*CORRELATION OF BEAM LOSS TO RESIDUAL ACTIVATION IN THE AGS**

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ABSTRACT and INTRODUCTION

Studies of beam loss and activation at the AGS have provided a better understanding of measurements of beam loss and how they may be used to predict activation. Studies have been done in which first order correlations have been made between measured beam losses on the distributed ionization chamber system in the AGS and the health physics recorded residual activation. These studies have provided important insight into the ionization chamber system, its limitations, and its usefulness in the prediction of activation based on monitored beam loss.

In recent years the AGS has run high intensity protons primarily for rare kaon decay experiments. In this mode of running the AGS typically accelerates beam from an injection momentum of 0.644 GeV/c up to a slow extracted beam (SEB) momentum of 24.2 GeV/c. The beam intensities are on the order of 4.5 x 10^{13} protons per AGS cycle at injection to as high as 1.9 x 10^{13} protons per AGS cycle at extraction. Residual activation varies around the AGS ring from the order of 5 mR/hour to levels of the order at 5 R/hour. The highest levels occur around the AGS beam catcher and the extraction equipment.

COMPARING BEAM LOSS TO ACTIVATION

The dose rate from activation induced by high energy particles interacting with a material such that a large number of isotopes are produced can be expressed by [1,2]

$$D = k\,\xi\,ln\,(1 + T/t), \qquad (1)$$

Where ξ is the number of high energy particles per interaction and k is a constant for any set of irradiation, target and geometrical conditions. The time T is the amount of time the material was bombarded with high energy particles (the irradiation time) and the time t is the time elapsed after the bombardment stopped (the cool-down time). There are two basic assumptions behind this relationship. The first is that a sufficiently large number of different isotopes are produced by spallation reactions such that the half-life distribution among isotopes can be approximated by a continuous function. The second assumption is that since activity is not measured until after over 15 minutes of cool-down has lapsed and before a period of two years has elapsed, reasonable limits can be placed on this continuous function to enable a relatively simple expression to be derived [3,4,5].

There are 120 ionization chamber monitors distributed around the AGS ring, one every 3° of the accelerator circumference. Each monitor is located on the underside of the main magnet girders along the outside of the ring. Each subtends two main magnets, these monitors were sampled at regular intervals while the AGS was running for its' physics program. At the end of the run a total of N measurements had been made of beam distributions around the ring. A single measurement is called r (ϕ, ϵ, n), where ϕ is the position (every 3°), ϵ corresponds to beam energy, and n represents one of N samples. Since the effect of a beam loss ξ_n decreases at some rate R_n, where ξ_n corresponds to a measurement made at a time t_n, then the weighted average beam loss distribution at the end of the physics run will be;

$$<r\,(\phi,\epsilon)> \;=\; \frac{\sum_n r\,(\phi,\epsilon,n)\cdot Rn}{\sum_n Rn} \qquad (2)$$

By taking Rn as

$$R = \ell n \left(1 + \frac{t_w}{t_f - t_n}\right), \qquad (3)$$

where t_w is the amount of time for beam loses (i.e.; beam is accelerated for ~ ½ sec so t_w is taken as 0.5 sec), and t_f is the time at which the run ended, then the measured beam loss is now weighted to the decay rate of the induced activation.

The absolute amount of beam lost is measured using beam current transformers. These also were sampled at regular intervals for the duration of the physics run. The weighted average beam loss at an energy ϵ for the entire run is then

$$<\xi(\epsilon)> \;=\; \frac{\sum_n \xi(\epsilon,n)\cdot Rn}{\sum_n Rn} \qquad (4)$$

The measured beam loss distribution around the AGS is

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$$<\xi(\phi,\epsilon)> \; = \; <\xi(\epsilon)> \cdot \frac{<r\;(\phi,\epsilon)>}{\sum\limits_{\phi}<r\;(\phi,\epsilon)>} \qquad (5)$$

The background activation and the background activation decay rate were measured before the physics run began. The activation added during the physics run was then calculated from the activation measured just after the physics run ended. So at a particular location ϕ the added activation due to beam lost during the physics run is

$$D\;(\phi) \; = \; \sum_{i=\epsilon} k\;(i) \cdot <\xi(\phi,i)> \cdot R \qquad (6)$$

where R = $ln(1 + T/t)$. (7)

Since the amount of material between a point of a beam loss and the point of which scattered particles interact with the ionization chamber is not a constant, the value of k will vary with the changing thickness of material around the ring. This is because the variations in the amount of target material/absorber will cause variations in the measured loss in the ionization chambers. Since there is a distinct periodicity in the location of elements in the AGS then these variations in k should show up systematically around the AGS. In order to try to normalize out these geometrical variations the above relationship is altered slightly. So,

$$D\;(\phi) \; = \; \sum_{i=\epsilon} \frac{k(i)}{g(\phi,i)} \cdot <\xi(\phi,i)> \cdot R \qquad (8)$$

In the AGS $<\xi(\epsilon)>$ occurs only at three particular times in the accelerator cycle. This simplifies the above sum to just three terms and this reduces the problem to n equations with 3n/12 + 3 unknowns. If g(ϕ) is not independent of energy then there are n/12 + 3 unknowns. For 120 monitors we can have as many as 33 unknowns (the periodicity of the AGS lattice is 12).

Data and Results

The results presented in this report represent the combination of data taken during two SEB physics runs at the AGS. When necessary, I distinguished between these two runs by labeling them RUN1 and RUN2, respectively.

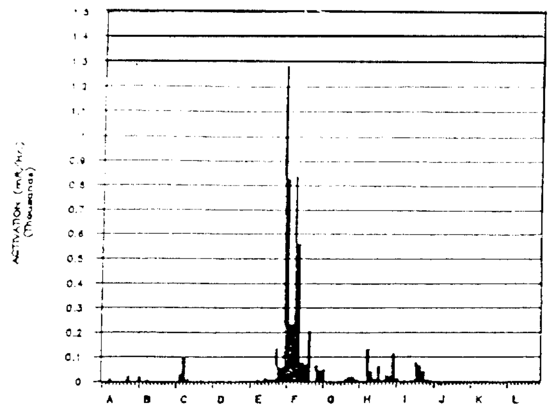
Figure 1 is an example of the activation added during RUN2. The uncertainty in these estimates is about ± 50%.

The weighted average beam loses are given in Table 1 below.

Table 1 Values of $<\xi(\epsilon)>$

	Irrad.T (Hours)	Cool t (Hours)	Inject. (200 MeV-1 GeV per hour)	Trans. (8 GeV) per hour	Ext. (24 GeV)
RUN1	455	5.75	1.9×10^{16}	8.3×10^{14}	3.4×10^{14}
RUN2	1000	46.0	2.8×10^{16}	1.2×10^{15}	6.0×10^{14}

Figure 1 Estimated Added Activation
RUN2



AGS Superperiods

The uncertainty in these values varies but are of the order of ± 10 - 25%. An example of the weighted average beam loss distributions at transition energies and at extraction energies are shown in Figures 3 and 4. These are also from RUN2. Uncertainties in these values also vary but are on the order of ± 100%.

Values for k/g were calculated using equation (8). As can be seen in Figures 1, 2 and 3 beam losses tend to be concentrated in certain areas. This greatly reduces the number of usable measurements. Figures 4 and 5 show the resulting values of k/g for transition energy losses and extraction energy losses versus other positions in a superperiod. (The exact location is given as a label for the data point, i.e., L10, G14, etc.) In both figures it can be seen that values of k/g for the upstream half of a superperiod (first 10 magnets) are consistently greater than values for the downstream half. This is actually quite easily explained. In the AGS, for every superperiod, the first 10 main magnets have their backlegs facing toward the outside of the ring while the last 10 main magnets have their backlegs facing towards the inside. Since loss monitors are located only on the outside the difference becomes obvious.

Since there is more material between the point of a loss and the point at which the scattered flux intersects an ionization chamber in the upstream half of a superperiod, then the expected signal from the chamber would be smaller, thus making ξ smaller and giving a larger value for k/g. So at least two values of g can be determined for each energy. In Table 2 the values for k/g, k, and g are presented.

Figure 2 Wt. Av. Loss Distributions
RUN2 Transition Losses

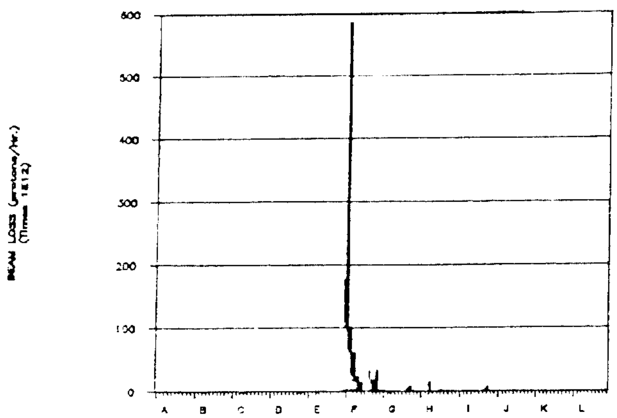


Figure 3 Wt. Av. Loss Distribution
RUN2 Extraction Losses

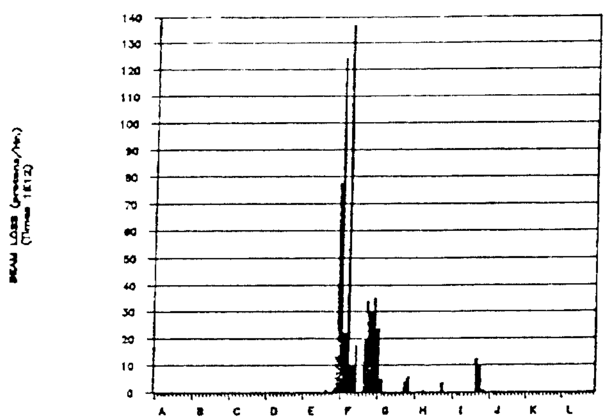


Figure 4 Value of k/g vs. Position
Transition Energy

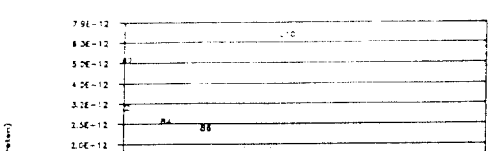
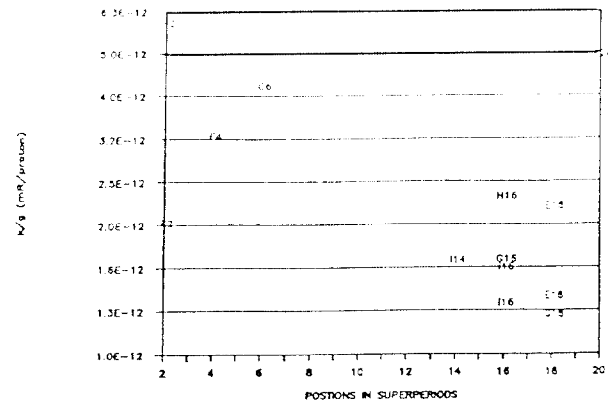


Table 2 Average Values of k/g, k and g

	US k/g	DS k/g	k	USg	DSg
Injection		5.8×10^{-15}			
(± Stand.Dev.)		±170%			
Transition	3.2×10^{-12}	6.0×10^{-13}	1.9×10^{-12}	0.59	3.2
(± Stand.Dev.)	± 56%	± 52%	± 51%	± 0.4	±0.5
Extraction	4.5×10^{-12}	1.6×10^{-12}	3.1×10^{-12}	0.69	1.9
(± Stand.Dev.)	± 24%	± 22%	± 21%	±0.2	±0.5

{Units for k/g and *k* are mR/hour/proton/hour}

Figure 5 Extraction Energy



CONCLUSION

An understanding of the AGS ionization chamber system has been greatly improved. At high energies there appears to be at least a factor of 2 difference in response between monitors in the upstream and downstream halves of a superperiod. At lower energies this factor appears to get even larger. By measuring the absolute amount of loss in the different locations around the AGS it is possible to predict within ± 50% the maximum amount of activity induced in those areas.

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REFERENCES

1. An Approximate Relation for the Prediction of the Dose Rate from Radioactivity Induced in High Energy Particle Accelerators, A .H. Sullivan, Health Physics, Vol. 12, (August 1972) pp.253-255.
2. Induced Radioactivity and its Relation to Beam Losses in the CERN 26 GeV Proton Synchrotron, A.H. Sullivan, Nuclear Instruments and Methods in Physics Research A257, (1987) pp.185-188.
3. Induced Radioactivity, Marscel Barbier, CERN, 12969.
4. Accelerated Health Physics, H. Wade Patterson and Ralph H. Thomas, LBL, U. of Colo., Berkeley, 1973.
5. Beam Loss and Induced Activation in the AGS, K.A. Brown, BNL AGS/AD/Tech. Note #337 (internal note), April 1990.
6. 1987 Particle Accelerator Conference, K. Brown and M. Tanaka, Studies of Induced Radioactivity at the AGS (BNL No. 39325).
7. Lessons for Kaon Factories from the CERN PS, Y. Baconnier, Intern. Workshop on Hadron Facilities Tech., Santa Fe., February, 1987.