national laboratories situated at Leatherhead, Berkeley and Marchwood. The Central Electricity Research Laboratories (CERL) at Leatherhead have made distinguished contributions to environmental research, particularly in atmospheric dispersion and hydroecology. Berkeley Nuclear Laboratories (BNL) is almost exclusively concerned with the safety and economics of nuclear power. In addition to research on structures, materials and instrumentation, which affect radiological safety indirectly, it also carries out a programme directly concerned with all aspects of health physics. It is the thesis of this paper that it is essential for a major utility company to maintain a vigorous health physics programme, and an attempt will be made to demonstrate this by a series of examples presented under the headings of Fundamental, Applied and Operational research.

2. Fundamental Research

It is the policy of the CEGB to protect its workers and the public in the light of the best available knowledge. Some of this knowledge is unpublished and, in order to become familiar with it, it is necessary to establish close links with specialists working in laboratories concerned with the basic sciences contributing to radiological protection. This can only be done by CEGB staff who are familiar with the terminology and have sufficient first hand experience to engage in an effective dialogue. Discussion of specific problems often leads to the additional benefit of a deeper understanding of the contributing sciences from which future trends can be more reasonably judged. Since the period elapsing between the ordering and operation of a station is several years it is important to forecast present trends in basic standards, and to be aware of deficiencies in present derived standards, in order to avoid expensive modifications.

The method of working depends on the particular topic and the following examples are chosen to illustrate different balances between execution and sponsorship.

2.1 Skin Dose Estimation

In many situations involving spent fuel examination or reactor maintenance the control of skin dose is important. Before instrument readings can be interpreted in terms of skin dose it is necessary to define what is meant by 'skin dose', and to agree over what areas of skin the limits should apply, and what units should be used to express the limits. These deceptively simple requirements raise many questions such as:-

> What is the depth and thickness of the layer of cells thought to be at risk? Is it peak or mean dose in that layer which is important? Does ICRP "averaging" procedure permit extrapolation to single hot spots? In view of the energy dependence of skin erythema should there be any modifying factors for dose equivalent in skin? Is it necessary to estimate skin dose in rems, or in rads in air at or near the body surface as suggested by some legislation?

Recognition that these questions have a bearing on day to day working practice[1] provoked discussion by the British Committee on Radiation Units and Measurements and by the Medical Research Council[2]. The CEGB had a special interest in the depth and thickness of the layer of cells thought to be at risk because the steepness of beta depth dose curves made those values critical for interpreting skin dosimeter readings. It appeared that these values were not known, and the customary value of 70 µm for the minimum depth of the basal layer of the epidermis certainly did not hold for all exposed body sites. As a result the staff of Berkeley Nuclear Laboratories collaborated with medical staff in London hospitals and carried out with Dr. Everall, a series of measurements whose significance in radiological protection has been described[3,4]. In the course of contributing to the acquisition of new knowledge the CEGB staff obtained a familiarity with the radiobiology of skin which was recorded in a series of internal reports which have been useful to designers and operators. The skin work is an example of cases where a deep understanding has enabled the CEGB to hold its own valid opinion on the standards used for protecting its workers.

2.2 Lung Dosimetry

The lung burdens or intakes of radioactive material giving 15 rem a year are normally calculated by averaging the energy of radioactive decay over a lung mass of 1 kg. When the material has a very high specific activity the permissible quantity of material may be contained in only a few particles. Thus although the mean dose to the lung is 15 rem the distribution of dose is highly non-uniform. Small volumes close to the particles may receive necrotic doses while the rest of the lung is substantially unirradiated. The obvious question is whether or not the risks of a lung burden depends on the specific activity of the material involved. ICRP publications offer conflicting advice, and yet the CEGB must have an opinion on which to base its present operational procedures and future design requirements. Having identified the problem the Research Department took the initiative in getting guidance on the interpretation of ICRP recommendations, and in discussing the research needed to obtain more definitive guidance. The hot-particle problem has been recognised for many years, but by showing its importance in practice the CEGB was able to add impetus to the biological studies. In this case the method of procedure is to operate a small contract with the Medical Research Council Radiobiology Unit at Harwell, and to participate in their work especially on physical aspects. This co-operation works well as the CEGB knowledge of the types of particles, and situations in which they could arise keeps the research work entirely relevant to real problems, and the CEGB develops an informed opinion about an aspect of radiation protection in which guidance is ambiguous.

2.3 Bone Dosimetry

The contract method of working is particularly useful when the CEGB wishes to become better informed about specialist studies by contributing to them. The dosimetry of bone seeking nuclides is clearly of importance to the power industry, and it is necessary to follow changes in the methods of determining bone burdens and permissible intakes. Where the utility needs the information it is very proper that it should contribute towards the research necessary to obtain it, and in this case we operated a small contract with Professor Spiers' group at the University of Leeds. Such contract work is fruitful when the contractor can take an intelligent interest, or even participate in some aspects. The sort of contract which was merely financial, and which resulted only in a report, would be of only marginal value.

2.4 Dose-risk Relationships

Many of the day to day decisions in health physics rely on an assumed form for the dose-risk relationship, which, following ICRP guidance is usually taken as linear. For example in a maintenance operation the linear hypothesis would see no difference in risks between 40 men receiving 1 rad each and 20 men receiving 2 rads each. Again, on the linear hypothesis the mean organ dose is the parameter of interest and the hot-particle problem disappears. It is perhaps in the environmental aspects of nuclear power that the shape of the relationship becomes extremely important since it influences decisions on the methods of disposing of effluent. The literature on dose-risk relationships is vast, mostly concerned with animal experiments with a little human data. In addition to following this, the CEGB is also concerned to follow up the speculative studies begun by Professor Mayneord some years ago[5]. Together with Mayneord we have developed a model which appears to fit the biological data available and which could have far reaching effects on the fundamental principles of dose control[6].

3. Applied Research

When safety criteria have been specified for working or public environments it is necessary to determine the constraints in design or operating conditions in order to meet them. The thorough imaginative enquiry that this entails usually involves going back to first principles and following a logical sequence of calculations capable of checking where experience is available. One example of this was an assessment of airborne releases[7], for which the reactor inventory of fission products[8] and heavy elements[9] had to be generated. The development of this work and examples of its application have been given[10,11]. By carrying out applied research within the utility company several important advantages are secured. Firstly the work is based on first hand information about specific plant and operation conditions, and secondly, the research staff are an integral part of the organisation concerned with drafting and assessing specifictions for the purchasing of new plant. Within the CEGB health physics research has identified the limitations on running reactors with failed fuel, it has contributed to stack height specifications, identified shielding problems, and improved the integrity of emergency monitoring services for both workers and the public.

4. Operational Research

As in any industry operational problems arise, some of which are most economically solved by reference to a central laboratory. Within the CEGB excellent relationships exist between the power stations and the laboratories resulting in a long history of research effectiveness. All types of problems arise, some of them involving little effort, others becoming projects involving several years work. Much of the operational work is concerned with ensuring the adequacy of techniques for measuring radiation and radioactivity. This frequently involves investigations at the power stations in which the environment requiring routine monitoring is properly defined by laboratory techniques. The characteristics of commercial instruments can then be determined with a view to giving guidance on the interpretation of their readings in practical situations. Occasionally it is necessary to develop a new instrument because no suitable commercial instrument is available. So far the CEGB has developed or sponsored about half a dozen instruments ranging from an exposure meter with an energy response extending to 6 MeV to a monitor measuring low concentrations of ^{35}S in gaseous emissions. A good account of one such development has been recently given[12]. As technology advances new measuring techniques become available and it is necessary to study them thoroughly in order to exploit them properly. For example, in recent years thermoluminescence has provided a valuable method of dose estimation whose applications in reactor health physics have been assessed[13]. Any assessment of a measuring technique requires calibration facilities of high integrity, and the CEGB established a facility shortly after its first reactors came up to power[14]. Such a calibration laboratory is concerned not only with accuracy but with determining the characteristics of instruments sufficiently well to have faith in their reliability and confidence in the interpretation of their results under field conditions[15]. The calibration facility is used for checking instruments from all the CEGB stations, and for disseminating sources and instruments which can be used for local checks. The standards used usually have to be developed and related to primary standards where these are available[16]. There is no doubt that the work of the facility has been essential to underwrite the integrity of measurements in the nuclear power industry, and that many of the problems solved would not have been identified if the industry had relied on outside contracts for obtaining opinions on its instruments and interpretations.

5. Conclusions

It is certainly the experience of the CEGB that a vigorous health physics research programme is essential in order for the Board to be an informed buyer of nuclear plant, and to be a responsible operator. The operational work, involving projects providing specific services or hardware is the most easily understood aspect of the programme, but this part cannot stand on its own. It is backed up by applied research concerned with identifying problems by objective analysis and developing general methods of solution. In turn the applied work has to be underwritten by fundamental work ensuring that the basic science of radiological protection is adequate and properly interpreted,

Within the CEGB the Research Department is advisory, and this gives health physics research the advantage of freedom to examine problems without any inhibitions. The integrity of this approach has certainly contributed to the confidence shown by the public and the inspecting Government departments.

The ground rules for radiological protection are discussed by many national and international bodies, whose publications are continually extended and revised as knowledge and technology advance. A major utility relies heavily on such bodies for guidance, which can only be provided in a relevant form if the utilities problems are articulately expressed. The CEGB recognises this, and the Research Department, among others, regards communication with national and international bodies as important. Such communication is not just to list new problems on which guidance would be welcome, but to make a positive contribution to the work involved.

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