BEAM LOSS SIMULATION OF SNS LINAC

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Abstract

We are developing a sophisticated system of beam loss pattern evaluation and residual radiation estimation. We have installed a number of Neutron Detectors (ND) and Ionization Chambers along the SNS LINAC. In this paper we present our implementation and simulation of the losses by inserting Faraday Cups, using Beam Stops and running Wire Scanners at different energies. The measured losses are simulated by 3-D transport codes (GEANT4, SHIELD, MCNPX). We compare two different sets of Beam Loss Monitors (BLM): Ionization Chambers (detecting X-ray and gamma radiation) and Photo-Multiplier Tubes with a neutron converter (detecting neutrons) and show that such a combination is a better way to measure beam losses than relying on detectors of only one type. We interpret the loss signal in terms of beam current lost in the SNS LINAC with accurate longitudinal loss distribution and plan to automate beam steering according to loss-monitor readings by using a Loss Pattern Database developed by simulating different loss scenarios with the transport codes.

INTRODUCTION

While the beam is being accelerated in the LINAC not all particles manage to traverse the entire system. Some of them are "lost," meaning that the particle hit some material and was absorbed, or penetrated some of the LINAC structure. This causes problems such as radiation around the LINAC, residual radiation and decreasing of LINAC power. All possible efforts should be made to minimize these losses.

The Loss Monitoring System has the following major goals: finding the physical locations of losses (places that were hit by lost particles); estimating the fraction of lost particles of the total beam; finding the reasons for such losses; and finding solutions to avoid the losses.

The primary goals of the system are: detection of secondary radiation caused by losses; mathematical and computer modeling of losses; comparison of the detected radiation; and projecting the most probable scenario that would cause the same losses.

DETECTORS

The main instruments for measuring losses in the LINAC are: BLMs (BNL [1]) sensitive to gamma radiation and NDs (INR, Russia [2]) sensitive to neutrons. The first type is an ionization chamber, and the second one is a PMT covered with scintillators sensitive to neutrons. The PMT's sensitivity is controlled by high-voltage bias, which makes it possible to use these detectors in a wide range of neutron flux intensities. The ionization chambers have no such capability.

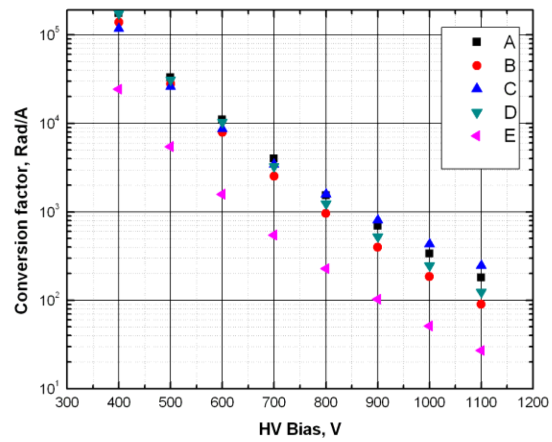

Figure 1: Typical HV dependence for NDs

COMPUTER SIMULATION

The major goals of Computer Simulation and Codes to be used include:

- Simulate different scenarios of particles losses in the LINAC. (PARMILA[3]).
- Simulate the full 3D transport of lost particles in the LINAC construction elements (including production of secondary particles and their further transport). Various Monte Carlo Transport Codes have been tried: SHIELD[4], MCNPX[5], GEANT4[6], EGS4[7], MARS[8].
- Simulate detector response for different scenarios of losses.
- Resolve the detector signals to obtain possible loss scenarios followed by those signals.

Unfortunately, all the codes that are useful for our purposes use different interfaces, programming languages, organizational concepts, input and output formats, etc. After careful consideration the GEANT4 has been chosen as the most appropriate code for following reasons:

- Vast flexibility of physics processes being simulated (this allows easy modifications of model properties without compromising the code integrity).
- Powerful geometrical capabilities of GEANT4 allow defining geometry setups of any complexity with no sacrifice of convenient-to-use modular structure.
- Outstanding geometry biasing and event management features of GEANT4 gives excellent opportunity for straightforward simulation of "lengthy" accelerator geometry (where the length of

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the accelerator is much greater than other dimensions).

- Object Oriented Design makes it easy to extend and interface GEANT4 to data acquisition and data analysis software.

All of the above provide for development of an integrated software environment that includes: loss monitor data acquisitions, loss simulation, and loss interpretation. The geometry definition is also shared with other accelerator applications (such as XAL[9]).

A number of default hadronic models are available in GEANT4. These models have to be treated very carefully since none of them is adequate as-is. That is why we are developing an in-house model (based on original GEANT4 hadronic models) to accommodate our needs.

SNS LINAC LOSS MONITORING

The Loss Monitoring system of the SNS warm LINAC consists of 36 BLMs and 20 NDs. The BLMs are not sensitive enough to pick up any signals unless the loss is huge and occurs close to the BLM. So the BLMs are able to see the gammas flying out of the Faraday Cup (which effectively imitates the 100% loss in local place).

The following plots show signals from BLMs and NDs taken when different Faraday Cups were inserted (the detector number and FC number increases along the length of the LINAC).

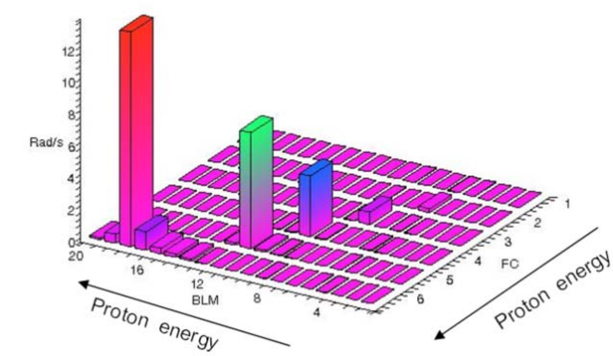

Figure 2. BLM Signals

As one can see on these plots the NDs are more sensitive to remote losses and BLMs.

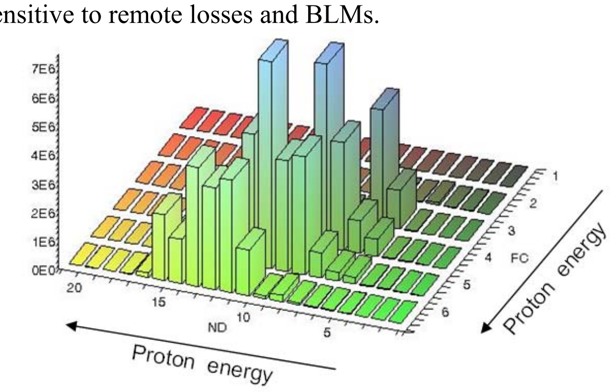

Figure 3. ND Signals

This confirms the choice of two different types of detectors as more efficient and providing more information about loss patterns.

The BLMs have the advantage of being faster than NDs, which allows for examination of the beam pulse shape, while ND signals have long exponential tails (due to the slowing down of neutrons in the moderator).

The ND signals were in good agreement with Monte-Carlo simulation of neutrons being produced in the Faraday Cup.

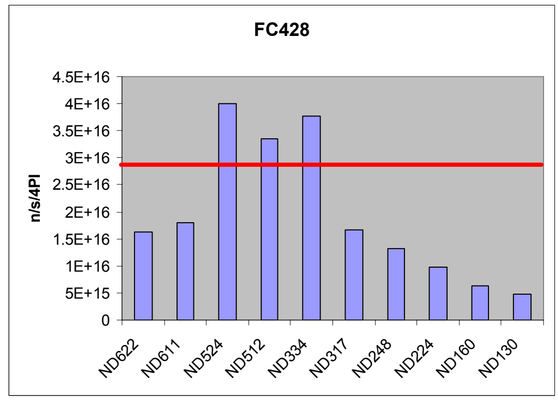

Figure 4. The calculated neutron intensity (red line) and measured results (blue bars)

This calculation was performed assuming that the neutron source in the Faraday Cup is isotropic (which is true to some extent since the main neutron production mechanism is neutron evaporation). But it shows that while this isotropic approach is good enough for rough estimation of neutron fluxes near the source (ND524, 512, 334 were close to the inserted FC), more-accurate simulation of geometry configuration and material composition is needed to fully understand readings of detectors picking up remote losses.

Figure 4 also shows that converting lost signal back into number of lost particles is no trivial task. There is no simple "conversion factor." The same loss reading could correspond to many different loss scenarios. This happens due to superimposition of signals originated in different locations. Thus, interpreting the loss in terms of beam current lost in the LINAC requires solving of integral equations (multidimensional Fredholm integral equations of the first type). The losses resulting from point source of loss (δ-function source) serve as an integral kernel. So running Monte-Carlo simulations builds this integral kernel.

The neutron detectors are also important for estimation of residual radiation. The hadrons (but not gammas) are the main input to residual contamination, so the measurements of neutron fluxes are more correlative to residual dose.

The rough calculation of low-energy neutron yield under proton irradiation shows that neutron detectors capable of detecting a wide range of neutron flux intensities are needed.

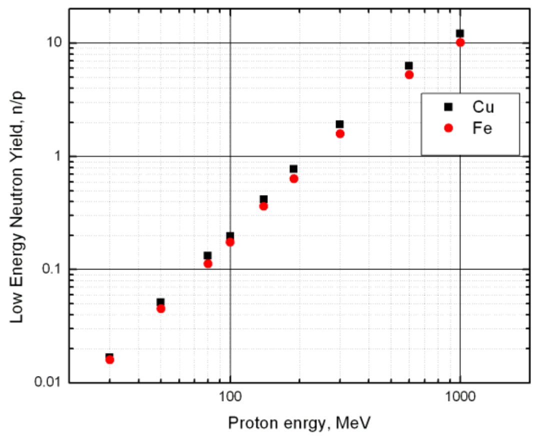

Figure 5. Calculated neutron yield from copper and iron targets.

All of the above allows us to conclude that both types of detectors have advantages and disadvantages: BLMs are less sensitive and pick up local losses only; NDs are much more sensitive and pick up remote losses, but the data are much harder to interpret.

At higher-energy regions (SCL, Ring, etc.) the disadvantages of BLMs are not so important. The BLMs are able to detect signal from Wire Scanner-induced losses.

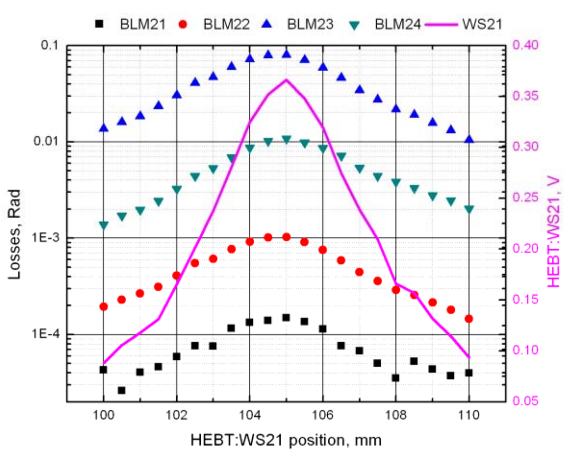

Figure 6. BLM signals correlate with WS position

FUTURE DEVELOPMENT OF LOSS MONITORING SYSTEM

The BLMs and NDs showed themselves well-suited for loss monitoring in the SNS LINAC. We have chosen the main simulation package and started mapping the real-world to simulation-model geometry. We are also in the process of developing specific hadronic models to suit our needs.

The possible algorithms to be used for solving the integral equation are modified Integral Equation Neumann Series and Monte-Carlo sampling.

The fully-automated software system to completely understand the losses at SNS is still in development.

CONCLUSIONS

Beam loss monitors are an essential part of the SNS operations and power ramp up. We are continuously improving detector design in collaboration with INR. Simulations are used to validate measurements and understanding of the entire system. Residual radiation measurements and comparison with predictions is the focus of our team. This will assure hands-on maintainability and repairs.

ACKNOWLEDGEMENT

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