R. P. Note #97

A Summary of Film Badge Spiking at Fermilab for 1991

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For the past few years Fermilab has conducted a program of testing film badges, called "spiking." This program provides a method of in-house evaluation of film badge results submitted by Landauer, a commercial supplier. The procedure is to irradiate a set of badges associated with fictitious employees with a known dose of gammas, neutrons, or a combination thereof. This is generally done on a quarterly basis. This note provides a summary of film badge spiking results for 1991.

The same set of 18 badge numbers is used for spiking each quarter. Three badges from this set are chosen at random for each of six subsets; each subset is given a different dose. Two subsets are given different doses of gammas only, two subsets are given different doses of neutrons only, and two subsets are given different combined doses of gammas and neutrons. The doses vary from quarter to quarter.

Quarterly Bar Graphs

The most straightforward means of visual evaluation on a quarterly basis is a bar graph comparing the *expected value* of the dose given the badges during spiking with the *measured value* of the dose returned by Landauer. Figures 1-8 show bar graphs comparing the expected and measured values of gamma and neutron doses for each quarter of 1991. The scale varies from one bar graph to another due to the variation in doses. These graphs show that the measured value generally agrees reasonably well with the expected value, although the agreement is usually better for gammas than for neutrons.

The exception to this trend is the test for October 1991, in which the expected gamma dose is considerably higher than the measured gamma dose. It is noteworthy that the survey instrument readings for this quarter also read lower than the expected value and the measured values are in good agreement with the recorded readings of the survey instruments. It seems likely that an error was made in calculating the expected gamma doses in October 1991.

Another anomaly which is evident in the October 91 data is the occurence of zero measured values for finite expected values. In these cases the expected values (25 mrem) were close to or less than the threshold at which the doses can be detected on the film badge. Such low doses should be avoided in future spiking tests as they render the test meaningless.

Fractional Differences

Although the bar graphs provide a good qualitative comparison between the expected and measured values, it is desirable to quantify the comparison. To this end, *fractional differences* are calculated and plotted in the following manner. The measured values of gammas and neutrons are both averaged for each subset of three badges. These average values are assigned an error equal to the standard deviation of the sample. The fractional difference is given by

$$f = \frac{E - M}{E},$$

where E is the expected value and M is the average measured value. The scaled error is given by

$$\sigma_f = \frac{\sigma}{E},$$

where σ is the standard deviation of M.

In the absence of any systematic error in the dose measurements, one would expect the fractional differences to be random in nature. Figures 9 and 10 show the fractional differences for gammas and neutrons, respectively, plotted against the expected value of the dose. There does not appear to be any significant trend in the data. The fractional uncertainties are in general larger for small doses, as would be expected. With the exception of the anomalous data from October, the gamma fractional differences tend to be low but this is usually less than a two sigma effect. The neutron data are centered fairly well on zero, although the neutron fractional differences are considerably larger than those for the gammas. The fractional differences do not appear to have any dependence on the expected dose.

Finally, the data were checked for consistency over time. The average fractional differences for gammas and neutrons were calculated for each quarter of 1991. The average is based on the six averages for each quarter (even though only four subsets of badges were exposed to each type of radiation. The two zero values are control groups). An error equal to the sample standard deviation (using the averages of each subset as the sample) is associated with each value of the average fractional difference. The results are shown in figures 11 and 12. Discounting the anomalous result of October 91, there does not appear to be any trend in the data over time.

Conclusions

A definitive statement on the consistency of the measured dose values returned by Landauer with the expected dose values given the test film badges at Fermilab is somewhat difficult to make because the errors in measurement are not known for either value. Whatever systematic errors may exist, however, do not appear to impact the measurements significantly; that is, the random errors dominate the results. The fractional difference between the measured dose and the expected dose does not seem to depend on the dose amount or the time of year. A possible exception to this latter finding is the gamma data for October 91, which is anomalous in that the recorded readings of the survey instruments do not agree with the expected value. The film badge spiking data from 1991 give no reason to suspect any significant systematic error in the dose measurements returned by Landauer.

Random errors do exist, however. The average fractional difference for the first three quarters of 1991 is -0.034 ± .073 for gammas and -0.046 ± .146 for neutrons. It is of interest to ask what effect these errors might have on an employee's dose measurements. To address this matter, consider the "average employee" wearing one of the spiked badges over the course of 1991. The question is "how much dose might the average employee have received in 1991 *and not known about* due to random errors in the dose measurements?" This can be estimated using the formula

$$\frac{\overline{M}}{1-\overline{f}} \approx \overline{E},$$

where $\overline{M}$ is the average measured annual dose from Landauer, $\overline{f}$ is the average fractional difference, and $\overline{E}$ is the average expected value for the year. The averages given here were taken only over the first three quarters of 1991 due to the questionable nature of the October data. During this time the "average spiked employee" received a measured gamma dose of 1015 ± 777 mrem and a measured neutron dose of 276 ± 143 mrem. Using the formula above, the average expected values are 982 mrem for gammas and 264 mrem for neutrons. Taking these values to be the doses received by the average spiked employee indicates that the average underestimation of the dose was 33 mrem for gammas and 16 mrem for neutrons.

The actual doses normally received at Fermilab are considerably smaller than those which are given to the spiked badges. Consider an employee whose measured gamma dose was less than the average spiked expected value by one standard deviation, that is 1015 - 777 = 238. The expected value for such an employee can be estimated by solving the above formula. However, since the fractional errors are larger for smaller doses a value f_l was calculated based solely on the fractional errors for smaller gamma doses (50 - 200 mrem). The value obtained for f_l is -0.052 ± .087. The result is an expected value of 226 mrem, which is an underestimation of 12 mrem. The conclusion of this study is that there is no serious underestimation of the dose received by the average Fermilab employee.

The author wishes to acknowledge Kathy Graden for taking the data and thank her for valuable discussions contributing to this note.

Figure 1 - Jan 91 Gamma

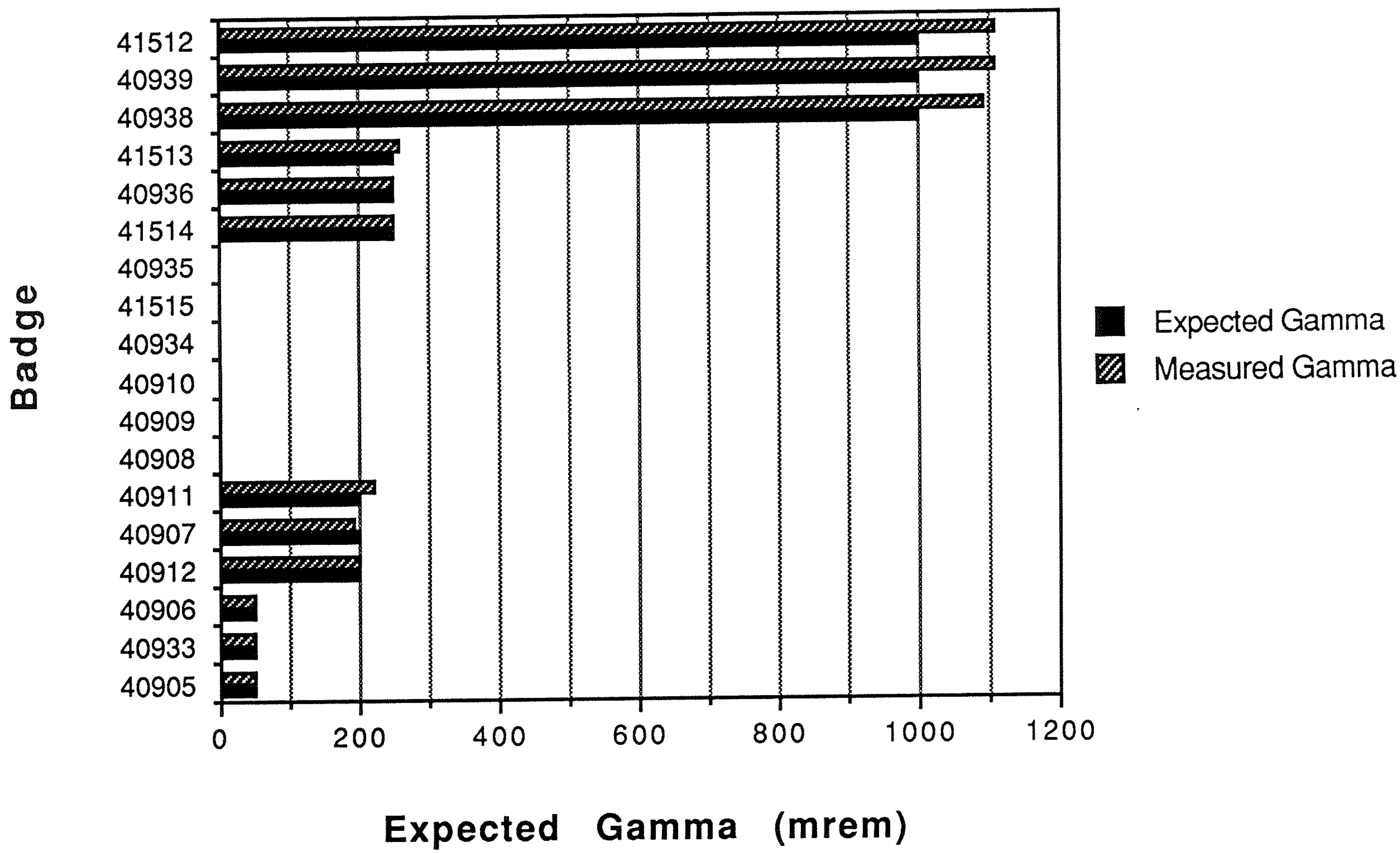

Figure 2 - Jan 91 Neutron

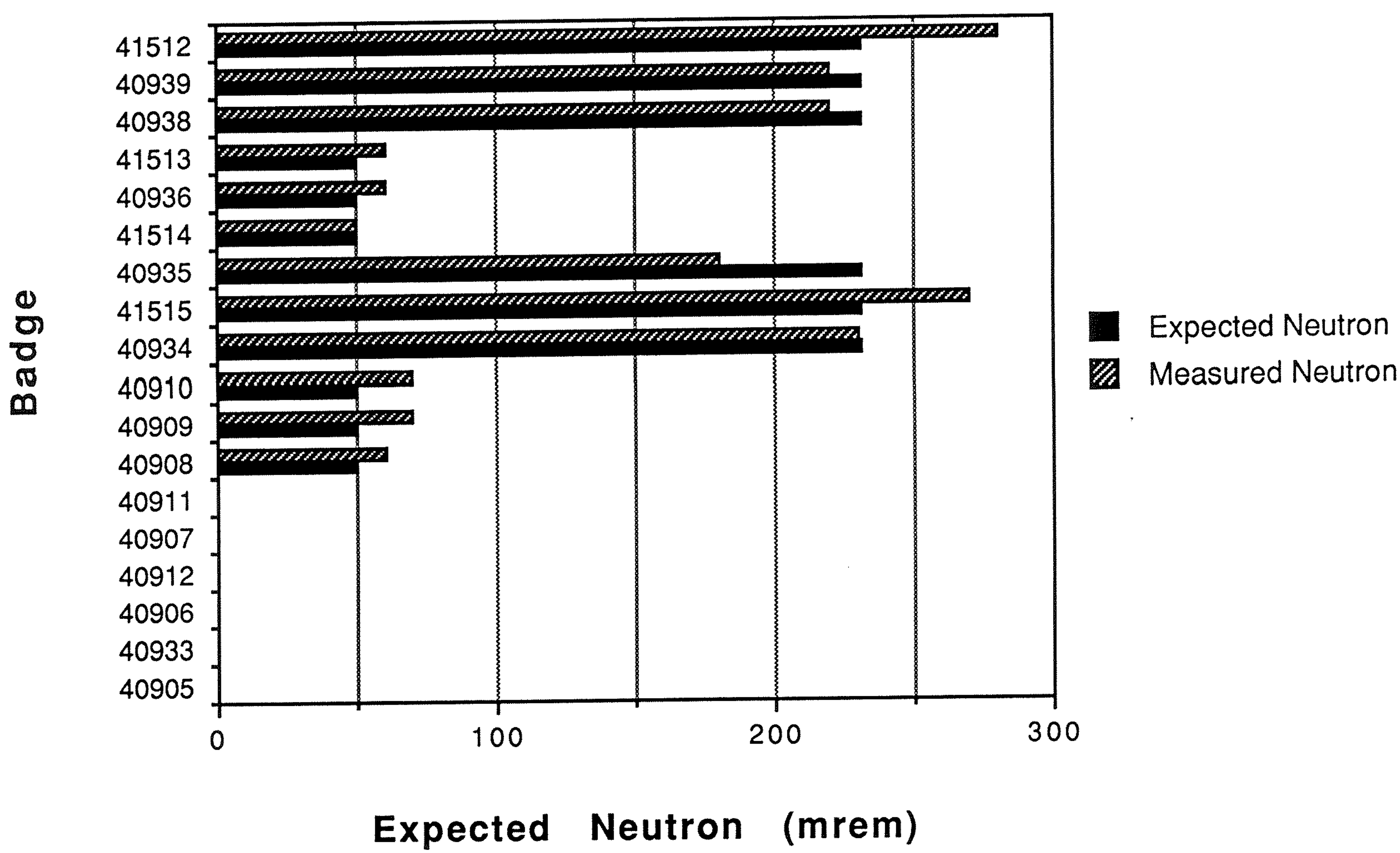

Figure 3 - April 91Gamma

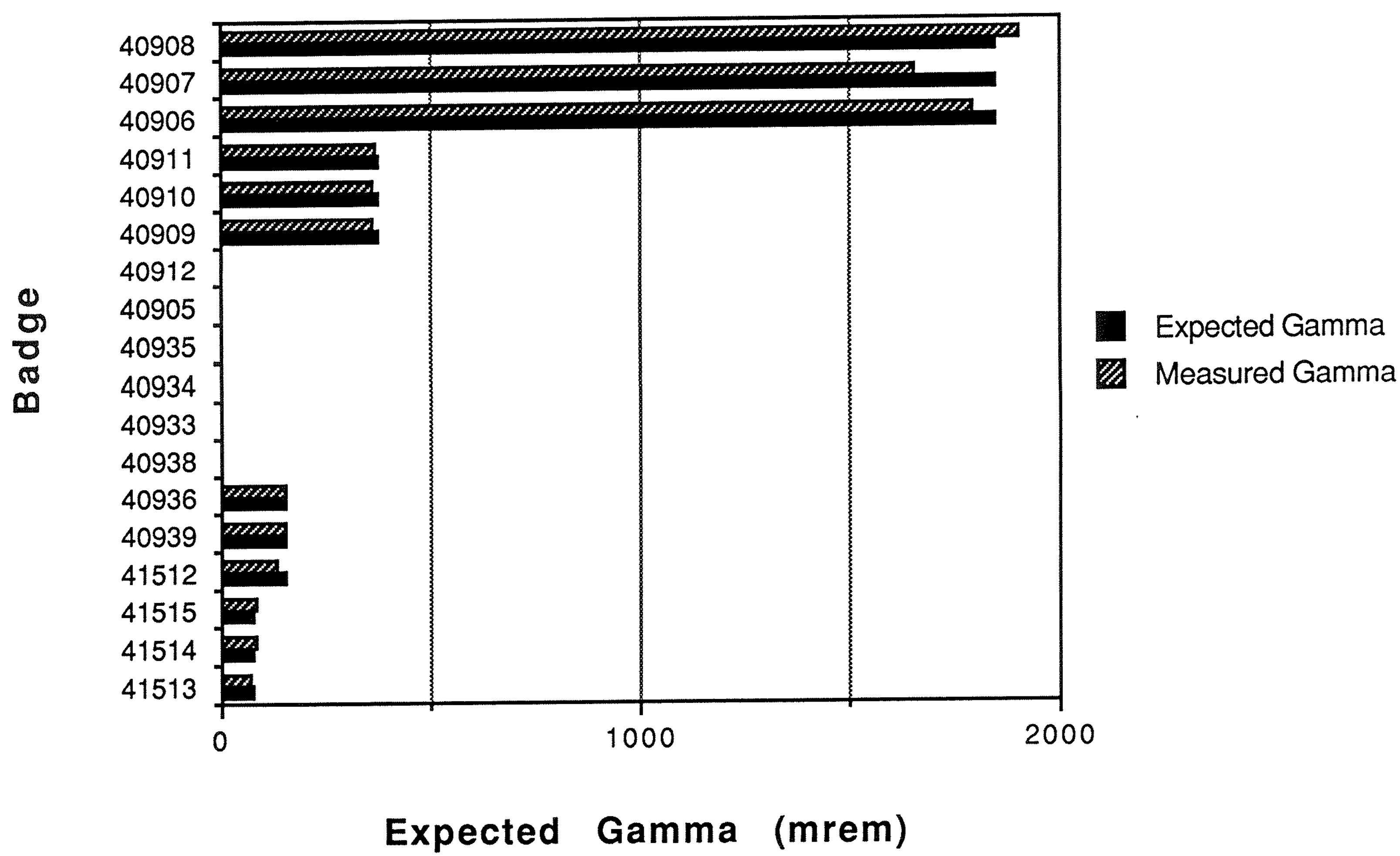

Figure 4 - April 91 Neutrons

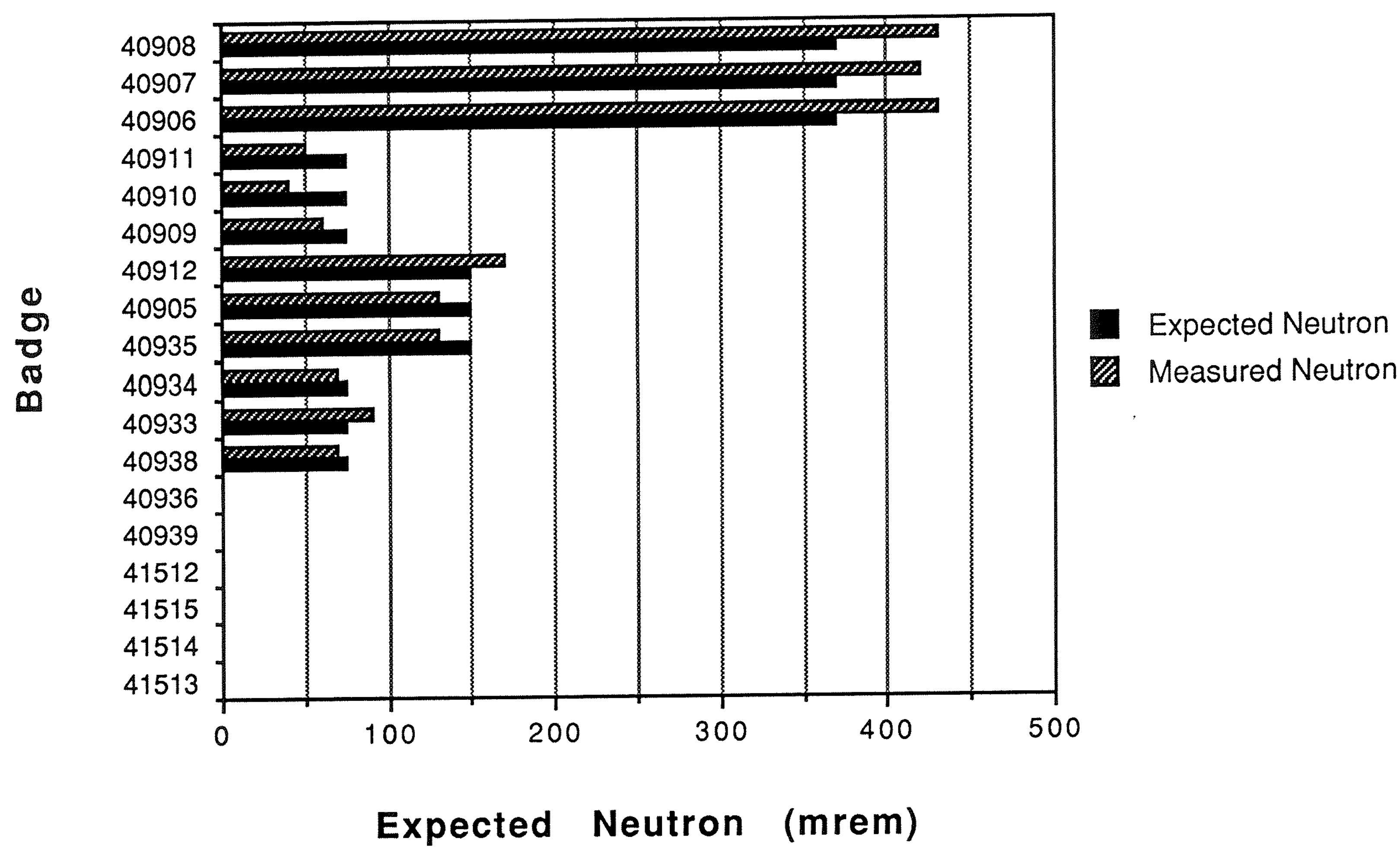

Figure 5 - July 91 Gamma

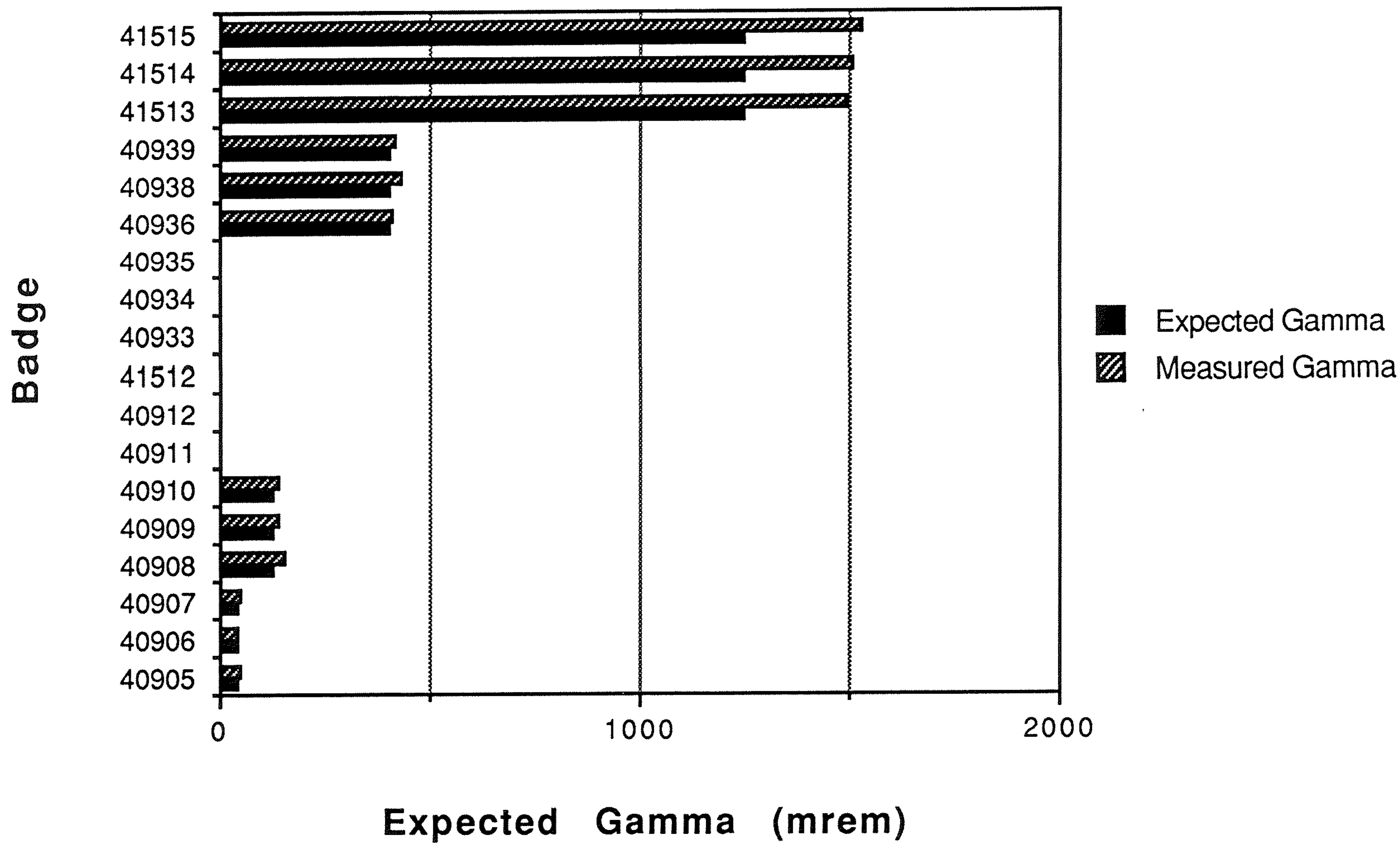

Figure 6 - July 91 Neutron

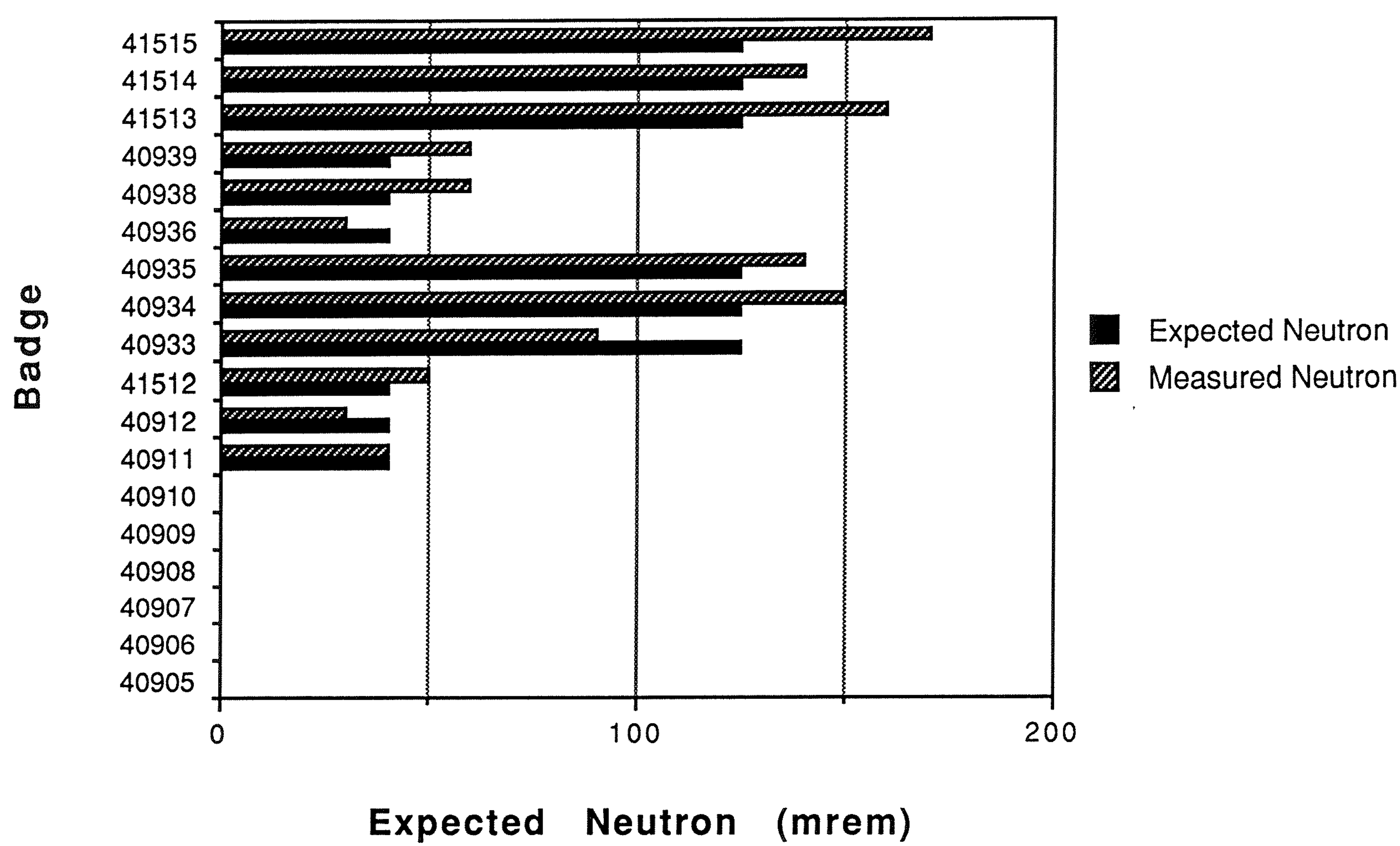

Figure 7 - Oct 91 Gamma

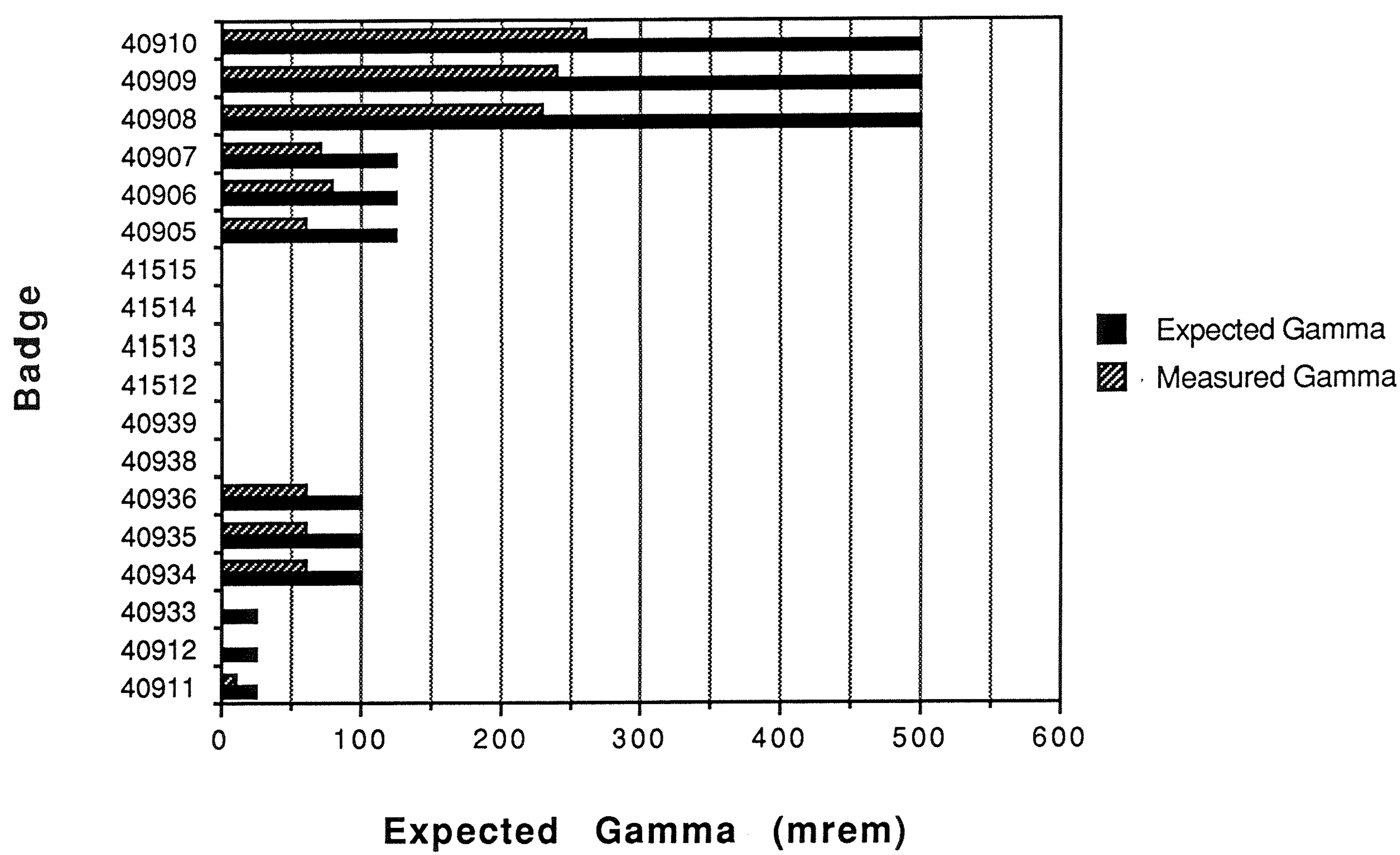

Figure 8 - Oct 91 Neutron

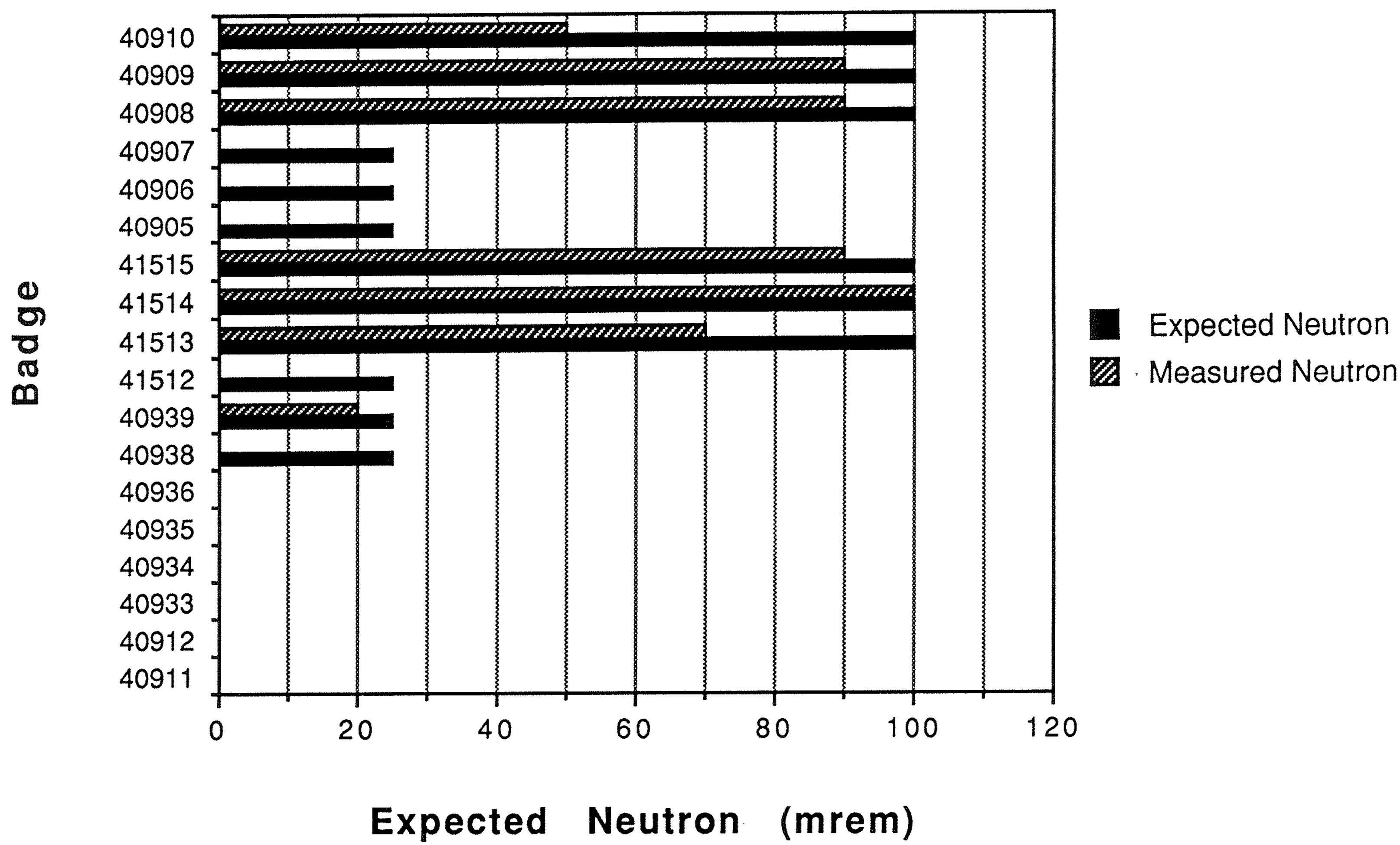

Figure 9 - 1991 GDIF vs Dose

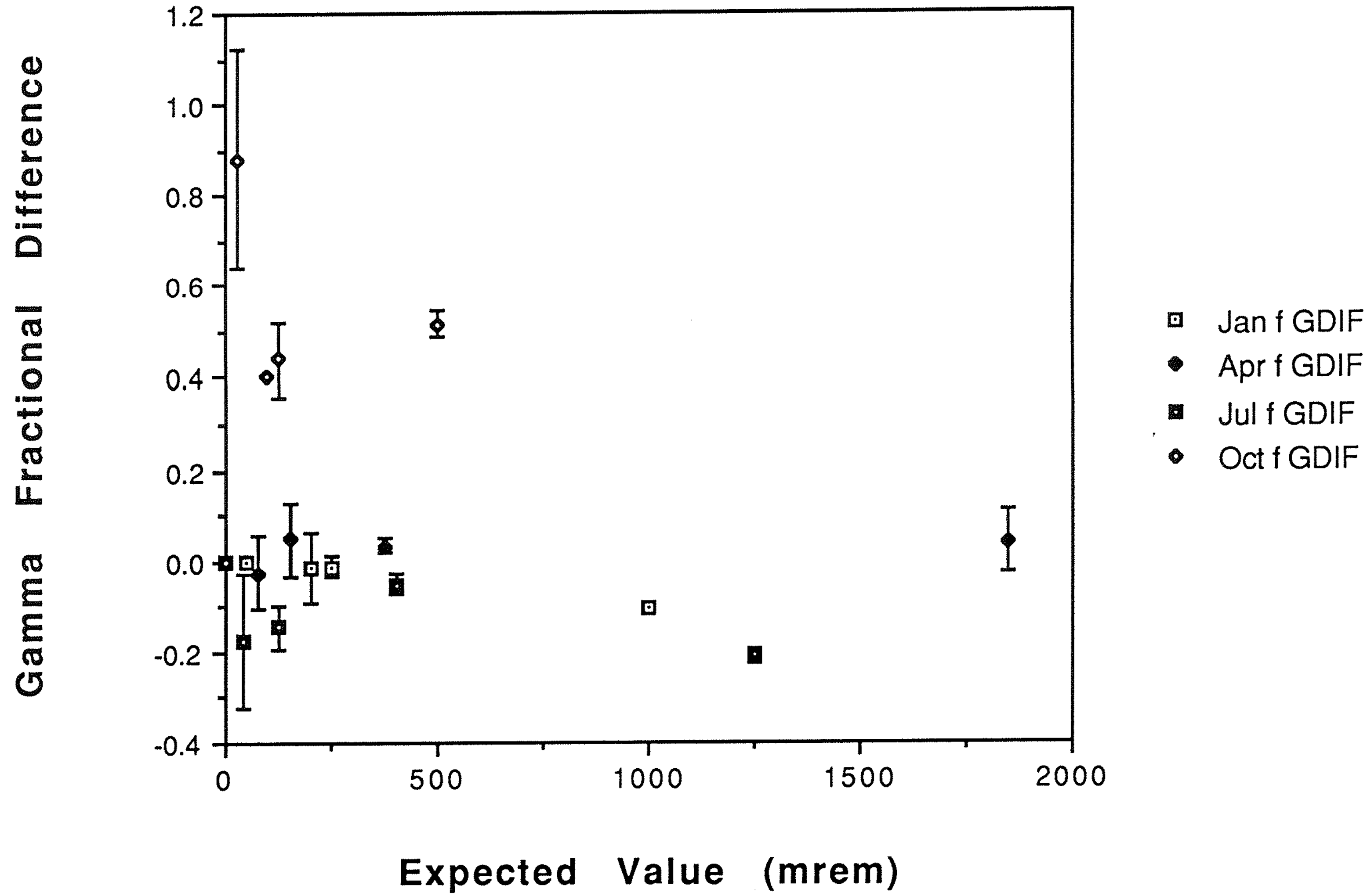

Figure 10 - 1991 NDIF vs Dose

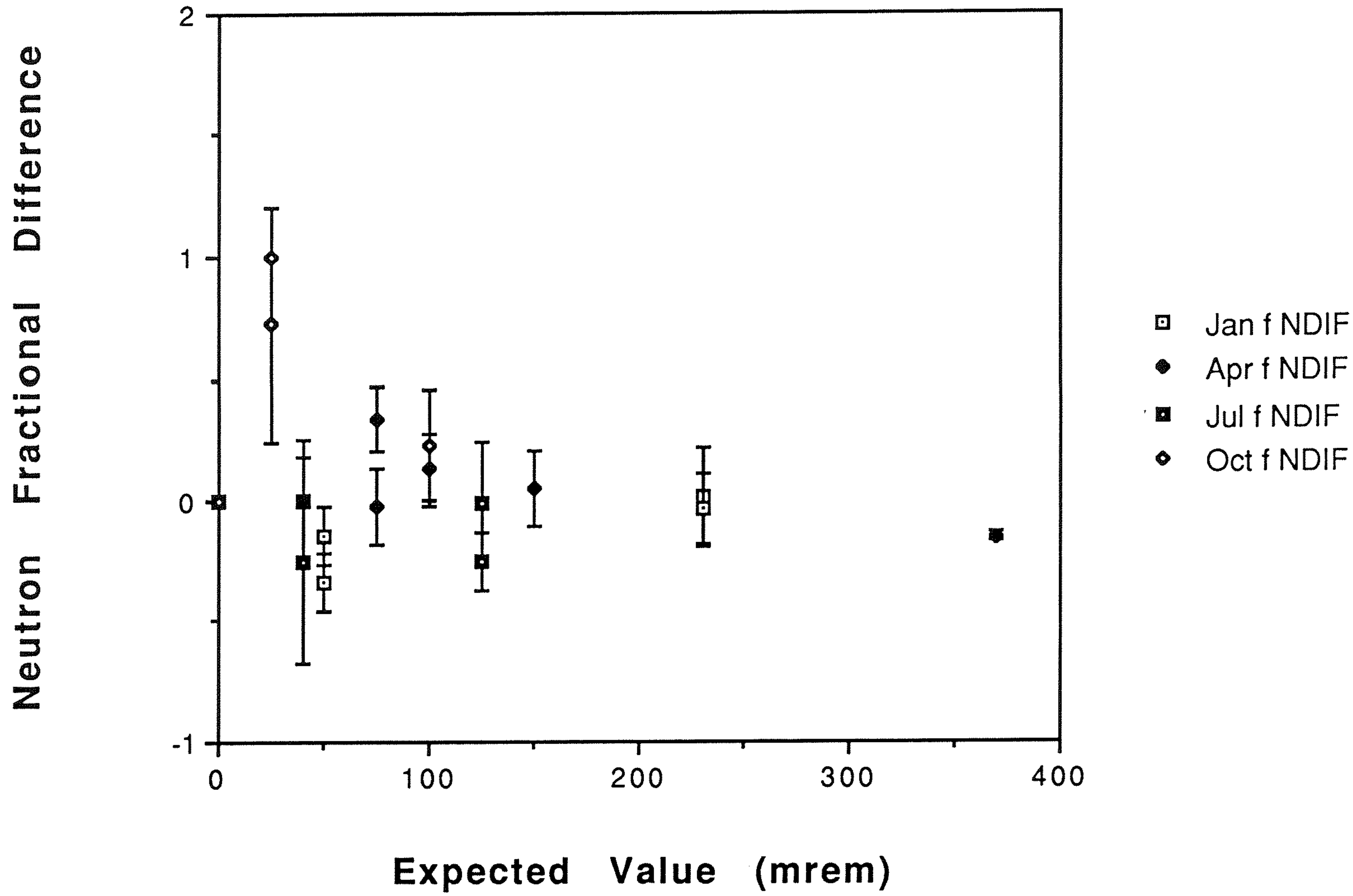

Figure 11 - 1991 Average f GDIF

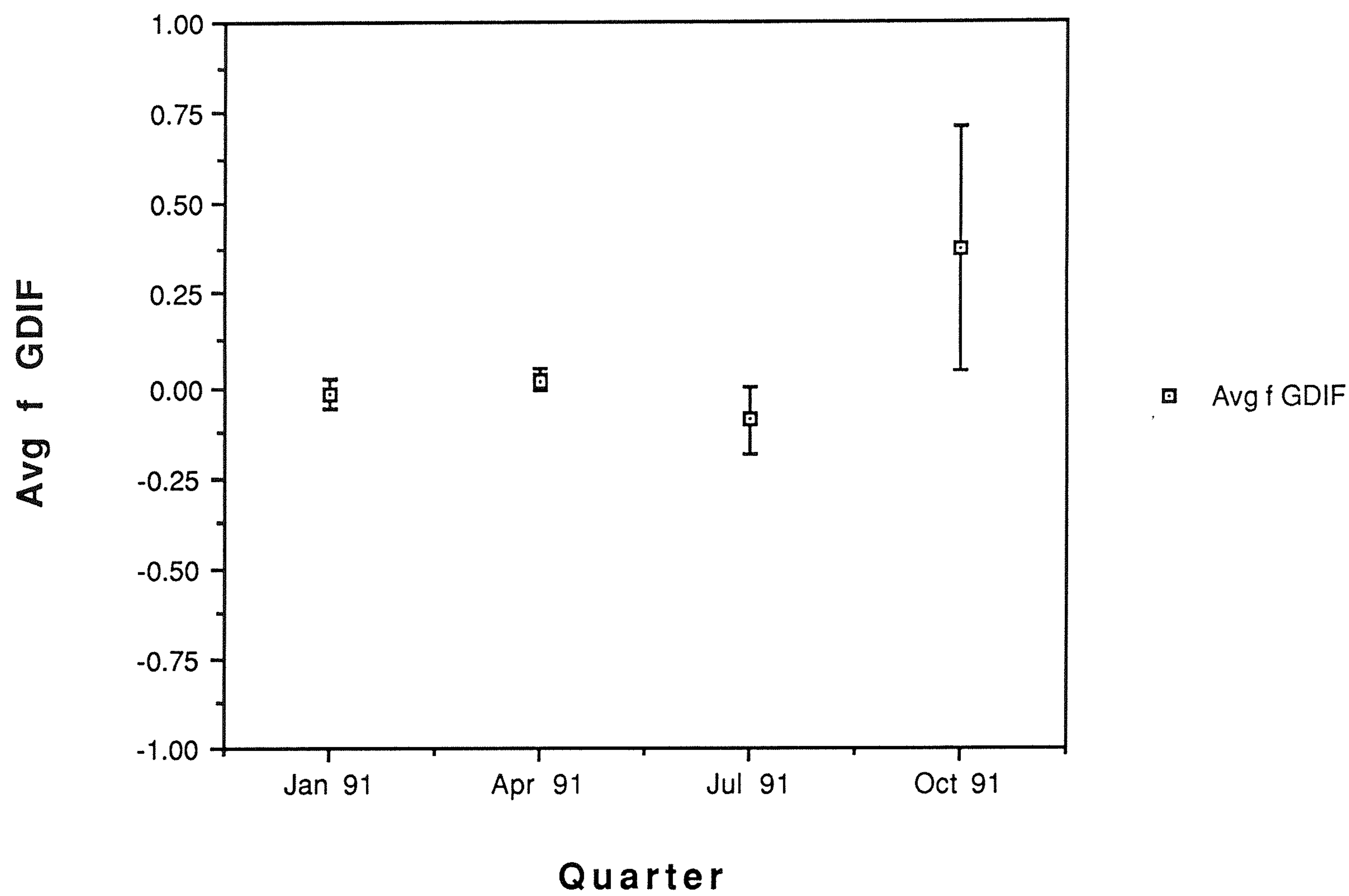

Figure 12 - 1991 Average f NDIF