ACTIVATION MODELS OF THE ISIS COLLECTORS

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Abstract

The ISIS facility at the Rutherford Appleton Laboratory is a pulsed neutron and muon source, for materials and life science research. The 163 m circumference, 800 MeV, 50 Hz rapid cycling synchrotron accelerates up to 3×10^{13} protons per pulse.

The maximum operating intensity of the synchrotron is limited by loss during acceleration, mainly due to the non-adiabatic longitudinal trapping process between 0 and 3 ms, corresponding to energies between 70 and 200 MeV. In order to minimise global machine activation and prevent component damage a beam collimation, or collector, system is installed in a five metre drift section in super-period one, to localise loss to this region.

This paper summarises new results from modelling of the beam collectors using the FLUKA code [1, 2]. Understanding the current performance of the collectors is important for high intensity beam optimisation and may influence future injection upgrade plans. Residual dose rates are compared to film badge measurements, predicted energy deposition results are compared to the measured heat load on the collector cooling systems and an assessment is made of the distribution of particles exiting the collector straight.

THE ISIS COLLECTORS

Upgrades were made to the ISIS collector system in 2001, as part of the refurbishment of straight one, in preparation for expected increased losses at higher energies following the dual harmonic RF upgrade [3]. The upgrade aimed to optimise machine protection within the tight constraints of the existing lattice and straight.

The collectors provide vertical betatron and combined horizontal betatron and momentum collimation. The primary jaws define the usable aperture and are split into upstream and downstream sections. The upstream jaw of each primary collector has a copper lip, designed to enhance the scattering from particles with shallow impact depths. Secondary, single jawed, collectors are located at optimal betatron phases downstream and are designed to minimise residual activation by intercepting out-scattered particles.

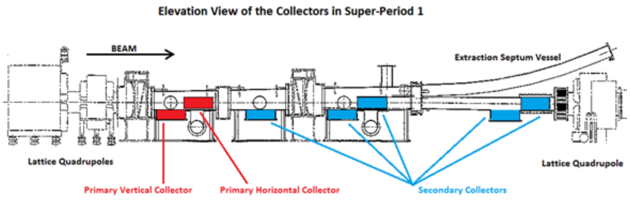

Figure 1: Elevation view of the primary and secondary collectors in super-period one.

The collector jaws are profiled to match the nominal beam envelope and are manufactured from high density graphite blocks mounted on water-cooled copper. In total there are now ten collectors: three Primary, VCP1, HCP1, HCP2 and seven Secondary, VCS0, VCS1, HCS1, HCS2, VCS2, HCS3 and HCS4, Figure 1.

All of the collector jaws are movable and can be positioned to achieve acceptances of 45-100%. When fully withdrawn each collector is 7 mm clear of the nominal beam envelope. The total length of graphite seen by the beam in each collector is 310 mm. Vertical extraction from the synchrotron at 800 MeV also takes place in super-period one and consequently there are no vertical collectors at the top of the vacuum vessel.

Previous simulations of proton out-scatter and beam loss, during the design and commissioning phase, agreed well with measurements. [3].

MOTIVATIONS FOR STUDY

A detailed and comprehensive study of the activation of the ISIS collector operation is important for beam loss control studies on the loss-limited synchrotron. Better understanding and control of beam losses will allow operation at higher intensities through localised activation and lower doses. These studies will form the basis for understanding the residual activation of machine components, the transverse and energy distribution of out-scattered particles and the response of beam diagnostics to secondary particles. Results from these studies will also help to produce collimator specifications, including materials and geometries, for future upgrades.

FLUKA MODEL

A model of the ISIS collector system has been built in FLUKA. The model includes the individual profiled graphite blocks and copper base for each collector and the surrounding vacuum vessel, Figure 2.

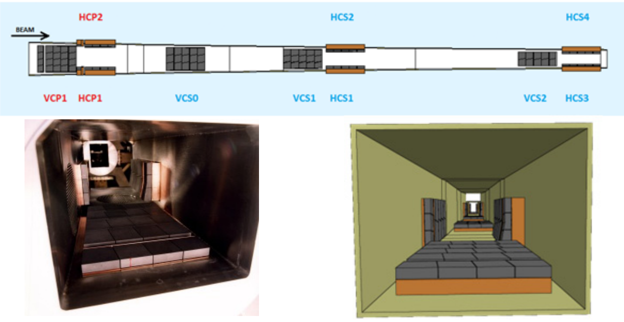

Figure 2: Schematic plan view of the collector system (top), photograph looking downstream in the collector system (bottom left) and a downstream view into the collector system from FLUKA (bottom right).

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The beam source for FLUKA was generated by an ORBIT simulation of the first 3000 turns of an ISIS cycle (-0.4 to 3 ms), when the majority of loss occurs [4, 5]. There were 2.66×10^{6} macro-particles in the ORBIT simulation, representing 2.8×10^{13} real particles. 5.1% were lost in super-period one which agrees with operational intensity monitor measurements. Loss is concentrated on the vertical (81.1%) and inner radius horizontal (18.6%) primary collectors with almost all of the lost particles having an energy of less than 100 MeV, as expected, Figure 3.

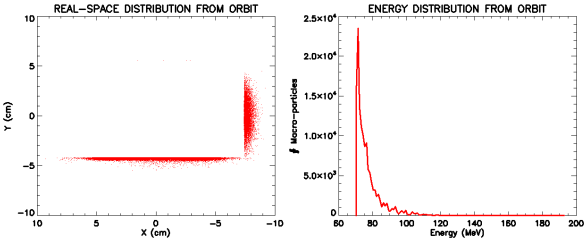

Figure 3: Real-space projection over all z-values and energy distribution of beam loss in super-period one from the first 3000 turns of an ORBIT simulation.

Rectangular black-body apertures were used to model the collector upstream faces in the ORBIT simulations, preventing lost beam from scattering. In FLUKA the available aperture is calculated at the position of the upstream collector edge, but the collectors are also profiled longitudinally.

To best approximate ISIS operational conditions in the FLUKA model both the upstream and downstream jaws of VCP1 and HCP1 were set to 75%, with the upstream and downstream jaws of HCP2 at 100% and 95% respectively and all of the secondary collectors were positioned to allow 80% clear aperture. In the ORBIT model the available apertures were set to 75% for VCP1 and HCP1 upstream and downstream jaws, with all other collector apertures set to 100%.

Within the FLUKA model multiple Coulomb scattering was enabled globally with the default optimisations, but for small steps, or near boundaries, single particle scattering is invoked. FLUKA 'precision' default particle production and transport thresholds were used.

RESULTS

Power and Energy Deposition

The total power dissipated in the ISIS collectors, calculated from energy depositions in FLUKA, is 663 W. The typical measured heat load on the collector cooling system is between 500 and 1500 W, but it is designed to withstand a maximum heat load of 10 kW. Variations in operational collector power loads are due to the differences in beam setup, including closed orbit or envelope errors and longitudinal instabilities. There are no orbit or envelope errors in the ORBIT model so it seems appropriate that the calculated value is towards the low end of the observed values.

In the FLUKA simulation 75.5% of the energy from the lost beam is deposited in the collectors, giving a measure of the efficiency of the collimation straight. Most of the beam energy is deposited in the collector blocks, although there is some energy deposited in the beam pipe by scattered particles, Figure 4. The extraction septum vessel was not modelled and therefore extra scattering and energy deposition is observed where the beam vacuum vessel reduces in size, z = 927 cm.

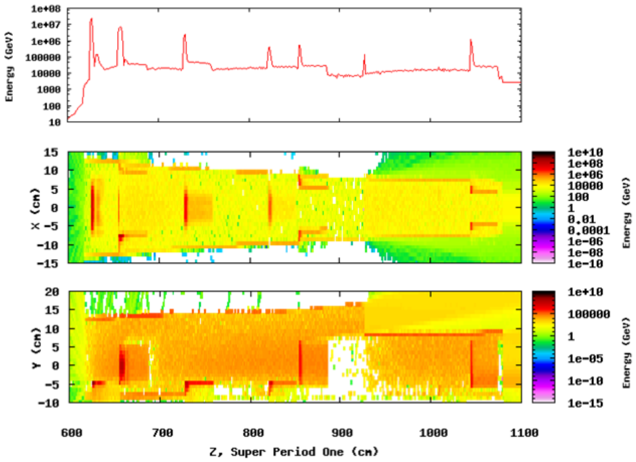

Figure 4: Projection, plan and elevation views of energy deposition along the collector straight. Peaks in the projection view correspond to collector faces and reduction of vacuum vessel size at 927 cm.

Residual Activation

In 2010 a set of dose rate measurements were made on the ISIS collectors to assess the activation [6]. After fifty days of synchrotron operation for an ISIS user cycle and thirty days of cool down, a set of twenty five Landauer Luxel+® [7] film-badge dosimeters were arranged 5×5 on a 20×40 cm grid and placed on top of the primary collector vacuum vessel for a twenty four hour period. The total doses measured by the dosimeters were converted to mSv/hr, assuming a constant dose rate, then linearly interpolated over the grid, Figure 5. The maximum dose rate was 173 mSv/hr.

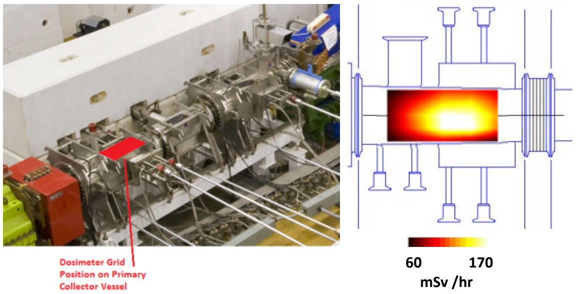

Figure 5: Photograph of the ISIS collector straight showing the region on the primary collector vessel where the grid of 5×5 dosimeters was placed (left). Interpolated dose rate results overlaid on schematic diagram of the same region (right).

The irradiation profile and cooling time was modelled in FLUKA as a constant 7.13×10^{13} real particles per second, using the ORBIT distribution. Initial results show that the maximum modelled dose rate was 415 mSv/hr, Figure 6.

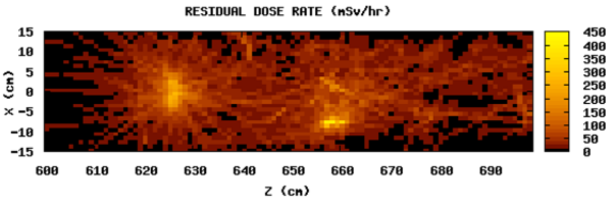

Figure 6: Plan view of the dose-equivalent rate over the primary collectors as calculated by FLUKA.

The FLUKA result is an average dose rate over all vertical planes in the primary collectors which includes contributions from all residuals. This is in comparison to the Landauer dosimeters which were 5 keV – 10 MeV gamma and beta detectors, therefore a higher predicted dose-rate from the model may be expected. Further refinements to the simulations will aim to better replicate the measurements.

Emerging Beam

The distribution of beam escaping from the end of the collector region was assessed. On average 2.06×10^{11} real particles emerged. Over 99% of these were protons and most had energies around 70 MeV, with the potential to be transported downstream, Figure 7. The non-proton products were mainly neutrons, electrons, photons, positrons, deuterons and alpha particles. Knowledge of both the transverse and energy distribution of particles escaping the collector region is important for downstream machine protection, especially the main dipole in super-period two [8].

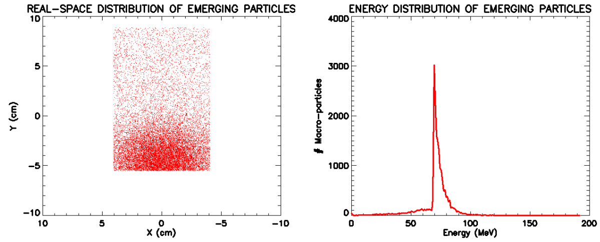

Figure 7: Real-space and energy distribution of scattered beam emerging from the end of the collector region.

CONCLUSIONS AND FURTHER WORK

A model of the collector straight in super-period one has been created in FLUKA and a representative beam distribution has been taken from beam loss in an ORBIT simulation of the ISIS synchrotron. Power and energy deposition agree with expectations from ISIS operations, and the model provides reasonable estimates for the resulting residual activation on the primary collectors. An initial assessment of the emerging beam distribution has been made.

Further work could be done to discriminate between the impact of different residuals on the dose rate within FLUKA. The emerging particles could also be tracked in the ORBIT model to see if they would fall out of downstream machine acceptance.

Improved knowledge of activation, scattering and secondary particle production will allow better optimisation and measurement of loss control on ISIS. Resulting improvements to machine protection and loss control are vital for future operations and upgrades.

Once the 70 MeV operation is well understood the model will be extended to predict residual activation for proposed 180 MeV injection scheme [9]. This upgrade aims to increase the beam intensity to 8×10^{13} protons per pulse, equivalent to 0.5 MW, whilst maintaining present radiation dose levels through a combination of reduced total losses and improved loss control.

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