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Physics

COMPUTER CALCULATIONS ON EXPONENTIAL DATA

by

R. R. Haefner

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ABSTRACT

A routine was developed for the IBM 650 computer to obtain a least squares fit to data obtained in a subcritical reactor. The routine can obtain (1) a hyperbolic sine fit when the absolute experimental uncertainty of the data is of the same magnitude at each point, (2) a hyperbolic sine fit when the relative uncertainty is the same at each point, and (3) a J_o (κr) fit when the relative uncertainty is the same at each point.

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COMPUTER CALCULATIONS ON EXPONENTIAL DATA

INTRODUCTION

The material buckling of the lattice of a thermal reactor can be determined in a subcritical assembly that has an external source of neutrons. If the lattice is contained in a cylindrical tank with a symmetric source of neutrons at the bottom, the assembly is called an "exponential" and the neutron flux at any point in the assembly may be expressed as:

$$\Phi(r,z) = \sum_{i=1}^{\infty} A_i \sinh \kappa_i(x-z) J_o\left(\frac{j_{o,i}}{R} r\right)$$

This equation holds if the points (r,z) are taken at equivalent lattice positions. Here, x is the extrapolated height and R is the extrapolated radius of the assembly; $j_{o,i}$ is the ith zero of J_o, the Bessel function of zero order.

If the data are taken sufficiently far from the source, only the first term in the series is needed. The equation then becomes

$$\Phi(r,z) = A \sinh \kappa(x-z) J_o\left(\frac{j_{o,1}}{R} r\right)$$

where $j_{o,1} = 2.4048$. The material buckling of the lattice is then given by $B^2 = (2.4048/R)^2 - \kappa^2$

The manual calculation of κ and R from the experimental data taken in such an assembly is very tedious and time consuming, since many runs are made on a given lattice in order to decrease the experimental uncertainty. The use of a medium-speed or high-speed computer can eliminate the tedium and can provide results soon after the data are taken.

SUMMARY

A routine for the IBM 650 computer was developed to obtain the best fit to axial data taken with a traveling monitor(1) (Type 1), to axial data taken with foils (Type 2), and to radial data taken with foils (Type 3). The routine can also obtain relative activities of foils, corrected for epithermal neutron background (Type 4), and uncorrected (Type 5). The computations are performed in the fixed decimal mode and yield a best fit by least squares.

This code uses approximately 1550 storage locations, including 150 positions for a hyperbolic sine and $J_o(x)$ subroutine(2), and 36 locations for an exponential subroutine(3). For any given problem, a maximum of twenty experimental points can be used. The maximum value of the argument of the hyperbolic sine is 6.9. Two variations of the routine are used, one allowing greater accuracy if $\kappa(x-z) \leq 4.4$ and the other allowing $\kappa(x-z)$ to reach 9.2, with less accuracy in the computation.

DISCUSSION

To eliminate manual computations as much as possible, the routine to compute the bucklings was amplified by a subroutine which processed raw experimental data into numbers used by the least squares routine. The basic data desired in the latter routine were thermal neutron fluxes as a function of height or radius in the exponential tank. Since the neutron source used at SRL[4] contributed a significant fraction of nonthermal neutrons, a correction had to be applied to the raw data. This was accomplished by obtaining neutron fluxes with and without a cadmium shutter between the source and the assembly. Subtraction of data taken with the shutter from those taken without the shutter provided the thermal neutron flux.

Neutron flux data were obtained from the activation of indium foils, or from a movable ion chamber, hereafter referred to as the "traveling monitor."[1] The foils were counted in sequence such that each foil produced approximately the same number of counts per unit counting period. Thus, it was assumed that the relative uncertainty of each experimental point was constant. The data from the traveling monitor were recorded on a Brown recorder. It was assumed that the uncertainty in these data resulted primarily from reading the chart, and was thus the same for all points, independent of the magnitude of the flux.

Five subroutines are available. The user designates his choice of one of these by inserting the digit corresponding to his problem into the proper storage.

Because it is necessary to process raw data before entering the least squares routine, the processing routines will be discussed first, followed by the three least squares routines. The numerical designation of type follows the chronological sequence of programming.

TYPE 5: RELATIVE FOIL ACTIVITIES-NO SHUTTER CORRECTION

The activity $f_i(t_o)$ of a foil at a time t_o minutes after the completion of irradiation is given by:

$$f_i(t_o) = \frac{c_i/a}{1 - \frac{c_i\tau}{a}} e^{\lambda(t_i - t_o)}$$

where

c_i = number of counts of the ith foil, minus background
a = counting time in minutes for the ith foil
τ = counter dead time in minutes
λ = decay constant for indium foils in $\min^{-1}$
t_i = elapsed time in minutes from the completion of the irradiation to the commencement of counting

The subtraction of background counts from the foil counts before making the dead-time correction is a good approximation for low backgrounds.

The value of t_o is chosen to increase the range of arguments for the exponential subroutine.

A sample input data sheet and the resultant output from a Type 402 IBM Accounting Machine are given in the Appendix. A maximum of twenty foil activities can be utilized in one run.

TYPE 4: RELATIVE FOIL ACTIVITIES-WITH SHUTTER CORRECTION

The foil activation, due to thermal neutrons, at time $t_o + \frac{a}{2}$ minutes after the completion of the irradiation is given by:

$$f_i = e^{\frac{-\lambda a}{2}} f_i(t_o)$$

$$= \frac{c_i/a}{1 - \frac{c_i \tau}{a}} e^{\lambda(t_i - t_o)} - P \frac{c_i'/a'}{1 - \frac{c_i' \tau}{a'}} e^{\lambda\left(t_i' - t_o + \frac{a'-a}{2}\right)}$$

P = ratio of source strength for the unshuttered experiment to that for the shuttered experiment. This quantity is calculated by the IBM 650 from the relative activities within a set of normalizing foils.

Primed and unprimed variables refer to the experiments with and without a cadmium shutter, respectively.

Sample input and output data are shown in the Appendix. Abbreviations NS and S refer to unshuttered and shuttered data, respectively.

TYPE 3: RADIAL BUCKLING DETERMINATION-FOIL DATA ONLY

The extrapolated radius of the subcritical assembly, R, was obtained by assuming that the thermal neutron flux could be fitted by the fundamental Bessel function $J_o(\kappa r)$, where $R = 2.4048/\kappa$.

The data were obtained from foils, each counted at such a time that all foils had the same relative uncertainty. Thus in fitting the theoretical curve by a least squares analysis, the relative error was minimized. The condition which applies to this treatment demands that

$$E_3 = \sum_{i=1}^{N} \left(\frac{f_i}{AJ_o(\kappa r_i)} - 1 \right)^2 \qquad \text{be a minimum.}$$

By setting $\frac{\partial E_3}{\partial A} = 0$ and $\frac{\partial E_3}{\partial \kappa} = 0$, one obtains

$$g_3(\kappa) = \sum_{i=1}^{N} \left(AJ_o(\kappa r_i) - f_i\right) \frac{f_i r_i J_1(\kappa r_i)}{\left[J_o(\kappa r_i)\right]^3} = 0$$

where $$A = \sum_{i=1}^{N} \frac{f_i^2}{\left[J_o(\kappa r_i)\right]^2} \div \sum_{i=1}^{N} \frac{f_i}{J_o(\kappa r_i)}$$

The routine computes $g_3(\kappa_1) = \alpha_1$, $g_3(\kappa_2) = \alpha_2$, and linearly extrapolates or interpolates from these results to obtain κ_3. Then, from $g_3(\kappa_3) = \alpha_3$, and $g_3(\kappa_2) = \alpha_2$, one obtains κ_4 by the same process. The system is considered to have converged when $\left|\kappa_{n+1} - \kappa_n\right| \leq 10^{-4}$.

Sample input and output information are given in the Appendix. The relative error at each point, $f_i/J_o(\kappa r_i)$, is included in the print-out, as well as $\epsilon^2 = \frac{1}{N-2}\left(\sum_{i=1}^{N}\left[f_i - AJ_o(\kappa r_i)\right]^2\right)$

TYPE 2: AXIAL BUCKLING DETERMINATION-FOIL DATA ONLY

The data obtained from the foils in the exponential should fit a curve $A \sinh \kappa(x-z_i)$ in the vertical direction. Previous experience with an IBM Card Programmed Calculator had shown that a three-parameter fit for A, κ, and x led to values of x that were incompatible with the value of moderator height plus the theoretical extrapolation distance, which is 0.71 times the transport mean free path for the moderator. Thus, the routine was developed to obtain a least squares fit for A and κ. The value of x was supplied by the user of the routine.

The system of foil counting was the same for Type 2 runs as for Type 3. Thus, it was required that

$$E_2 = \sum_{i=1}^{N} \left[\frac{f_i}{A \sinh \kappa(x-z_i)} - 1\right]^2$$ be a minimum.

By setting $\frac{\partial E_2}{\partial A} = 0$ and $\frac{\partial E_2}{\partial \kappa} = 0$ one obtains

$$g_2(\kappa) = \sum_{i=1}^{N} \left[A \sinh \kappa(x-z_i) - f_i \right] \frac{f_i (x-z_i) \cosh \kappa(x-z_i)}{\sinh^3 \kappa(x-z_i)} = 0$$

where $$A = \sum_{i=1}^{N} \frac{f_i^{\,2}}{\left[\sinh \kappa(x-z_i)\right]^2} \div \sum_{i=1}^{N} \frac{f_i}{\sinh \kappa(x-z_i)}$$

The routine to obtain κ is iterative, and similar to that for Type 3. Three separate routines are available. They are used when Max $[\kappa(x-z)] \leq 4.4$, ≤ 7.5, and ≤ 9.2. The accuracy in the computation of κ decreases when the larger values of the function are encountered.

Sample input and output data are shown in the Appendix. It should be noted that ϵ^2 is not the function that is minimized, since

$$\epsilon^2 = \frac{1}{N-2} \sum_{i=1}^{N} \left[f_i - A \sinh \kappa(x-z_i) \right]^2$$

TYPE 1: AXIAL BUCKLING DETERMINATION-FOR TRAVELING MONITOR RESULTS

A value of the axial buckling, $-\kappa^2$, was obtained from traveling monitor results by fitting the data to a curve of the form A sinh $\kappa(x-z)$. Again, the least squares fit was obtained for A and κ, while the value of x was supplied by the user of the routine. Limitations on κ are the same as given for Type 2. Since the absolute error in f_i was the same for each value of z_i, the quantity

$$E_1 = \sum_{i=1}^{N} \left[f_i - A \sinh \kappa(x-z_i) \right]^2$$

was required to be a minimum. For $\frac{\partial E_1}{\partial A} = 0$, and $\frac{\partial E_1}{\partial \kappa} = 0$,

$$g_1(\kappa) = \sum_{i=1}^{N} \left[A \sinh \kappa(x-z_i) - f_i \right] (x-z_i) \cosh \kappa(x-z_i) = 0$$

where $$A = \sum_{i=1}^{N} f_i \sinh \kappa(x-z_i) \div \sum_{i=1}^{N} \sinh \kappa(x-z_i)$$

Sample input and output data are given in the Appendix.

FLOWSHEETS AND PROGRAMMING

The Appendix contains the flowsheets used in the programming.

The L-1 load routine[5] is used to read the input data into the IBM 650.

Copies of the program deck and details of the programming are available upon request.

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SAMPLE INPUT DATA

TYPE I

Run No. 1076

Without Shutter

FOIL NO.	LOC.										REMARKS
	0090	0	0	0	0	0	0	0	0	0	0	
	0091	0	0	0	0	0	0	1	0	7	7	Run No. (With Shutter)
	0092		0	0	0	0	0	0	0	0	0	Counting Time: Minutes (No Shutter)
	0093	0	4	6	9	0	0	0	0	0	0	Power Ratio (without shutter: with shutter Type 1 (.XXXX000000)
	0094	1	7	0	0	0	0	0	0	0	0	X; XXX.XX00000
	0095	0	0	0	0	0	0	0	0	0	1	Type 1, 2, 3, or 4
	0096	0	0	0	0	2	0	0	0	0	0	Number of Points
	0097	0	8	2	5	5	5	0	0	0	0	Date: Mo XX Day XX Year XX 0000
	0098	0	2	0	0	0	0	0	0	0	0	$\kappa^{(o)}$ .XXXX000000
	0099	0	0	0	0	0	0	1	0	7	6	Run No. 000000XXXX (No Shutter)
	0100		9	1	5							$C_1:T_1$ Counts XXXXX Time, Minutes XXX.XX
	0101		3	7	3		0	0	0	0	0	Z_1 XXX.XX00000
	0102		8	6	0							$C_2:T_2$
	0103		4	0	8		0	0	0	0	0	Z_2
	0104		8	0	0							$C_3:T_3$
	0105		4	4	4		0	0	0	0	0	Z_3
	0106		7	5	0							$C_4:T_4$
	0107		4	7	9		0	0	0	0	0	Z_4
	0108		6	9	5							$C_5:T_5$
	0109		5	1	4		0	0	0	0	0	Z_5
	0110		6	5	0							$C_6:T_6$
	0111		5	5	0		0	0	0	0	0	Z_6
	0112		6	1	0							$C_7:T_7$
	0113		5	8	5		0	0	0	0	0	Z_7
	0114		5	7	5							$C_8:T_8$
	0115		6	2	0		0	0	0	0	0	Z_8
	0116		5	3	5							$C_9:T_9$
	0117		6	5	6		0	0	0	0	0	Z_9
	0118		5	0	0							$C_{10}:T_{10}$
	0119		6	9	1		0	0	0	0	0	Z_{10}

Exponential Fit

DATE

PAGE 1

FOIL NO.	LOC.														REMARKS
	0	1	2	0		4	6	5							$C_{11}:T_{11}$
	0	1	2	1		7	2	6		0	0	0	0	0	Z_{11}
	0	1	2	2		4	3	5							$C_{12}:T_{12}$
	0	1	2	3		7	6	2		0	0	0	0	0	Z_{12}
	0	1	2	4		4	0	5							$C_{13}:T_{13}$
	0	1	2	5		7	9	7		0	0	0	0	0	Z_{13}
	0	1	2	6		3	8	0							$C_{14}:T_{14}$
	0	1	2	7		8	3	2		0	0	0	0	0	Z_{14}
	0	1	2	8		3	5	5							$C_{15}:T_{15}$
	0	1	2	9		8	6	8		0	0	0	0	0	Z_{15}
	0	1	3	0		3	3	0							$C_{16}:T_{16}$
	0	1	3	1		9	0	3		0	0	0	0	0	Z_{16}
	0	1	3	2		3	0	5							$C_{17}:T_{17}$
	0	1	3	3		9	3	9		0	0	0	0	0	Z_{17}
	0	1	3	4		2	8	5							$C_{18}:T_{18}$
	0	1	3	5		9	7	4		0	0	0	0	0	Z_{18}
	0	1	3	6		2	6	5							$C_{19}:T_{19}$
	0	1	3	7	1	0	0	9		0	0	0	0	0	Z_{19}
	0	1	3	8		2	4	5							$C_{20}:T_{20}$
	0	1	3	9	1	0	4	5		0	0	0	0	0	Z_{20}
	0	1	4	0		0	0	0	0	0	0	0	0	0	Counting Time, Normalizing Foils: Minutes
	0	1	4	1											Normalizing Foils A (No Shutter) $C_A:T_A$
	0	1	4	2											B $C_B:T_B$
	0	1	4	3											C $C_C:T_C$
	0	1	4	4											D $C_D:T_D$
	0	1	4	5											E $C_E:T_E$
	0	1	4	6											F $C_F:T_F$
	0	1	4	7	0	0	0	0	0	0	0	0	0		Number of Normalizing Foils (No Shutter)

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Run No. 1077

With Shutter

FOIL NO.	LOC.											REMARKS
	1777											Normalizing Foil A With Shutter $C_A:T_A$
	1778											B " " $C_B:T_B$
	1779											C " " $C_C:T_C$
	1780											D " " $C_D:T_D$
	1781											E " " $C_E:T_E$
	1782											F " " $C_F:T_F$
	1783	0	0	0	0	0	0	0	0	0	0	
	1784	0	0	0	0	0	0	0	0	0		Number of Normalizing Foils (with shutter)
	1785		0	0	0	0	0	0	0	0	0	Counting Time, Shutter Run: Minutes
	1786		7	1	5							$C_1:T_1$ Shutter Run Counts xxxxx Time xxx.xx
	1787		7	1	0							$C_2:T_2$
	1788		7	0	5							$C_3:T_3$
	1789		6	9	5							$C_4:T_4$
	1790		6	9	0							$C_5:T_5$
	1791		6	8	0							$C_6:T_6$
	1792		6	8	0							$C_7:T_7$
	1793		6	7	5							$C_8:T_8$
	1794		6	7	0							$C_9:T_9$
	1795		6	6	0							$C_{10}:T_{10}$
	1796		6	5	0							$C_{11}:T_{11}$
	1797		6	4	5							$C_{12}:T_{12}$
	1798		6	4	0							$C_{13}:T_{13}$
	1799		6	3	0							$C_{14}:T_{14}$
	1800		6	2	0							$C_{15}:T_{15}$
	1801		6	1	0							$C_{16}:T_{16}$
	1802		6	0	5							$C_{17}:T_{17}$
	1803		5	9	5							$C_{18}:T_{18}$
	1804		5	9	0							$C_{19}:T_{19}$
	1805		5	8	0							$C_{20}:T_{20}$

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PRINT-OUT FOR TYPE 1

z_1	NS Chart Reading	S Chart Reading	
37.3	09150	07150	00000
40.8	08600	07100	00000
44.4	08000	07050	00000
47.9	07500	06950	00000
51.4	06950	06900	00000
55.0	06500	06800	00000
58.5	06100	06800	00000
62.0	05750	06750	00000
65.6	05350	06700	00000
69.1	05005	06600	00000
72.6	04650	06500	00000
76.2	04350	06450	00000
79.7	04055	06400	00000
83.2	03800	06300	00000
86.8	03555	06200	00000
90.3	03300	06100	00000
93.9	03050	06050	00000
97.4	02850	05950	00000
100.9	02653	05900	00000
104.5	02459	05800	00000

z_1	f_1	f_1/A sinh	NS Run #	Pwr. Ratio
37.3	0.8814	0.9980	1076	.04690
40.8	0.8267	1.0031	1076	.04690
44.4	0.7669	0.9995	1076	.04690
47.9	0.7174	1.0024	1076	.04690
51.4	0.6626	0.9928	1076	.04690
55.0	0.6181	0.9951	1076	.04690
58.5	0.5781	0.9984	1076	.04690
62.0	0.5433	1.0068	1076	.04690
65.6	0.5035	1.0035	1076	.04690
69.1	0.4695	1.0055	1076	.04690
72.6	0.4345	0.9984	1076	.04690
76.2	0.4047	1.0023	1076	.04690
79.7	0.3754	0.9986	1076	.04690
83.2	0.3504	1.0026	1076	.04690
86.8	0.3264	1.0083	1076	.04690
90.3	0.3013	1.0019	1076	.04690
93.9	0.2766	0.9936	1076	.04690
97.4	0.2570	0.9968	1076	.04690
100.9	0.2376	0.9968	1076	.04690
104.5	0.2186	0.9952	1076	.04690

Date	Type	Kappa	X	ϵ^2	S Run #	A
8-25	55 1	.01955	170	000.0047	1077	.13224

SAMPLE INPUT DATA

TYPE 2

Run No. 1084
Without Shutter

FOIL NO.	LOC.														REMARKS
	0	0	9	0	0	0	0	0	0	0	0	0	0	0	
	0	0	9	1	0	0	0	0	0	0	1	2	3	4	Run No. (With Shutter)
	0	0	9	2	3	0	0	0	0	0	0	0	0	0	Counting Time: Minutes (No Shutter)
	0	0	9	3					0	0	0	0	0	0	Power Ratio (without shutter: with shutter Type 1 (.XXXX000000)
	0	0	9	4	1	4	5	0	0	0	0	0	0	0	X; XXX.XX00000
	0	0	9	5	0	0	0	0	0	0	0	0	0	2	Type 1, 2, 3, or 4
	0	0	9	6	0	0	0	0	1	6	0	0	0	0	Number of Points
	0	0	9	7	0	8	0	9	5	5	0	0	0	0	Date: Mo XX Day XX Year XX 0000
	0	0	9	8	0	6	3	0	0	0	0	0	0	0	$\kappa^{(o)}$ .XXXX000000
	0	0	9	9	0	0	0	0	0	0	1	0	8	4	Run No. 000000XXXX (No Shutter)
	0	1	0	0	1	4	6	2	5	0	5	6	5	0	$C_1:T_1$ Counts XXXXX Time, Minutes XXX.XX
	0	1	0	1	1	0	8	5	0	0	0	0	0	0	Z_1 XXX.XX00000
	0	1	0	2	1	4	5	3	3	0	6	6	2	0	$C_2:T_2$
	0	1	0	3	1	0	2	2	0	0	0	0	0	0	Z_2
	0	1	0	4	1	3	3	4	1	0	8	2	5	0	$C_3:T_3$
	0	1	0	5	0	9	5	9	0	0	0	0	0	0	Z_3
	0	1	0	6	1	4	3	0	7	0	9	5	5	0	$C_4:T_4$
	0	1	0	7	0	8	9	5	0	0	0	0	0	0	Z_4
	0	1	0	8	1	5	0	6	6	1	1	2	1	0	$C_5:T_5$
	0	1	0	9	0	8	3	2	0	0	0	0	0	0	Z_5
	0	1	1	0	1	7	5	5	7	1	2	2	1	0	$C_6:T_6$
	0	1	1	1	0	7	6	9	0	0	0	0	0	0	Z_6
	0	1	1	2	1	9	2	8	9	1	3	8	3	0	$C_7:T_7$
	0	1	1	3	0	7	0	5	0	0	0	0	0	0	Z_7
	0	1	1	4	2	5	0	1	5	1	4	4	8	0	$C_8:T_8$
	0	1	1	5	0	6	4	2	0	0	0	0	0	0	Z_8
	0	1	1	6	2	7	5	8	0	1	6	4	0	0	$C_9:T_9$
	0	1	1	7	0	5	7	9	0	0	0	0	0	0	Z_9
	0	1	1	8	3	4	7	5	0	1	7	3	8	0	$C_{10}:T_{10}$
	0	1	1	9	0	5	1	5	0	0	0	0	0	0	Z_{10}

Exponential Fit

DATE

PAGE 1

Type 2
Run No. 1084 (Continued)

FOIL NO.	LOC.			REMARKS
	0120	40396	19070	$C_{11}:T_{11}$
	0121	04520	00000	Z_{11}
	0122	51739	20080	$C_{12}:T_{12}$
	0123	03880	00000	Z_{12}
	0124	60516	21750	$C_{13}:T_{13}$
	0125	03250	00000	Z_{13}
	0126	57202	25450	$C_{14}:T_{14}$
	0127	02610	00000	Z_{14}
	0128	46187	30250	$C_{15}:T_{15}$
	0129	01980	00000	Z_{15}
	0130	61067	31240	$C_{16}:T_{16}$
	0131	01350	00000	Z_{16}
	0132			$C_{17}:T_{17}$
	0133		00000	Z_{17}
	0134			$C_{18}:T_{18}$
	0135		00000	Z_{18}
	0136			$C_{19}:T_{19}$
	0137		00000	Z_{19}
	0138			$C_{20}:T_{20}$
	0139		00000	Z_{20}
	0140	30000	00000	Counting Time, Normalizing Foils: Minutes
	0141	21807	03020	Normalizing Foils A (No Shutter) $C_A:T_A$
	0142	21091	03350	B $C_B:T_B$
	0143	19649	03670	C $C_C:T_C$
	0144	19434	04000	D $C_D:T_D$
	0145	19176	04330	E $C_E:T_E$
	0146	17506	04660	F $C_F:T_F$
	0147	00000	00006	Number of Normalizing Foils (No Shutter)

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Run No. 1234

With Shutter

FOIL NO.	LOC.			REMARKS
	1777	37164	10110	Normalizing Foil A With Shutter $C_A:T_A$
	1778	35316	10430	B " " $C_B:T_B$
	1779	32990	10760	C " " $C_C:T_C$
	1780			D " " $C_D:T_D$
	1781			E " " $C_E:T_E$
	1782			F " " $C_F:T_F$
	1783	00000	00000	
	1784	00000	00003	Number of Normalizing Foils (with shutter)
	1785	30000	00000	Counting Time, Shutter Run: Minutes
	1786	42614	05480	$C_1:T_1$ Shutter Run Counts xxxxx Time xxx.xx
	1787	36035	06810	$C_2:T_2$
	1788	32340	07800	$C_3:T_3$
	1789	30586	08460	$C_4:T_4$
	1790	14202	15080	$C_5:T_5$
	1791	12998	16060	$C_6:T_6$
	1792	12295	17050	$C_7:T_7$
	1793	12667	17380	$C_8:T_8$
	1794	11954	18370	$C_9:T_9$
	1795	11590	19360	$C_{10}:T_{10}$
	1796	11010	20350	$C_{11}:T_{11}$
	1797	10305	21710	$C_{12}:T_{12}$
	1798	07249	25620	$C_{13}:T_{13}$
	1799	07469	26620	$C_{14}:T_{14}$
	1800			$C_{15}:T_{15}$
	1801			$C_{16}:T_{16}$
	1802			$C_{17}:T_{17}$
	1803			$C_{18}:T_{18}$
	1804			$C_{19}:T_{19}$
	1805			$C_{20}:T_{20}$

Exponential Fit DATE PAGE 3

PRINT-OUT FOR TYPE 2

No. of Norm. Foils	NS Norm. Foil Data		S Norm. Foil Data	
NS S	Counts	Time	Counts	Time
6.3	21807	3020	37164	10110
6.3	21091	3350	35316	10430
6.3	19649	3670	32990	10760
6.3	19434	4000	00000	00000
6.3	19176	4330	00000	00000
6.3	17506	4660	00000	00000

z_i	NS Foil Data		S Foil Data	
108.5	14625	5650	42614	05480
102.2	14533	6620	36035	06810
95.9	13341	8250	32340	07800
89.5	14307	9550	30586	08460
83.2	15066	11210	14202	15080
76.9	17557	12210	12998	16060
70.5	19289	13830	12295	17050
64.2	25015	14480	12667	17380
57.9	27580	16400	11954	18370
51.5	34750	17380	11590	19360
45.2	40396	19070	11010	20350
38.8	51739	20080	10305	21710
32.5	60516	21750	07249	25620
26.1	57202	25450	07469	26620
19.8	46187	30250	07840	27620
13.5	61067	31240	08044	28750

z_i	f_i	f_i/A sinh	NS Run #	Pwr. Ratio
108.5	0.0050	1.1001	1084	.23676
102.2	0.0072	1.0476	1084	.23676
95.9	0.0094	0.9251	1084	.23676
89.5	0.0148	0.9684	1084	.23676
83.2	0.0222	0.9753	1084	.23676
76.9	0.0333	0.9825	1084	.23676
70.5	0.0489	0.9645	1084	.23676
64.2	0.0743	0.9859	1084	.23676
57.9	0.1105	0.9857	1084	.23676
51.5	0.1648	0.9829	1084	.23676
45.2	0.2464	0.9886	1084	.23676
38.8	0.3713	0.9958	1084	.23676
32.5	0.5504	0.9932	1084	.23676
26.1	0.8418	1.0157	1084	.23676
19.8	1.2508	1.0153	1084	.23676
13.5	1.9233	1.0504	1084	.23676

8-09	55	2	.06295	145	000.6486	1234	.00094
Date		Type	Kappa	X	ϵ^2	S Run #	A

SAMPLE INPUT DATA

TYPE 3

Run No. 0001
Without Shutter

FOIL NO.	LOC.										REMARKS
	0090	0	0	0	0	0	0	0	0	0	0	
	0091	0	0	0	0	0	0	0	0	0	2	Run No. (With Shutter)
	0092	3	0	0	0	0	0	0	0	0	0	Counting Time: Minutes (No Shutter)
	0093					0	0	0	0	0	0	Power Ratio (without shutter: with shutter Type 1 (.XXXX000000)
	0094						0	0	0	0	0	X; XXX.XX00000
	0095	0	0	0	0	0	0	0	0	0	3	Type 1, 2, 3, or 4
	0096	0	0	0	0	0	8	0	0	0	0	Number of Points
	0097	1	0	0	3	5	5	0	0	0	0	Date: Mo XX Day XX Year XX 0000
	0098	0	3	1	0	0	0	0	0	0	0	$\kappa^{(o)}$ .XXXX000000
	0099	0	0	0	0	0	0	0	0	0	1	Run No. 000000XXXX (No Shutter)
	0100	4	6	6	6	0	2	1	7	6		$C_1:T_1$ Counts XXXXX Time, Minutes XXX.XX
	0101		4	9	5		0	0	0	0	0	Z_1 XXX.XX00000
	0102	4	7	4	1	0	2	2	4	5		$C_2:T_2$
	0103		4	6	2		0	0	0	0	0	Z_2
	0104	4	4	3	1	0	2	3	2	7		$C_3:T_3$
	0105		4	4	5		0	0	0	0	0	Z_3
	0106	4	0	6	1	0	2	3	9	8		$C_4:T_4$
	0107		4	0	7		0	0	0	0	0	Z_4
	0108	4	2	9	7	0	2	4	9	8		$C_5:T_5$
	0109		3	8	8		0	0	0	0	0	Z_5
	0110	4	6	1	4	0	2	5	3	3		$C_6:T_6$
	0111		3	2	0		0	0	0	0	0	Z_6
	0112	4	6	8	0	0	2	6	0	0		$C_7:T_7$
	0113		2	3	5		0	0	0	0	0	Z_7
	0114	4	5	5	7	0	2	6	6	7		$C_8:T_8$
	0115		1	5	4		0	0	0	0	0	Z_8
	0116											$C_9:T_9$
	0117						0	0	0	0	0	Z_9
	0118											$C_{10}:T_{10}$
	0119						0	0	0	0	0	Z_{10}

Exponential Fit

DATE

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Type 3
Run No. 0001 (Continued)

FOIL NO.	LOC.			REMARKS
	0120			$C_{11}:T_{11}$
	0121		00000	Z_{11}
	0122			$C_{12}:T_{12}$
	0123		00000	Z_{12}
	0124			$C_{13}:T_{13}$
	0125		00000	Z_{13}
	0126			$C_{14}:T_{14}$
	0127		00000	Z_{14}
	0128			$C_{15}:T_{15}$
	0129		00000	Z_{15}
	0130			$C_{16}:T_{16}$
	0131		00000	Z_{16}
	0132			$C_{17}:T_{17}$
	0133		00000	Z_{17}
	0134			$C_{18}:T_{18}$
	0135		00000	Z_{18}
	0136			$C_{19}:T_{19}$
	0137		00000	Z_{19}
	0138			$C_{20}:T_{20}$
	0139		00000	Z_{20}
	0140	30000	00000	Counting Time, Normalizing Foils: Minutes
	0141	05426	00000	Normalizing Foils A (No Shutter) $C_A:T_A$
	0142			B $C_B:T_B$
	0143			C $C_C:T_C$
	0144			D $C_D:T_D$
	0145			E $C_E:T_E$
	0146			F $C_F:T_F$
	0147	00000	00001	Number of Normalizing Foils (No Shutter)

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Run No. 0002

With Shutter

FOIL NO.	LOC.			REMARKS
	1777	8020	2700	Normalizing Foil A With Shutter $C_A:T_A$
	1778	7510	2850	B " " $C_B:T_B$
	1779	7810	3000	C " " $C_C:T_C$
	1780			D " " $C_D:T_D$
	1781			E " " $C_E:T_E$
	1782			F " " $C_F:T_F$
	1783	00000	00000	
	1784	00000	00003	Number of Normalizing Foils (with shutter)
	1785	10000	00000	Counting Time, Shutter Run: Minutes
	1786	10530	7200	$C_1:T_1$ Shutter Run Counts xxxxx Time xxx.xx
	1787	12660	7350	$C_2:T_2$
	1788	13390	7500	$C_3:T_3$
	1789	12090	7650	$C_4:T_4$
	1790	14460	7810	$C_5:T_5$
	1791	11730	7950	$C_6:T_6$
	1792	13350	8100	$C_7:T_7$
	1793	13410	8250	$C_8:T_8$
	1794			$C_9:T_9$
	1795			$C_{10}:T_{10}$
	1796			$C_{11}:T_{11}$
	1797			$C_{12}:T_{12}$
	1798			$C_{13}:T_{13}$
	1799			$C_{14}:T_{14}$
	1800			$C_{15}:T_{15}$
	1801			$C_{16}:T_{16}$
	1802			$C_{17}:T_{17}$
	1803			$C_{18}:T_{18}$
	1804			$C_{19}:T_{19}$
	1805			$C_{20}:T_{20}$

Exponential Fit DATE PAGE 3

PRINT-OUT FOR TYPE 3

No. of Norm. Foils	NS Norm. Foil Data		S Norm. Foil Data		
NS S	Counts	Time	Counts		Time
1.3	05426		08020		02700
1.3	00000		07510		02850
1.3	00000		07810		03000
1.3	00000		00000		00000
1.3	00000		00000		00000
1.3	00000		00000		00000
r_i	NS Foil Data			S Foil Data	
49.5	46660	21760	10530		07200
46.2	47410	22450	12660		07350
44.5	44310	23270	13390		07500
40.7	40610	23980	12090		07650
38.8	42970	24980	14460		07810
32.0	46140	25330	11730		07950
23.5	46800	26000	13350		08100
15.4	45570	26670	13410		08250
r_i	f_i		$f_i/A\ J_o$	NS Run #	Pwr. Ratio
49.5	0.4159		1.0221	1	.47991
46.2	0.4595		1.0121	1	.47991
44.5	0.4742		0.9925	1	.47991
40.7	0.4764		0.9002	1	.47991
38.8	0.5740		1.0364	1	.47991
32.0	0.6570		1.0330	1	.47991
23.5	0.7252		1.0053	1	.47991
15.4	0.7695		0.9850	1	.47991
10-03	55 3	.03089	000 000.6516	2	.08279
Date	Type	Kappa	ϵ^2	S Run #	$10^{-1}A$

SAMPLE INPUT DATA

TYPE 4

Run No. 0001

Without Shutter

FOIL NO.	LOC.														REMARKS
	0	0	9	0	0	0	0	0	0	0	0	0	0	0	
	0	0	9	1	0	0	0	0	0	0	0	0	0	3	Run No. (With Shutter)
	0	0	9	2	3	0	0	0	0	0	0	0	0	0	Counting Time: Minutes (No Shutter)
	0	0	9	3					0	0	0	0	0	0	Power Ratio (without shutter: with shutter Type 1 (.XXXX000000)
	0	0	9	4						0	0	0	0	0	X; XXX.XX00000
	0	0	9	5	0	0	0	0	0	0	0	0	0	4	Type 1, 2, 3, or 4
	0	0	9	6	0	0	0	0	2	0	0	0	0	0	Number of Points
	0	0	9	7	0	9	0	6	5	5	0	0	0	0	Date: Mo XX Day XX Year XX 0000
	0	0	9	8					0	0	0	0	0	0	$\kappa^{(o)}$ .XXXX000000
	0	0	9	9	0	0	0	0	0	0	0	0	0	1	Run No. 000000XXXX (No Shutter)
	0	1	0	0		2	7	9	8		1	5	5	0	$C_1:T_1$ Counts XXXXX Time, Minutes XXX.XX
	0	1	0	1						0	0	0	0	0	Z_1 XXX.XX00000
	0	1	0	2		2	7	1	6		1	9	0	0	$C_2:T_2$
	0	1	0	3						0	0	0	0	0	Z_2
	0	1	0	4		2	5	8	9		2	2	5	0	$C_3:T_3$
	0	1	0	5						0	0	0	0	0	Z_3
	0	1	0	6		2	5	0	3		2	6	8	0	$C_4:T_4$
	0	1	0	7						0	0	0	0	0	Z_4
	0	1	0	8		4	0	6	5		2	9	5	0	$C_5:T_5$
	0	1	0	9						0	0	0	0	0	Z_5
	0	1	1	0		3	7	6	2		3	4	0	0	$C_6:T_6$
	0	1	1	1						0	0	0	0	0	Z_6
	0	1	1	2		3	9	6	2		3	7	5	0	$C_7:T_7$
	0	1	1	3						0	0	0	0	0	Z_7
	0	1	1	4		3	7	7	2		4	0	0	0	$C_8:T_8$
	0	1	1	5						0	0	0	0	0	Z_8
	0	1	1	6		9	1	3	6		4	4	9	0	$C_9:T_9$
	0	1	1	7						0	0	0	0	0	Z_9
	0	1	1	8		8	7	6	3		4	8	1	0	$C_{10}:T_{10}$
	0	1	1	9						0	0	0	0	0	Z_{10}

Exponential Fit

DATE

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Type 4
Run No. 0001 (Continued)

FOIL NO.	LOC.			REMARKS
	0120	9184	5590	$C_{11}:T_{11}$
	0121		00000	Z_{11}
	0122	8883	5920	$C_{12}:T_{12}$
	0123		00000	Z_{12}
	0124	21015	6340	$C_{13}:T_{13}$
	0125		00000	Z_{13}
	0126	20041	6680	$C_{14}:T_{14}$
	0127		00000	Z_{14}
	0128	21965	7020	$C_{15}:T_{15}$
	0129		00000	Z_{15}
	0130	21063	7360	$C_{16}:T_{16}$
	0131		00000	Z_{16}
	0132	36675	7750	$C_{17}:T_{17}$
	0133		00000	Z_{17}
	0134	34740	8100	$C_{18}:T_{18}$
	0135		00000	Z_{18}
	0136	37645	8500	$C_{19}:T_{19}$
	0137		00000	Z_{19}
	0138	36135	8840	$C_{20}:T_{20}$
	0139		00000	Z_{20}
	0140	30000	00000	Counting Time, Normalizing Foils: Minutes
	0141	49179	13770	Normalizing Foils A (No Shutter) $C_A:T_A$
	0142	51755	13420	B $C_B:T_B$
	0143	54216	13000	C $C_C:T_C$
	0144	61400	14150	D $C_D:T_D$
	0145	58811	14600	E $C_E:T_E$
	0146	55785	14970	F $C_F:T_F$
	0147	00000	00006	Number of Normalizing Foils (No Shutter)

DATE PAGE 2

Run No. 0003
With Shutter

FOIL NO.	LOC.			REMARKS
	1777	59240	19140	Normalizing Foil A With Shutter $C_A:T_A$
	1778	63580	19550	B " " $C_B:T_B$
	1779	63138	19860	C " " $C_C:T_C$
	1780	64842	22270	D " " $C_D:T_D$
	1781	62462	21200	E " " $C_E:T_E$
	1782	58921	23280	F " " $C_F:T_F$
	1783	00000	00000	
	1784	00000	00006	Number of Normalizing Foils (with shutter)
	1785	30000	00000	Counting Time, Shutter Run: Minutes
	1786	3609	2900	$C_1:T_1$ Shutter Run Counts xxxxx Time xxx.xx
	1787	3358	3250	$C_2:T_2$
	1788	3318	3800	$C_3:T_3$
	1789	3087	4150	$C_4:T_4$
	1790	5564	1300	$C_5:T_5$
	1791	5301	1650	$C_6:T_6$
	1792	5207	2150	$C_7:T_7$
	1793	5050	2500	$C_8:T_8$
	1794	4816	4600	$C_9:T_9$
	1795	4476	4950	$C_{10}:T_{10}$
	1796	4441	5350	$C_{11}:T_{11}$
	1797	4164	5700	$C_{12}:T_{12}$
	1798	5272	6100	$C_{13}:T_{13}$
	1799	4879	6450	$C_{14}:T_{14}$
	1800	4881	6850	$C_{15}:T_{15}$
	1801	4508	7200	$C_{16}:T_{16}$
	1802	4055	9100	$C_{17}:T_{17}$
	1803	3827	9450	$C_{18}:T_{18}$
	1804	3778	9850	$C_{19}:T_{19}$
	1805	3535	10200	$C_{20}:T_{20}$

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PRINT-OUT FOR TYPE 4

No. of Norm. Foils		NS Norm. Foil Data		S Norm. Foil Data	
NS	S	Counts	Time	Counts	Time
	6.6	49179	13770	59240	19140
	6.6	51755	13420	63580	19550
	6.6	54216	13000	63138	19860
	6.6	61400	14150	64842	22270
	6.6	58811	14600	62462	21200
	6.6	55785	14970	58921	23280

NS Foil Data		S Foil Data	
2798	01550	3609	02900
2716	01900	3358	03250
2589	02250	3318	03800
2503	02680	3087	04150
4065	02950	5564	01300
3762	03400	5301	01650
3962	03750	5207	02150
3772	04000	5050	02500
9136	04490	4816	04600
8763	04810	4476	04950
9184	05590	4441	05350
8883	05920	4164	05700
21015	06340	5272	06100
20041	06680	4879	06450
21965	07020	4881	06850
21063	07360	4508	07200
36675	07750	4055	09100
34740	08100	3827	09450
37645	08500	3778	09850
36135	08840	3535	10200

Relative Activity	NS Run # 10^{-1}	Pwr. Ratio
83277100	1	.03602
88920200	1	.03602
82282700	1	.03602
89227700	1	.03602
194790900	1	.03602
188861000	1	.03602
215105000	1	.03602
207201200	1	.03602
722246400	1	.03602
726159300	1	.03602
860644900	1	.03602
873102900	1	.03602
2413863800	1	.03602
2408249600	1	.03602
2783990800	1	.03602
2794014400	1	.03602
5367419200	1	.03602
5306386900	1	.03602
6100101300	1	.03602
6111884900	1	.03602

9-06	55 4 0 00000 000	3	.00000
Date	Type	S Run #	

SAMPLE INPUT DATA

TYPE 5

Run No. 0091
Without Shutter

FOIL NO.	LOC.											REMARKS
	0090	0	0	0	0	0	0	0	0	0	0	
	0091	0	0	0	0	0	0					Run No. (With Shutter)
	0092	3	0	0	0	0	0	0	0	0	0	Counting Time: Minutes (No Shutter)
	0093					0	0	0	0	0	0	Power Ratio (without shutter: with shutter Type 1 (.XXXX000000)
	0094						0	0	0	0	0	X; XXX.XX00000
	0095	0	0	0	0	0	0	0	0	0	5	Type 1, 2, 3, or 4
	0096	0	0	0	0	2	0	0	0	0	0	Number of Points
	0097	1	0	1	0	5	5	0	0	0	0	Date: Mo XX Day XX Year XX 0000
	0098					0	0	0	0	0	0	$\kappa^{(o)}$ .XXXX000000
	0099	0	0	0	0	0	0	0	0	9	1	Run No. 000000XXXX (No Shutter)
	0100		5	9	3	4		2	0	5	0	$C_1:T_1$ Counts XXXXX Time, Minutes XXX.XX
	0101						0	0	0	0	0	Z_1 XXX.XX00000
	0102		5	8	9	4		2	4	0	0	$C_2:T_2$
	0103						0	0	0	0	0	Z_2
	0104		5	9	9	2		2	7	5	0	$C_3:T_3$
	0105						0	0	0	0	0	Z_3
	0106		5	8	2	8		3	1	0	0	$C_4:T_4$
	0107						0	0	0	0	0	Z_4
	0108		2	7	9	6		3	5	0	0	$C_5:T_5$
	0109						0	0	0	0	0	Z_5
	0110		2	6	6	4		3	8	5	0	$C_6:T_6$
	0111						0	0	0	0	0	Z_6
	0112		2	6	9	7		4	2	0	0	$C_7:T_7$
	0113						0	0	0	0	0	Z_7
	0114		2	4	5	5		4	5	7	0	$C_8:T_8$
	0115						0	0	0	0	0	Z_8
	0116	2	2	6	6	7		6	2	6	0	$C_9:T_9$
	0117						0	0	0	0	0	Z_9
	0118	1	8	9	4	5		7	6	1	0	$C_{10}:T_{10}$
	0119						0	0	0	0	0	Z_{10}

Exponential Fit

DATE

PAGE 1

Type 5
Run No. 0091 (Continued)

FOIL NO.	LOC.			REMARKS
	0120	21254	7960	$C_{11}:T_{11}$
	0121		00000	Z_{11}
	0122	20243	8300	$C_{12}:T_{12}$
	0123		00000	Z_{12}
	0124	7558	8640	$C_{13}:T_{13}$
	0125		00000	Z_{13}
	0126	7324	8970	$C_{14}:T_{14}$
	0127		00000	Z_{14}
	0128	8347	9110	$C_{15}:T_{15}$
	0129		00000	Z_{15}
	0130	7787	9640	$C_{16}:T_{16}$
	0131		00000	Z_{16}
	0132	41794	10030	$C_{17}:T_{17}$
	0133		00000	Z_{17}
	0134	40426	10370	$C_{18}:T_{18}$
	0135		00000	Z_{18}
	0136	33689	10720	$C_{19}:T_{19}$
	0137		00000	Z_{19}
	0138	32451	11060	$C_{20}:T_{20}$
	0139		00000	Z_{20}
	0140	0000	00000	Counting Time, Normalizing Foils: Minutes
	0141			Normalizing Foils A (No Shutter) $C_A:T_A$
	0142			B $C_B:T_B$
	0143			C $C_C:T_C$
	0144			D $C_D:T_D$
	0145			E $C_E:T_E$
	0146			F $C_F:T_F$
	0147	00000	0000	Number of Normalizing Foils (No Shutter)

DATE PAGE 2

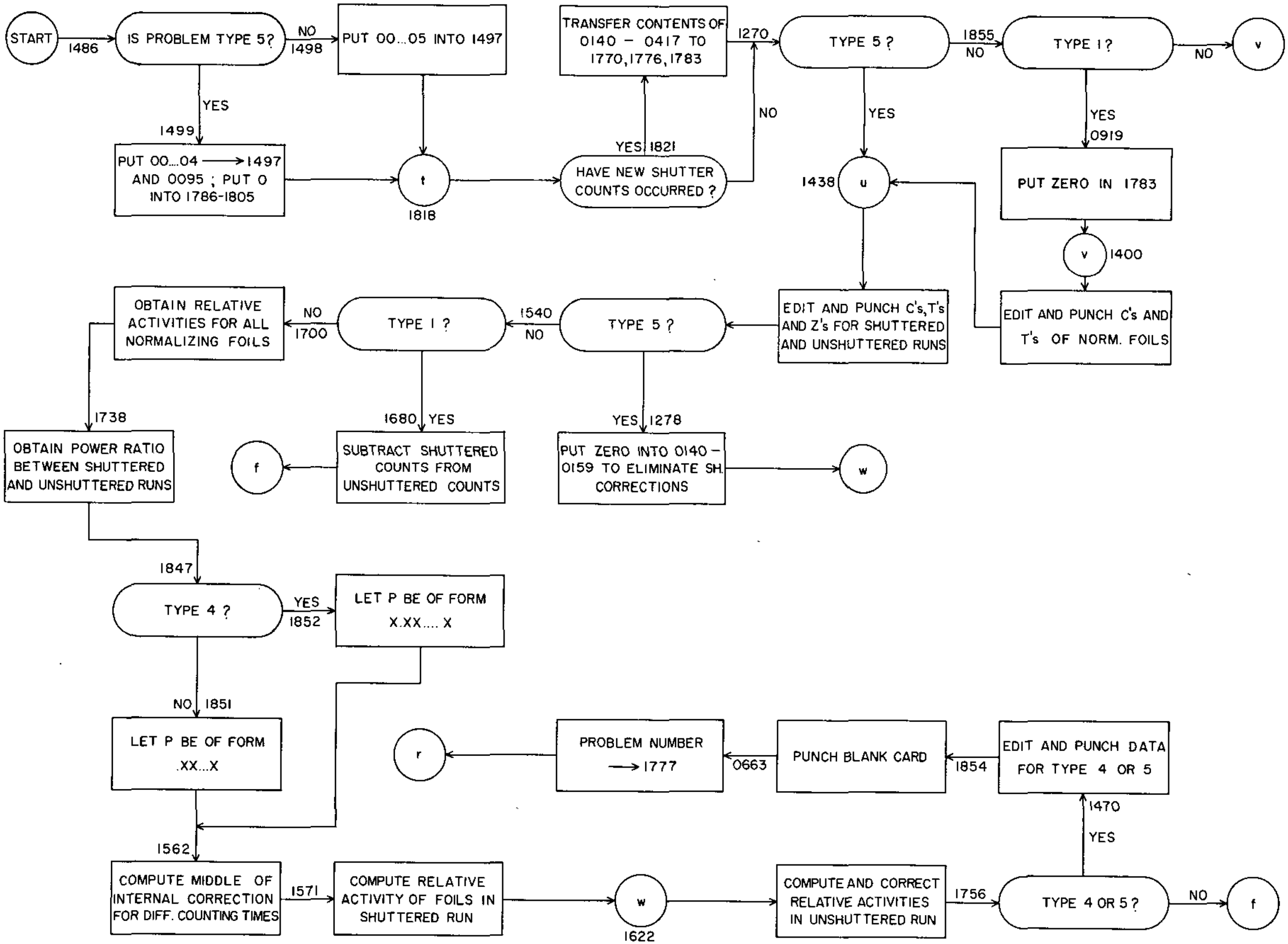
PRINT-OUT FOR TYPE 5

Foil Data

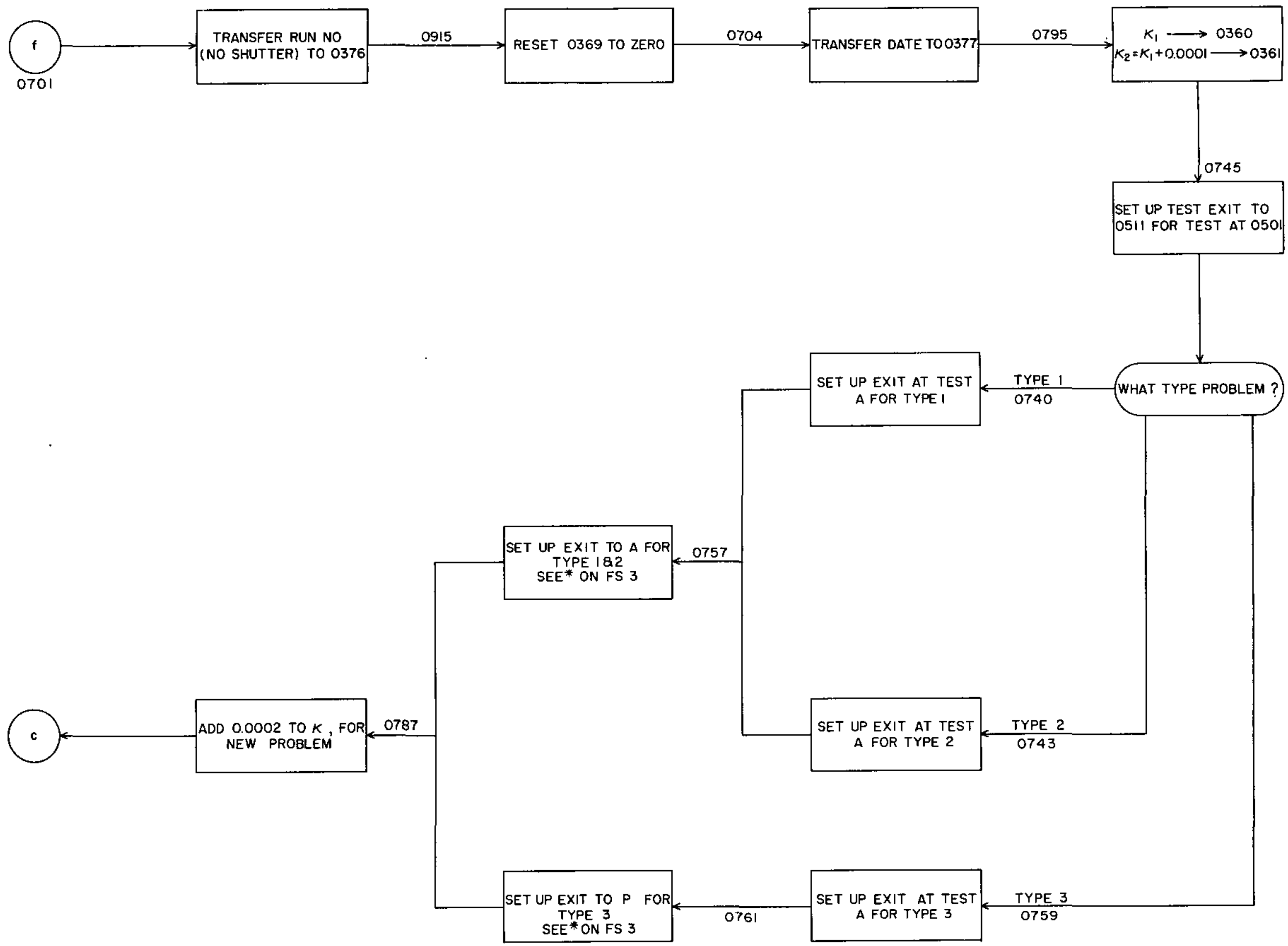
Counts	Time
5934	02050
5894	02400
5992	02750
5828	03100
2796	03500
2664	03850
2697	04200
2455	04570
22667	06260
18945	07610
21254	07960
20243	08300
7558	08640
7324	08970
8347	09110
7784	09640
41797	10030
40426	10370
33689	10720
32451	11060

Relative Activity	Run No.
422743800	91
439167400	91
467038100	91
475045600	91
239101900	91
238246800	91
252289300	91
240758500	91
2825023500	91
2796027900	91
3289551000	91
3269081300	91
1256886000	91
1270342400	91
1475724000	91
1472136200	91
8639883000	91
8715297900	91
7537578400	91
7573648300	91

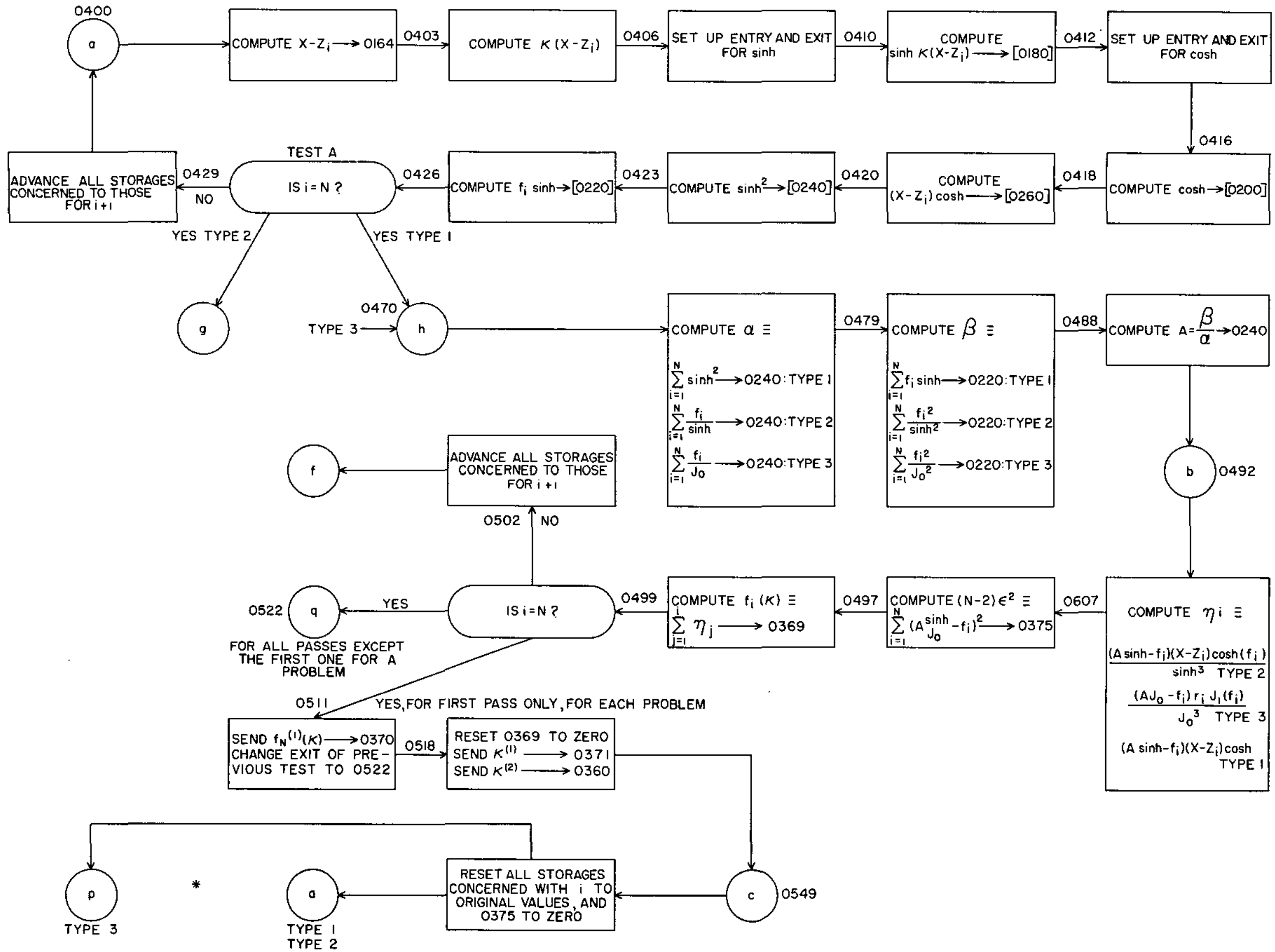
Date	Type
10-10	55 5 0 00000 000



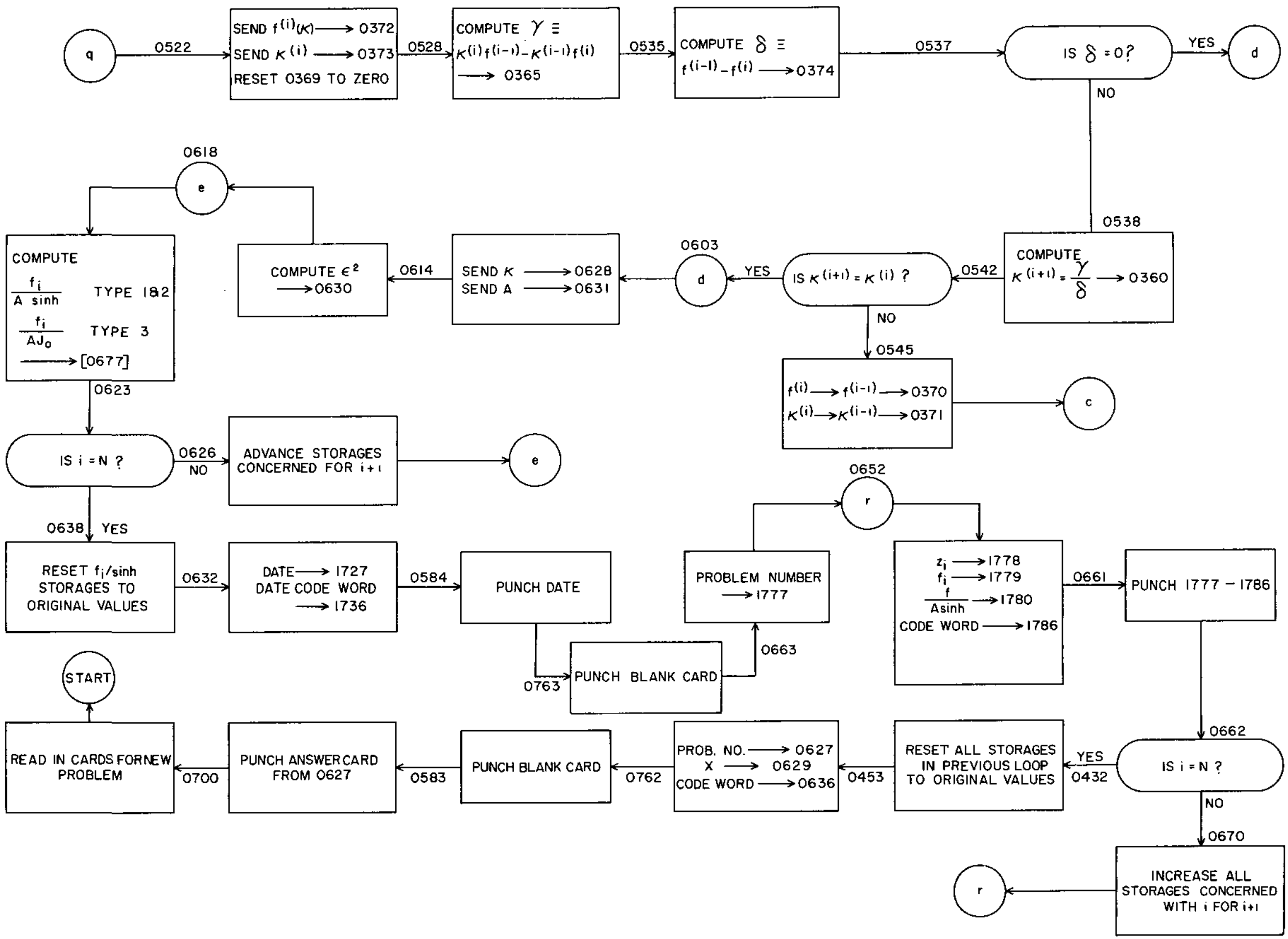
FLOWSHEET NO. 1 – RELATIVE ACTIVITIES COMPUTATION



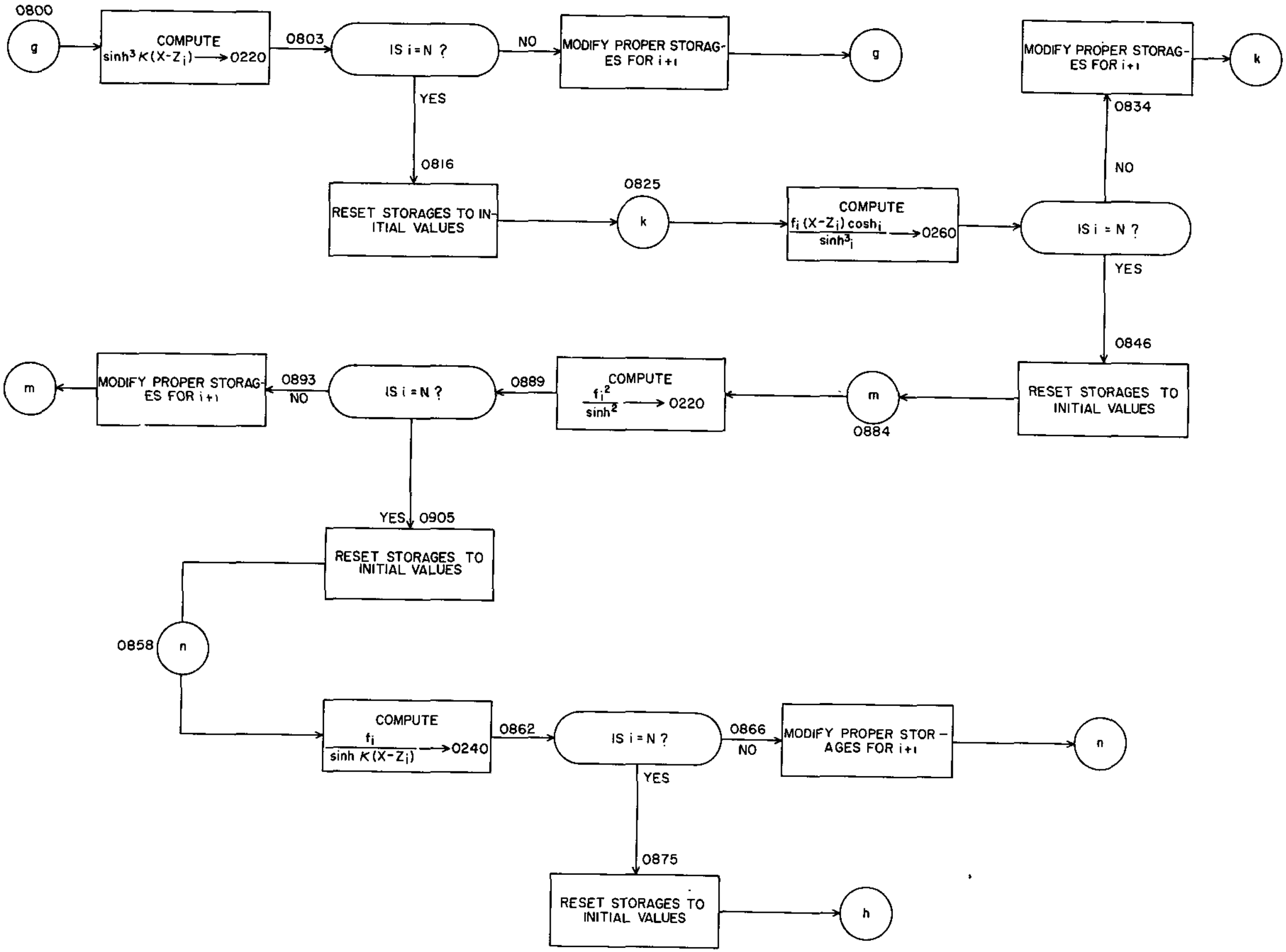
FLOWSHEET NO. 2 - INITIAL ROUTINE AND SELECTOR



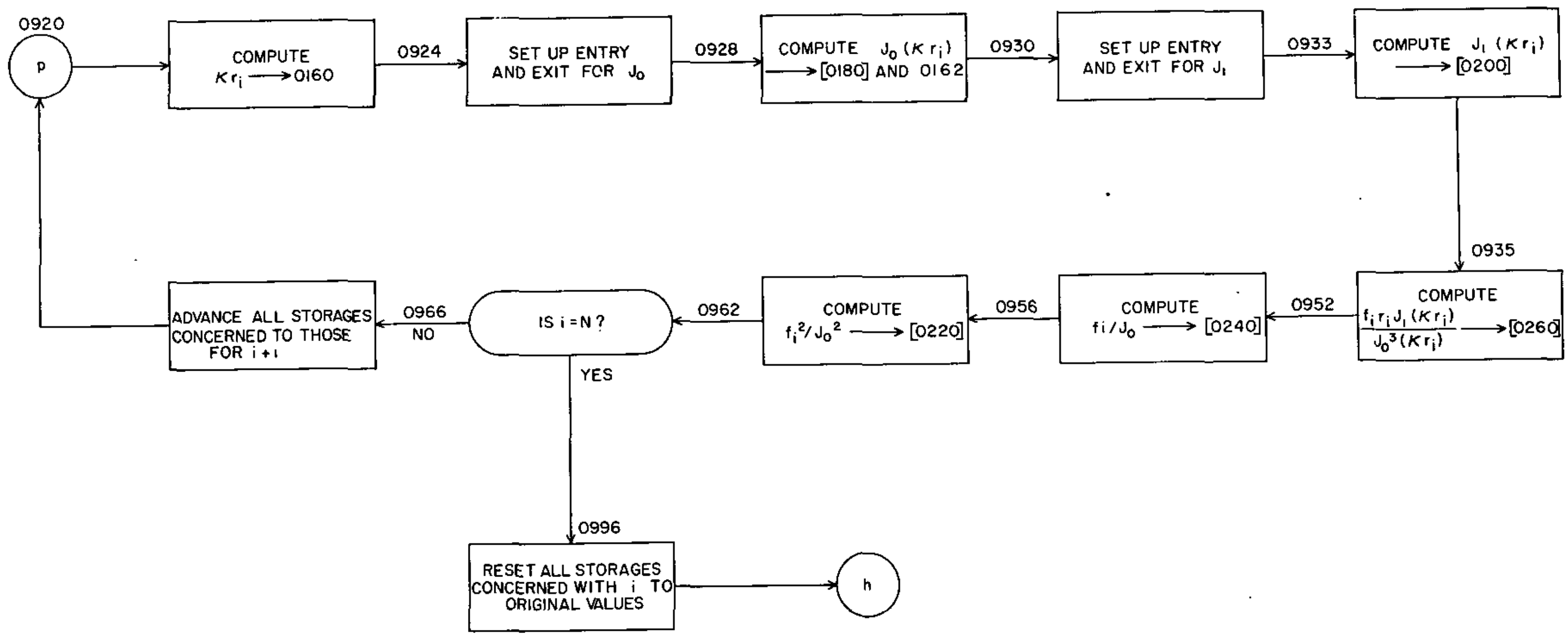
FLOWSHEET NO. 3 - MAIN COMPUTATION FOR TYPES 1, 2, AND 3



FLOWSHEET NO. 4 - LINEAR EXTRAPOLATOR AND PUNCHING FOR TYPES 1, 2, AND 3



FLOWSHEET NO. 5 - ROUTINES USED ONLY FOR TYPE 2



FLOWSHEET NO. 6 - ROUTINES USED ONLY FOR TYPE 3