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OPTIMIZATION OF FISSION FRAGMENT CATCHER FOIL EXPOSURE TIME

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Abstract of Document # [illegible]

Title: OPTIMIZATION OF FISSION FRAGMENT CATCHER FOIL EXPOSURE TIME

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ABSTRACT

The exposure time for fission fragment catcher foils, used in nuclear reactor power mapping, was arbitrarily set at 20 minutes early in the history of ANP. Work performed to evaluate this choice and to attempt an optimization of the exposure time is reported. A true optimum was not found. Forty minute runs are suggested, however, as a practical optimization and as an alternative to the 20 minute runs in current usage.

OPTIMIZATION OF FISSION FRAGMENT CATCHER FOIL EXPOSURE TIME - J.N. Renaker, R.G. Clark

Fission fragment catcher foils are used to map the power distribution in reactors. For most of the power mapping work at ANPD, the foils are exposed in a reactor for 20 minutes. This value was chosen arbirtarily and has been used without experimental or analytical examination. The present work is an attempt to evaluate the original choice and to indicate an optimum exposure time, if possible.

An optimum exposure time can be defined, in general terms, as that time which allows high catcher foil activity to be obtained quickly, cheaply, and safely. To generate data to be used for the optimization, catcher foils were exposued for various times ranging from 10 to 120 minutes. The reactor power level was adjusted to insure suitable foil activity for each exposure time. Power normalization foils were usually included with each run.

For this series of runs, the catcher foils were placed in close contact with bare, enriched uranium in the fueled region of a nuclear reactor. After irradiation, each catcher foil was counted* for five (5) one-minute counts during the interval from 40 to 60 minutes after shutdown. The activity of each foil, corrected for counter dead time, was plotted as a function of count time, and the activity at 50 minutes was then read from the curve. These counts at 50 minutes after shutdown were corrected for the variations in reactor power from run to run by use of the ratios of the saturated activities of the normalizer foils. The plot of the normalized catcher foil activities are shown in Figure 1.

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*Foils were counted in the $\alpha/\beta\gamma$, PC-3, Nuclear Measurements Corp. counter.

The reactor power level was adjusted, from run to run, to give the desired foil activity, using the reading of the log n recorder as a rough estimate of the desired power level. From the normalizer foil data, it was possible to calculate the log n setting, i.e. the power level, at which the run should have been made to achieve the desired counting activity at 50 minutes after shutdown for various exposure times. This information is presented in Figure 2.

To indicate the effect of exposure time on the build-up of the longer-lived fission products, an investigation was made of variations in the fission products decay scheme for various exposure times. As in previous runs, catcher foils were placed in contact with bare enriched uranium in the fueled region of a reactor. The foils were exposed for various lengths of time at power levels indicated in Figure 2. Normalizer foils were not included in these runs. After exposure the foils were quickly retrieved from the core and counting was started about 4 minutes after shutdown. Frequent counts were taken until about 55 minutes after shutdown. The observed counts were corrected for counter dead time and were plotted as a function of time since reactor shutdown. The fission product decay curve for each exposure time was normalized such that the value on the decay curve at 50 minutes after shutdown agreed with the activity at 50 minutes given in Figure 1. The decay curves, so normalized, are plotted in Figure 3. Also indicated in Figure 3 are the activities at 5 minutes and at 50 minutes after shutdown.

ANALYSIS

The following definitions are employed in the analysis of the data:

C (t)	is the observed count rate, corrected for counter dead time, at <u>t</u> minutes after shutdown.
N (std)	is the saturated activity of normalizer foils for a standard run.
N (x)	is the saturated activity of normalizer foils for a given run made at a given power level.
A (t)	is the catcher foil activity, normalized to a constant power level, at <u>t</u> minutes after shutdown.
P (x)	is the observed power level for a given run, as indicated by the reading on the log <u>n</u> recorder.
P (300)	is the power level at which the run should have been made to achieve 300,000 counts per minute at 50 minutes after shutdown.
A (30)/A (50)	is the change of the foil activity over a typical counting interval.
T	is the foil exposure time, in minutes.
t	is the decay time, in minutes after shutdown.

From these, the following quantities may be formulated:

$$A\ (50) = C\ (50) \times \frac{N\ (std)}{N\ (x)} \quad ; \quad \text{where } N\ (x) = k\ P\ (x)$$

and

$$P\ (300) = P\ (x) \times \frac{300{,}000}{C\ (50)}$$

therefore:

$$A\ (50) \times P\ (300) = \text{a constant}$$

A plot of A (50) x P (300) versus exposure time is presented in Figure 4. The scatter of the points is to be expected since P (300) is derived from a reading of the chart of the log <u>n</u> meter. Electronic drift and errors in reading the log scale can easily account for an error of ± 10% in the value of P (300). A ± 10% error is indicated for each point in Figure 4.

It is current practice to normalize foil activities to constant power by means of normalizer foils rather than by reference to the electronic reactor monitoring instruments. The data of this report vindicates this practice.

As a general approach to optimization of exposure time, consider the following four factors:

P (x)	Considering the potential health hazard, it is desirable to run at as low a power level as permissible.
C (50)	It is desirable to maximize the activity of the catcher foils to increase statistical reliability of the measured counts.
T	Exposure time should be kept short to reduce operator fatigue and reactor operating time, yet long enough to minimize timing errors.
A (30)/A (50)	It is desirable that this ratio be as close to 1.000 as possible to allow a greater length of time after shutdown during which reliable counts may be obtained. This ratio should approach 1.000 as a limit as the exposure time is lengthened.

Intuitively, it would appear that the value of the fraction:

$$\frac{P\ (x)\ T}{C\ (50)} \quad \frac{A\ (30)}{A\ (50)} = \frac{P\ (300)\ T}{300{,}000} \quad \frac{A\ (30)}{A\ (50)} = \text{a constant x } P\ (300)\ T \quad \frac{A\ (30)}{A\ (50)}$$

might be a minimum at the optimum value of T. Table 1 tabulates the values of the factors involved and Figure 5 gives a plot of the above fraction versus exposure time. Although Figure 5 does not pin-point an optimum exposure time, it does suggest that a short run is best, in terms of the four factors considered.

TABLE I

PARAMETERS FOR OPTIMIZATION OF FOIL EXPOSURE TIME

T	C (50)	A (50)	$\frac{A\ (30)}{A\ (50)}$	P(x)	P(300)	$P(300) \times T \times \frac{A(30)}{A(50)}$	P(300)xA(50)
10 min	3.54×10^5	1.03×10^5	1.767	0.30	0.25	4.4	2.6×10^5
20 min	2.86×10^5	1.83×10^5	1.694	0.15	0.16	5.4	2.9×10^5
40 min	3.09×10^5	3.09×10^5	1.602	0.10	0.097	6.2	3.0×10^5
60 min	2.33×10^5	4.05×10^5	1.533	0.065	0.084	7.7	3.4×10^5
80 min	4.05×10^5	4.75×10^5	1.5*	0.09	0.067	8.0	3.2×10^5
120 min	3.08×10^5	5.81×10^5	1.4*	0.05	0.049	8.2	2.8×10^5

The curve suggests the trivial optimum run length of zero minutes. This result is not very helpful and a different approach is considered below.

It was felt necessary to place limits on the ranges of the above four factors and to weigh each factor according to its relative importance. For instance, it is seen that the value of A (30)/A (50) varies very slowly with exposure times between 10 and 120 minutes. From previous experience, suitable count rates are available for sufficient lengths of time to permit adequate measurement. This means that normal variation of the ratio A (30)/A (50) does not present serious problems. For the purpose of exposure time optimization, A (30)/A (50) will be considered a constant.

It is felt that foil runs of about 10 minutes and less are not desirable due to the increased importance of timing errors and the large fraction of the time spent in leveling the power of the reactor. For these reasons, 20 minutes is tentatively set as the shortest exposure time. On the other end of the range, there is no definite maximum exposure time, although it is realized that operator fatigue increases and safety decreases as the run becomes longer. As a general rule, run times are not allowed to become longer than necessary. Also, because runs are not made on a 'mass production'

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*These values were obtained by extrapolation of a smooth curve.

basis, it is assumed that there would not be a significant difference in the number of runs per day using exposure times of 40 to 60 minutes. These things considered, 60 minutes has been tentatively set as the maximum length for routine runs.

It is current practice to adjust the power level for a given run to provide between 100,000 and 400,000 counts per minute in a time range of from 30 to 80 minutes after shutdown. To aid in reducing the overall radiation hazard, the upper power limit was arbitrarily set for these runs and corresponds to a log n meter reading of about 0.3. A lower limit, if one is needed, might be 0.003. In Table 1, it is seen that the value of P (300), the power level required to give count rates and count times in the desired ranges, is approaching the arbitrary upper limit of operation for exposure times of 10 minutes. Also, if the critical assembly were to be used to study cores larger than the present core, even higher power levels would be required to achieve the desired foil activity for 10 minute runs.* This indicates that exposure times of 20 minutes or longer are desirable.

The final term in the optimization function to be considered is $\dot{C}$ (50), or A (50) if all runs are made at the same power level. From Figure 3, it appears that the greatest increase of A (50) with exposure time occurs with short runs. As the runs become longer, A (50) increases more slowly due to the tendency to saturate the longer-lived fission products. Figure 6 is a plot of $\frac{\partial^2 A\ (50)}{\partial t^2}$, the second derivative of A (50) with time, versus exposure time. Figure 6, combined with the A (5) and A (50) curves in Figure 3, indicates that the operator is rewarded with fairly large increases in foil activity for runs up to about 40 minutes long. Much beyond 40 minutes, the rate of increase of foil activity is fairly low.

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*Foil activation is proportional to specific power and thus for equal activations larger cores give greater reactor power.

A practical optimization is obtained by combining the results of the last few paragraphs. The term A (30)/A (50) varies only slightly over the range of exposure times considered here. Considering the necessary power levels, the length of time required to level the reactor, and the inherent timing errors, it would appear that 20 minutes should be the shortest run. Considering operator fatigue and safety, 60 minutes has tentatively been set as the maximum exposure time for the types of runs usually made. The second derivative of foil activity with exposure time indicates that 40 minutes could be an optimum value. This value, conveniently, falls within the range of exposure time imposed by the other factors. Therefore, after development of appropriate decay tables, 40 minutes will be used as an alternative to the 20 minutes exposure time now in common usage.

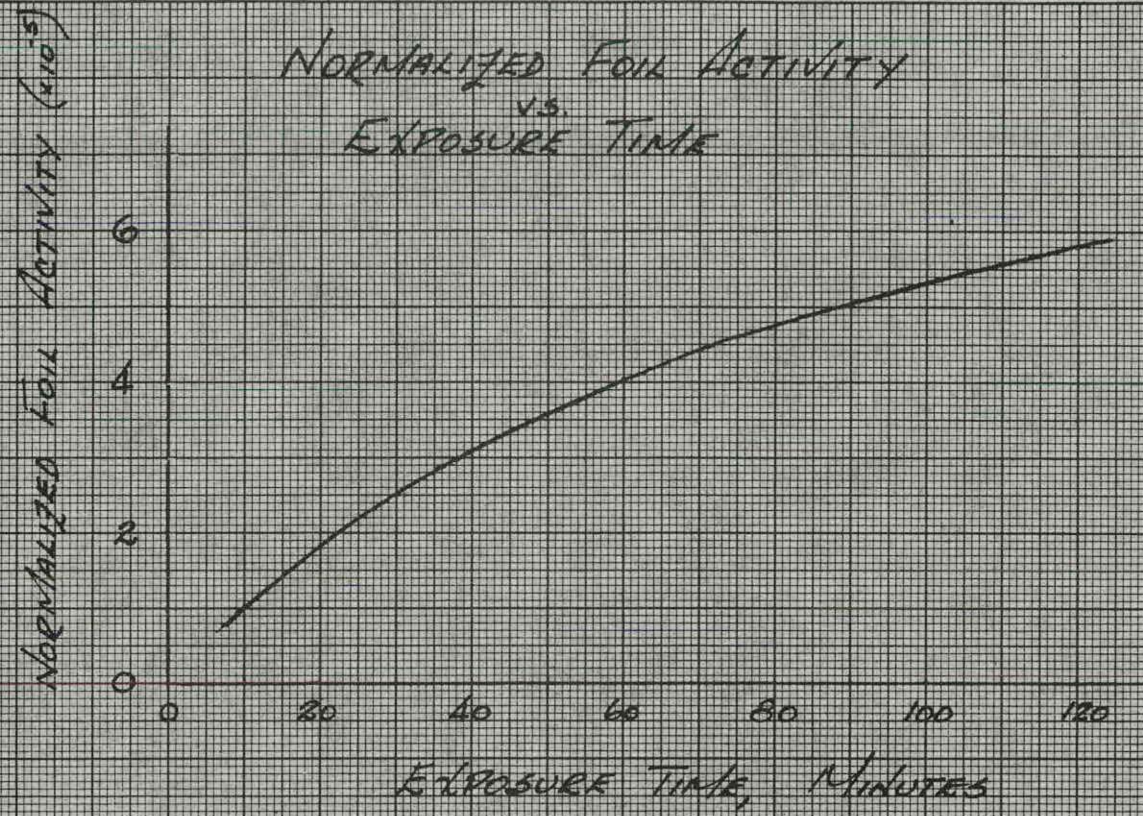

NORMALIZED FOIL ACTIVITY
VS.
EXPOSURE TIME
NORMALIZED FOIL ACTIVITY (x10⁻⁵)
0
2
4
6
0
20
40
60
80
100
120
EXPOSURE TIME, MINUTES

FIG. 1

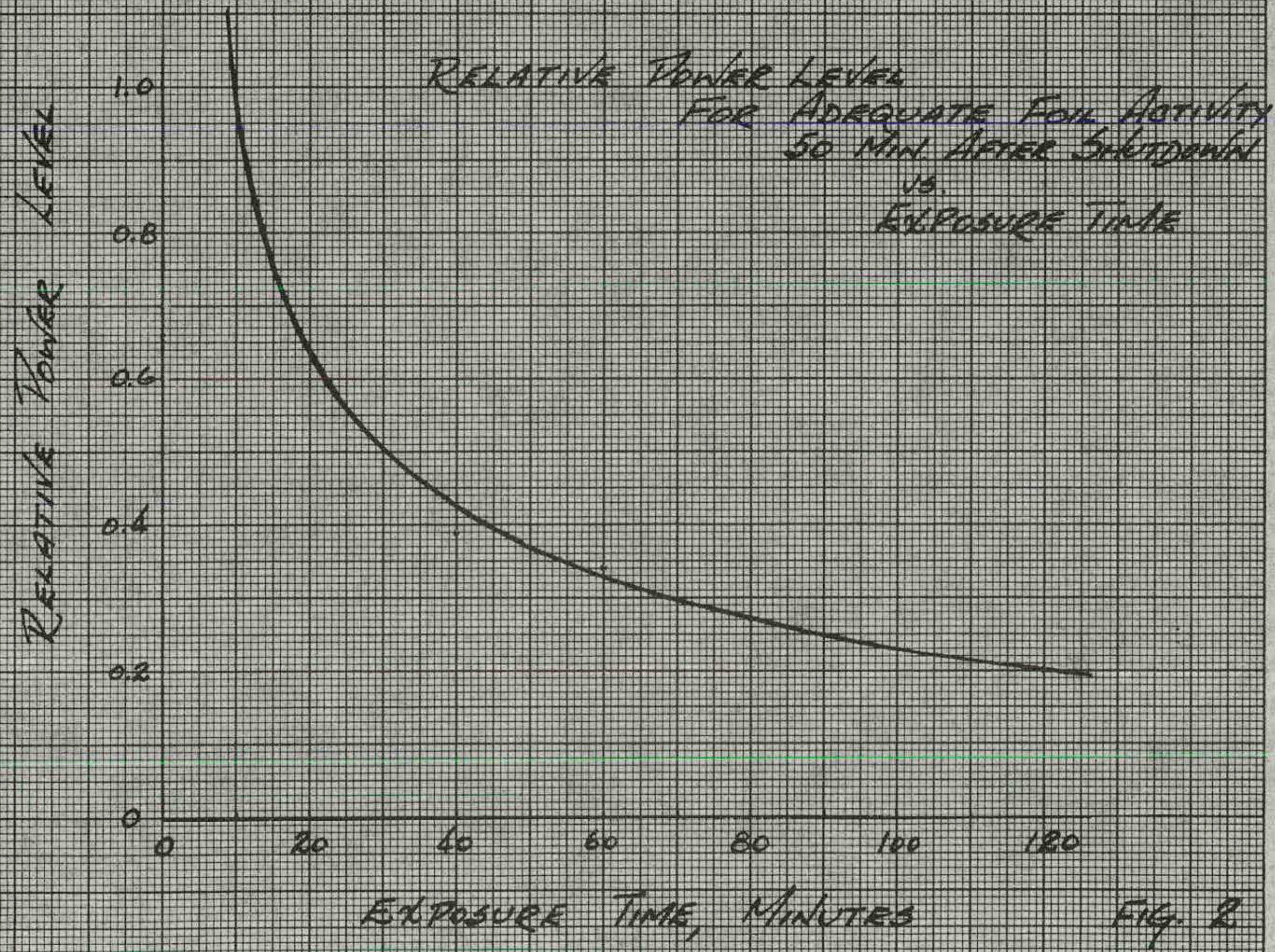

RELATIVE POWER LEVEL
FOR ADEQUATE FOIL ACTIVITY
50 MIN. AFTER SHUTDOWN
VS.
EXPOSURE TIME
RELATIVE POWER LEVEL
0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100
120
EXPOSURE TIME, MINUTES

FIG. 2

RELATIVE FOIL ACTIVITY
AND
FISSION FRAGMENT DECAY CHARACTERISTICS
VS.
TIME FROM START OF RUN

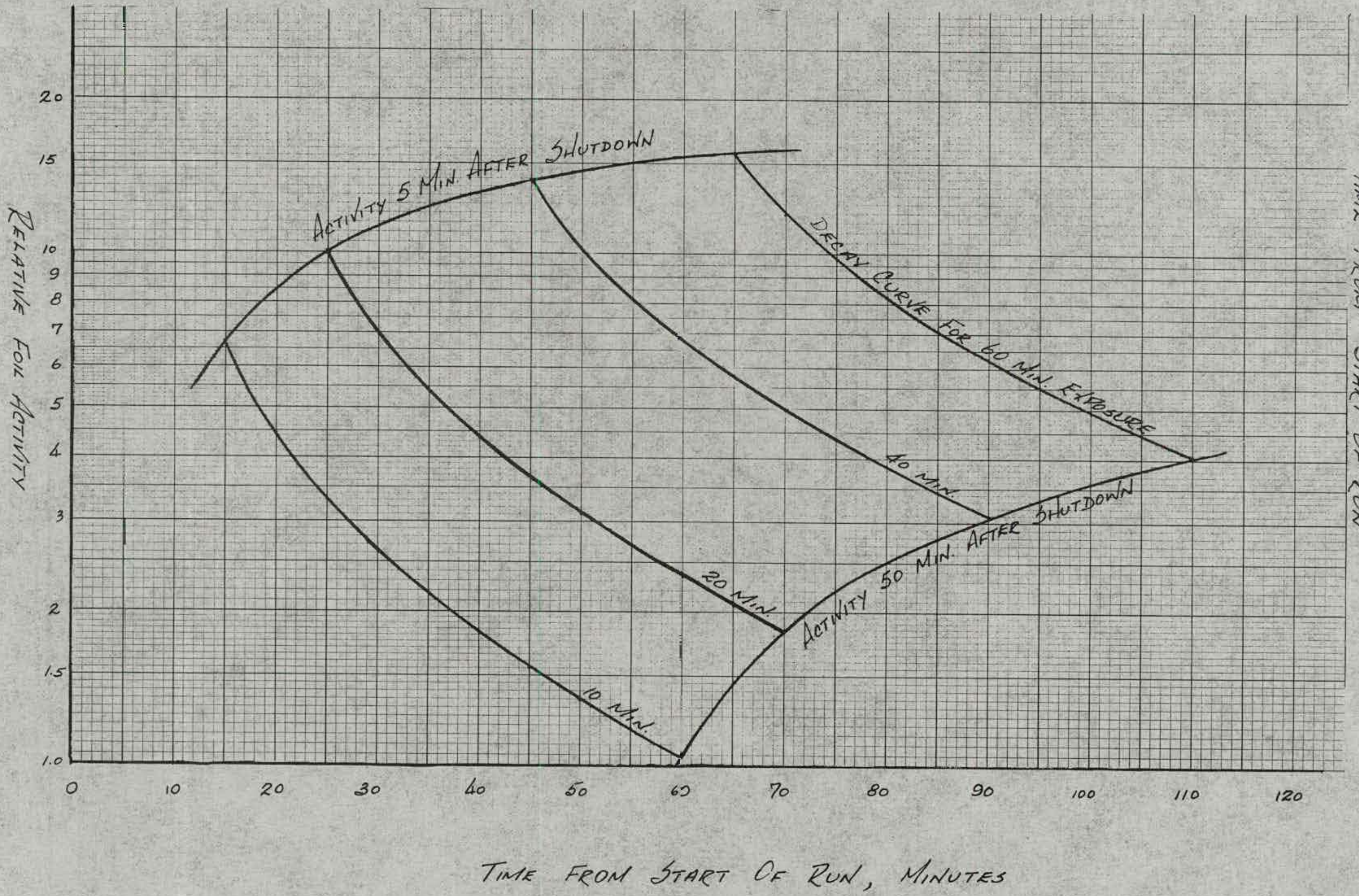
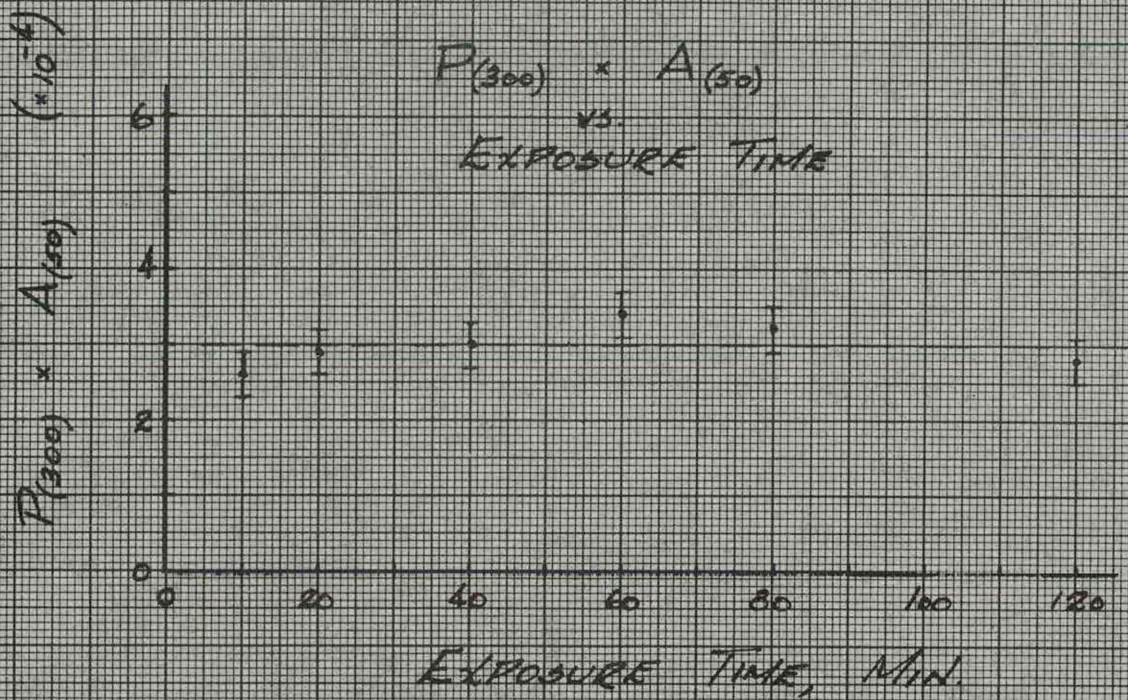


Fig. 3



P(300) × A(50)
vs.
Exposure Time
P(300) × A(50) (×10^-4)
0
2
4
6
0
20
40
60
80
100
120
Exposure Time, Min.

Fig. 4

Optimization Function
vs.
Exposure Time
P(300) T A(30)/A(50)
0
2
4
6
8
10
0
20
40
60
80
100
120
Exposure Time, Min.

Fig. 5

SECOND DERIVATIVE OF $A_{(60)}$ WITH TIME
vs.
EXPOSURE TIME

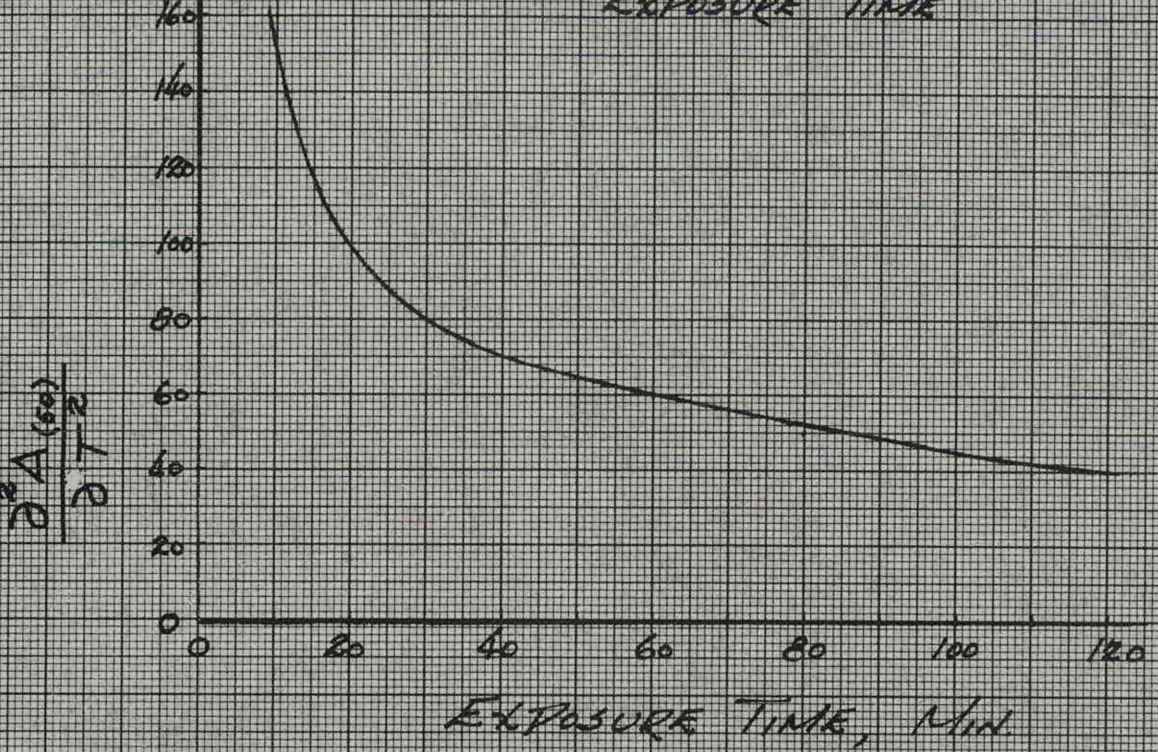


FIG. 6