BEAM INDUCED RADIATION PROBLEMS AND CURES

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ABSTRACT

ISIS, the high intensity pulsed neutron source at the Rutherford Appleton Laboratory, operates with a mean proton beam power in excess of 160 kW at a beam energy of 800 MeV. Beam loss is controlled to prevent damage to machine components and localise high levels of induced radioactivity. A description is given of how ISIS is operated so as to minimise the induced activity. Details are provided of the procedures and formalised methods of control that enable the manual handling of activated machine components within limited, collective personnel doses.

1 INTRODUCTION

ISIS, the high intensity accelerator based pulsed neutron source at the Rutherford Appleton Laboratory (RAL), now operates regularly at its design intensity of 200 μA (2.5 E13 ppp at 50 Hz). This is equivalent to a mean proton beam power of 160 kW at the extracted beam energy of 800 MeV. Operating with such beam power could, due to uncontrolled beam loss, result in severe component damage and give high levels of induced radioactivity. Such damage is invariably unexpected, disruptive to scheduled running and expensive in several ways. There will be increased costs, involving financial and personnel resources, in providing for the manufacture and rebuild of spare components, the provision of secure active waste storage areas and the eventual disposal of the damaged but highly active component. The requirement to provide additional compensating operating time may effect other planned work. There will also be the possible loss of goodwill from the scientific community.

Somewhat lower levels of beam loss may give less component damage but could give, over a period of time, such high levels of induced activity that a manual ‘hands-on’ or ‘active handling’ maintenance regime, such as that used on ISIS, would not be possible. (Remote handling techniques are necessary in the target station and will not be discussed here).

It is therefore necessary at all times to operate in a manner which minimises beam loss (and therefore induced activity levels) and to have in place methods of working which ensure that the requirements of the UK Ionising Radiation Regulations 1985, which are based upon the International Commission on Radiological Protection recommendations, are met.

2 GENERAL CONSIDERATIONS

Induced activity is a major hazard on ISIS (contamination much less so). The Ionising Radiation Regulations calls for the setting up of radiation controlled areas, the issuing of Local Rules and the appointment of Radiation Protection Supervisors and a Radiation Protection Advisor, who ensure compliance. It also gives three principles for work in active areas:

- every practice resulting in an exposure to ionising radiation shall be justified by the advantages it produces;
- all exposures shall be kept as low as reasonably achievable (ALARA);
- that specified dose limits shall not be exceeded.

In order to comply with the first principle each and every entry to a controlled area must be justified on the basis that it is necessary in order to maintain the facilities operational status. To maintain a ‘hands-on’ maintenance regime, and to comply with the second and third principles, ISIS is operated so as to minimise beam loss. Experienced operators continuously observe

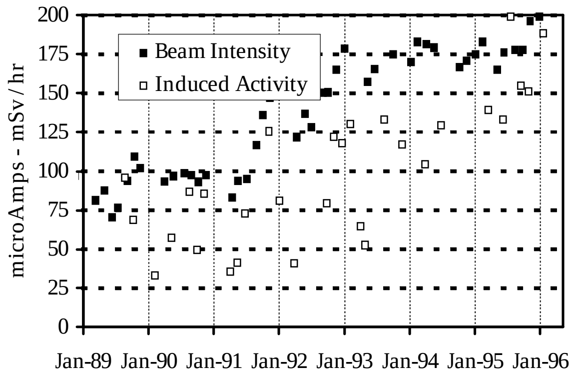

Figure 1. Average beam intensity/induced activity.

machine conditions and monitoring systems are used to detect beam loss and trip off the beam if such loss exceeds predetermined levels. There is, however, always beam loss, caused during machine setting up and machine physics periods and by the inefficiencies of the beam trapping or acceleration processes, beam instabilities, beam/residual gas scattering, failure of components or incorrect operation of the accelerators. This beam loss will result in above background levels of induced activity of components. Fig. 1 shows a correlation between average ‘beam on target’ operating intensity and total induced activity. This has occurred even though the allowed rate of beam loss has been maintained constant over the period.

3 MINIMISING BEAMLOSS

3.1 General operational control

Minimising beam loss, at all operating levels, is achieved in the first instance via administrative action by the operation crews, headed by an experienced Duty Officer. Following laid down and frequently reviewed operational procedures, changes in machine characteristics and performance are acted upon immediately. Continuous on-line information e.g. beam loss spill, beam intensity and position and various efficiency factors, provides the Duty Officer with sufficient data for him to be able to assess and judge the performance of the accelerators and to take any action as necessary. An ‘on call’ system enables advice and support to be available 24 hours a day during operational periods. Backing this operator (or manual) system of control are two independent monitoring systems operable at all machine repetition rates except ‘base rate’. Used when beam physics experiments, setting up operations or when investigation of fault conditions is required, this default repetition rate (50/32 Hz) enables such work to proceed unhindered by frequent interruption to beam. Such periods of operation, which can lead to an increase in activity levels, are carefully controlled.

3.2 Beam loss monitoring system.

Previously described [1], the beam loss monitoring system (BLM’s) provides a real time on-line display of prompt beam loss, together with beam warning, automatic beam trip and data logging. Analogue signals from each of 66 ionisation chambers, located close to the accelerators and extracted proton beamline, are integrated over the appropriate machine pulse lengths and fed to three dedicated graphics displays in the Main Control Room (MCR). These beam loss displays, covering the linac, synchrotron and extracted proton beamline, are a powerful diagnostic during machine running providing ‘at a glance’ indication of correct machine running. The integrated signals are also fed to a beam interlock unit where any signal greater than a predetermined level will result in either a warning or the beam being tripped. This monitoring, carried out on a pulse by pulse basis, gives a warning message for one pulse above the trip level and initiates a beam trip for 20 consecutive pulses above the trip level i.e. within 400 msec. Each analogue signal can also be accessed and monitored for diagnostic purposes.

The distribution of prompt beam loss, as shown by the synchrotron BLM’s, and taken with ISIS operating at a beam current of 200 μA (2.5 E13 protons per pulse), is shown in Fig. 2. As can be seen the loss is confined to superperiods 1 and 2 where graphite beam collectors

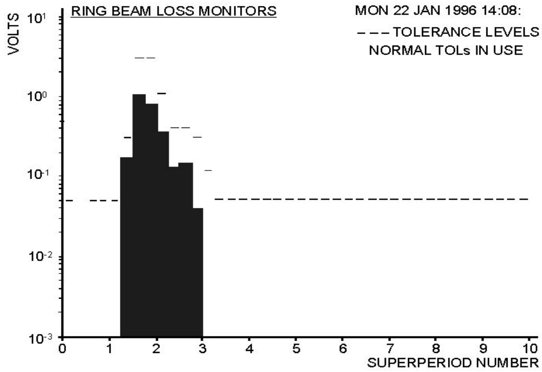

Figure 2. Prompt beam loss in the synchrotron.

intercept beam lost in the trapping process, typically of the order of 12%. There is no loss in the rest of the ring above the 1 mV level. The horizontal bars indicate the trip level allocated for each loss monitor. A typical trip level outside superperiods 1 and 2 is 50 mV, equivalent to a beam loss of 1 E11 ppp at injection and 2 E9 ppp at extraction.

3.3 Beam Intensity monitoring system.

The intensity monitoring system, based upon the analogue signals derived from toroidal current transformers, provides real time intensity data from the accelerators and the extracted proton beam line. In a system analogous to that for the BLM’s described above, the signals are processed to give efficiency figures, data logging and a beam loss warning and beam trip facility.

The individual analogue signals are also available for diagnostic purposes. Displays in the MCR give the intensity in protons per pulse, and efficiency figures, derived from the intensity data, for the injection, trapping, acceleration, extraction and extracted beam transport processes. Warning of increased loss of intensity for any of the above processes is given over two time periods, 20 minutes and 30 seconds. Automatic beam trips are initiated either for a 25 pulse averaging loss, or for 3 consecutive pulse loss. The beam is therefore switched off in 60 msec, before any severe damage might occur.

The current intensity loss warning and trip levels are shown in Table 1. With these levels and an injected beam of 2.9 E13 ppp, warnings of increased injection loss are displayed for loss exceeding 3.1%, averaged over 20 minutes, and for loss exceeding 4.5% averaged over 30 seconds. A beam trip will occur for loss

Table 1. Tolerances for Intensity Loss (1988 levels in brackets).

LOSS AT (protons/pulse)	20 MINUTES WARNING	30 SECONDS WARNING	25 PULSE AVERAGING TRIP	3 PULSE IMMEDIATE TRIP
INJECTION	9.0 E+11 (7.0 E+11)	1.3 E+12 (1.0 E+12)	1.5 E+12	4.9 E+12
TRAPPING	4.2 E+12 (1.5 E+12)	4.3 E+12 (2.0 E+12)	4.5 E+12 (3.0 E+12)	4.9 E+12
ACCELERATION	2.0 E+11 (7.0 E+11)	2.5 E+11 (1.0 E+12)	5.0 E+11 (1.2 E+12)	2.0 E+12
EXTRACTION	1.0 E+11 (2.5 E+11)	2.0 E+11 (4.0 E+11)	5.0 E+11	1.0 E+12
EPB LINE	6.2 E+11 (1.5 E+11)	6.5 E+11 (3.0 E+11)	7.0 E+11 (5.0 E+11)	1.0 E+12
TOTAL LOSS	5.2 E+12 (2.0 E+12)	5.6 E+12 (2.5 E+12)	6.0 E+12 (3.0 E+12)	6.1 E+12 (4.9 E+12)

exceeding 5.2% averaged over 25 pulses and for loss exceeding 16.9% for three consecutive pulses. These tolerance levels are quite tight when compared with the typical 2-3% loss currently achieved.

The two independent systems provide different but complementary levels of protection. The beam intensity monitoring system gives early warning of increased beam loss and a fast beam trip in the event of equipment malfunction, whilst the more sensitive BLM system can detect and act on loss, caused for example by equipment instability, not detected by the beam intensity system.

4 INDUCED ACTIVITY

Over 200 hundred predetermined points around the accelerators are regularly monitored for levels of induced activity, usually prior to any maintenance or installation work. This data is analysed, in a spreadsheet format, to give information regarding trends in induced activity and therefore changes in accelerator operating conditions. The histogram, Fig 3, shows the average 'on contact' induced activity for all superperiods of the synchrotron, except superperiod 1 (SP1), together with the injection (HEDS) and extraction beam transport lines (EPB). The beam collectors situated in SP1 give high levels of activity > 50 mSv/hr, and are only measured when necessary.

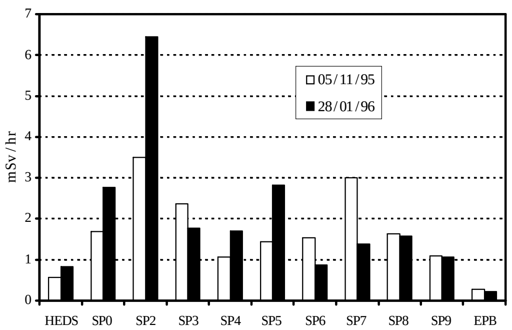

Figure 3. Average induced activity.

The two sets of data shown cover the period of the recently achieved 200 µA operation and show that the induced activity has increased in the HEDS, in SP0, (the injection area) and in SP2, 4 and 5. In the other areas of the synchrotron the induced activity has actually decreased. It is possible to continue this type of analysis by looking at the loss patterns making up, for example, the increased loss in SP2 so giving trends of loss on particular components. Correlation is then sought with accelerator operating conditions.

This data, whilst useful to the machine physicists, is of primary importance when planning and scheduling maintenance and installation work. It is clear, from Fig. 3, that even in the 'cooler' areas of the accelerator, on contact levels are at or approaching the 1 mSv/hr level. Personnel working in these areas could therefore receive high radiation doses in a very short time. Forward planning and control of all work is therefore essential if dose levels are to be minimised. The data is also available to project engineers responsible for the design and modification of components enabling them to be kept up to date and aware of the level of hazard that may be met in any particular area of the machine.

5 WORK IN RADIATION CONTROLLED AREAS

It was recognised in the early stages of ISIS that good design practices and the use, where possible, of time saving devices built into components would reduce installation and removal times. These devices range from the use of kinematic mounts, so that components can be pre-aligned before installation, to the use of 'quick disconnects' for electrical and water connections. A manual hands-on maintenance regime could not be sustained without such devices and their continual design and development.

Planning is an essential part of dose minimisation and a written hazard assessment, for each major job, is prepared by the project engineer together with the installation engineer and Health Physics advisors. This assessment breaks down the job into its component tasks and, after determining induced activity levels around the area of work, allocates a time to each task and the expected dose to personnel. Extensive use is made of photographs, drawings and previous experience. Any requirement to design, manufacture and test special shielding or tools will be highlighted. Detailing the work in this way enables possible problems to be discussed, identified and resolved before the work starts. Trial or dummy runs are performed for major new installations and these will often highlight potential installation problems.

The nature of work carried out in the radiation controlled areas range from relatively simple and quick maintenance jobs, such as replacing failed vacuum gauge heads, to complex jobs such as replacing a magnet assembly which can involve many different and often complex tasks. It is important that a high degree of control is exerted for all work, however simple, and at all stages, so as to minimise occupancy of the radiation controlled areas.

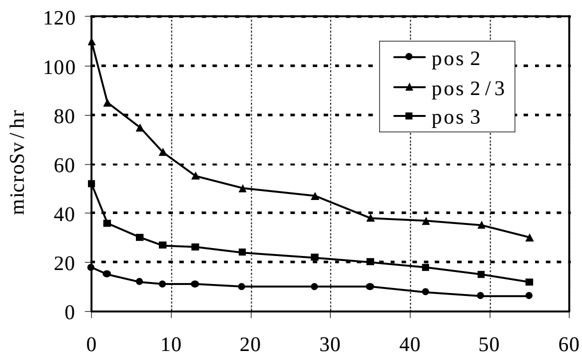

Figure 4. Synchrotron induced radiation decay.

All work in the controlled areas must be authorised by the Duty Officer who, in his capacity as a Radiation Protection Supervisor, is responsible for ensuring that all work in radiation areas satisfy the requirements of the Ionising Radiation Regulations. He carries out a detailed induced activation survey of the work area and assesses each separate job to be undertaken. He will be advised by health physics personnel especially when a job hazard assessment has been prepared. If necessary he issues a Radiation Permit to Work to the work supervisor, which details, amongst other things, dose limit, personal dosimetry to be worn and the precautions and conditions that need to be taken in order to minimise the overall dose. This Permit is signed by all personnel engaged in the activity signifying that they understand the nature of the hazard and the conditions and precautions that apply. All work, once underway, is continually assessed by the Duty Officer and Health physics personnel to ensure that conditions of the Permit are being followed and that dose levels are not exceeding expected levels. In addition, the project and installation engineers will continuously monitor work progress with reference to the hazard assessment and the received dose.

Minimising collective dose for all work in active areas involves the use of one or more of the following standard methods for radiological protection against external radiation - Time - Distance - Shielding.

5.1 Time

The collective effect of the natural half-life decay of the various nuclides making up the overall induced activity level is shown in Fig. 4. During the first 8 weeks of a major shutdown there is an initial steep decay, over the first 10 to 15 days, followed by a more constant decay. To obtain the maximum benefit from this natural decay no major installation or maintenance work, in the more active areas, is scheduled to start earlier than 20 days into a shutdown. Restricting time of occupancy in active areas, as detailed in the hazard assessment, is another important feature in minimising dose.

5.2 Distance

In a hands-on regime it is almost always beneficial to operate at a distance with, for example, long handled devices.This is not true if an increase in operating time

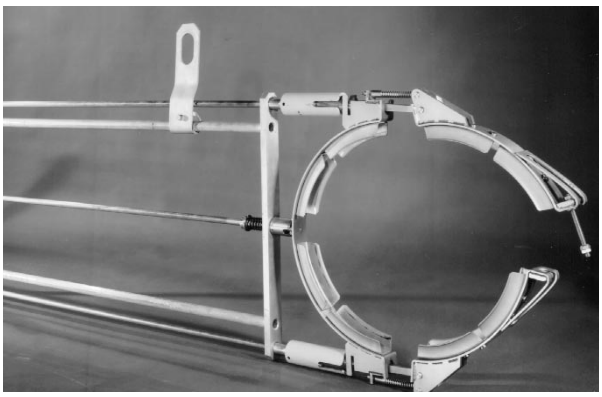
Figure 5. Long-handled vacuum clamp.

in using a device counteracts the benefit of distance. They must, therefore, be well designed for quick and simple operation. They are especially effective for repetitive tasks where many similar tasks are required to be carried out. An example is the device for making and breaking UHV vacuum clamps in the synchrotron, Fig. 5. This enables an operator to remain at a distance of over 2 metres so reducing the operator-received dose by over an order of magnitude.

5.3 Shielding

Use is made of a variety of shielding techniques to reduce background activity to levels were work is assessed as able to proceed. Large concrete blocks are manipulated into position to shield open areas from gross radiation effects. These cannot however, due to their bulk, easily provide localised shielding around equipment and beam pipes and so use is made of purpose built contour or profile shielding, Fig. 6, and local personnel shields to give more detailed protection. Constructed of lead, and lead glass for windows, they can easily be craned into position from a distance. Lead sheet is extensively used to provide additional local shielding as required.

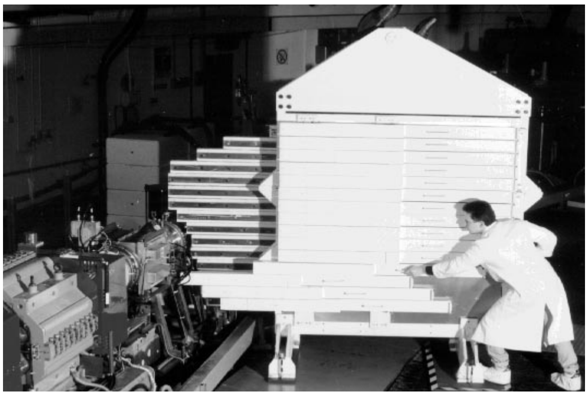

Figure 6. Profile Shielding

It is clearly of benefit to use, whenever possible, a combination of the above three methods of radiological protection and install purpose designed equipment, especially where frequent and immediate access to active areas is necessary. An example is the new semi-automated foil change mechanism, which has a lengthened loading platform, automated vacuum and foil loading processes, and purpose built shielding. These changes, when compared with the previous foil change mechanism, have increased the distance from active components, reduced the time of occupancy and reduced the ambient induced activity levels. The overall effect has been to reduce the collective dose for a foil change by a factor of five. The creation of a less stressful environment is an added benefit. and has resulted in foil replacement, which requires a calm approach and a steady pair of hands, being carried out more successfully.

6 CONCLUSIONS

ISIS operates a hands-on regime for all work in the accelerator areas. Control of beam loss by means of administrative action and by automatic beam loss warning and beam trip systems minimises beam loss during operational periods. Suitable design of components facilitate the easy removal and adjustment of equipment. Procedures and methods of assessment are used to control rigorously all work carried out. That these controls and procedures are increasingly successful can be seen in Fig. 7. A generally falling level of collective dose, for all ISIS personnel, has been achieved in spite of increased operating intensity and induced activity levels. No individual has received a dose of more than 5 mSv in any year.

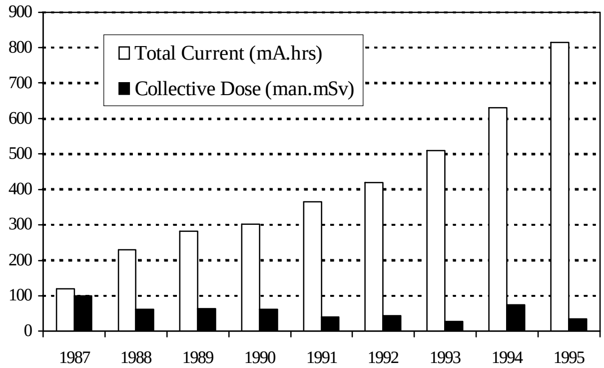

Figure 7. Collective dose rates.

These collective dose levels are also consistent with operating an ‘active handling’ maintenance regime within the reduced occupational dose limits currently being promulgated.

7 ACKNOWLEDGEMENTS

The continuing successful operation of the ISIS accelerators is due to the dedication and resourcefulness of all staff in ISIS Source Divisions.

8 REFERENCES

[1] M.A. Clarke-Gayther, A.I. Borden and G.M Allen, Global Beam Loss Monitoring Using Long Ionisation Chambers at ISIS. Proc. EPAC 94, London, 1994, p 1634.