R. P. Note 103

The Effects of Summer Temperatures and Humidity on Film Badge Readings

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December 1992

1.0 Introduction

For the past few years, Fermilab has conducted a program of testing the reliability of film badge readings performed by a vendor. The procedure, called "spiking," is to irradiate a set of badges associated with fictitious employees with a known dose of gammas, neutrons, or a combination thereof. The badges are currently provided by Landauer, Inc. Spiking is typically performed on a quarterly basis.

Prior to July 1992, the badges used for spiking had all been kept in the climate-controlled environment of Wilson Hall throughout the month of their issue. Given the fact that film is sensitive to heat and humidity, the question arises whether an employee who wears a film badge outdoors receives a film badge reading as reliable as one who wears one in Wilson Hall, especially during the summer.

To address this question, the test badges were divided into two groups, labeled A and B. Group A was kept in the usual location in a file cabinet on the seventh floor of Wilson Hall. Group B was placed in the barn at Site 3, where they would be protected from direct precipitation but otherwise exposed to essentially outdoor weather conditions. A Micronta digital thermometer/hygrometer was placed at each location to monitor the temperature and relative humidity. These were checked twice a day on most working days through July and August. At some point during each month, each group of badges was exposed to identical amounts of gamma and/or neutron radiation. At the end of each month, the badges were sent to Landauer for processing. The purpose of this experiment is to look for any systematic differences in the accuracy of reading Groups A and B.

2.0 Temperature and Humidity

The environmental data (temperature and humidity) at both locations were monitored over a period of two months. Since two sets of film badges were involved in this test, the environmental data are presented here in two segments, corresponding to the time periods over which the two sets of badges were monitored. The first set of badges was monitored from July 2 to August 3. The second set was monitored from August 3 to September 2.

The temperature data are shown in figures 1 through 4. Since the readings were generally taken around 8:00 AM and 5:00 PM these figures do not reflect the highest or lowest temperatures of any given day, but are closer to an average. Nevertheless, a cycling effect is apparent, especially in the data from Site 3. A similar effect is apparent in the humidity data, shown in figures 5 through 8. The error bars are the manufacturer's stated uncertainty in the reading of the thermometer/hygrometer.

The average values of the environmental data are shown in Table 1. It is interesting that the temperature averages are essentially the same for groups A and B; it is the standard deviations due to temperature cycles which differ appreciably.

Table 1 - Average Environmental Values

	Group A July	Group B July	Group A Aug.	Group B Aug.
Average temperature	21.7 ± 0.9 °C	22.3 ± 3.7 °C	21.2 ± 0.5 °C	21.1 ± 5.8 °C
Average humidity	55 ± 5 %	69 ± 9 %	53 ± 4 %	65 ± 9 %

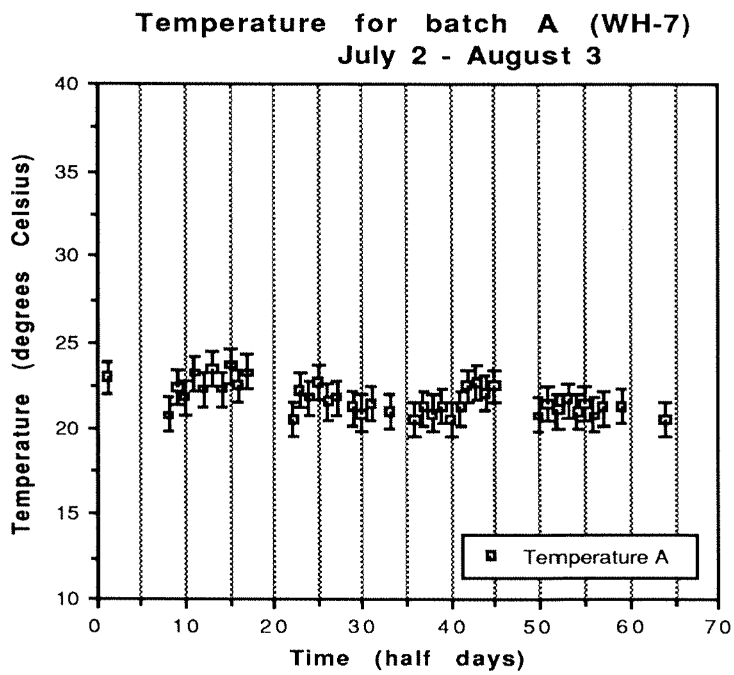

Figure 1

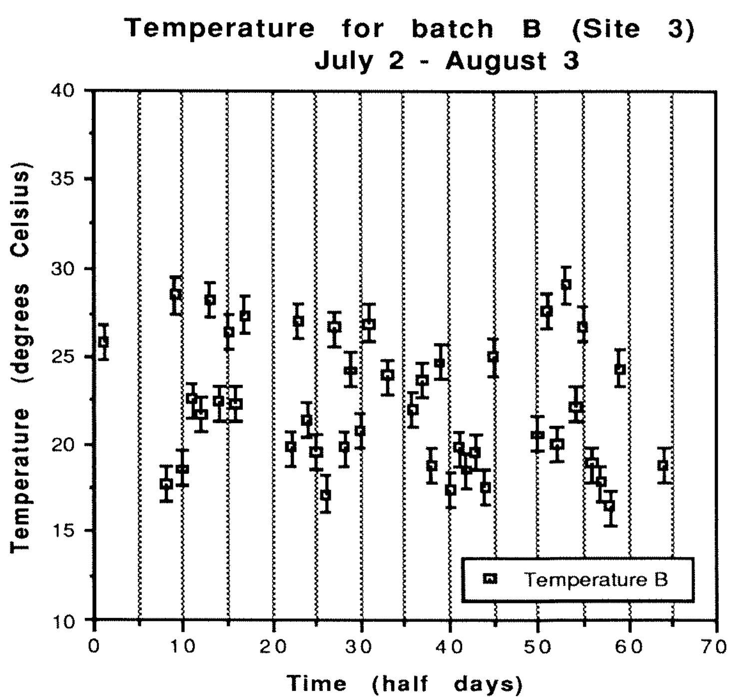

Figure 2

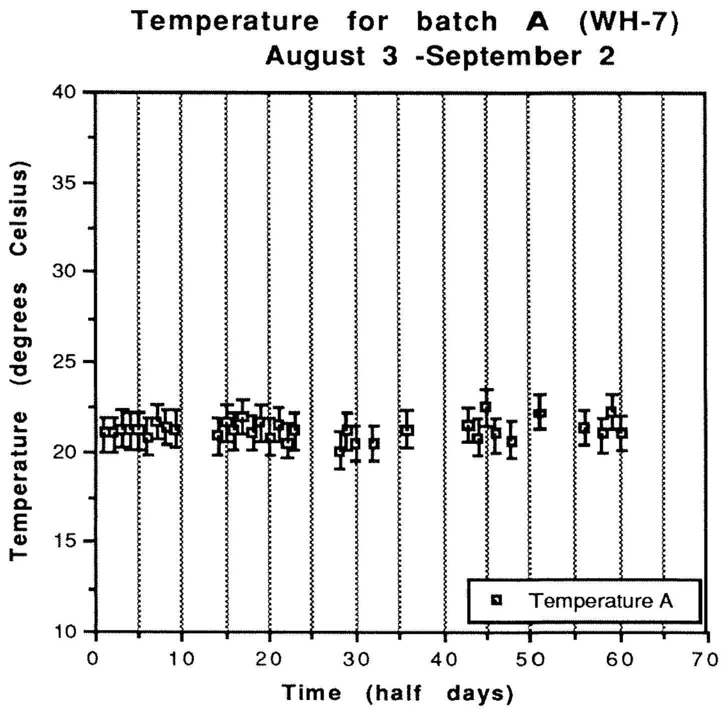

Figure 3

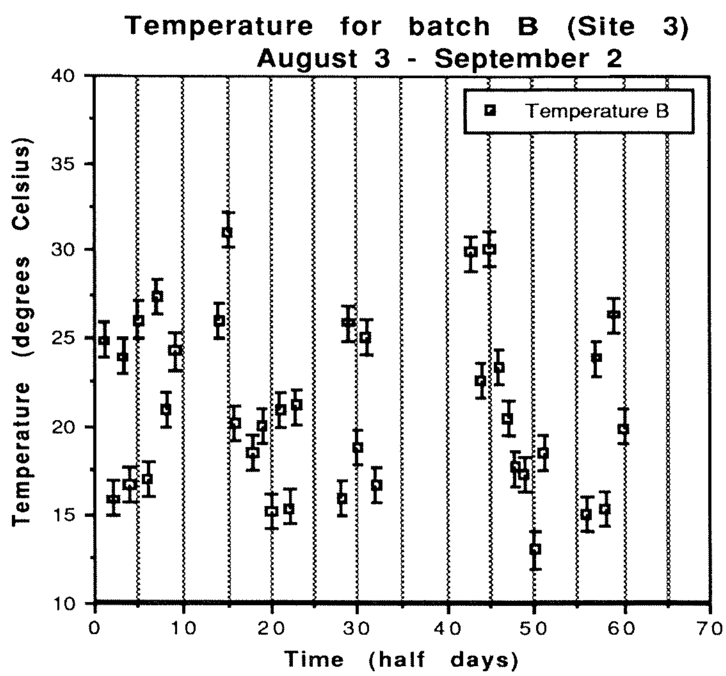

Figure 4

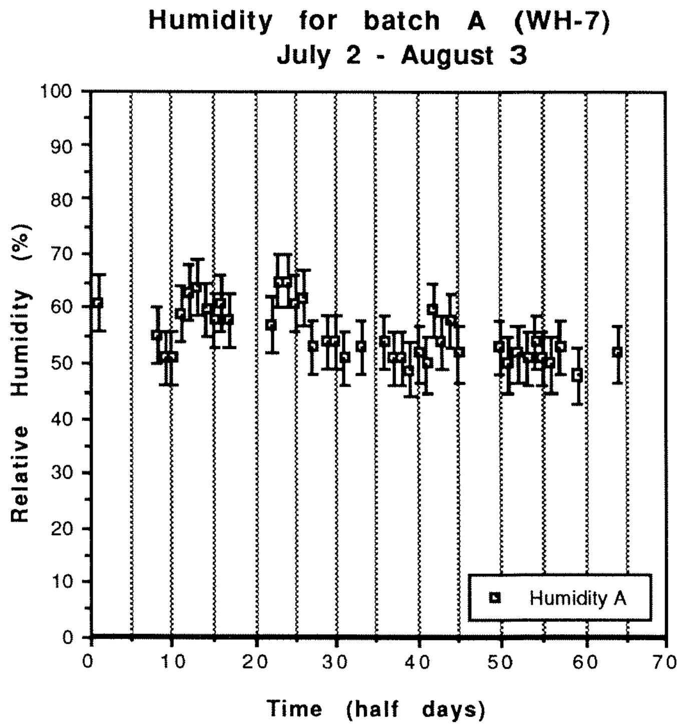

Figure 5

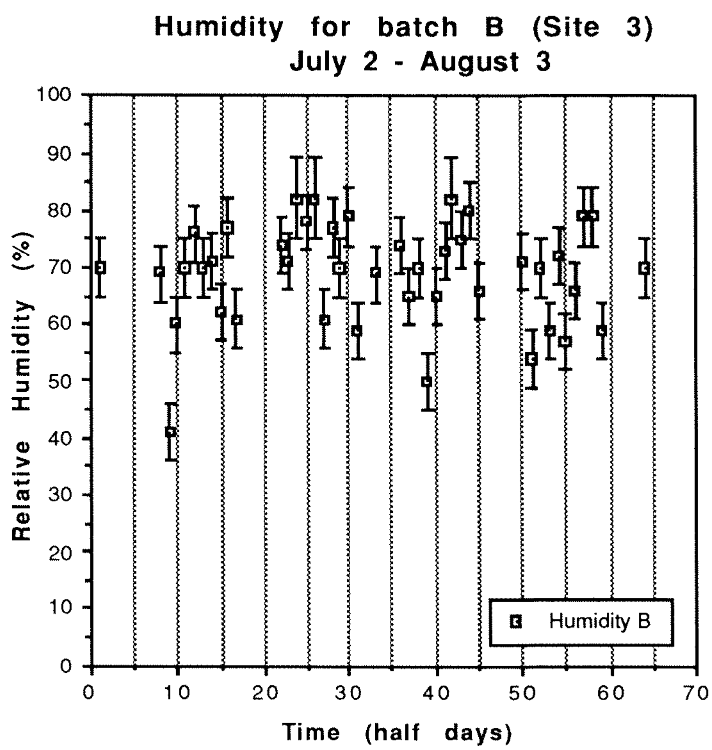

Figure 6

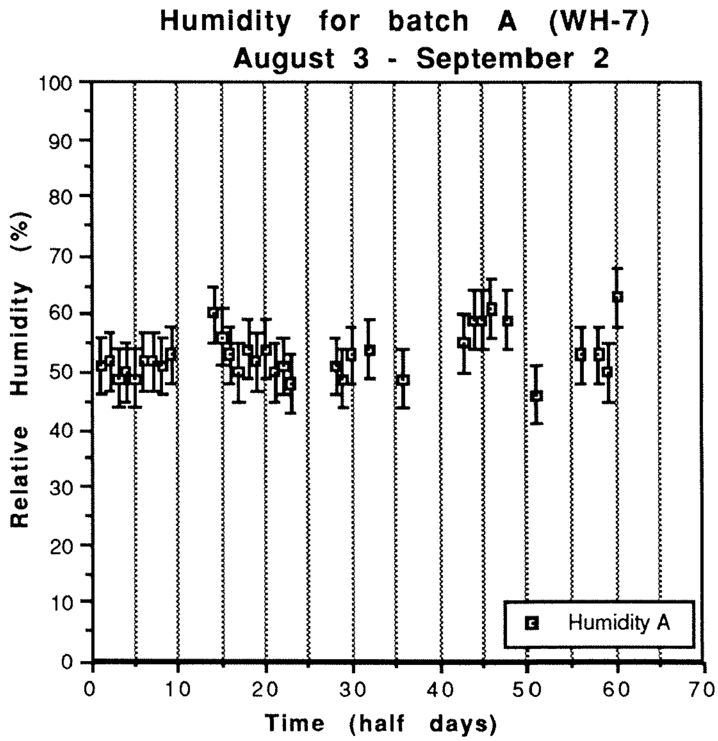

Figure 7

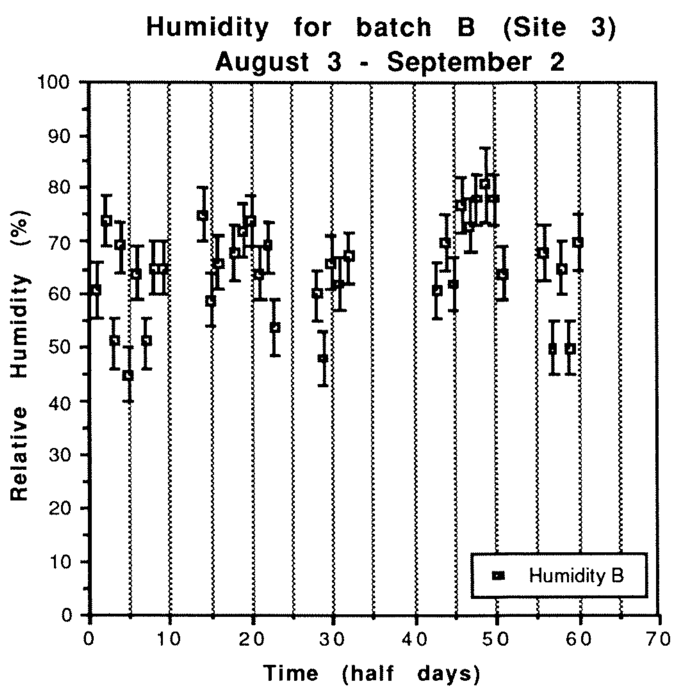

Figure 8

3.0 Gamma Exposure

Each badge consists of two sections: film for recording gammas and charged particles and lexan for recording neutrons. Both sets of badges (July and August) were dosed with gammas from the Cs^{137} source 137-8.1-1 at the source projector facility. Each month the badges from groups A and B were given identical doses (identical exposure times at identical distances from the same source). The gamma dose for July was 97 ± 3 mrem. The gamma dose for August was 978 ± 22 mrem. These doses were obtained by multiplying the exposures by 0.96. The uncertainties are discussed below.

3.1 Errors in the Gamma Exposure

Three sources of error are considered in calculating the gamma exposure: the calibration error of the source[1], the error in exposure time and the error in source-to-badge distance.

The exposures are regulated by an automatic timer. The uncertainty in time is due to the finite amount of time required to lift the source out of its shield, thereby activating the timer, and the time required for it to drop back into its shield after the preset time has expired. The uncertainty is estimated to be 1 second.

The nominal source-to-badge distance is measured by a tape measure extending along a rail and moving along this rail in tandem with a table, on which the badges are placed. The badges are mounted on a frame which will hold nine badges at a time. The source-to-badge distance was measured as the distance from the source (considered to be a point source) to the center of the frame. This distance was 240 cm. The greatest distance between the center of the frame and the center of any badge was 13.3 cm. From the Pythagorean theorem, the greatest deviation of the source to badge distance was therefore 0.45 cm.

3.2 Calculation of the Gamma Exposure

The gamma exposure was calculated according to the following formula:

$$X = \dot{X} \exp(-\lambda T) \frac{t}{R^2} \quad (1).$$

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[1] RP Note 83, *Calibration of Radioactive Sources Used by Fermilab ES&H Section for Instrument Calibration and Characterization*, F. Krueger (1989).

Here $\dot{X}$ is the calibrated exposure rate (28 R/hr at 1m)[1], λ is the decay constant (0.023), T is the decay time since calibration (7.97 years), R is the distance from the source to the badges (241.4 cm for July; 240.0 cm for August) and t is the exposure time (90 s for July; 900 s for August). The fractional uncertainty in the exposure is

$$\frac{\Delta X}{X} = \frac{\Delta \dot{X}}{\dot{X}} + 2\frac{\Delta R}{R} + \frac{\Delta t}{t} \qquad (2).$$

4.0 Neutron Exposure

In addition to the gamma radiation, the badges for July were exposed to neutron radiation from Americium-Beryllium source Am241Be-7.2-1. A lead sheath was placed over the source to block out gamma emissions. As described below, the calculated neutron dose was 91 ± 18 mrem. A tissue-equivalent ion chamber (HPI 1010) placed beside the badges indicated an average reading of 8.2 mrad/hr. The average quality factor of the neutrons is 7.9. This would indicate a dose equivalent of 65 mrem since the exposure time was one hour. The uncertainty in the instrument reading is estimated to be 20%[2].

4.1 Errors in the Neutron Exposure

The uncertainties considered here are those in the source-to-badge distance and the exposure time. These errors are considerably larger than the corresponding errors for the gamma exposure and dominate the uncertainty of the dose measurement.

The source-to-badge distance, as measured with a meter stick, was 50.4 ± 1 cm to the center of the badge cluster. The half-diagonal of the badge cluster was 21.2 cm. Again using the Pythagorean theorem, the uncertainty in distance $\delta R = 4.4$ cm.

The source was placed and removed by hand. The uncertainty in exposure time is estimated as 1 minute. The total exposure time was one hour.

In addition to these uncertainties, an anomaly occurred during the exposure. At some point during the hour six of the badges fell from the cluster onto the floor. Since the badges were unattended during this time, it is impossible to know exactly when this took place or what effect

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[2] RP Note 94, *Fermilab's Radiological Calibration Intercomparison*, F. Krueger and K. Vaziri (1992).

it had on the dose these badges received. The badge numbers were 40912, 40933, 40934, 40935, 40938 and 40939; all from batch A. This will be discussed further in section 5.2.

4.2 Calculation of the Neutron Dose

In a manner analogous to eq. (1), the neutron dose is given by

$$D = \dot{D}_0 \exp(-\lambda T)\frac{t}{R^2} \quad (3).$$

The calibrated dose rate from ref. [1] is 23.254 mrem/hr at 1 m; the decay constant $\lambda = -1.60 \times 10^{-3}$; the time since calibration T = 4.3 yr.; the exposure time t = 1 hr; the source-to-badge distance R is taken to be 50.4 cm.

The fractional uncertainty in the dose equivalent is

$$\frac{\delta D}{D} = \frac{\delta t}{t} + 2\frac{\delta R}{R} = .193 \quad (4).$$

5.0 Results

For each irradiation of the badges, two comparisons are made. First, the dose measured by Landauer is compared to the actual dose given to the badges. Secondly, the results of this first comparison are compared between groups A and B.

5.1 Gamma Results

Comparisons of the gamma dose equivalent measured by Landauer with the actual dose equivalent given the badges in July are shown for groups A and B in Figures 9 and 10, respectively. Landauer's uncertainty in determining the dose is not known, but their report claims a minimum detectable level for film of 10 mrem. If this figure is taken as Landauer's uncertainty and added in quadrature with the uncertainty in the administered dose (3 mrem), the "uncertainty" of the comparison, that is the distance between the two bars for each badge in the bar graphs within which the values may be considered identical, is 10.4 mrem. The average value for July Group A is 109 mrem; that for July Group B is 111 mrem. Statistically, there is no significant difference either between the actual dose and the measured dose, or between the measured doses for Groups A and B.

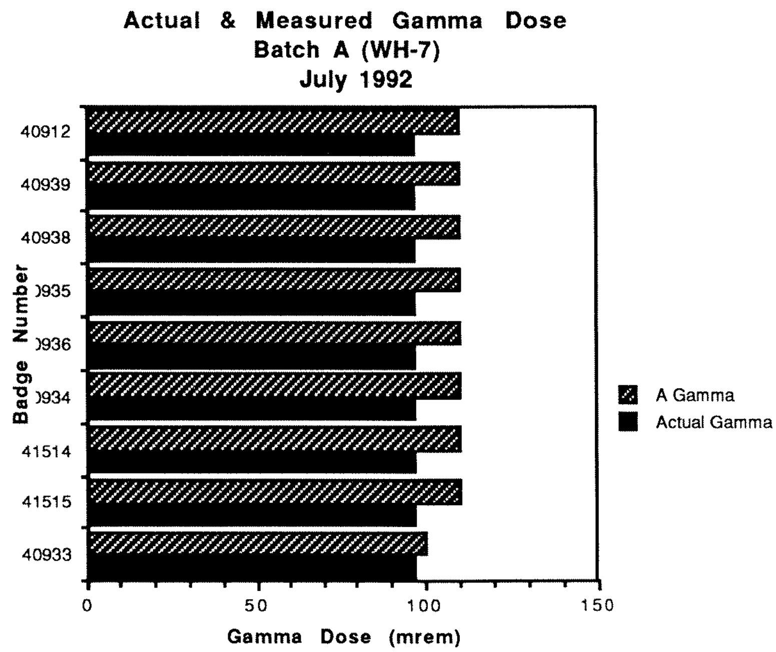

Figure 9

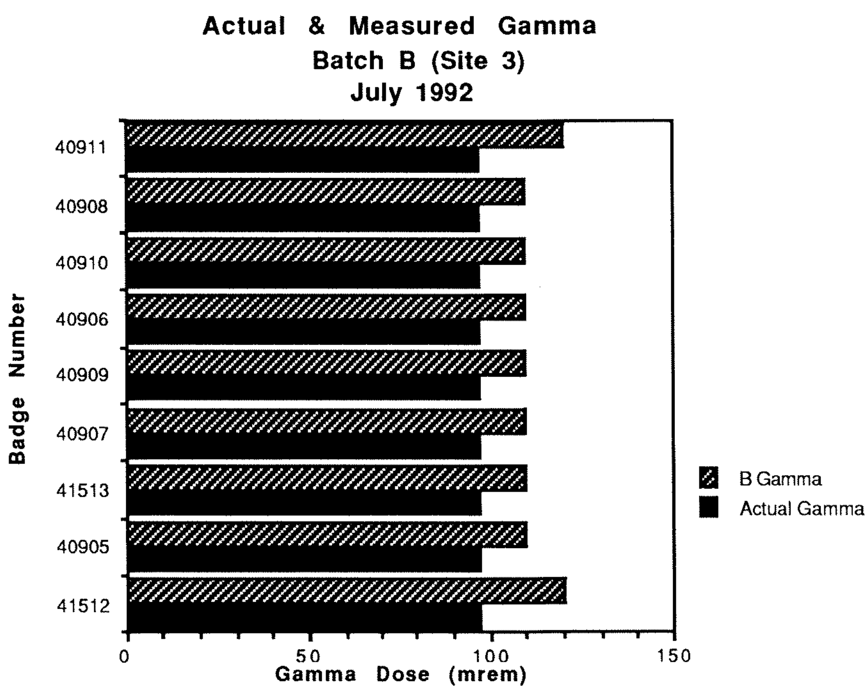

Figure 10

The gamma comparisons for August are shown in Figures 11 and 12. Applying the same criterion to the gamma measurements for August, combining a 10 mrem measurement uncertainty with a 22 mrem dose uncertainty gives a comparison "uncertainty" of 24 mrem. The average value for group A is 1032 mrem; that for group B is 1020 mrem. Again, the difference between the measured dose and actual dose is not statistically significant. There is virtually no difference between Groups A and B.

5.2 Neutron Results

The comparisons for the neutron doses are shown in Figures 13 and 14 for Groups A and B, respectively. Landauer claims a minimum reporting dose of 20 mrem for fast neutrons and again, this figure is taken as the uncertainty in the measurement. Combined in quadrature with the 18 mrem uncertainty in the dose, this gives a comparison "uncertainty" of 27 mrem.

Group A contains six badges which fell of off the rack during the neutron exposure. These include the four largest discrepancies between measured and actual dose (40912, 40939, 40934, 40933) but also include two badges whose measured and actual values agree very well (40938, 40935). All of the other badges from both groups show reasonable agreement between the measured and actual values. The average measured neutron dose for Group A is 73 mrem; that for Group B is 86 mrem. There is no statistically significant difference between the measured values of Group A and Group B, discounting the badges which fell on the floor.

6.0 Conclusion

The above comparisons lead to two basic conclusions. First, there is no serious discrepancy between the doses measured by Landauer and the doses actually administered to the film badges, either for neutrons or for gammas. Secondly, the differences between an indoor environment and an outdoor environment during summer conditions at Fermilab do not influence the quality of the dose measurements.

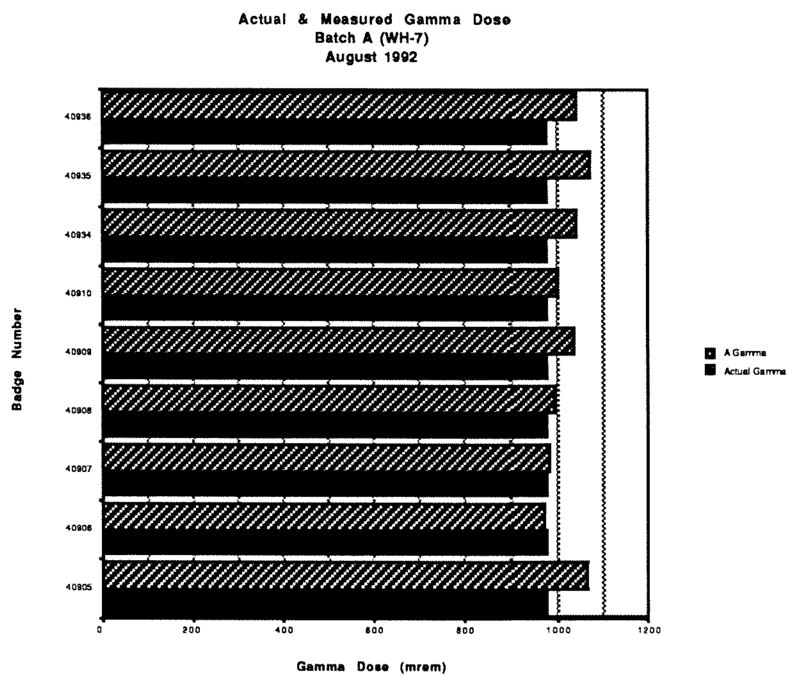

Figure 11

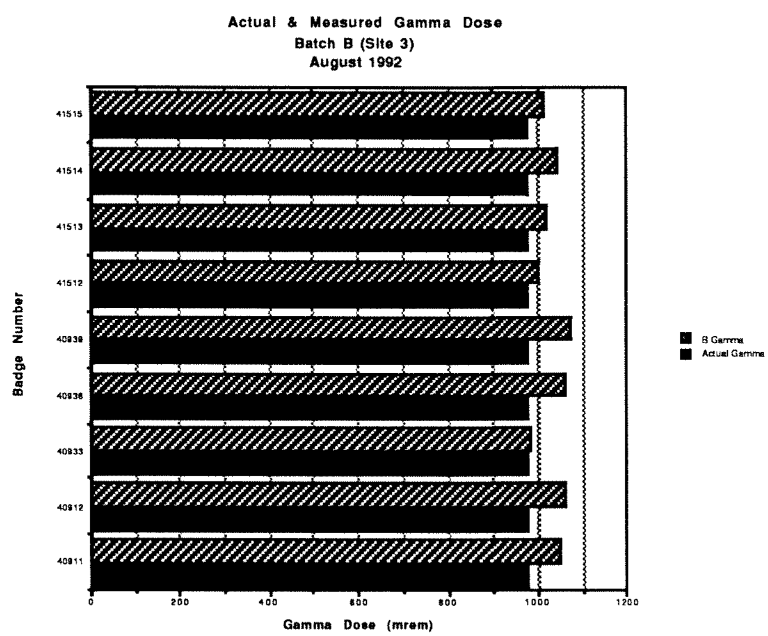

Figure 12

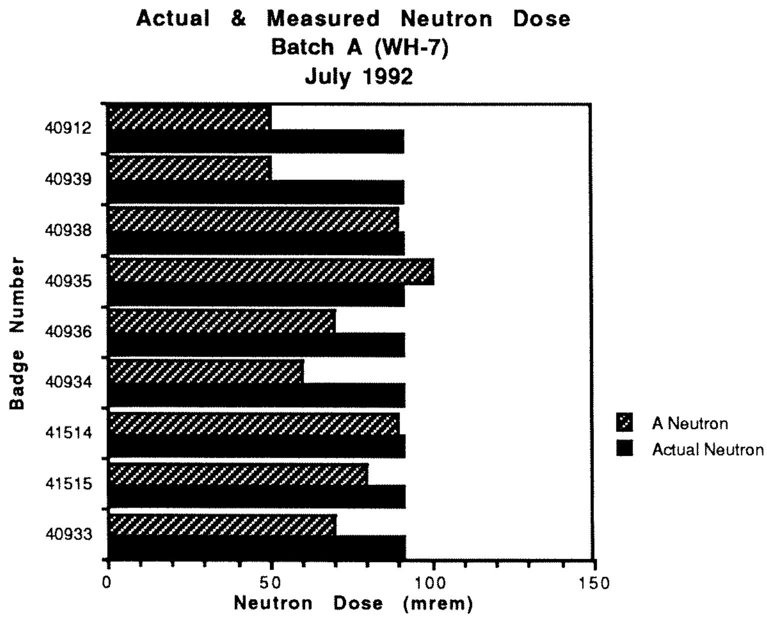

Figure 13

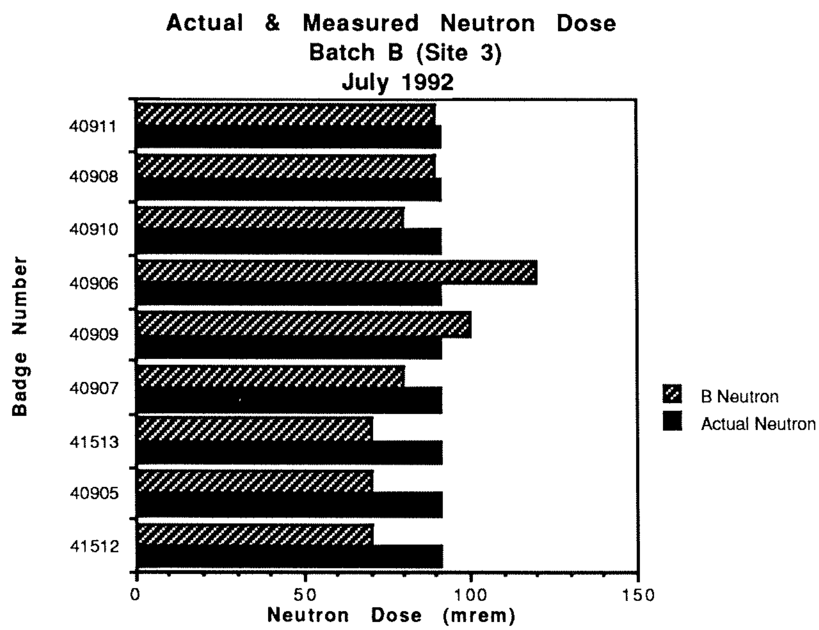

Figure 14