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USAGE OF CHIPMUNKS AND SCARECROWS IN TEVATRON RADIATION FIELDS

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The usage of the Fermilab standard ion chamber based radiation detectors in Tevatron radiation fields requires that their characteristics be well understood in order to use them properly both as dose rate monitors and as components of interlock systems. This note reports on some of these characteristics in the hope that future operations will benefit from the proper usage of these instruments.

1. Setting of Trip Levels in Tevatron Beams

In interlock systems used in the experimental areas, radiation trips occur when a specified instantaneous dose rate is exceeded. This statement is true whether one is referring to the so-called "new system" developed in the former Meson area by P. Czarapata and coworkers or the prehistoric "old system" developed by the three experimental areas separately (three versions of the wheel invented separately?). It is clear that the average dose per hour, D_{av} is related to the instantaneous dose rate received during a spill, D_s (assuming a uniform dose rate during the spill) by

$$D_{av} = D_s t_s / t_b \qquad (1)$$

where t_s is the spill duration (sec) and t_b is the Tevatron beam cycle time (sec). Now we must look at how the ion chamber in the chipmunk or scarecrow responds to a time-varying field. Figure 1 shows the time dependence of the instantaneous dose rate where the repetitive cycle begins with a spill starting at t = Ø. In this figure it is assumed that all beam losses are uniform during each spill. All time constants are neglected except the beam-related ones defined by this figure and that of the ion chamber integrator, t_c, normally set equal to 2Ø sec (see Radiation Physics Note # 8 by L. Coulson and R. Meadowcroft, August 23, 1976, for an explanation of this choice of time constant). The dose rate is assumed to be sufficiently large to be able to ignore the discrete character of the current digizer output (2.5E-Ø3 mrem/pulse for the Chipmunk, 2.5E-Ø2 mrem/pulse for the Scarecrow) yet small enough to avoid saturation of the digitizer ($\lesssim$ 4 kHz).

Recalling some facts about RC circuits, it is possible to write down the following expressions for the temporal response of the digitizer outputs expressed as an instantaneous dose rate,

$D_c(t)$, in units of mrem/hr;

$$D_c(t) = D_s[1 - e^{-t/t_c}] \qquad t < t_s$$

$$\left.\begin{aligned} D_c(t) &= D_s[1 - e^{-t_s/t_c}]e^{-(t-t_s)/t_c} \\ &= D_1(t) \end{aligned}\right\} \qquad t_s < t < t_b$$

$$D_c(t) = D_1(t) + D_s[1 - e^{-(t-t_b)/t_c}] \qquad t_b < t < t_b + t_s$$

$$\left.\begin{aligned} D_c(t) &= D_1(t) + D_s[1 - e^{-t_s/t_c}]e^{-[t-(t_b+t_s)]/t_c} \\ D_c(t) &= D_1(t) + D_2(t) \end{aligned}\right\} \qquad t_b + t_s < t < 2t_b$$

We thus note the pattern where

$$D_i(t) = D_s[1 - e^{-t_s/t_c}]e^{-[t-(i-1)t_b - t_s]/t_c} \qquad \text{and}$$

$$D_c(t) = \sum_{i=1}^{n-1} D_i(t) + D_s\left[1 - e^{-(t-nt_b)/t_c}\right] \qquad (n-1)t_b < t < (n-1)t_b + t_s$$

during the n^{th} spill.

$$D_c(t) = \sum_{i=1}^{n} D_i(t) \qquad (n-1)t_b + t_s < t < nt_b$$

after the n^{th} spill but before the $n+1^{st}$ spill.

Obviously, the maximum value of $D_c(t)$ occurs at the end of a spill after an equilibrium is reached after some number of spills. Thus, the maximum instantaneous response of the detector, $D_{max}(n)$ at the end of the n^{th} spill is

$$D_{max}(n) = \sum_{i=1}^{n} D_i(t) \qquad (\text{at } t = (n-1)t_b + t_s)$$

removing the common factor, and evaluating at $t = (n-1)t_b + t_s$,

$$D_{max}(n) / D_s[1 - e^{-t_s/t_c}] = e^{-(n-1)t_b/t_c} + \ldots + e^{-t_b/t_c} + 1$$

Substituting,

$$D_{max}(n) = D_{av}(t_b/t_s)[1 - e^{-t_s/t_c}]\left\{1 + e^{-t_b/t_c} + \ldots + e^{-(n-1)t_b/t_c}\right\} \quad (2)$$

It is obvious that when Tevatron conditions of $t_b = 60$ sec is coupled with the normal value $t_c = 20$ sec, the exponential series factor converges quite rapidly after a very few terms (spills) to a value of 1.052. In fact, after the first spill it equals 1.0 and after the second spill it already equals 1.050.
For comparison, under former 400 GeV conditions with the old Main Ring; $t_b = 10$ sec, $t_c = 20$ sec, the series converges to 2.541 in the following manner:

after spill #	value
1	1.00
2	1.61
3	1.97
4	2.20
5	2.33
6	2.41
7	2 46
8	2.49

Obviously, other cycle times can be dealt with accordingly. It is clear the under Tevatron running conditions, the response of the detector is almost completely independent of its past history, unless dose rates during previous spills have been much larger than during a spill in question. Contrary to the situation with the old Main Ring, we are now truly sensitive to single pulse dose rates. This has an important consequence in that under the former operating conditions, we were essentially averaging over several beam spills to obtain a given average dose rate while with the Tevatron such averaging is nonexistent. It follows that in a situation where one is setting a trip point fairly close to the normal dose rate, a small instantaneous "glitch" may generate a trip in the Tevatron mode which would have not been encountered if averaged over several accelerator spills. This may actually account for some radiation trips.

Incorporating the factor of 1.052 into equation (2) and also substituting the other values of the various time parameters for a "slow spill" of 20 seconds it is found that

$$D_{max}(\infty) = 1.995\ D_{av} \qquad (3)$$

which agrees with a measurement by S. Butala in which he compared the meter face of a chipmunk with the output of the digitizer on a scaler during slow spill Tevatron operation and obtained a factor of 2. For a case of fast extraction, $t_s \approx 1$ msec,

$$D_{max}(\infty) = 3.156\ D_{av} \qquad (4)$$

would result. Of course, for fast extraction, the rate limitations of the digitizer become a more serious consideration. For comparison, at $t_s = 1$ sec, $t_b = 10$ sec, and $t_c = 20$ sec (old Main Ring operation) $D_{max}(\infty) = 1.239 D_{av}$. With $t_s = 1.0E{-}03$ sec, $t_b = 10$ sec, and $t_c = 20$ sec, $D_{max}(\infty) = 1.2700 D_{av}$. These results are consistent with the measurements of Coulson and Meadowcroft for the choice of $t\ = 20$ sec.

At this point I examine the criteria of Chapter 6 of the Fermilab Radiation Guide with respect to "accident conditions" with interlocked radiation detectors used as summarized in the following table;

mrem/trip	precaution	trips/hr to reach 250 mrem
$D < 0.25$	none	1000
$0.25 < D < 2.5$	minimal occupancy	100
$2.5 < D < 10$	posted, min. occ.	25
$10 < D < 50$	fenced, occ. by "auth. personnel"	5

Here, D is the dose per trip of the interlocks

In any outdoor area, one cannot allow more trips per hour than the number which would imply 250 mrem without performing a search and secure to assure that the area is unoccupied. The right hand column lists the number of trips allowed per hour under this criterion. As one can see, 0.25 and 2.5 mrem cause no problem because there are not enough Tevatron cycles in an hour to reach 250 mrem. 10 mrem per pulse would require 25 spills to reach 250 mrem. Since the present interlock scheme penalizes the beam tuner 2 minutes at the second trip, it is also impossible to have more than about 20 trips per hour. Thus, it is only at 50 mrem/trip that the number of trips per hour allowed requires separate attention.

In view of the fact that the following relation holds between D_{spill}, the dose per spill, and D_{av} :

$$D_{av} = (3600\ D_{spill})/t_b \quad \text{(mrem/hr)} \qquad (5)$$

and also the fact that a trip point is chosen to be a given value of D_{max} (mrem/hr), the following two expressions can be obtained for the two cases at hand in a Tevatron cycle;

$$\text{Fast Spill:} \quad D_{max} = 189\ D_{spill} \quad \text{(mrem/hr)} \qquad (6)$$

$$\text{Slow Spill:} \quad D_{max} = 120\ D_{spill} \quad \text{(mrem/hr)} \qquad (7)$$

Substituting, one can construct the following table of trip point settings (mrem/hr) which yield the indicated trip point (mrem/spill). Also given are peak digitizer rates for chipmunk detectors (=10X the digitizer rate of a scarecrow placed in the same radiation field):

trip point (mrem/spill)	fast spill setting (mrem/hr)	fast spill digitizer (Hz)	slow spill setting (mrem/hr)	slow spill digitizer (Hz)
0.25	47	5.2	30	3.3
2.5	470	52	300	33
10	1900	211	1200	133
50	9500	1055	6000	666
1.67*	315	35	200	22

*1.67 mrem/spill corresponds to D_{av} = 100 mrem/hr, a "normal condition" maximum for fenced outdoor areas at Fermilab.

In like manner, this approach could be applied to other accelerator cycles.

Of course, one may want to be somewhat more conservative than indicated by the above. For example, it is not always clear that one desires to use enough interlocked detectors to have one at every possible loss point without unacceptably increasing the down time due to the random failures of a large number of detectors. In such cases, it might be advisable to put in a safety factor of, say, ten to assure that distant loss points were still being monitored. This technique still provides for a consistent way of determining the interlock trip points without retrofitting the entire interlock system to be settable in terms of dose per trip.

2. Chipmunk Quality Factor Settings

Irrespective of the accelerator cycle under consideration, experience shows that the quality factor settings of the chipmunks have cause considerable operational confusion. This is principly due to the usage of these devices along with old style interlocks to achieve trip points different from those provided by the so-called

S-levels. The S-levels, I am told, were never intended to be used as interlock components in the first place but have been used extensively for that purpose anyhow.

The fundamental output of a chipmunk is that of the charge digitizer which internally spits out one pulse/Ø.5E-Ø3 mrad of absorbed dose (directly proportional to the number of ion pairs produced by the energy deposition in the chamber). For those interested in the statistics involved, one digitizer pulse corresponds to 7.2EØ6 ion pairs in the chamber. This is about 2ØØ MeV at 3Ø eV/ion pair and thus represents a fairly large number of particles interacting in the chamber volume. The quality factor toggle switch manipulates these pulses as follows:

QF=5 (neutrons) setting--------no change

QF=2.5 (mixed) setting---------every other pulse removed, i.e. serves as a divide by 2

QF=1 (muons) setting-----------four out of five pulses removed, i.e. serves as a divide by 5

Thus, the number of pulses which get past this division process is the same, 1/2, or 1/5 of the original number produced by the digitizer depending upon the setting chosen. It is these secondary pulses which become the MUX pulses, select the "S" levels, and drive the meter face. Thus the toggle switch settings must be understood to be properly applied. It is the purpose of this part of the note to clear up certain misunderstandings on this subject. The "digitizer pulses" referred to in part 1 of this note refer, in fact, to the MUX pulses.

A. Normal usage--The toggle is set to the correct quality factor for a given field (the preferred mode of operation)

1. Neutrons (QF=5) Here one pulse/Ø.5E-Ø3 mrad means one pulse per 2.5E-Ø3 mrem of dose equivalent. The meter face reads correctly in mrem/hr (subject to the consideratons in the first part of this note, of course). The S levels are are as follows:

S1	Ø < H < 2.5	(mrem/hr)
S2	2.5 < H < 2Ø	"
S3	2Ø < H < 5Ø	"
S4	H > 5Ø	"

where H is the dose equivalent rate in mrem/hr. Here MUX pulses emerge from the detector at the same rate as the digitizer pulses assuming the dose rate in the radiation field is such that saturation of the digitizer is not a consideration.

2. Mixed field (QF=2.5) Here one pulse/Ø.5E-Ø3 mrad from the digitizer produces a MUX pulse rate of one pulse/1.ØE-Ø3 mrad. The quality factor of the field implies one pulse/2.5E-Ø3 mrem so that the meter face reads correctly in terms of mrem/hr and the S levels are thus at their "standard" values.

3. Muons (QF=1) One pulse/Ø.5E-Ø3 mrad from the digitizer produces a MUX pulse rate of one pulse/2.5E-Ø3 mrad but the quality factor of unity in the radiation field implies that one has one

MUX pulse/2.5E-03 mrem. Thus again, the meter face reads correctly in terms of dose equivalent rate and the S levels have their standard ranges.

4. Thus, as long as the toggle switch is set to the correct value for the radiation field to be monitored, the MUX pulses will always represent 2.5E-03 mrem/pulse, the meter face will read correctly, and the S level ranges will be the standard ones. This is obviously the most desirable usage of the instruments.

B. Unusual usage--setting of the toggles for different quality factors than the value representative of the radiation field being monitored. These will be discussed separately for each possible setting of the toggle switches.

1. QF=5 Setting, muon radiation field

Here one gets one pulse/0.5E-03 mrad and since the field is muons one has one pulse/0.5E-03 mrem. The meter face and S levels will act as if one pulse = 2.5E-03 mrem. Thus the meter face will read 5 X high compared to the true dose equivalent rate and the S level ranges will be as follows:

S1	$0 < H < 0.5$	(mrem/hr)
S2	$0.5 < H < 4$	"
S3	$4 < H < 10$	"
S4	$H > 10$	"

MUX pulses will come out at such a rate that the new EAD interlock system will trip at dose equivalent rates 1/5 of the numerical values set on the thumbwheels.

2. QF=5 Setting, mixed radiation field

The quality factor of 2.5 now implies that one MUX pulse represents 1.25E-03 mrem so that the meter face will read high by a factor of 2 and the S level ranges will be as follows:

S1	$0 < H < 1.25$	(mrem/hr)
S2	$1.25 < H < 10$	"
S3	$10 < H < 25$	"
S4	$H > 25$	"

The new EAD interlocks will thus trip in dose equivalent rates equal to 1/2 of the nominal thumbwheel settings.

3. QF= 2.5 Setting, muon radiation field

Here one gets only one MUX pulse/1.0E-03 mrad after the division process. In a muon (QF=1) radiation field this amounts to 1 pulse/1.0E-03 mrem so that the meter face will read high by a factor of 2.5 and the S level ranges will be as follows:

S1	$0 < H < 1.0$	(mrem/hr)
S2	$1.0 < H < 8$	"
S3	$8 < H < 20$	"
S4	$H > 20$	"

in terms of the true dose equivalent rate. The new EAD interlocks will trip at 2/5 of the numerical mrem/hr setting on the thumbwheels.

4. QF = 2.5 Setting, neutron radiation field

Here 1 MUX pulse/1.0E-03 mrad after division will result. In a QF=5 field we thus get one pulse/5.0E-03 mrem of dose equivalent. The meter face will thus read low by a factor of 2 compared to the true dose equivalent rate and the S level ranges will be:

S1	0 < H < 5.0	(mrem/hr)
S2	5.0 < H < 40	"
S3	40 < H < 100	"
S4	H > 100	"

The new EAD interlocks will trip at dose equivalent rates 2 times the numerical values on the thumbwheels.

5. QF = 1 Setting, mixed radiation field

Here the division processes results in one MUX pulse/2.5E-03 mrad so that in a QF = 2.5 radiation field, we get one pulse/6.25E-03 mrem of dose equivalent. The meter face thus reads low by a factor of 2.5 and the S levels ranges are:

S1	0 < H < 6.25	mrem/hr
S2	6.25 < H < 50	"
S3	50 < H < 125	"
S4	H > 125	"

The new EAD interlocks will trip at dose equivalent rates 2.5 times the thumbwheel settings.

6. QF = 1 Setting, neutron radiation field

After division, one MUX pulse/2.5E-03 mrad in a QF=5 field implies one pulse/12.5E-03 mrem of dose equivalent. The meter face will read low by a factor of 5 and the S level ranges will be as follows:

S1	0 < H < 12.5	mrem/hr
S2	12.5 < H < 100	"
S3	100 < H < 250	"
S4	H > 250	"

The new EAD interlocks will trip in dose rates 5 X the level specified on the thumbwheels.

Figure 2 is a "wallet card" which contains the essence of the above results. It should be kept in mind that personnel who replace detectors must be careful to match the toggle switch setting of the detector being replaced to that of the failed detector to avoid some rather spectacular and unexpected shifts in trip points as noted above. I would like to thank John Larson for some useful discussions in connection with the writing of this note.
It is the hope of the author that this note will help to determine reasonable interlock settings in a more consistent

manner in order to achieve the desired level of radiation safety without causing undue amounts of down-time.

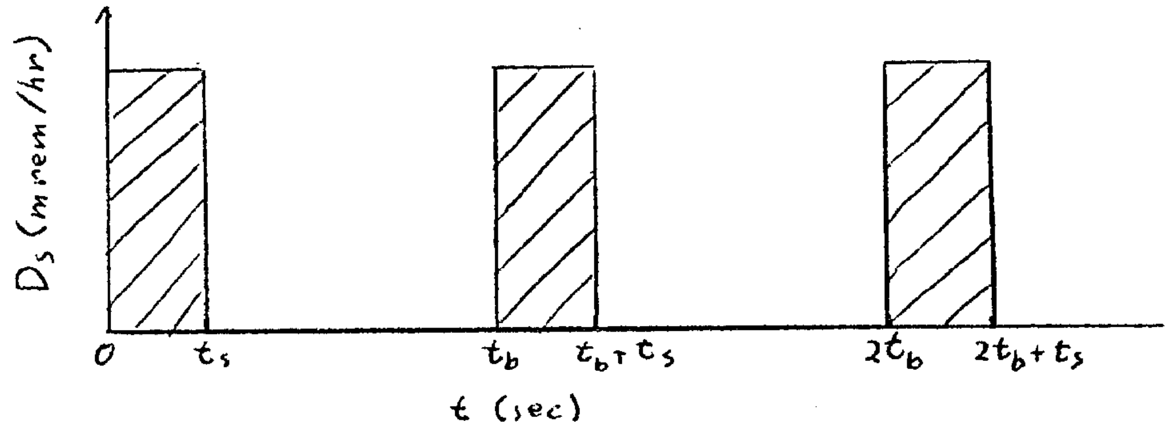

FIGURE 1 Instantaneous dose rate D_s plotted as a function of time t during the accelerator cycle defined in the text.

METER SETTINGS		TYPE OF RADIATION FIELD		
QF's	S-LEVELS	NEUTRONS	MIXED	MUONS
NEUTRONS QF = 5	S-2 [2.5]	2.5	1.25	0.5
	S-3 [20]	20 {x1}	10 {x0.5}	4 {x 0.2}
	S-4 [50]	50 (2.5)	25 (1.25)	10 (0.5)
MIXED QF = 2.5	S-2 [2.5]	5	2.5	1
	S-3 [20]	40 {x2}	20 {x1}	8 {x 0.4}
	S-4 [50]	100 (5)	50 (2.5)	20 (1)
MUONS QF = 1	S-2 [2.5]	12.5	6.25	2.5
	S-3 [20]	100 {x5}	50 {x2.5}	20 {x1}
	S-4 [50]	250 (12.5)	125 (6.25)	50 (2.5)
[ ] = METER FACE TRIP { } = NEW RAD. SYSTEM ( ) = µREM/PULSE				

FIGURE 2 "Wallet Card" of "S" level settings. The entry denoted "New Rad. System" gives the ratio of true dose equivalent rate at the trip point to that found on the thumbwheel settings in the new EAD interlocks.