Measuring Correlations Between Beam Loss and Residual Radiation in the Fermilab Main Injector

Bruce C. Brown
Main Injector Department Accelerator Division
Fermilab, Batavia, IL, USA

Introduction

Fermilab Main Injector (high intensity mode)

- Accelerates 8 GeV protons to 120 Gev
- Produces ~400 kW of proton beam power
- Powerful correction system => stable orbits
- Slip stack Injection – some un-captured beam
- Additional 8 GeV losses
- Loss Varies due to Injected Beam Quality
  - (transverse emittance, momentum spread)

Residual Radiation Issues

Beginning in June 2004, in anticipation of increased beam intensity for neutrino production a program to monitor residual radiation was implemented.

Bar Coded Locations were identified and residual radiation measurements regularized starting on 10 October 2005

Improved Beam Loss Monitor (BLM) electronics permitted logging of losses (each cycle) beginning on 11 October 2006

Correlations between these measurement are described in this presentation.

Relating Residual Radiation to Losses

MARS Simulation of typical secondary collimator installation with trim dipole, quadrupole, secondary collimator, mask …

Stable orbit => loss geometry constant

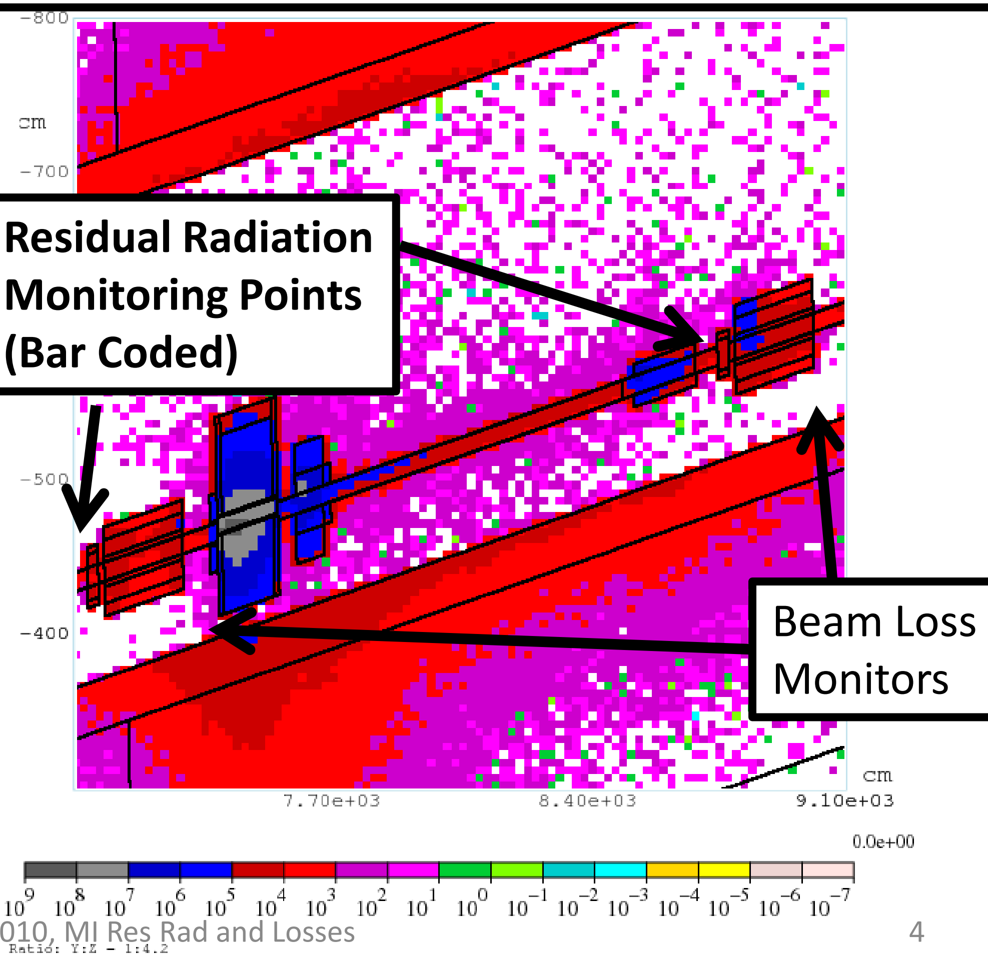
loss + machine geometry
defines radiation field

radiation field defines pattern of residual radiation isotope production

ionization in Beam Loss Monitors (BLM's) defined by radiation field

residual radiation at Monitoring Point defined by radiation field

residual radiation will be proportional to time weighted integral of nearby losses



Formulas for Fitting

The BLM system records (for each monitor) a loss integral (LI) for each MI Cycle. We sum these over ten minute intervals (T_s = 600 sec) – to quantas, LIj.

$$LI_j = \sum_{t=t_j}^{t_j+T_s} LI(t)$$

For each isotope we sum these quantas weighted by the half-life

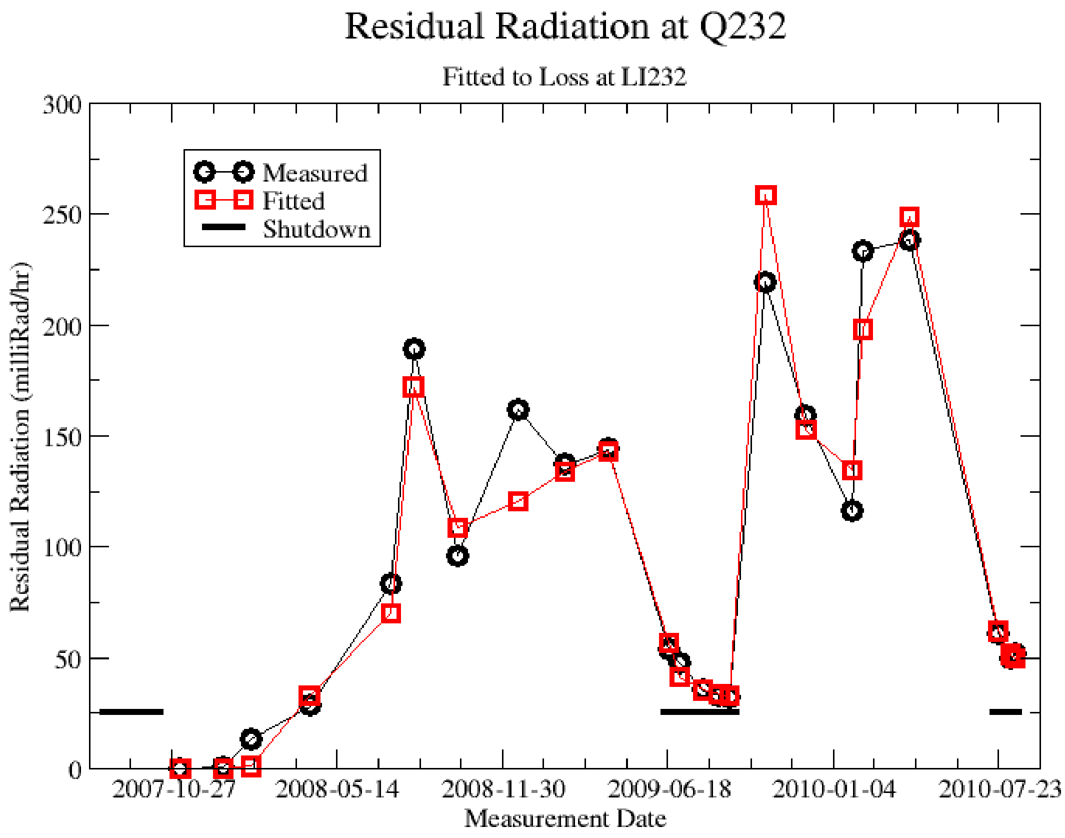
$$LW(I,T_M) = \sum_j \; LI_j \, x \, \frac{\ln 2}{\tau_I} \, 2^{-(T_M - T_j)/\tau_I}$$

The fitting hypothesis assumes that the measured residual radiation at measurement time, T_M is a linear sum of the weighted quata sums over the set of isotopes

$$RR(T_M) = \sum_I E_I \, x \, LW(I,T_M)$$

The physics of the loss pattern and isotope production, loss monitor geometry, bar code monitor location geometry and Geiger tube energy response multiply to create one linear constant E_I.

Residual Radiation History



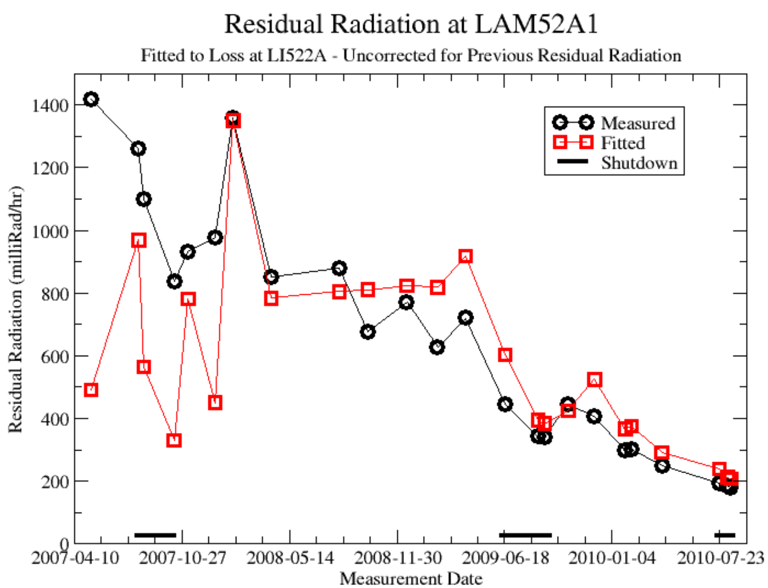
Loss history at Quadrupole Between primary and first secondary collimator

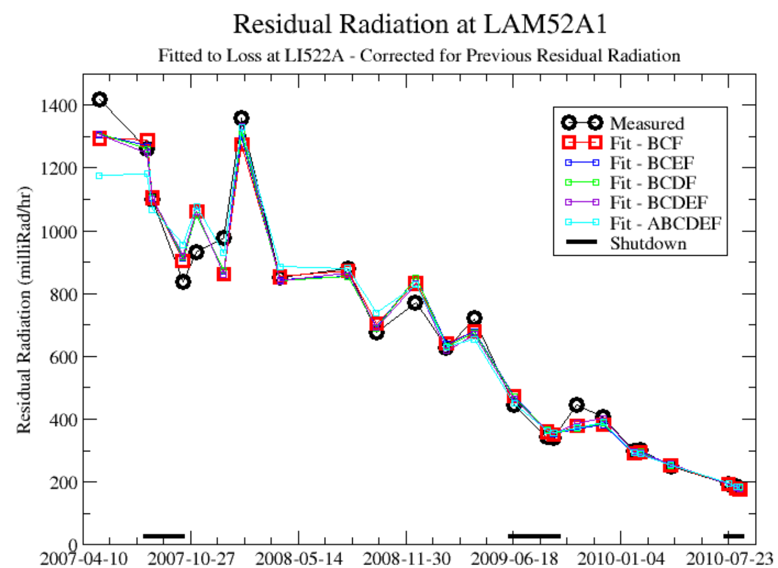
τ	E * 10000
312.3 days	0.2002
5.591 days	0.2336
2.5789 hrs	0.5087

Add Old Residual Radiation to Fit

Residual Radiation measurement are available for times before the implementation of the current BLM readout system. When activation (and residual radiation) has dropped, adding the old radiation measurement (as a fraction with only the longest lifetime) improves the fit.

$$RR(T_M) = \sum_I \; E_I \; x \; LW(I, T_M) + \; f \; x \; RR(T_R) \, 2^{-(T_M - T_R)/\tau_I}$$





Note all fits are nearly the same at most measurements

Parameters for Fits at LAM52A1

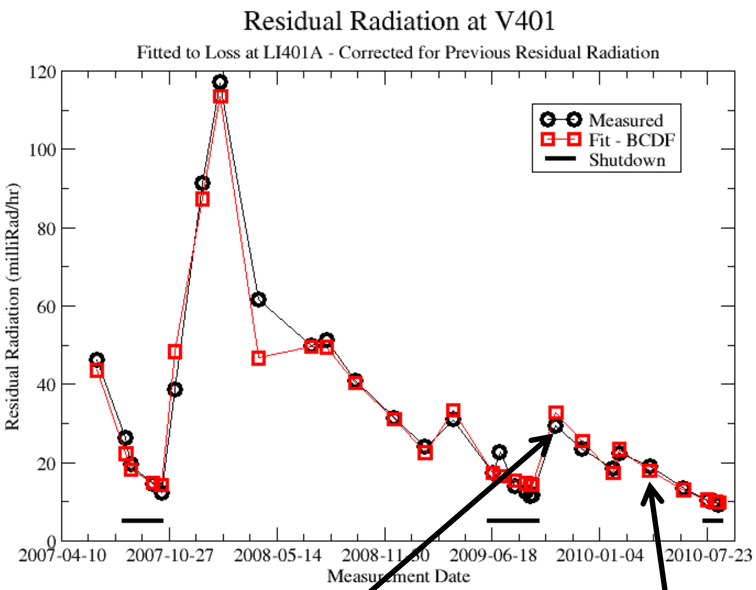
Label	Isotope	Half life
A	22Na	2.6 years
B	54Mn	312.3 days
C	52Mn	5.591 days
D	24Na	15 hours
E	52Fe	8.275 hours
F	56Mn	2.58 hours

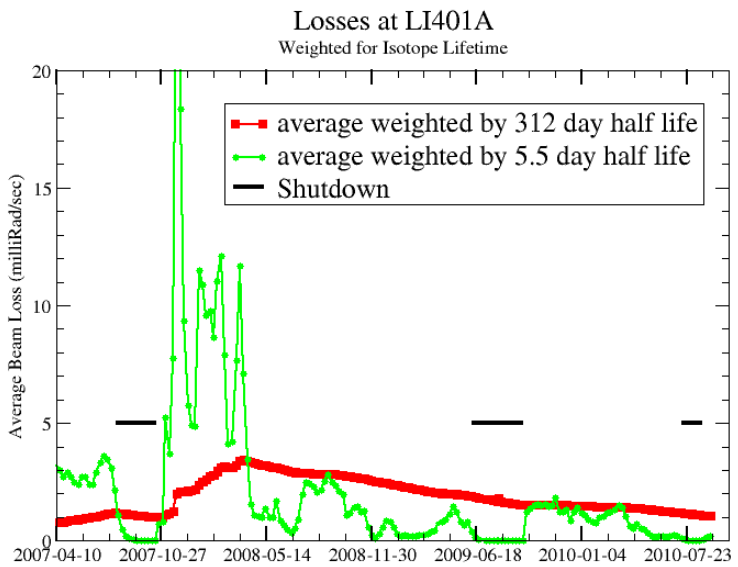
Fits by matrix inversion do not constrain parameters to be positive resulting in unphysical parameters for some data sets. fits are quite plausible description of data, nevertheless, so one is free to use them for predicting residual radiation decay.

A	B	C	D	E	F
-1.0585	0.3709	0.1210	0.2857	-0.3872	0.4640
	0.2494	0.1446	0.3360	-0.4837	0.6708
	0.2480	0.1948			0.3929
	0.2523	0.1741		0.1053	0.1620
	0.2528	0.1611 0	0.0779		0.2116

Fit Data for Loss in 2010 Work Area

Installed Gap Clearing Kickers in 2009 Shutdown





Reduced Aperture Due to Kicker

Improved Collimation To Capture Beam Loss

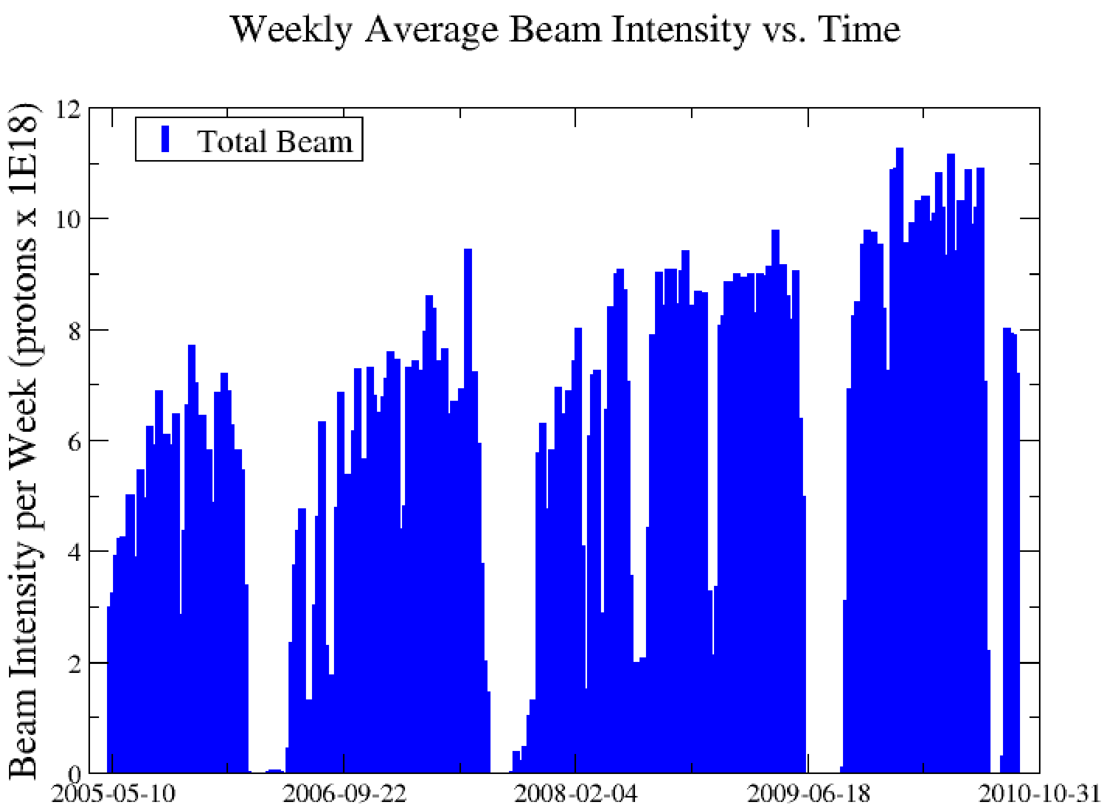
Comments and Status - I

- Fits provided by present console program provide adequate residual radiation prediction despite not being ‘good fits’ (poor χ^2)
- Residual radiation measured repeatedly (1 minute intervals or less) better constrains half life information – limited to a few locations
- MARS simulates isotope production. Need to develop ways to cross check with measurements

Comments and Status - II

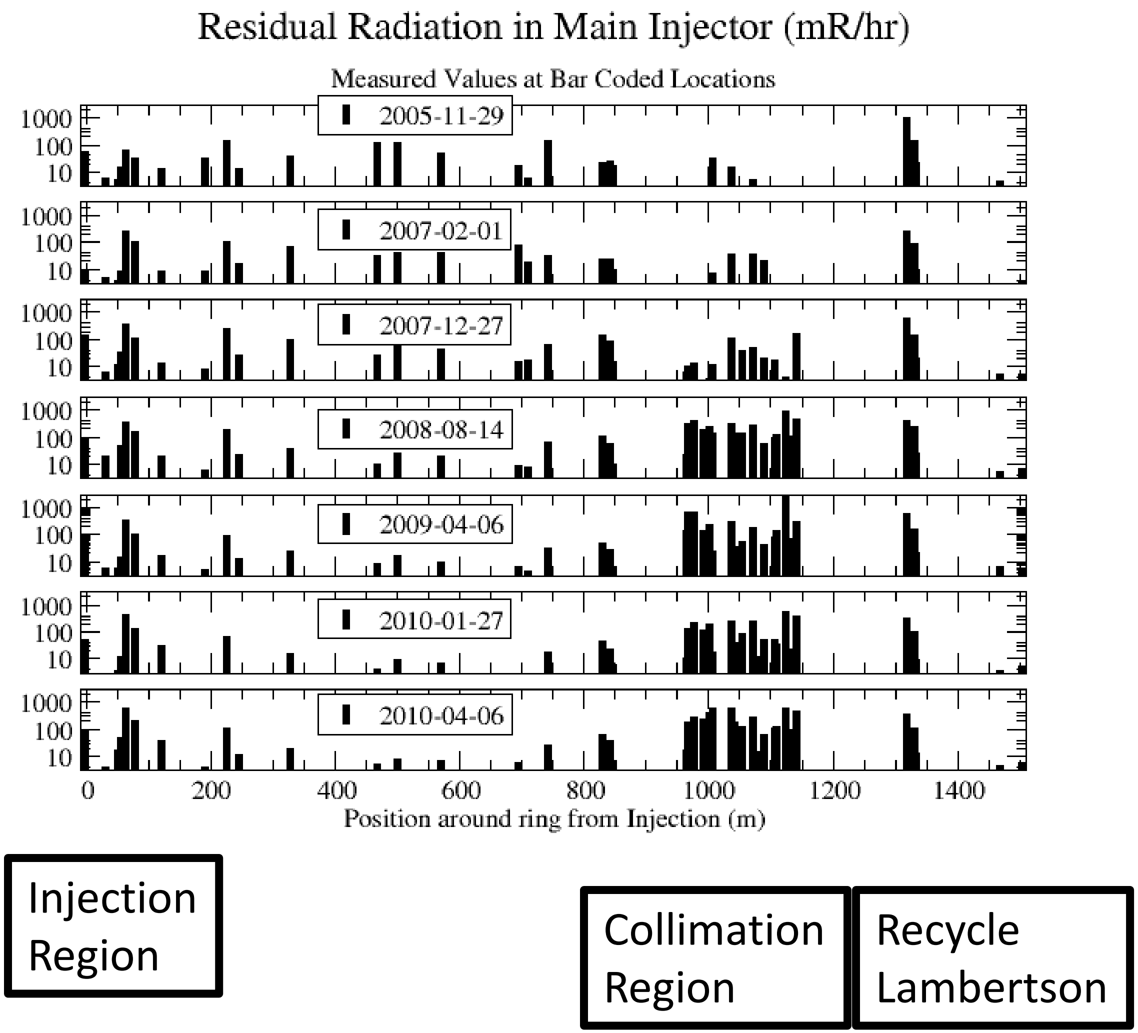
- Residual Radiation data has been assessed - OK
- Many issues found in data log of BLM – these are being addressed to provide clean data but issues have little effect on these fits.
- Have little indication of important residual radiation with long half life – seeking to develop plan to assess limits
- We currently see no impediment to plans for 700 kW operation of Main Injector with 5% loss.

Progress in Beam Intensity

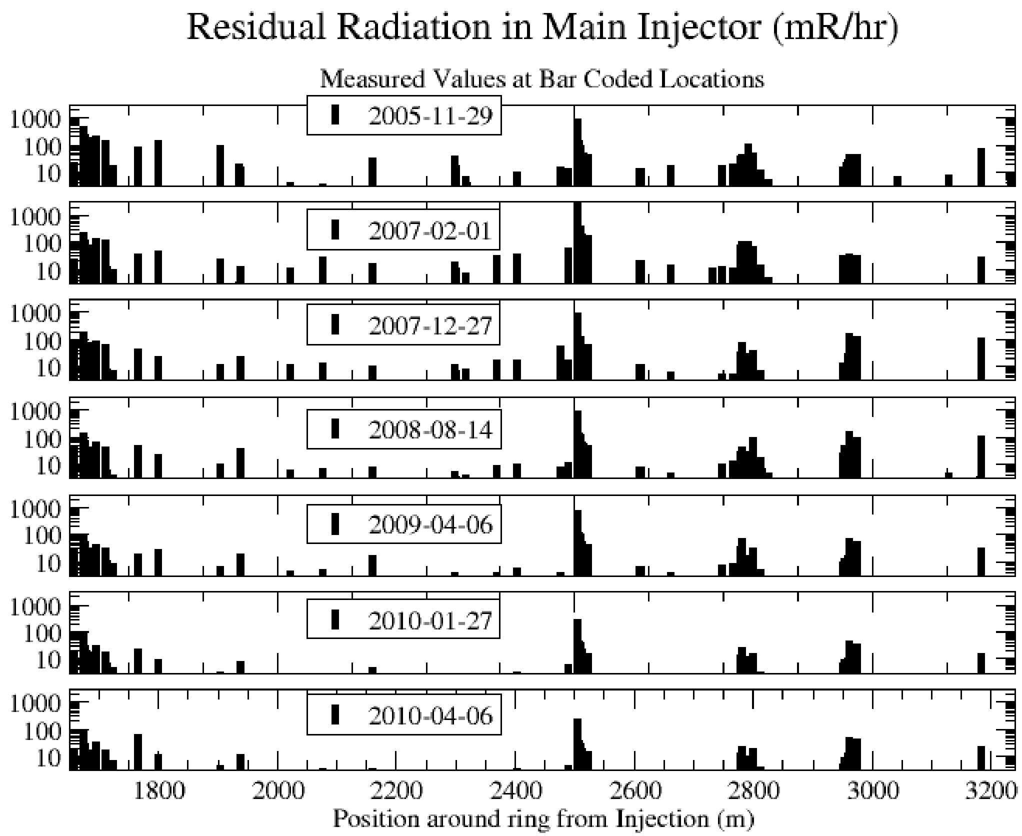


Protons for Pbar Production used one Booster Batch, Slip Stacked two Batches Starting December 2004
NuMI (Neutrinos at the Main Injector) began receiving beam in Spring 2005 with 5 Booster Batches.
Moved to 9 Batches for NuMI and 2 Batches for Pbar in

Progress in Residual Radiation



Progress in Residual Radiation



Abort Lambertson

Beam Extraction Lambertsons

Summary

A tool to use beam loss measurements to predict residual radiation has been developed.

It provides adequate information to predict radiation exposure for planning work.

Continued attention to loss issues has resulted in reduced tunnel radiation in the Fermilab Main Injector except at collimator region.

Progress in Beam Intensity