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Decay Rate of Long-Lived Radioactivity Induced in the AGS Ring during the FY1994 HEP/SEB Run

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Technical Note

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1. Introduction

The AGS proton beam intensity has been rapidly increasing with the Booster and by upgrading AGS machine components (specially the rf system) and adding beam diagnostic tools. During the 3-month long FY1994 HEP/SEB run, $2.0\text{-}4.0 \cdot 10^{13}$ protons per pulse were continuously accelerated at AGS compared to $1.2\text{-}1.8 \cdot 10^{13}$ ppp a few years ago. The beam intensity is expected to increase to $5\text{-}6 \cdot 10^{13}$ ppp during the FY95 HEP/SEB run, which will last 4-5 months. This makes the AGS the most intense source for secondary beams and is essential for the ongoing and future AGS HEP program (rare kaon decay, g-2 and neutrino oscillation). On the other hand, beam-loss induced radioactivity in the AGS ring is also increasing as well since 1) the SEB extraction efficiency remains 95-96% due to the finite thickness of the H20 electrostatic septum and 2) the AGS still has a high loss at injection despite increasing the injection momentum from 0.644 to 2.32 GeV/c and 3) an increase of beam emittance with intensity. Exposure to it accounts for a major part of the dose received by the AGS personnel and constrains hand-on maintenance work and AGS operation.

This note is to estimate the average properties of long-lived radioactivity induced by beam losses at the AGS during the FY94 HEP/SEB(p) run based on the AGS ring radiation survey results conducted by Health Physics.

2. Data

2.1 AGS Main Ring Radiation Survey

Health Physics personnel conducted a complete radiation survey of the AGS ring a) on 08 August 1994 after a 7-day cooling time from the end of the HEP/SEB run and b) on 01 November 1994 immediately (2.5 hours) after the end of the HIP/SEB(Au) run. The radiation level (dose rate D in mrad/hr) was measured at 30 cm (=12") both *inside* and *outside* from the vacuum pipe (Inconel 750) at the upstream end of 240 AGS straight sections with a dosimeter (Teletector). Results are plotted in Figures 1.a and 1.b in semilog scale. The similar fine structure is revealed in both figures. The predominant peaks are located at injection and extraction areas, and are summarized in the following table together with the measurement on 16 March 1994 during a machine study/setup period:

Straight Section	23. Mar.94† R_{out}, R_{in} [mrad/h]	08.Aug.94†† R_{out}, R_{in} [mrad/h]	01.Nov.94 R_{out}, R_{in} [mrad/h]	Device
L20	400, 500	2000, 2000	400, 600	injection septum
A15	25, 23	1500, 700	150, 150	pulsed quad
E20	800, 1000	1300, 2000	400, 600	beam catcher
F05	200, 200	1800, 2500	500, 700	extraction septum
F10	300, 200	1500, 5000	250, 1200	extraction septum

†Prior to the HEP/SEB run, the machine study/setup was conducted with a moderate beam intensity without extraction. The beam catcher was positioned such that it did catch most of beam loss.
††During the HEP/SEB run, the E20 beam catcher did not efficiently catch lost beam especially during extraction since it was positioned further inside than the standard position where the catcher appeared to intercept the circulating beam.

2.2 AGS Performance

In Figures 2.a and 2.b, AGS performance during the 3-month FY94 HEP/SEB(p) run and the 2-month FY94/95 HIP/SEB(Au) run are displayed in terms of beam intensity measured at various acceleration stages from the AGS daily log:

Figure 2.a — @Linac, AB_{inj}, AB_{ext}, AGS_{inj}, AGS_{early}, AGS_{late}, AGS_{ext}, and SEB

Figure 2.b — @AB_{inj}, AB_{ext}, AGS_{inj}, AGS_{ext} and SEB

The following table illustrates *typical* AGS performance during the HEP and HIP runs.

	AB_{ext}	AGS_{inj}	AGS_{ext}	SEB	
HEP/SEB†	4.4	3.3	2.9	2.8	10^{13} ppp
(efficiency)		(75)	(88)	(96)	(%)
HIP/SEB	6.6	1.7	1.2	0.9	10^{8} ipp
(efficiency)		(26)	(71)	(75)	(%)

†The machine was optimized to gain higher beam intensity for the SEB users rather than to minimize beam loss.

It is clear that the (Au^{77+}) beam loss at AGS during the HIP run is more than three orders of magnitude less than one during the HEP run. Therefore, we can safely assume that any induced radioactivity by the gold beam during the HIP run is negligible and regard this period as a continuous cooling period.

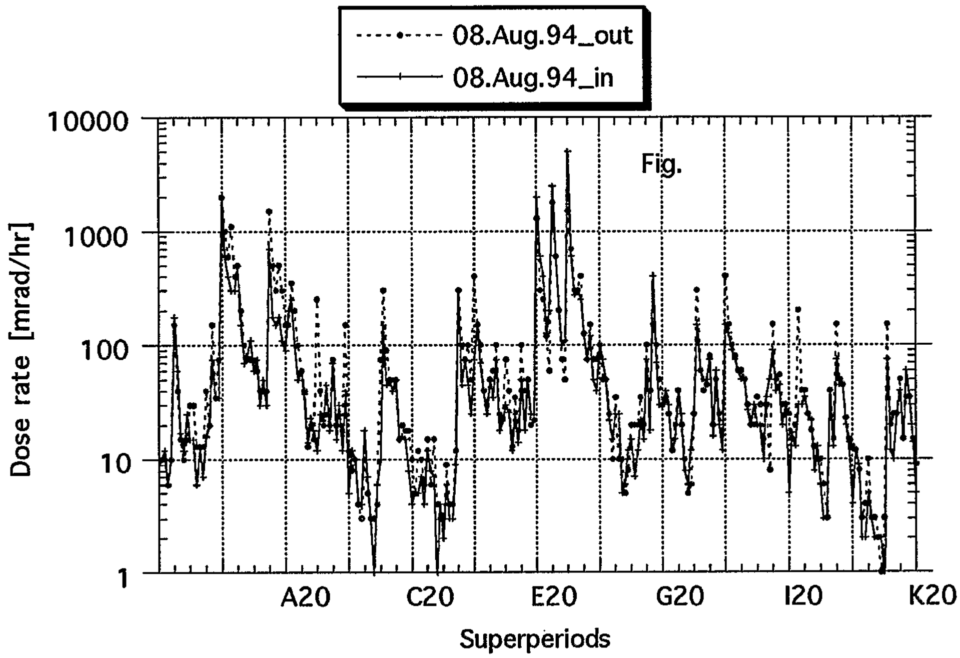

Fig. 1.a HP AGS Ring Radiation Survey results a week after FY94 HEP/SEB run.

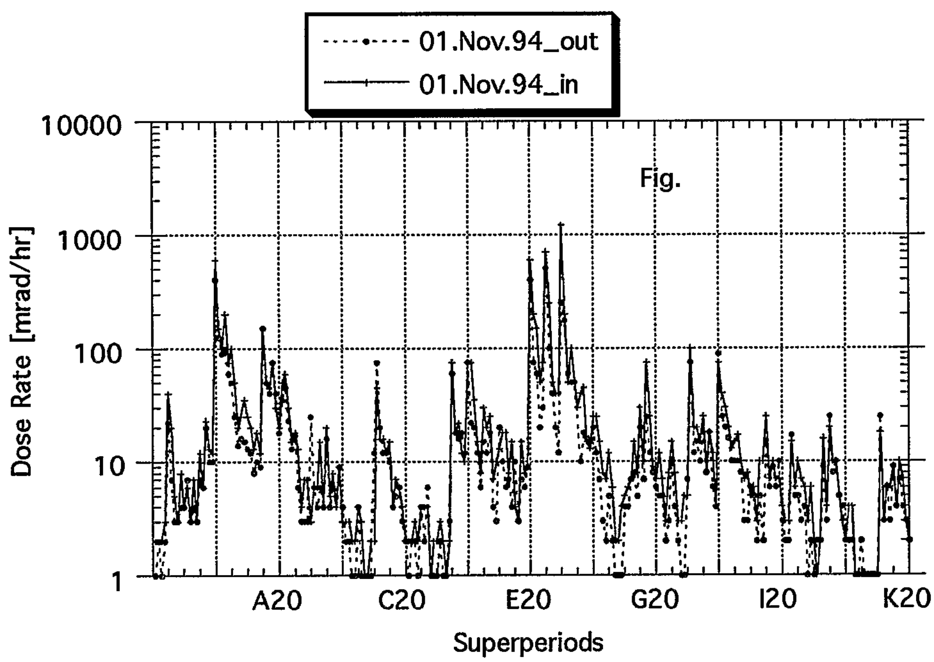

Fig. 1.b HP AGS Ring Radiation Survey results after FY94/95 HIP/SEB run.

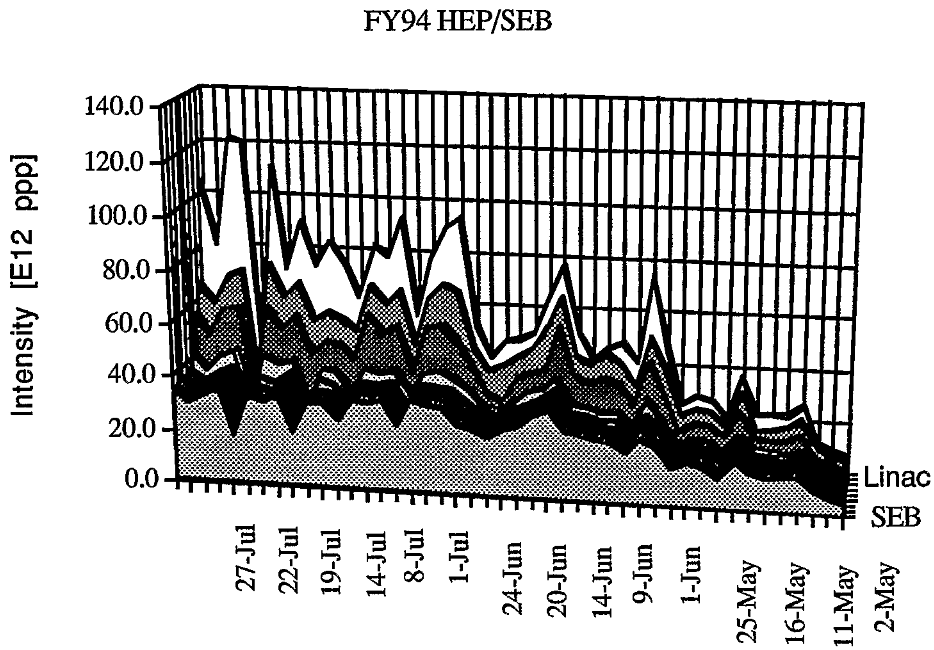

Fig. 2.a The proton beam intensity observed at various acceleration stages during the HEP run.

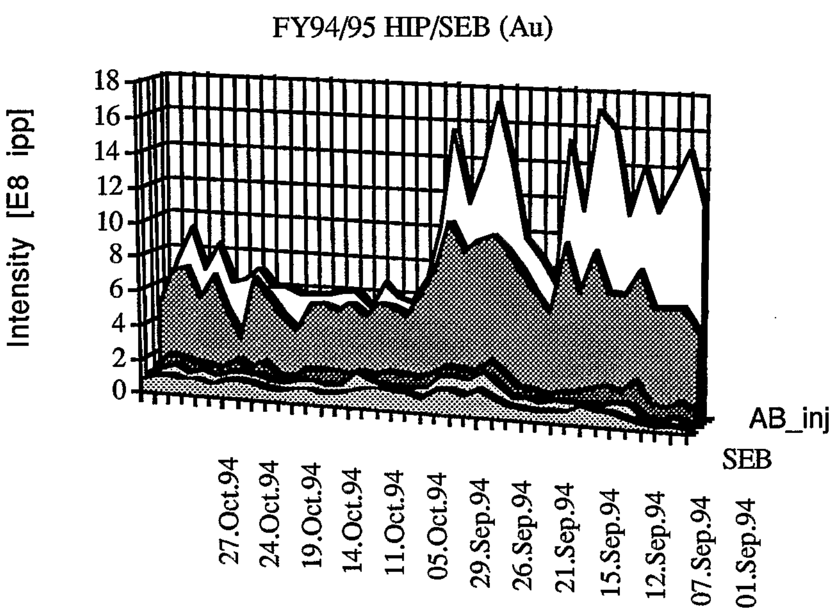

Fig. 2.b The gold beam intensity observed at various acceleration stages during the HIP run.

3. Analysis and Results

The dose rate D [rad/hr] at 30 cm distance from a thick material of Fe, Cu or Ni which are irradiated with a high energy (> a few hundred MeV) particle beam Φ [protons/s] will be estimated by Sullivian's relation [1]:

$$D\ [\mathrm{rad/hr}] = K\cdot\Phi\cdot\ln\left(\frac{T+t}{t}\right)$$

where $K \approx 4.1\cdot10^{-12}$, is a constant for any given set of irradiation, material and geometrical conditions, t is the cooling time and T the irradiation time, assuming that many different kinds of isotopes are produced and the distribution of their mean lives is similar to a natural one. Thus, we expect that the average dose rate ratio $R = D(t_2)/D(t_1)$ = D(01Nov)/D(08Aug) with T = 90 days, $t_1 = 7$ and $t_2 = 90$ days would be about 0.26 as shown *in* Figure 3, *ignoring a contribution from residual radioactivity induced during the setup/study* period and accumulated over 30 years of AGS operation (see reference[2] for a detailed analysis of K and Φ for the pre-Booster AGS).

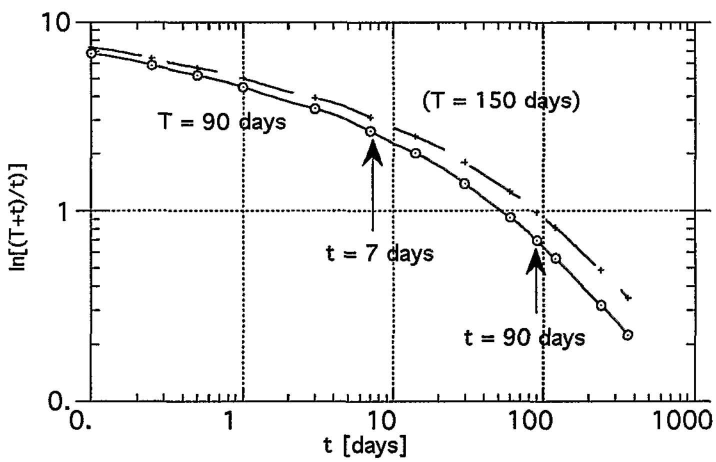

Fig.3 A plot of ln((T+t)/t) vs t(days).

The measured dose ratios R = D(01Nov)/D(08Aug) are plotted for the *outside* and *inside* data separately in Figure 4. The overall average dose rate ratio R is somewhere around 0.25, which is consistent with the prediction of Sullivan's relation although it shows that the value of R_{out} is systematically lower than the value of R_{in}.

Figures 5.a and 5.b plot D(01Nov) vs D(08Aug) for the outside and inside data, respectively. If we fit the data with a linear fit $D(t_2)=R\cdot D(t_1)$, we find that $R_{out} = 0.19 \pm 0.02$ and $R_{in} = 0.28 \pm 0.02$, which could approximately be translated to the average mean lifetime of *long-lived* induced radioactivity in the AGS ring to be $\tau_{out} \approx 53 \pm 5$ days and $\tau_{in} \approx 71 \pm 5$ days since the first measurement was done after a week of cooling time and short-lived induced radioactivity ($\tau <$ a few days) should have already died out quickly after the machine shutdown.

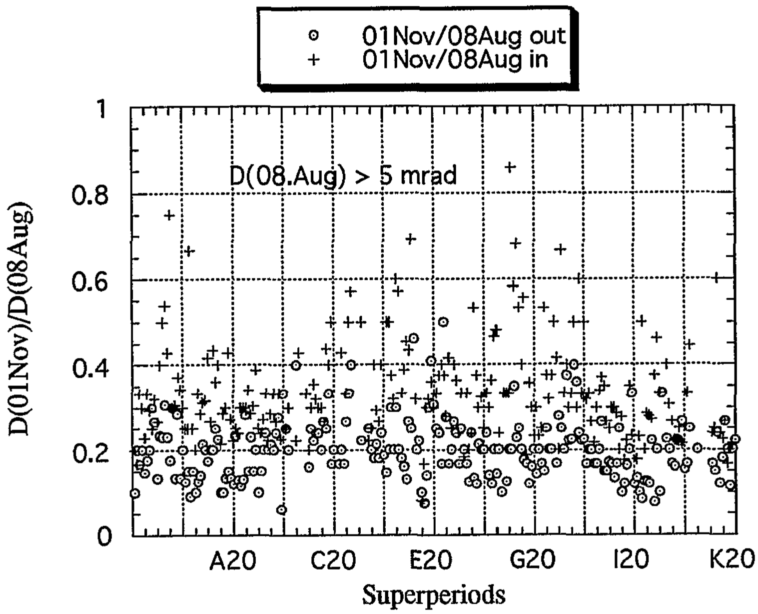

Fig. 4 The measured ratio D(01Nov)/D(08Aug) around the ring.

It is not so obvious why the decay rate measured inside is faster than outside. However, we know that *on average:*

1. For the normal AGS operation, most of lost or aborted beam is usually dumped inside at the catcher. The beam lost during SEB extraction ends up mostly inside at the catcher, then at SMF05 and SMF10.
2. D_{out}(08Aug) ≈ D_{in}(08Aug). ☞ See Fig. 1.a.
3. D_{out}(01Nov) < D_{in}(01Nov) except at E20, F5, F10, G17. ☞ See Fig. 1.b.
4. ΔD_{out}(=D_{out}(08Aug)-D_{out}(23Mar)) > ΔD_{in}(=D_{in}(08Aug)-D_{in}(23Mar)). ☞ See Fig. 5.
5. D_{out}(23Mar) < D_{in}(23Mar).

Thus, we may conclude that:

- $D_{out} > D_{in}$ from *residual long-lived* radioactivity accumulated over the AGS lifetime before FY94.
- During the FY94 HEP/SEB run, beam loss occurred primarily ***outside at AGS injection and/or acceleration***.

Therefore, only a small fraction of D_{out}(08Aug) can be attributed to contamination from *residual long-lived radioactivity* but it is not the case for D_{in}(08Aug). As a result, we expect that the decay rate measured ouside is faster than inside.

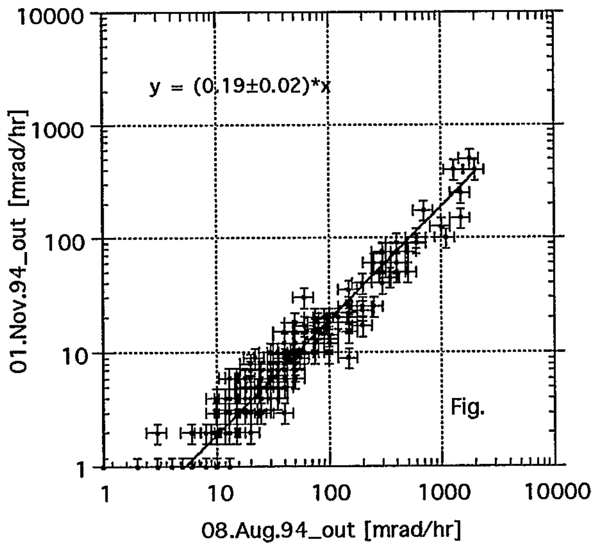

Fig.4.a D_{out}(01Nov) vs D_{out}(08Aug). The errors are 20% of the data.

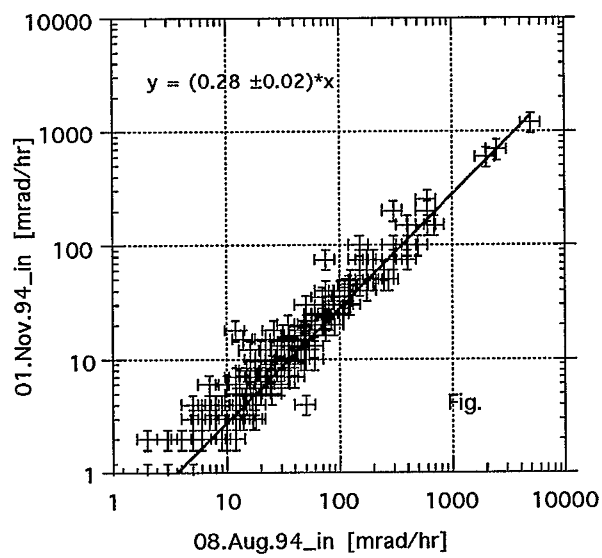

Fig.4.b D_{in}(01Nov) vs D_{in}(08Aug).

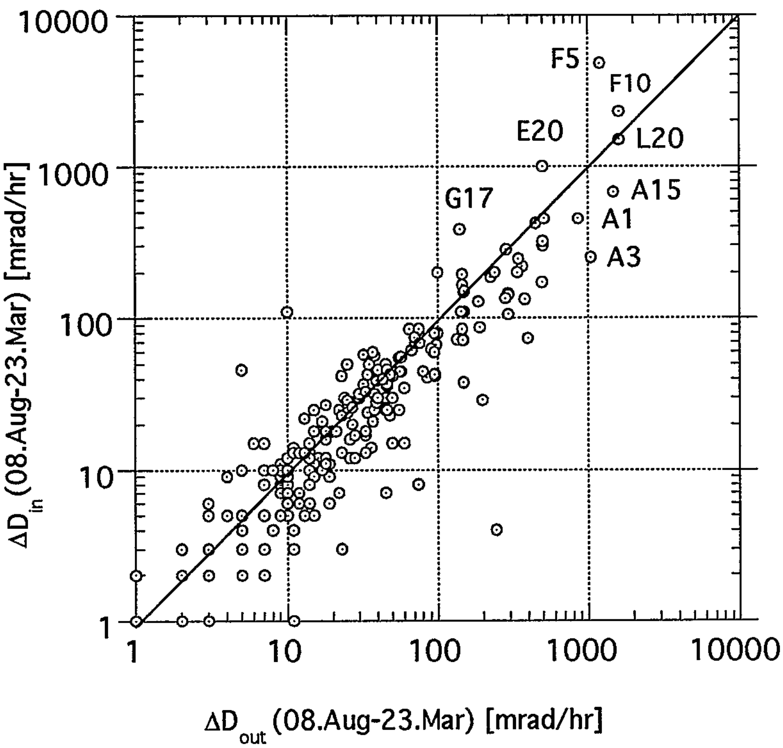

Fig. 5. ΔD_{in}(=?D_{in}(08Aug)-D_{in}(23Mar)) vs ΔD_{out}(=D_{out}(08Aug)-D_{out}(23Mar)).

References

[1] A.H. Sullivan, Health Physics, **23**, 253 (1972).

[2] K.A. Brown and M .Tanaka, BNL-46170 and AGS/Tech Note No. 264 (1986).
K. Brown, AGS/Tech/Note No. 337 (1990).
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