BASIS FOR THE DESIGN OF RADIOLOGICAL PROTECTION INSTRUMENTATION FOR NUCLEAR FACILITIES

J A B Gibson and M Marshall
Environmental & Medical Sciences Division
D J Ryden and R D Watkins
Instrumentation & Applied Physics Division
Harwell Laboratory of the UKAEA

INTRODUCTION

Radiological protection (RP) is vital to the design of all nuclear plant and the RP instruments to be installed or used in the plant must be of a high standard of reliability to ensure safe working and minimum risk. Plant size, type and inventory of radioactive materials will influence the complexity of the instruments ranging from simple monitoring for tritium in air in a luminizing facility to the full range of monitoring around nuclear reactors and in fuel reprocessing plants with: external gamma-ray and neutron detectors; radioactive gas monitors; and beta/gamma-ray and alpha particle detectors for radioactive aerosols. Installed instruments should have a standard of reliability comparable to reactor instrumentation and portable and personal dosemeters for delineating fields and measuring personnel dose for record purposes must be robust and designed for the purpose for which they are used.

RADIOLOGICAL BASIS FOR PLANT DESIGN

In the UK nuclear industry there are many codes of practice for the safe design of plant and its operation. There is a recent code of practice[1] (with a guidance note) specifically to give radiological guidelines. Radiological principles in the UK are based upon ICRP recommendations[2] which are converted to regulations[3] and a code of practice[4] by the UK Health & Safety Executive (HSE), with advice from the UK National Radiological Protection Board (NRPB).

The design dose targets[1], prior to optimisation of the design using cost benefit analysis, are, for radiation workers: 10 mSv/yr averaged over radiation workers on a particular plant; 15 mSv for any individual radiation worker; 150 mSv/yr extremity dose equivalent to an individual. The design target for non-radiation workers is 5 mSv/yr and 0.5 mSv for a typical member of the most exposed group of the public. These targets are in line with the latest guidance from NRPB[5] which anticipates ICRP recommendations but which has not yet been accepted by the HSE. It should be noted that the HSE regulations[3] require a management investigation if an individual's dose equivalent exceeds 15 mSv in a year, or if a woman of reproductive capacity exceeds 13 mSv to the abdomen in any consecutive 3 months period (10 mSv during a declared term of pregnancy). Also the operational controls for non-radiation workers and typical members of the public will be the same as the design targets[1].

INSTALLED RADIOLOGICAL PROTECTION INSTRUMENTS

The RP instrument engineer has to translate the operational requirements into instruments to demonstrate compliance and indicate levels above 10% of established limits. There is a code of practice for installed RP instruments[6] which is designed to assist the health physicist in specifying the requirement and then to provide guidance on satisfying the request and installing the instruments. RP instruments required in a plant would include:

criticality monitors; gamma-ray & neutron monitors; radioactive gas monitors in working areas & stacks, sampling and monitoring equipment for airborne alpha & beta-particle aerosols in working areas & stacks; hand & clothing monitors; liquid waste monitors. RP instruments will normally have alarms which should not be falsely triggered and need a high standard of reliability and availability (low maintenance down time) which should be comparable with that demanded of nuclear reactor instrumentation[7,8].

Specification by the Health Physicist. The specification starts with a definition of the operational characteristics, viz: sources & radiations, hazards, permitted doses, alarm levels, type of measurement, accuracy and degree of sophistication required. The radiation environment must be specified; for example radon and its daughters can interfere with measurements of alpha radioactivity in air and ventilation, weather and building design can all influence the radon activity level. Background radiation from gamma-rays or neutrons can be variable and interfere with measurements as can shielding and backscattering from structures. All of these effects need to be considered in the specification. The non-radiation environment is equally important, viz: temperature, pressure, humidity, vibration, electrical interference, corrosion, contamination & cleaning and accessibility; all need to be considered and ranges of operation specified. This specification exercise needs to be interactive to avoid over-stringent requirements which could be expensive and to ensure that the sensitivity of any equipment is identified before it is provided.

Specification by the Instrument Engineer. A target technical specification should be produced for preliminary consideration and discussion with the Health Physicist. This will provide an overall design specifying the measurement required, sampling techniques (if applicable), the alarm levels and failure indicators. Availability, ie 'the sum of the times for which the system is in the inoperative failed state divided by the total time during which it should be operative', and reliability ie 'the characteristic of an item expressed by the probability that it will perform a required function under stated conditions for a stated period of time', need to be agreed with instrument user. Information display has become a major part of the specification as plants come under computer control and RP instruments are required to provide their information centrally. Alarms (visible and audible) are still required close to the instrument and autonomous operation in the event of a computer failure is highly desireable. Information handling and centralised instrument require increasing amounts of computer software which is itself subject to the same availability and reliability audits that are applied to the hardware. This provision of software may reduce the reliance on human influences but they must still be considered. Hardware is completed by specification of power supplies (with battery back-up?), cables (reduce interference) and the physical supports for the instruments. Detailed manufacturing & test procedures, and quality assurance are needed before supply costs can be estimated.

Supply, Maintenance and Documentation. Finally comes installation, maintenance and documentation: it is usual for RP installed instruments to have a life of many years and so complete documentation at the start of installation is vital to reliability, maintainability and availability.

PORTABLE AND TRANSPORTABLE RADIOLOGICAL PROTECTION INSTRUMENTS

The specification procedures for portable and transportable equipment[9] is very similar to that for installed equipment except that it is much more

difficult to define the environment in which it will be used. Equipment will certainly be subject to more physical shocks if it is carried or worn and, whilst it should be robust enough for the purpose, it should clearly indicate when it has failed as the instrument, for example, a gamma-ray or neutron survey meter or contamination monitor is acting as the radiation sense organ of the user. Thus the instrument designer should maximise the identification of revealed faults and minimise the number of unrevealed faults. Other instruments will include personal alarm monitors for external radiation or for sampling and counting aerosols of alpha and beta particles. Separate specifications for instruments using passive detectors, eg film dosemeters and personal air samplers, need a combination of the requirements for portable and installed equipment for reading or counting the passive element.

COMPUTER SOFTWARE

As indicated above, the need to provide remote control and reading of installed and even portable RP instruments is producing an increasing requirement to provide software with at least the same reliability and availability as the hardware. Also it is unlikely that the software designer will have a completely free hand in choosing either his hardware or programming language which may be fixed by the overall plant control system. It is possible to provide, at some expense, direct software control within the instrument by preprogramming but once the output reaches the central control this flexibility of approach is lost.

Firstly it is necessary for the user to define an overall requirement in terms of immediate information, manipulation of data, recording of historical data, printouts, displays, failure indicators (including pump failures on samplers) & alarms and interaction with other programs. There may be a variety of installed instruments, eg measuring external gamma radiation, neutrons, gases, tritium, particulates, etc; and uses, eg workplace, stack, natural environment. Each type of instrument will require its own software although there may be much that is in common. Pocket dosemeters can be used for access control to restrict and record doses received: this information on individual access and dose may be recorded for comparison with recording dosemeters (film or thermoluminescent dosemeters). The results of all measurements and dose assessments for an individual will need to be stored to provide the legal dose records[10].

The development of expert systems to handle emergencies and provide rapid dose assessments and evaluations is an area of increasing importance in order to provide information quickly and prompt for further measurements[11].

TYPICAL ASSESSMENT PROCEDURE FOR RP INSTRUMENTATION

Ideally RP instrumentation should form part of the overall plant design from its inception so that sampling points can be fixed, instrument locations decided and cable runs organised. Fitting RP instruments into existing plant is more common but the principles are the same. The stages are as follows.

A Examine the plant and its potential hazards to workers and the public.
B Consider the RP design limits for within the plant and for releases to the environment under normal and accident conditions.
C Decide upon the operation of the RP service, its expertise, facilities for emergencies, services which can be bought in, eg bioassay.
D List all the possible RP instruments that might be required with monitoring levels (minimum & maximum) and possible methods of detection.

E Prepare simple specification giving: range of measurements; special requirements (eg separation of plutonium activity from radon background); uncertainties over the range; electrical requirements (eg power supplies, interference, alarms, reliability, availability); computer imput; test facilities; and environment (radiation and non-radiation).

F Look for connected requirements, where with a small modification an instrument can be used for 2 purposes, and interaction between instruments.

G Consider available instruments and decide where R&D is required to satisfy the specification.

H Define the computer software requirements for installed monitors (on-line) and off-line personnel dosimetry.

I Propose locations for RP instruments, cables, connectors (interfaces), racks, power supplies.

J Provide a provisional cost estimate for R&D, procurement, software and operation of the RP instruments and the RP service.

It is important that an instrument engineer is involved in the last two stages and before procurement in providing complete specifications, final costings, supply, installation, documentation, warranty and maintenance schedules. None of this procedure can be completed without reference to the customer (plant designer) and to the Health Physicist who will interpret the results from the RP instruments and software.

References

1. JOHNSTONE, I., BROWN, M.L., CHAPMAN, B., HAYNS, M.R., HIND, J.R., McKEAGUE, R., NAYLER, S.L., PECKOVER, R.S., TAIG, A.R., TAYLOR, R., MEGGITT, G.C. and JACKSON, R.G. Code of Practice and Guidance Note: (Provisional) Radiological Guideline for the Design and Operation of UKAEA Plant, SRD R456, 1987.
2. International Commission on Radiological Protection Publication 26, Annals of the ICRP 1, 3, 1977.
3. Health and Safety Commission. The Ionising Radiations Regulations 1985, HMSO, London, 1985.
4. Health and Safety Commission. Approved Code of Practice. The Protection of Persons against Ionising Radiation arising from any Work Activity, HMSO, London, 1985.
5. CLARKE, R.H. Interim Guidance on the Implications of Recent Revisions of Risk Estimates and the ICRP 1987 Como Statement. NRPB-GS9, 1987.
6. POWELL, R.G. Code of Practice and Design Principles for Installed Radiological Protection Systems. AERE-R9374, HMSO, 1979.
7. BRITISH STANDARD NO 4877 Recommendations for General Principles of Nuclear Reactor Instrumentation. BSI. London, 1972.
8. EAMES, E.R. Principles of Reliability for Nuclear Reactor Control and Instrumentation Systems, SRD R1, 1971.
9. WELLS, F.H. and POWELL, R.G. Code of Practice and Design Principles for Portable and Transportable Radiological Protection Systems. AERE-R9995, HMSO, 1980.
10. GIBSON, J.A.B., BULL, R.K. MARSHALL, M. and SMITH, J.W. Interpretation of Internal dose Calculations for Dose Record Keeping. Proc. 7th Int. Congress of IRPA, Sydney, 1988.
11. GIBSON, J.A.B., HARRISON, K.G., DELAFIELD, H.J. and BAKER, D.M. Nuclear Accident dosimetry Faciflity and Research & Development to improve Measurements and Interpretation. Proc. 7th Int. Congress of IRPA, Sydney, 1988.