Paper 28

Dose Control at a Cyclotron Facility

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1 Introduction

High energy cyclotrons have been in use for several decades for the production of radionuclides used in the diagnosis of diseases. Manufacturing capacity has increased to meet demand but the nature of the business, particularly the need to supply the short-lived products to a world-wide market, has placed pressure on the suppliers to increase machine efficiency and to optimise production and maintenance programmes.

This paper reviews the characteristics of commercial cyclotrons, the manufacturing cycles, dose control regimes and radiation dose performance.

2 Product Applications and the Manufacturing Cycle

Nuclear medicine studies of heart disease, tumours, infections and other conditions are commonly carried out using radionuclides with acceptable decay and emission characteristics, gallium 67, indium 111 and thallium 201 being particularly suitable. These are electron capture nuclides, with half-lives of the order of three days and emitting a range of low and medium energy photons, which can be produced by bombarding metallic targets in high energy cyclotrons.

The manufacturing cycle is dictated principally by the short half-lives and the need to make the products available for supply each working day. The cyclotrons are required to operate throughout the 24 hour day and at relatively high availability. Irradiation is followed by chemical separation and the treatment processes necessary for compliance with pharmaceutical and radionuclidic purity criteria; this paper deals only with dose control at the irradiation stage.

3 Machine Characteristics

Commercially operated cyclotrons are used to accelerate negative or positive ions to energies up to 30 Mev. They require powerful electromagnets and radiofrequency power and they operate under high vacuum. They are housed in massively shielded concrete vaults and require remotely controlled transfer systems for the removal of the irradiated targets. Facilities external to the vaults include the plant rooms which house ancillary equipment, control rooms and workshops.

The machines require a wide range of services, electrical, vacuum, compressed air, hydraulic and cooling, all of which must operate under high dose rate conditions. They are constructed to high precision from components that require accurate alignment. Non-metallic materials are susceptible to radiation damage but their use cannot be avoided for components such as insulators. The choice of materials is often determined by the need to limit the dose rates which result from the adventitious activation of components.

The machines are therefore complex, high precision devices that are required to operate reliably at high availability.

4 Occupational Radiation Risks

The cyclotrons operate at relatively high beam currents which result in dose rates in the vaults of up to 30Gy/hr and there is therefore the risk of acute exposure of personnel. The machines are provided with interlocks, normally incorporating captive key systems, which are used to control power and to increase the effectiveness of vault search procedures. The electrical elements of the interlocks are hard-wired and are independent of the machine operational controls. Emergency stops are provided within the vaults.

The concrete shielding reduces dose rates in external operational areas to very low levels and, as a consequence, the majority of operator dose is received during maintenance. Dose rates in the vaults are about 50 mSv/hr on completion of target irradiation. During the 24 hour decay period that precedes the commencement of routine maintenance, which includes such operations as foil and ion source replacement and insulator inspections, the dose rates decrease to about 0.05 mSv/hr. Annual doses to operators are below 10 mSv effective dose and 30 mSv to extremities. Doses from direct radiation are more significant than internal doses; localised contamination may occur within the vaults but intakes are rarely significant.

5 Dose Management

The cyclotron group were among the higher exposure groups identified in the Company during initiatives taken in the late 1980s to reduce operator exposures. At the Corporate level annual dose targets were progressively decreased and at the operational level dose management arrangements were further developed, ownership of the dose control systems moving away from the health physics support teams and towards the cyclotron group.

Dose measurement during maintenance, in which the operators often work in very close proximity to activated components, is particularly challenging. Dosimetry systems include single or multiple body dosemeters, supplementary dosemeters and electronic dosemeters, some of which can be read remotely by staff supporting the in-vault servicing. Normalisation procedures are followed to correct doses recorded on the electronic dosemeters against those recorded on the body dosemeters.

The availability of electronic dosemeters has permitted more frequent dose analyses, operator doses now being reviewed daily against control levels. The data from these analyses and the mapping of dose rates during decay periods in the vaults enable the accurate prediction of dose for a wide range of maintenance tasks.

6 Routine Maintenance

Machine-related initiatives are centred on improving either the performance of the machines or the efficiency of the maintenance operations.

Improvements to the machines themselves can result in higher performance and thus shorter irradiation times. The use of low activation metals, leading to lower activation dose rates, and the availability of spare components, which permit increased decay periods prior to workshop maintenance, are simple methods which contribute to dose reduction. Increased knowledge of the machine characteristics has enabled the optimisation of preventative and breakdown maintenance and this has led to a reduction in the range of routine maintenance tasks and, as a result, lower operator doses.

Techniques used to reduce exposures times during maintenance include the use of improved service couplings. Where breathing protection is required it is possible to achieve optimum protection in respect of external and potential internal exposure; a self-contained respirator may be preferable to an air-fed suit if the relative ease of operation results in a reduction of task time and hence the more significant external exposure . The use of photographs of plant, video recordings of previous operations and mock-ups can also contribute to task efficiency and reduce exposures.

The evaluation of the skills required during maintenance has enabled each task to be skill-rated. This information is then used to determine which tasks should be carried out by the higher skilled staff and which should be allocated to service groups which have a broader range of site maintenance responsibilities. Conservation of the exposure of the smaller number of skilled cyclotron staff can be of particular significance in the event of breakdown or major maintenance where the work can often be carried out only by this group.

7 Machine Rebuild

The routine maintenance referred to above is carried out weekly within the normal cycle of operations. The deterioration of major components after some years of operation does, however, lead eventually to the need for machine rebuild. This requires the dismantling of the main components and services, the whole operation extending over several weeks. Effective planning is clearly vital in order to minimise the effect on manufacturing programmes and to avoid recourse to alternative sources of supply.

The detailed engineering planning and the analysis of tasks and dose potential are typical of those used in major engineering operations in both the nuclear and non-nuclear fields. The techniques referred to in the control of routine maintenance take on even greater importance. Spares must be made available, tooling prepared and staff at various skill levels allocated by task. The data which have been accumulated on component activation and decay rates is key to programming the task sequences; particular care is taken to identify those components with the longer-lived activation nuclides which could become more significant contributors to dose over the longer rebuild period. Extensive use is made of photographs and video recordings in the training of staff.

The safety case for the rebuild, which includes the allocations of individual and collective dose, is formally documented, assessed and peer reviewed. The conditions of approval require hold-points at key stages beyond which work cannot proceed without formal authorisation.

This approach to rebuild has been found to be effective. Optimum use is made of the various skill levels and of the necessary health physics support to ensure that doses are controlled within the limits set for each operation.

8 Dose Performance

The ALARA programmes have been successful in reducing both individual operator dose and collective dose. Over the period from 1990 to the present, maximum annual individual doses have decreased from 15 mSv to less than 8 mSv while annual collective doses have decreased from 160 man mSv to 100 man mSv. These reductions have been achieved despite an increase in overall output.

9 Summary

Significant reductions in individual and collective dose in the cyclotron group have been achieved over the last ten years. This has been the result of commitment by managers at Company and unit level and by the setting of aggressive dose targets. Improved technology and dosimetry systems, the use of dose mapping techniques, innovative approaches to task analysis and the application of management skills to the planning of maintenance work have all contributed to this success. Major gains have been made but the initiatives continue as a part of the Company's commitment to the ALARA programme.