APPENDIX E

Evaluation of Differential Shim Rod Worths from Measured Time-Dependent Flux Profiles

The methods used to evaluate differential shim rod worths from measured flux transients following small shim rod displacements are discussed in Section 6.2. Results of these analyses are given in Section 7.3. The purpose of this appendix is to illustrate these data analysis methods for one particular case, namely, the movement of the D6 shim rod from 12.00 in. to 12.36 in. in core 179AX7. This detailed example corresponds to case 2 given in Table 30 (p. 96).

The flux transient was recorded with a multichannel scaler using the amplified and shaped signal from a fission chamber as input. Table E.1 shows the recorded flux trace. After the reactor operated at a low steady state power level for some time, the D6 shim rod movement began while data was being recorded in channel 44 and ended during the time channel 86 was active. The dwell time in each channel was 0.400 see and no data was recorded beyond channel 469.

Some of the data channels were corrected for obvious noise spikes. A simple smoothing routine, based on statistical considerations, was used for this purpose. Using this routine, a data point was rejected if it fell more than 4σ away from the previous data point where σ is the square root of the channel counts. The adjusted data point was obtained by linear interpolation. Table E.2 shows the adjusted channel counts obtained from this data smoothing process.

The overall resolving time of the detection system was measured to be 1.5 μsec. This value was used to correct the data for counting losses using the equation below.

$$N_c = N/(1 - N\, t_r/ t_d)$$

where N_c is the corrected count, N the uncorrected count, t_r the resolving time, and t_d the dwell time (0.400 see). Table E.4 shows the corrected channel counts.

It is convenient to normalize the data in Table E.3 to the average value of the counts per channel for those channels corresponding to the time before the beginning of the flux transient. The first 42 channels in Table E.3 were used for this purpose. Table EA gives the normalized channel counts corrected for noise spikes and counting losses.

Before determining the $n(t_2)/n(t_l)$ flux ratios shown in Table 30, a portion of the flux profile near the beginning of the flux transient was fit to a seventh-degree polynomial by the least squares process. The fit, shown in Table E.5 and Fig. E.1, is based on data from channels 101 to 221 in Table E.3. From this fit the flux ratios shown in Table 30 were determined. Thus, for case 2:

$$[n(t_2)/n(t_l)]exp = n(40.0\ sec)/n(20.0\ see) = NC(l\ 86)/NC(l\ 36)$$

$$= 3954.2/2447.3 = 1.61574$$

where the times t_2 and t_l are measured with respect to the end of the rod movement and where the NC's are the corresponding channel counts in channels 186 and 136, respectively.

Section 6.2 discusses how the differential rod worth is obtained from this measured flux ratio. Basically, the relative time-dependent flux, n(t)/n(0), is calculated following a step-change in reactivity using the point kinetics model. The reactivity is adjusted until the calculated flux at time t_2 relative to the flux at time t_1 agrees with the above measured value.

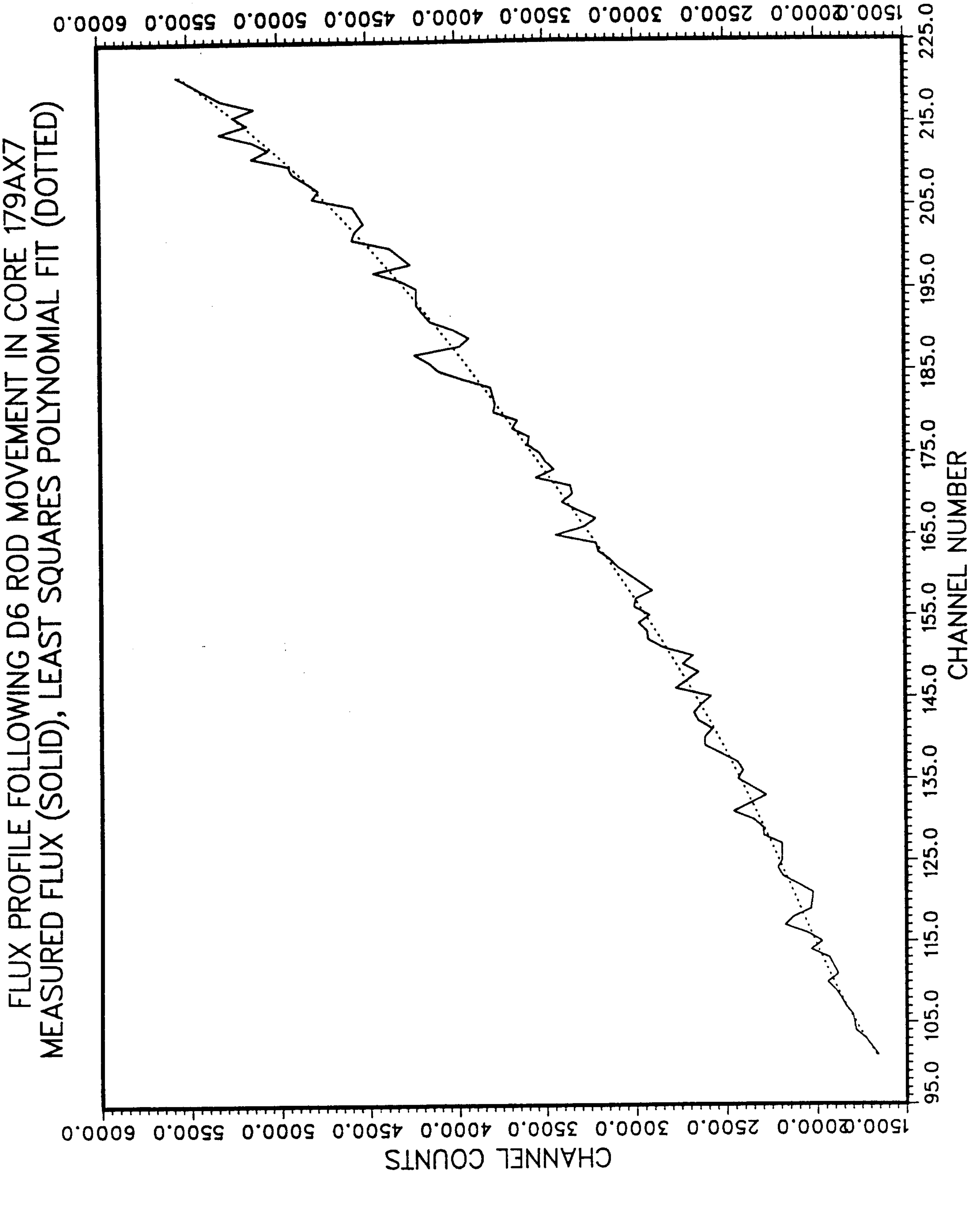

FLUX PROFILE FOLLOWING D6 ROD MOVEMENT IN CORE 179AX7
MEASURED FLUX (SOLID), LEAST SQUARES POLYNOMIAL FIT (DOTTED)
CHANNEL NUMBER
CHANNEL COUNTS

Table E.6 shows some of the results of this analysis. The kinetic parameters were taken from Table 19 (Core 179.f\) for delayed fission neutrons and from Table 20 for delayed photoneutrons. In Table E.6 PNEH2 and PNEBE are the average values for the photoneutron effectiveness for deuterium and beryllium, respectively. TEXP is the effective time during which the reactor operated at steady power before the reactivity step. The method used to evaluate the roots of the inhour equation (p. 53) required writing the equation in the following polynomial form:

$$F(\omega) = \omega^{m+1} + f_l\omega^m + f_2\,\omega^{m-1} + \ldots + f_m\omega + f_{m+1}$$

where m is the number of delayed neutron groups. The roots of the polynomial are those values of co for which F(ω) vanishes. Table E.6 shows the values of the polynomial coefficients (f_m), the roots (or zeros) of the polynomial, and the corresponding periods and reactivities. Since the shim rod displacement produced a positive reactivity insertion, all the periods are negative except one, which is the asymptotic period. The fact that each root of the inhour equation produces the same reactivity shows that the zeros were evaluated correctly.

The method used to evaluate the zeros of the polynomial form of the inhour equation produced incorrect results for problems containing more that 16 delayed neutron groups. Therefore, the data in Table 20 was reduced to five delayed photoneutron groups for beryllium and five for deuterium. This reduction from 18 to 10 equivalent delayed photoneutron groups has a negligible effect on the final value obtained for the differential shim rod worth. This is because the omitted groups have very small decay constants and because the 10-group set was used to determine γ_P (Be) and $\gamma_P(^2H)$ (see Section 6.3).

Table E.7 gives the calculated values for the $A_{j,}$ B_j and C coefficients (see p. 53) needed to determine the time-dependent relative flux n(t)/n(0). Only the results for k_0 = 1.00000 were used in the final analyses.

Calculated values for the relative fluxes, n(t)/n(O), are given in Table E.8. Times at which the relative fluxes were calculated are with respect to the instantaneous reactivity step change. Measured from the center of the time for the rod movement, t_j = 28.4 see and t2 = 48.4 sec. From the data at the top of Table E.8, the calculated flux ratio at these times is

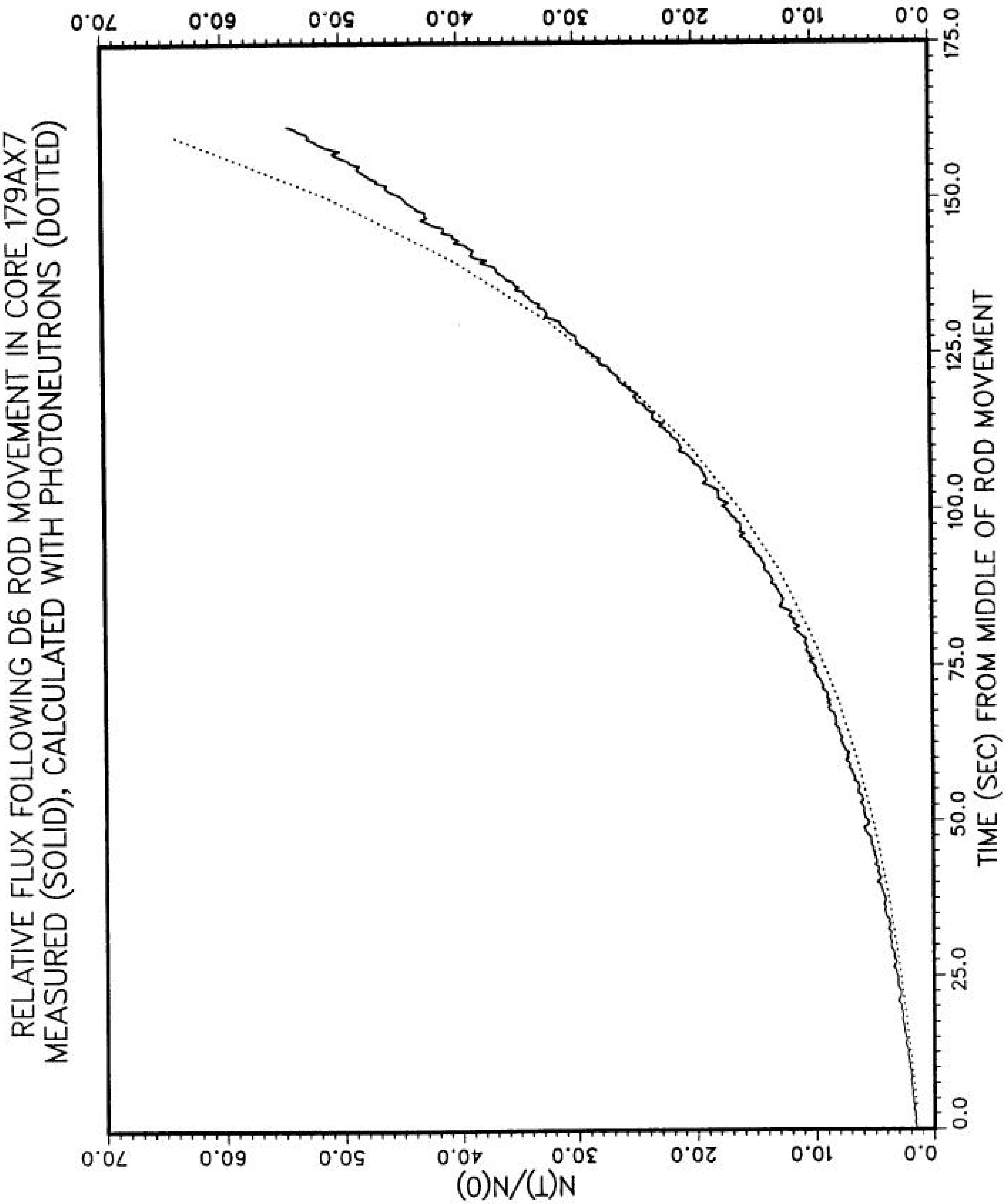
$$[n(t_2)/n(t_l)]calc = 4.92232/3.04648 = 1.61574$$

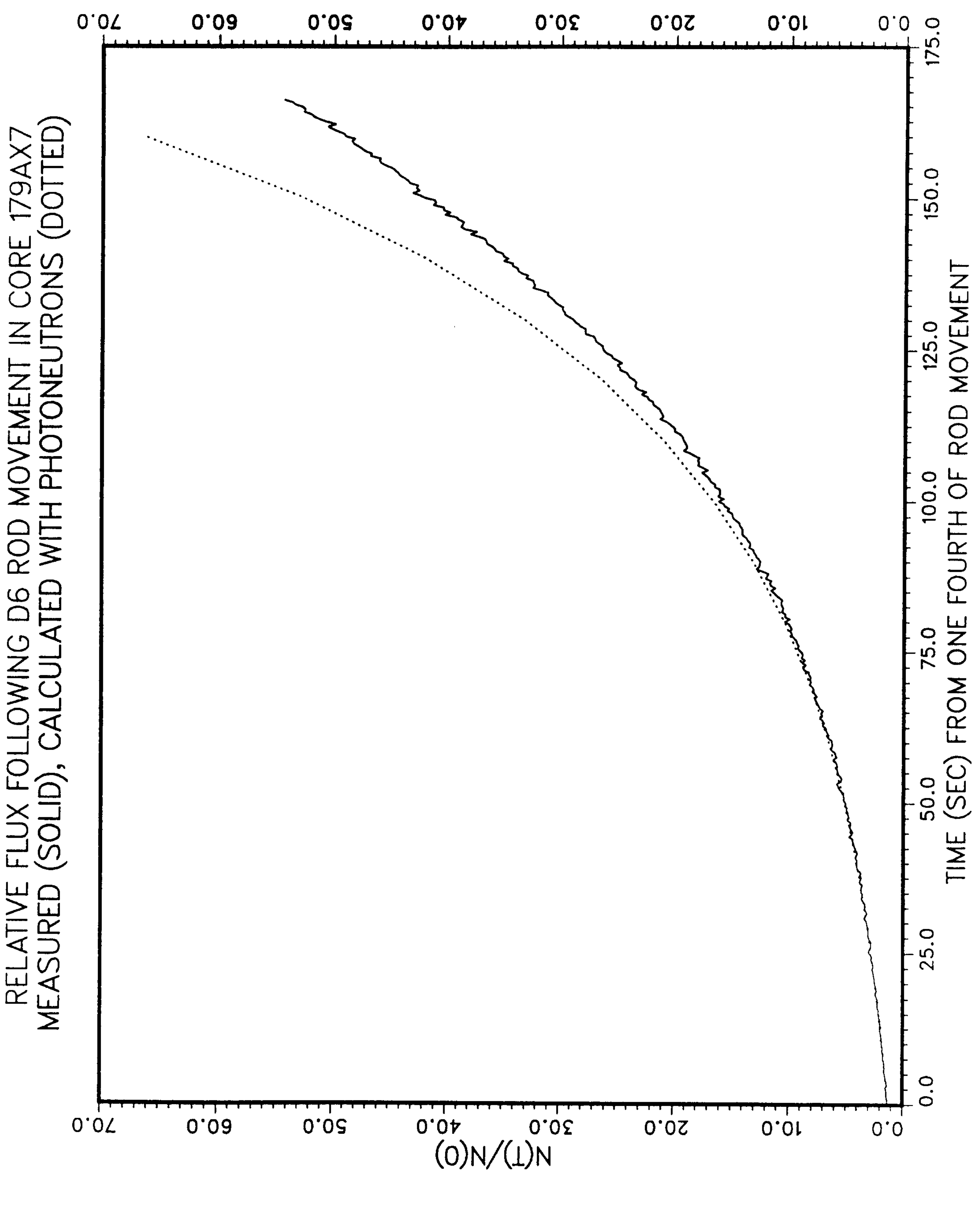
which shows that the calculations have succeeded in matching the value for the measured flux ratio given earlier. The differential rod worth needed to produce this flux ratio is

$$\%\delta k/k/in. = 100(l.51093D-03)/0.36 = 0.4197$$

and is shown at the bottom of Table E.8 (and Table 30).

Figure E.2 is a plot of the measured and calculated relative fluxes as a function of time from the reactivity step change. For this plot the measured time-dependent flux is for an effective reactivity step taken to be at the center of the rod movement time (i.e., T' = T/2 where T = 16.8 sec). In the early pan of the curve, where the calculated flux ratio was matched to the measured one, the two plots are in reasonable agreement. At larger times, however, temperature-induced negative reactivity feedback effects cause the measured transient to drop below the calculated one. A similar curve is shown in Fig. E.3 where the effective reactivity step was chosen to be at one fourth of the rod movement time (T' = T/4). This choice results in a closer match between the measured and calculated flux profiles for times less than about 85 seconds. For this particular case the measured differential worth was 0.4223 %δk/k/in., somewhat closer to the calculated value (Table 30) than the result given earlier for the case with T' = T/2. However, it is not always true that better results are obtained for T' = T/4 than for T' = T/2. To be consistent, all the differential shim rod worths given in Table 31 were evaluated assuming that the effective reactivity step occurred at the middle of the rod movement time.


RELATIVE FLUX FOLLOWING D6 ROD MOVEMENT IN CORE 179AX7
MEASURED (SOLID), CALCULATED WITH PHOTONEUTRONS (DOTTED)
N(T)/N(0)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
TIME (SEC) FROM MIDDLE OF ROD MOVEMENT
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0


RELATIVE FLUX FOLLOWING D6 ROD MOVEMENT IN CORE 179AX7
MEASURED (SOLID), CALCULATED WITH PHOTONEUTRONS (DOTTED)
N(T)/N(0)
TIME (SEC) FROM ONE FOURTH OF ROD MOVEMENT
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0

The estimated error (1 a) In the differential worth measurement of the D6 shim rod in core 179AX7 (Table 30, case 2) results from the following three sources.

Source	% Error in Differential Worth
Uncertainty in T'	0.61
Uncertainty in Rod Displacement	1.39
Uncertainty in Measured Flux Ratio	3.50
Total (Quadrature):	3.81

This error estimate does not include uncertainties in the delayed neutron parameters.