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# ANALYSIS OF CALIBRATION DATA FOR MOBILE WHOLE BODY COUNTERS

By

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# ANALYSIS OF CALIBRATION DATA FOR MOBILE WHOLE BODY COUNTERS

J. L. Carter

The calibration runs of the mobile whole body counters M-WBC-A and M-WBC-B using sugar phantoms have been analyzed to obtain the factors which are needed to convert counts per 10-minute interval to body burden of radionuclides in children. The final results of the analysis are given in Tables I and II. A description of the method and a discussion of the work are given later.

Table I shows the functional forms of the relationships which it is assumed will be used to convert the counter measurements on an individual into body burden. This table is a generalization of the one in Form 54-1200-106(5-67) which is used to record whole body counter data for adults. Table II contains the values of the parameters appearing in these functions, as evaluated from the analysis of the sugar phantom runs. In addition, parameters are given for determination of $I^{131}$ body burden; these were calculated because, although no provision is made in Table I for the rountine measurement of this isotope, it is occasionally measured in special cases, and data from a M-WBC-B calibration run were available.

The factor $F_{xx}$ converts net counts for radionuclide x in the photopeak channels for x into body burden. The functional form of this factor for M-WBC-A is the same as that used earlier in analyzing these same data.[1] This empirical formula was retained because it fits the data at least as adequately as other simple linear or exponential forms, it simplifies inversion,

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1. J. F. Honstead, "A Program for Evaluating Environmental Radiation Doses to Children." (undated). See also F. J. Honstead, "A Program for Evaluating Environmental Radiation Doses to Children in the Vicinity of the Hanford Project in Washington," Radiol. Health Data and Reports 9, (Aug. 1968).

0027874

and time and funding did not permit a more careful analysis. The $F_{xx}$ for M-WBC-B requires the additional height factor to account for the measurement practice of adjusting the travel of the variable speed bed according to the height of the subject. The factor $G_{xy}$ corrects the total counts in the photopeak channels of radionuclide y for the counts contributed by Compton scattering of the higher energy gamma rays from radionuclide x, so that the net counts for y can be determined. For consistency in treatment, the functional form for $G_{xy}$ for both counters was chosen to be the same as the $F_{xx}$ for M-WBC-A. Since only the ratio of counts is needed to determine $G_{xy}$, the variable speed of the M-WBC-B bed has no affect and a height factor is not required.

Description and Discussion of Analysis Procedure

The data of Table II were obtained by the following procedure:

1. The working data for each radionuclide calibration run were obtained. These were the net counts in each of the standardized groups of channels for each phantom. Usually two or more runs had been made for each phantom. The raw data consisting of paper tape printouts for each channel were available and proved to be essential to the analysis; these data had already been summed for the standard channel groupings and tabulated for most runs. Except for some of the $K^{40}$ calibrations for M-WBC-B, the background had been subtracted before the raw data were printed; for these raw $K^{40}$ data with background, the background data were also available and tabulated. The scatter of some of the tabulated data led to a closer examination of the raw data, which in several cases resulted in the correction of tabulated entries. Some addition and transcription errors were found and one phantom run was corrected for background which had apparently not been subtracted. Another phantom run was salvaged by

estimating the counts in one channel missed in the printout. The most significant corrections were in the $Na^{24}$ calibrations of M-WBC-B. Here the raw data printout showed that the peak in the $Na^{24}$ spectrum did not occur in channels 137-138, as it should if the width per channel were the expected 20 kev, but was frequently a few channels lower. The tabulated data for one of the two runs had allowed for this by adjusting the actual channel numbers whose counts were summed; the data for other run was corrected by a similar adjustment. The $Na^{24}$ spectrum contains subsidiary peaks in the $K^{40}$ photopeak channels and these peaks were also shifted from their usual channels, so that channel adjustment was required; these corrections were made to data for both runs. The $Na^{24}$ spectrum data were sufficiently smooth in the other channels that they were not corrected. Corrections were also made in the tabulated background data for use with the $K^{40}$ raw data including background. In these multiple runs there was appreciable variation with time in both the calibration and background data. The corrected background subtracted from each calibration run was calculated by linear interpolation between the background runs bracketing it in time.

2. The counts per unit body burden were calculated for the photopeak channels of each radionuclide. With very few exceptions, the total burden of each phantom was the product of its weight by the radionuclide source strength per pound. The source strength was corrected for decay from reference values as follows: for $Na^{24}$ and $I^{131}$ to the start time of the run for each phantom, for $Zn^{65}$ and $Cs^{137}$ to the day of the run, no correction for $K^{40}$. In making these source corrections it was discovered that in the previous M-WBC-A calibrations, the PDT-PST conversion had been applied in the wrong direction for $Na^{24}$ and the decay correction had not

been made for $Cs^{137}$. As had obviously also been recognized in the previous $Na^{24}$ calibration of M-WBC-A, it was evident from the magnitude of the data and the time sequence of the runs that an error of 1 hour had been made in recording the time for one phantom run on the raw data tape; this time was corrected in the analysis.

3. The parameters in the $F_{xx}$ conversion factors were found for each radionuclide. These were determined from a least squares fit to the linear relation

$$z = a + bW$$

with

$W$ = weight of the phantom in pounds

$z$ = ln (counts per unit body burden) for M-WBC-A

= ln (counts per unit body burden) x (H + 11.0) for M-WBC-B

$H$ = height of the phantom in inches.

The parameters a and b were found from the standard forms

$$b = \frac{\overline{Wz} - \overline{W}\,\overline{z}}{\overline{W^2} - \overline{W}^2}$$

$$a = \overline{z} - b\overline{W}$$

Then $F_{xx} = e^{-z}$, giving $A_{xx} = e^{-a}$ and $B_{xx} = -b$.

The calculations were done by hand using a Wang Model 320 calculator.

With one exception, the means were calculated by giving equal weight to each phantom in each calibration run. The exception was the $K^{40}$ calibration of M-WBC-B, for which there were from 9 to 18 measurements for each phantom size. Here the mean, $\overline{x}$, and the standard deviation, s, of the counts for each phantom size were determined, weighting each

measurement equally. The least squares fitting was then made with z calculated using $\bar{x}$ for the counts for the phantom and with $\bar{x}/s$ used as a weighting function; this function is appropriate for $1/\sigma$ weighting of $\ln \bar{x}$ if s is the standard deviation in $\bar{x}$.

4. The scattering fraction $F_s$ and the parameters in the $G_{xy}$ correction factor were determined for each of the sets of Compton scattering channels of each radionuclide. The $F_s$ for a set of channels is the ratio of the counts in those channels to the counts in the photopeak channels. The parameters in the $G_{xy}$ were determined by essentially the same least squares procedure as were the $F_{xx}$ parameters, with the $\ln F_s$ replacing z. In these cases, however, $A_{xy} = e^a$ and $B_{xy} = b$. With the exceptions of the $K^{40}$ and $I^{131}$ calibrations of M-WBC-B, the $F_s$ and the averages were obtained by use of the computer code WBC. This code, which was almost completed by R. J. Eby, formerly of Columbia River Studies Section, was put in operation and proved useful in the evaluation of these parameters. The exceptional $K^{40}$ calibration, because if its modified treatment, and the $I^{131}$ calibration, because of its minimal calulation, were done completely by hand using a Wang Model 320 calculator.

Discussion of Results

Though Table II gives the results in useable form, it does not reveal any information on how accurate the results might be. Figures 1 through 15 are included for this purpose. These figures show graphically the relation of the least squares fitted lines to the points used in their fitting. The individual points are shown, except for the $K^{40}$ calibration data for M-WBC-B, which show the means and standard deviations of the runs for each phantom size. For several of the radionuclides, some 10 or so repeat runs were made for a particular phantom size; these data were not used in fitting the lines, but their means and standard deviations are given on the graphs. Usually these means lie within a standard deviation of the line. Also shown on the graph for the photopeak channels of each radionuclide in the M-WBC-A calibrations is the least squares line obtained in previous analysis[1] of the same data. This line has been corrected for a different source strength in two cases, so that a comparison with the present data is more meaningful. The difference between the two lines is apparent. Part of this difference can be attributed to slight differences in numbers of points or in relative counts in the two analyses. However, most of the difference is attributable to different least squares assumptions. In terms of the present analysis, the previous analysis assumed

$$W = \alpha + \beta z$$

as the line to be fitted, thus interchanging the roles of W and z as independent and dependent variables. The results in the two cases are equivalent only if the correlation coefficient, $r = (\overline{zW} - \overline{z}\,\overline{W})/(\overline{W^2} - \overline{W}^2) = 1$, which is not true here. As this least squares procedure attributes all the uncertainty of a point to the dependent variable, this variable should be the quantity

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containing the measured counts. Since z is the dependent variable in the present analysis, the present results are preferred.

These figures show that there is an appreciable amount of scatter in the data. Indeed, the standard deviation in the repeat runs with a given phantom size is usually significantly greater than that attibutable to counting statistics alone. Other factors thus control the accuracy and reproducibility of the data. Although the validity of the practice of rebuilding the phantom for each run was recognized, it was disturbing at first that so much variation in the data resulted. Later it was realized that similar variation is undoubtedly associated with the actual measurements on individuals and that the calibration should reflect as well as possible the uncertainty introduced by these variations. For this reason, all the calibration runs made by varying the phantoms through the standard sizes were used in evaluating the parameters.

This scatter in the data further indicated that, under the time and funding limitations imposed, attempts to find a more satisfactory correlation function were not warranted at this time. There are, however, indications of systematic variations of the data as a function of phantom size that, with further investigation, could be correlated with more complex combinations of phantom parameters than just the weight. Some effort was made to determine an effective phantom thickness from the details of the phantom construction and to attempt to correlate these systematic variations with this parameter. This effort was dropped for lack of time, but may well be worth reviving later.

The scatter in the data raises the further question as to how adequate the calibrations are for the purposes at hand. No attempt will be made to

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supply a definite answer. Some measure of the accuracy can, of course, be obtained from examining the figures. In addition, some data are given in Table III which supply another measure. This table shows the values of the conversion and correction factors for each radionuclide as evaluated for a 154 pound "standard man." Also shown are the mean and standard deviation of similar factors calculated from these calibration runs by assuming no dependence on weight. The factors from Form 54-1200-106(5-67) are also given for further comparison. The difference between the two values for a given counter in comparison with the standard deviation of the constant value is a rough indication of the uncertainty. All these clues suggest at best a 5 to 10 percent, perhaps a 40 to 50 percent, uncertainty in the values of the individual factors. These uncertainties are reflected in a complex manner in the determination of the net counts of the radionuclides, particularly those with the lower energy photopeaks, but combine so as to increase the uncertainty in the results as more calibration factors become involved. An overall uncertainty of a factor of 2 would not be unexpected in the conversion of $Zn^{65}$ or $Cs^{137}$ net counts to body burdens, due to the calibration alone. Relative measurements should of course be more accurate than this.

A more careful analysis of the data, including an error analysis, would seem to be justifiable.

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## Table I

### Mobile Whole Body Counter Calibration Relations

| Radionuclide: (Channels) | $Na^{24}$ (127-142) | $K^{40}$ (68-78) | $Zn^{65}$ (52-60) | $Cs^{137}$ (30-36) | GOK (10-20) |
|---|---|---|---|---|---|
| Definitions: | $T_{Na}$=total counts | $T_K$=total counts | $T_{Zn}$=total counts | $T_{Cs}$=total counts | $T_{GOK}$=total counts |
| | $N_{Na}=Na^{24}$ counts | $N_K=K^{40}$ counts | $N_{Zn}=Zn^{65}$ counts | $N_{Cs}=Cs^{137}$ counts | $N_{GOK}$=GOK counts |
| Correction Formula: | $N_{Na}=T_{Na}$ | $N_K=T_K-G_{Na,K}N_{Na}$ | $N_{Zn}=T_{Zn}-(G_{Na,Zn}N_{Na} + G_{K,Zn}N_K)$ | $N_{Cs}=T_{Cs}-(G_{Na,Cs}N_{Na} + G_{K,Cs}N_K + G_{Zn,Cs}N_{Zn})$ | $N_{GOK}=T_{GOK}-(G_{Na,GOK}N_{Na} + G_{K,GOK}N_K + G_{Zn,GOK}N_{Zn} + G_{Cs,GOK}N_{Cs})$ |
| Calibration Formula: | nCi $Na^{24}=F_{Na}N_{Na}$ | grams $K^{40}=F_KN_K$ | nCi $Zn^{65}=F_{Zn}N_{Zn}$ | nCi $Cs^{137}=F_{Cs}N_{Cs}$ | |

Notes:

(a) "Total counts" is the sum of counts for 10-minute interval in indicated channels, less background.

(b) $I^{131}$(channels 16-20) is not explicitly included, as these channels are not separately monitored routinely.

(c) The F and G are functions depending on weight (and possibly height) of subject

M-WBC-A $\quad F_{xx} = A_{xx}e^{B_{xx}W} \quad G_{xy} = A_{xy}e^{B_{xy}W}$

M-WBC-B $\quad F_{xx} = A_{xx}(H + 11.0")e^{B_{xx}W} \quad G_{xy} = A_{xy}e^{B_{xy}W}$

Table II

Mobile Whole Body Counter Calibration Parameters

| Source Radionuclide (x) | Analyzer Channels (y) | M-WBC-A Parameters $A_{xy}$ | M-WBC-A Parameters $B_{xy}$ | M-WBC-B Parameters $A_{xy}$ | M-WBC-B Parameters $B_{xy}$ |
|---|---|---|---|---|---|
| | | | | 0.0001491 | |
| $Na^{24}$ | $Na^{24}$ | .01146 | .000788 | .001499 | -.000876 |
| | $K^{40}$ | 1.0874 | -.000599 | .9568 | .000461 |
| | $Zn^{65}$ | .3103 | .001158 | .2844 | -.000020 |
| | $Cs^{137}$ | .3213 | .000782 | .2781 | .000685 |
| | $I^{131}$ | .4530 | .000934 | .3182 | .000209 |
| | GOK | 1.3018 | .000498 | .7369 | .000031 |
| $K^{40}$ | $K^{40}$ | .0925 | .001704 | .0012705 | .0001296 |
| | $Zn^{65}$ | .1589 | .003528 | .16436 | .000497 |
| | $Cs^{137}$ | .1431 | .002529 | .12913 | .000834 |
| | $I^{131}$ | .2110 | .001412 | .13720 | .002199 |
| | GOK | .4975 | .004318 | .40346 | -.000563 |
| $Zn^{65}$ | $Zn^{65}$ | .01694 | .001893 | .0002347 | .000371 |
| | $Cs^{137}$ | .1792 | .002063 | .1665 | .002285 |
| | $I^{131}$ | .2155 | .002654 | .1669 | .001744 |
| | GOK | .6160 | .002566 | .3942 | .001420 |
| $Cs^{137}$ | $Cs^{137}$ | .00839 | .002195 | .0001211 | .000815 |
| | $I^{131}$ | .3052 | -.001361 | .2088 | .000907 |
| | GOK | .8829 | -.001759 | .4303 | .001515 |
| $I^{131}$ | $I^{131}$ | -- | -- | .0001118 | .000153 |
| | GOK | -- | -- | 1.415 | -.000050 |

M-WBC-A: $F_{xx} = A_{xx}\, e^{B_{xx}W}$ $\qquad G_{xy} = A_{xy}\, e^{B_{xy}W}$

M-WBC-B: $F_{xx} = A_{xx}(H + 11.0'')e^{B_{xx}W}$ $\qquad G_{xy} = A_{xy}\, e^{B_{xy}W}$

$F_{xx}$ in nanocuries/counts in 10 minutes for $Na^{24}$, $Zn^{65}$, $Cs^{137}$, and $I^{131}$ and in gms K/counts in 10 minutes for $K^{40}$.

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Table III

Comparison of 154-lb. Standard Man Factors

| | Radionculide | Channels | Standard Man Factors: M-WBC-A Exponential[a] | M-WBC-A Constant[b] | M-WBC-B Exponential[a] | M-WBC-B Constant[b] | Form 54-1200-106(5-67) |
|---|---|---|---|---|---|---|---|
| 2.75 | $Na^{24}$ | $Na^{24}$ | .0129(.0127) | .01214 ± .00028 | .01244* | .01328 ± .00055* | .0115 |
| | | $K^{40}$ | .991 | 1.041 ± .019 | 1.0272 | .9947 ± .0753 | 1.05 |
| | | $Zn^{65}$ | .371 | .3381 ± .0127 | .2835 | .2845 ± .0174 | .403 |
| | | $Cs^{137}$ | .362 | .3405 ± .0098 | .3090 | .2937 ± .0135 | .426 |
| | | $I^{131}$ | .523 | .4860 ± .0277 | .3286 | .3245 ± .0274 | -- |
| | | GOK | 1.406 | 1.354 ± .109 | .7404 | .7414 ± .0652 | 2.06 |
| 1.46 | $K^{40}$ | $K^{40}$ | .1203(.1287) | .1048 ± .0041 | .1231* | .12181 ± .00079* | .1277 |
| | | $Zn^{65}$ | .274 | .2064 ± .0151 | .1857 | .1740 ± .0115 | .249 |
| | | $Cs^{137}$ | .2113 | .1733 ± .0198 | .1468 | .1403 ± .0138 | .185 |
| | | $I^{131}$ | .262 | .2369 ± .0374 | .1925 | .1649 ± .0151 | -- |
| | | GOK | .968 | .6880 ± .0777 | .3700 | .4031 ± .0430 | .66 |
| 1.12 | $Zn^{65}$ | $Zn^{65}$ | .0227(.0240) | .01923 ± .00064 | .02361* | .02291 ± .00051* | .0242 |
| | | $Cs^{137}$ | .2461 | .2079 ± .0099 | .2367 | .1973 ± .0122 | .260 |
| | | $I^{131}$ | .3241 | .2608 ± .0136 | .2183 | .1901 ± .0120 | -- |
| | | GOK | .915 | .7408 ± .0382 | .4906 | .4382 ± .0243 | 1.08 |
| 0.062 | $Cs^{137}$ | $Cs^{137}$ | .0118(.0127) | .00982 ± .00045 | .01304* | .01221 ± .00031* | .0121 |
| | | $I^{131}$ | .2475 | .2768 ± .0109 | .2401 | .2256 ± .0341 | -- |
| | | GOK | .6733 | .7789 ± .0445 | .5436 | .4877 ± .0837 | 1.05 |
| 0.36 | $I^{131}$ | $I^{131}$ | -- | --- | .01088* | .01074 ± .00032* | -- |
| | | GOK | -- | --- | 1.404 | 1.410 ± .0376 | -- |

a $F = Ae^{BW}$

b $F = \overline{F}$

* For better comparison, travel of bed assumed 95 inches as in M-WBC-A.

M-WBC-A $Na^{24}$ Calibration

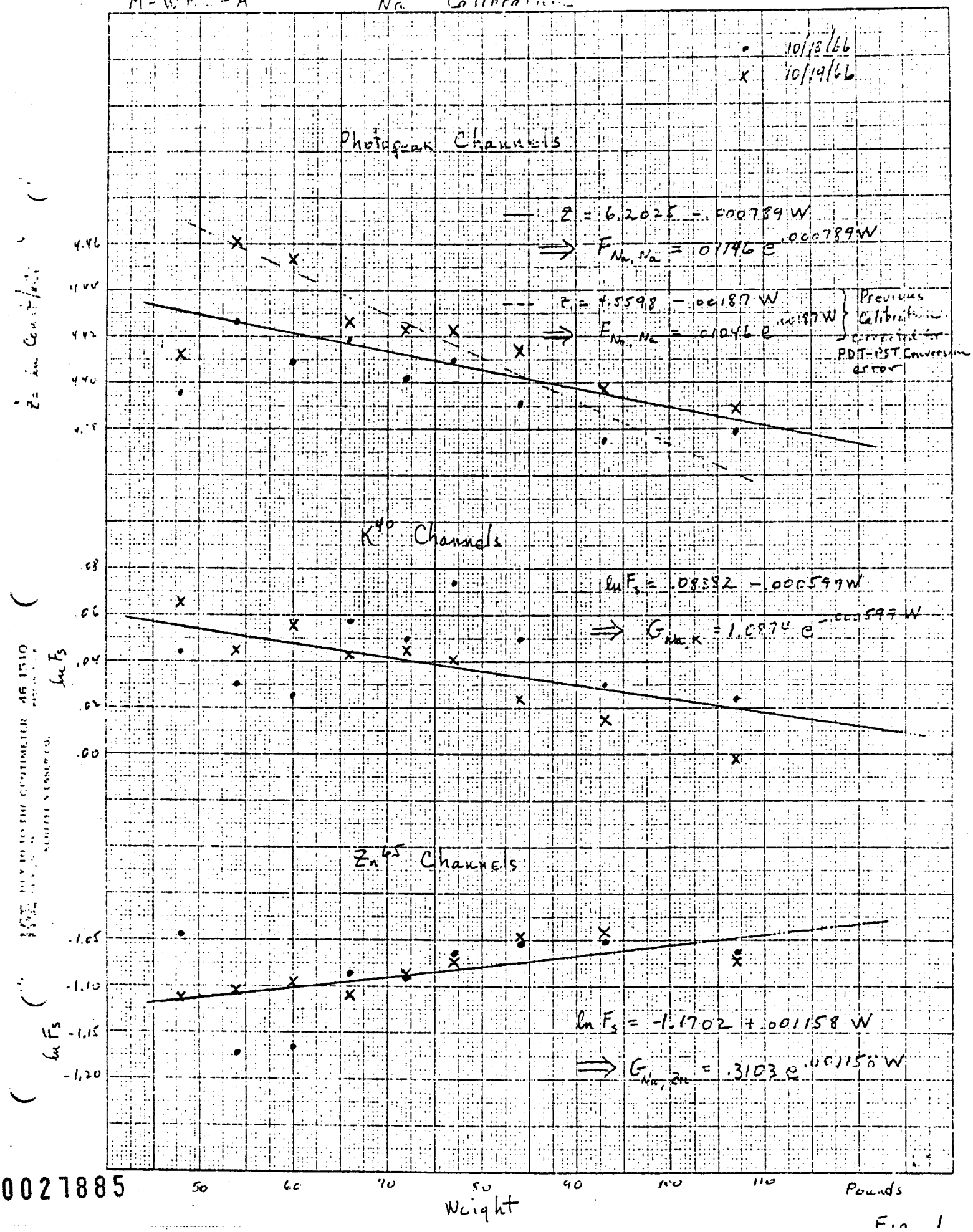


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Fig. 1

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M-WBC-A

$Na^{24}$ Calibration

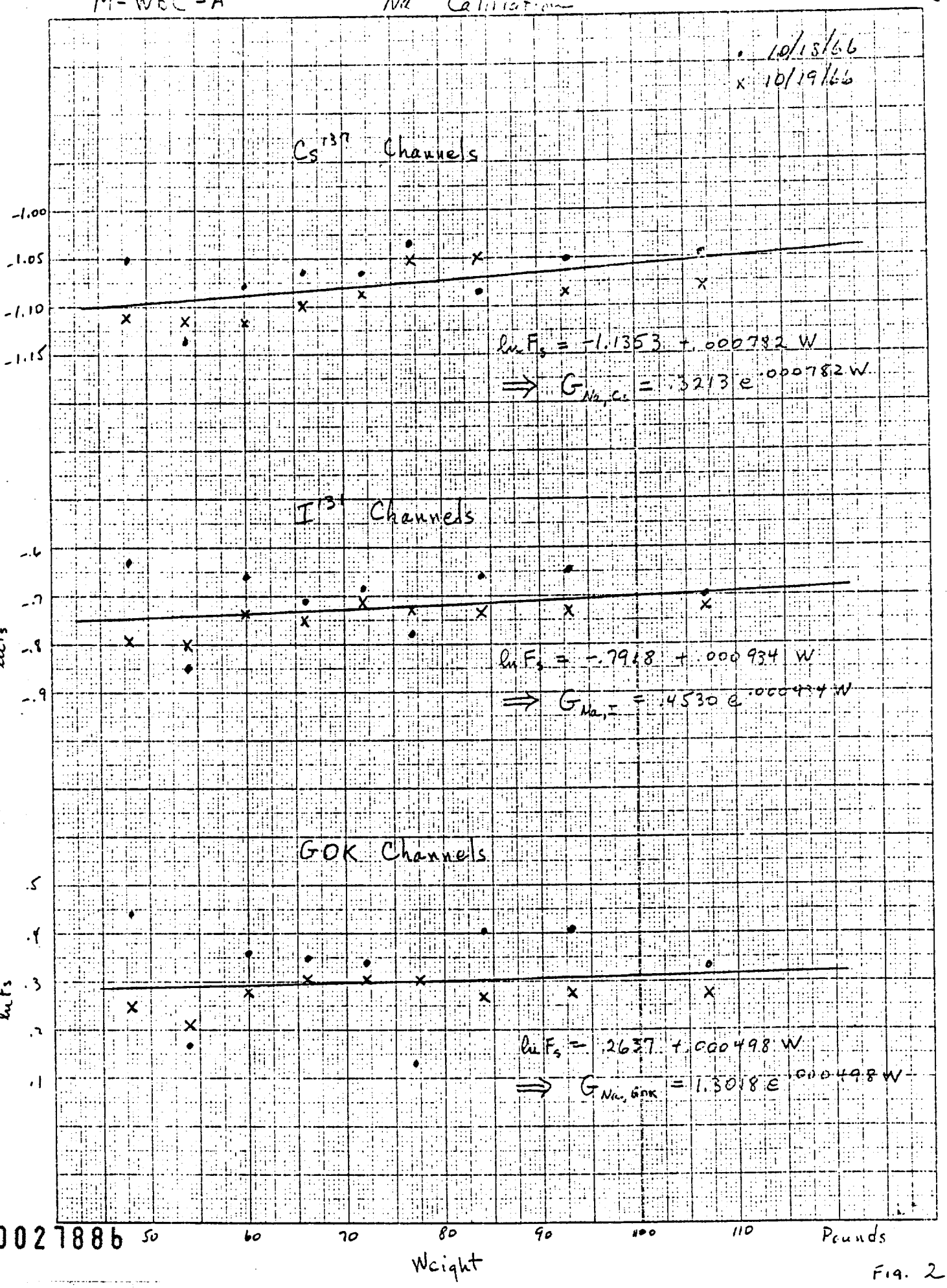


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Fig. 2

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M-WBC-A

# $K^{40}$ Calibration

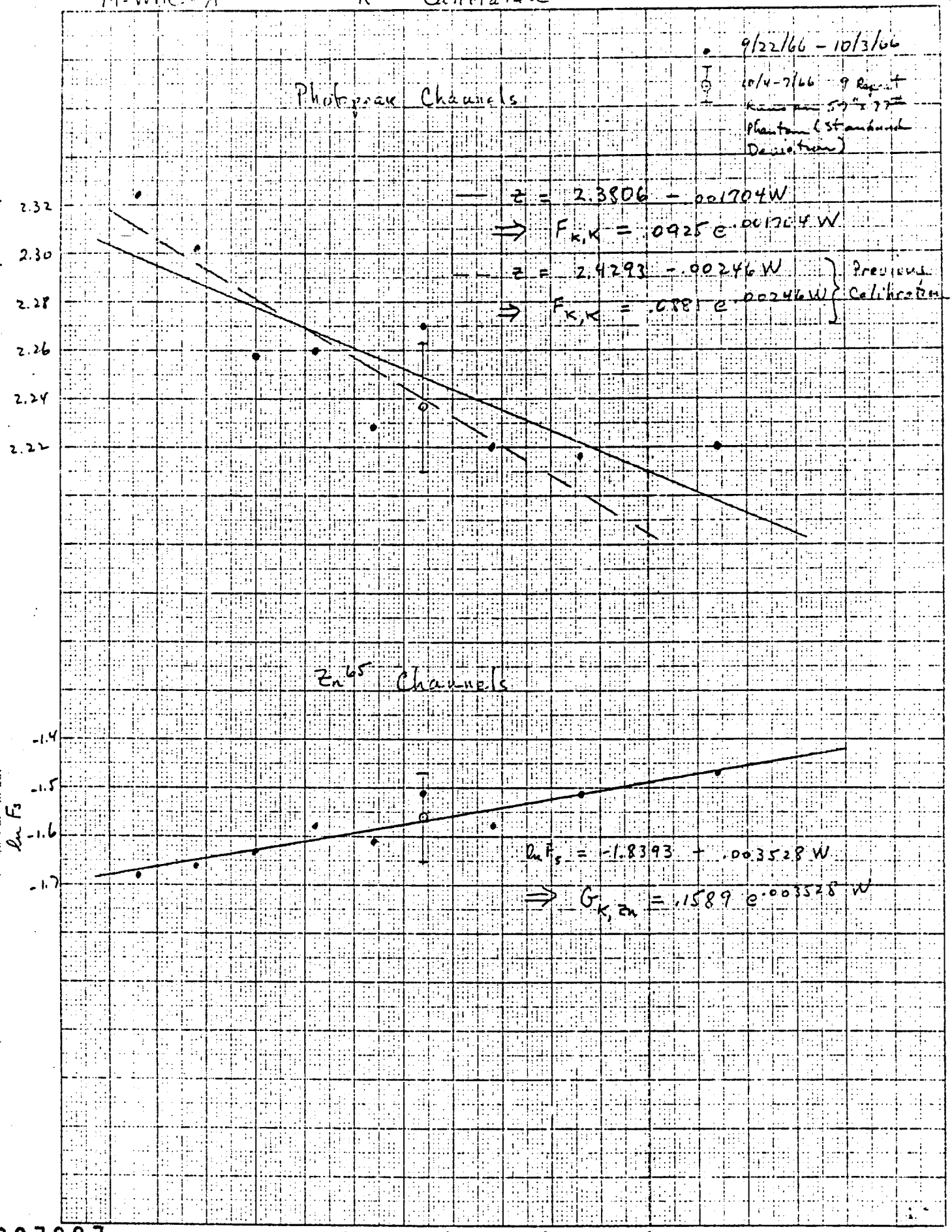


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Fig. 3

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JLC

M-WBC-A

# $K^{40}$ Calibration

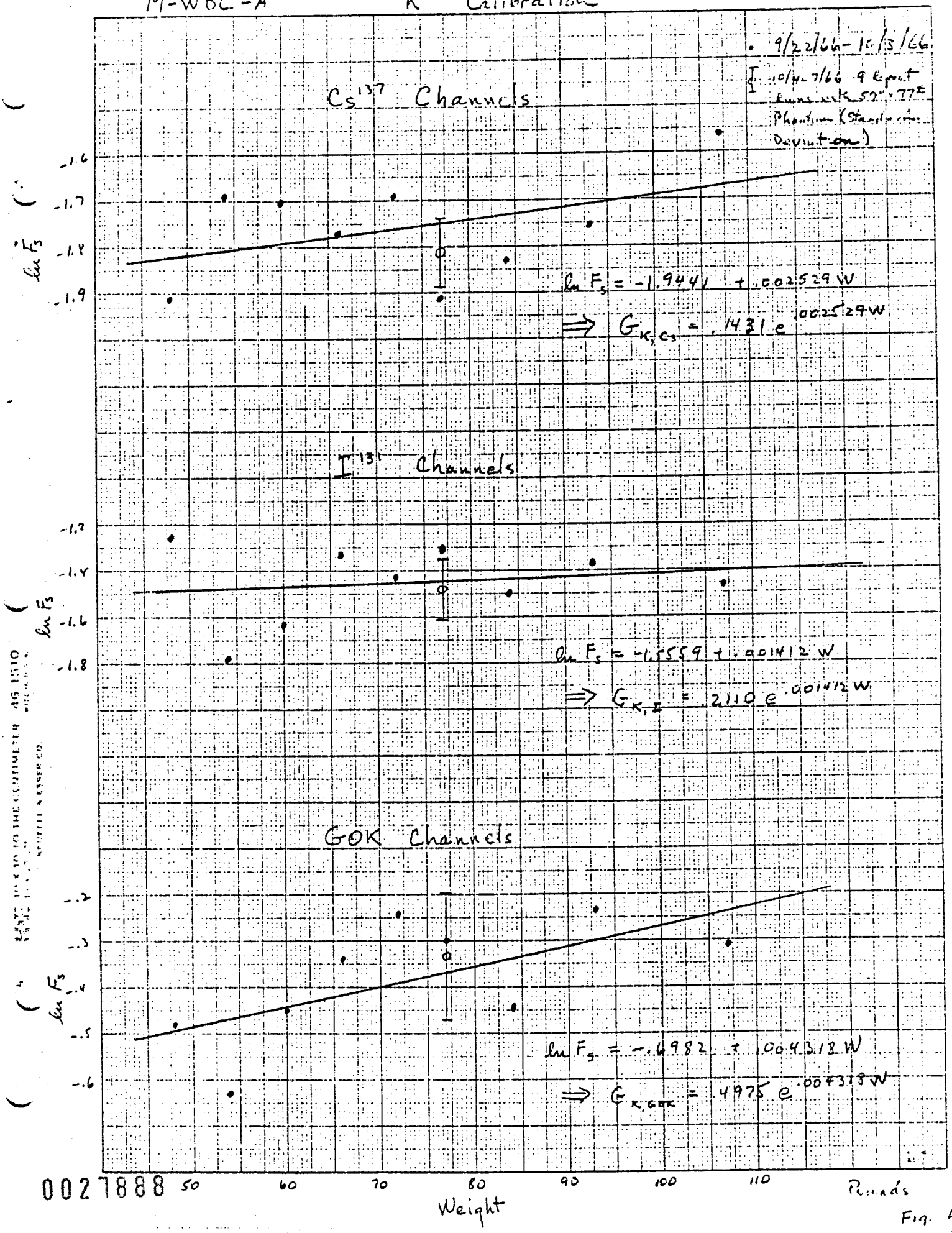


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Fig. 4

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M-WBC-A $Zn^{65}$ Calibration

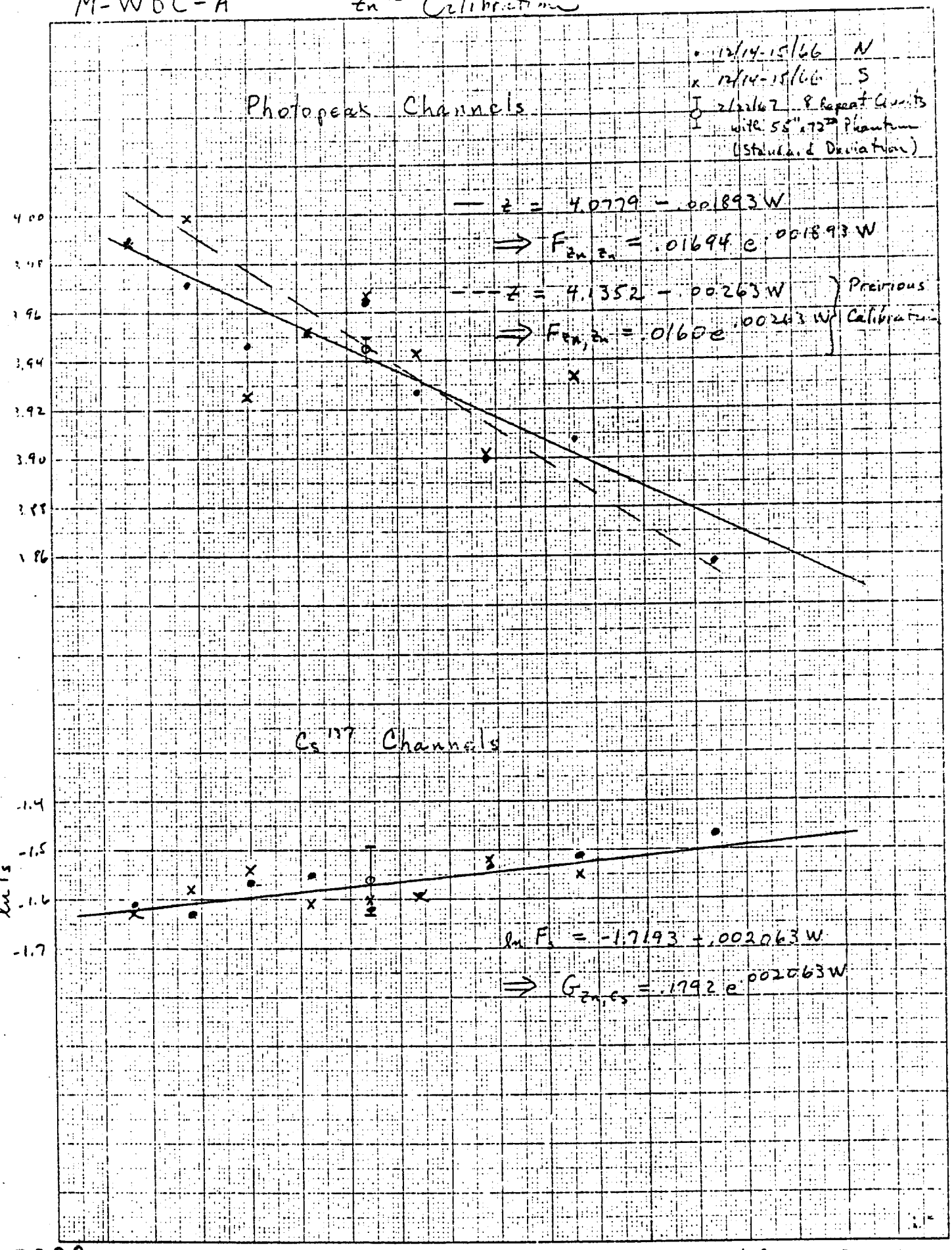


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Fig. 5

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M-WBC-A

# $Zn^{65}$ Calibration

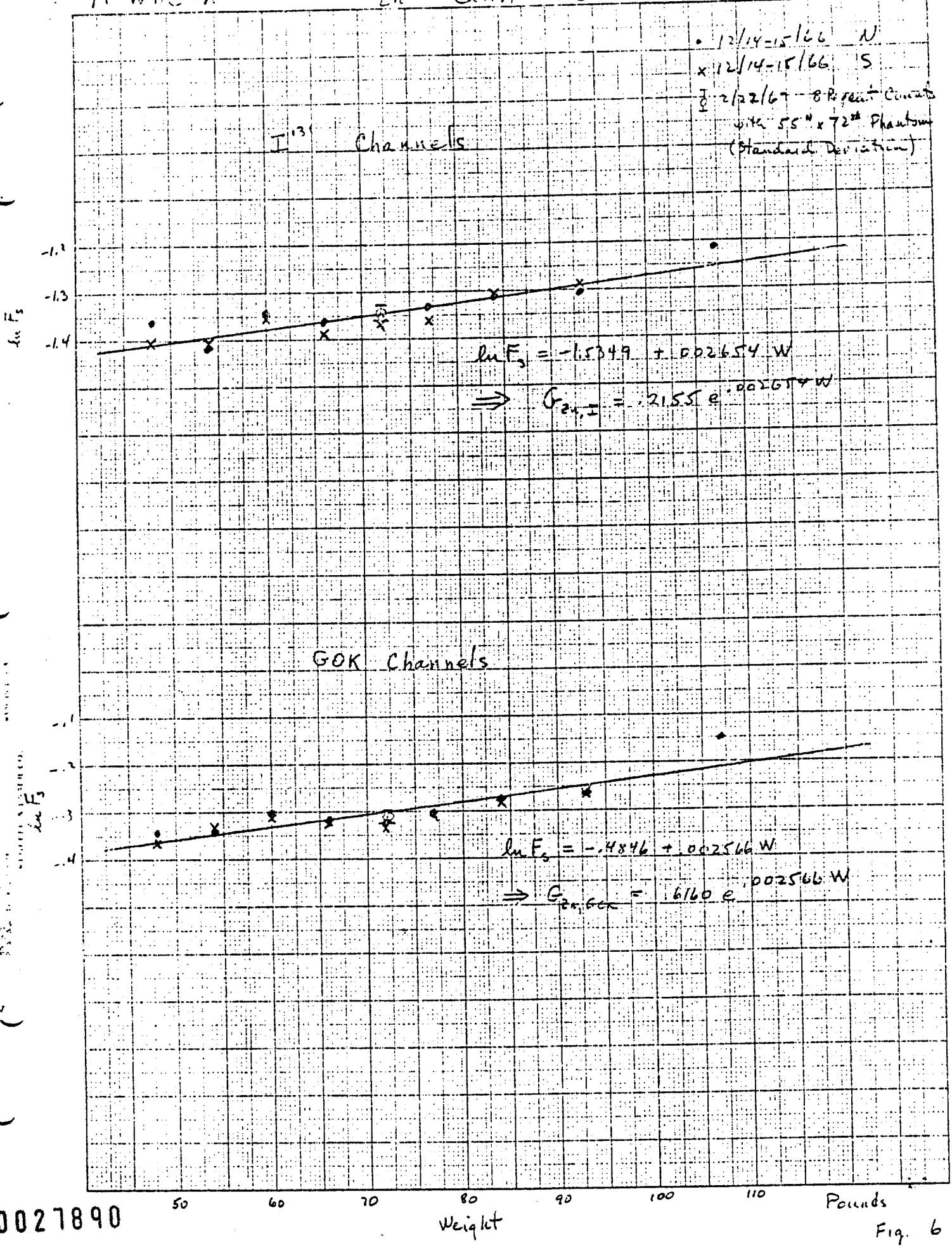


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Fig. 6

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M-WBC-A

# $Cs^{137}$ Calibration

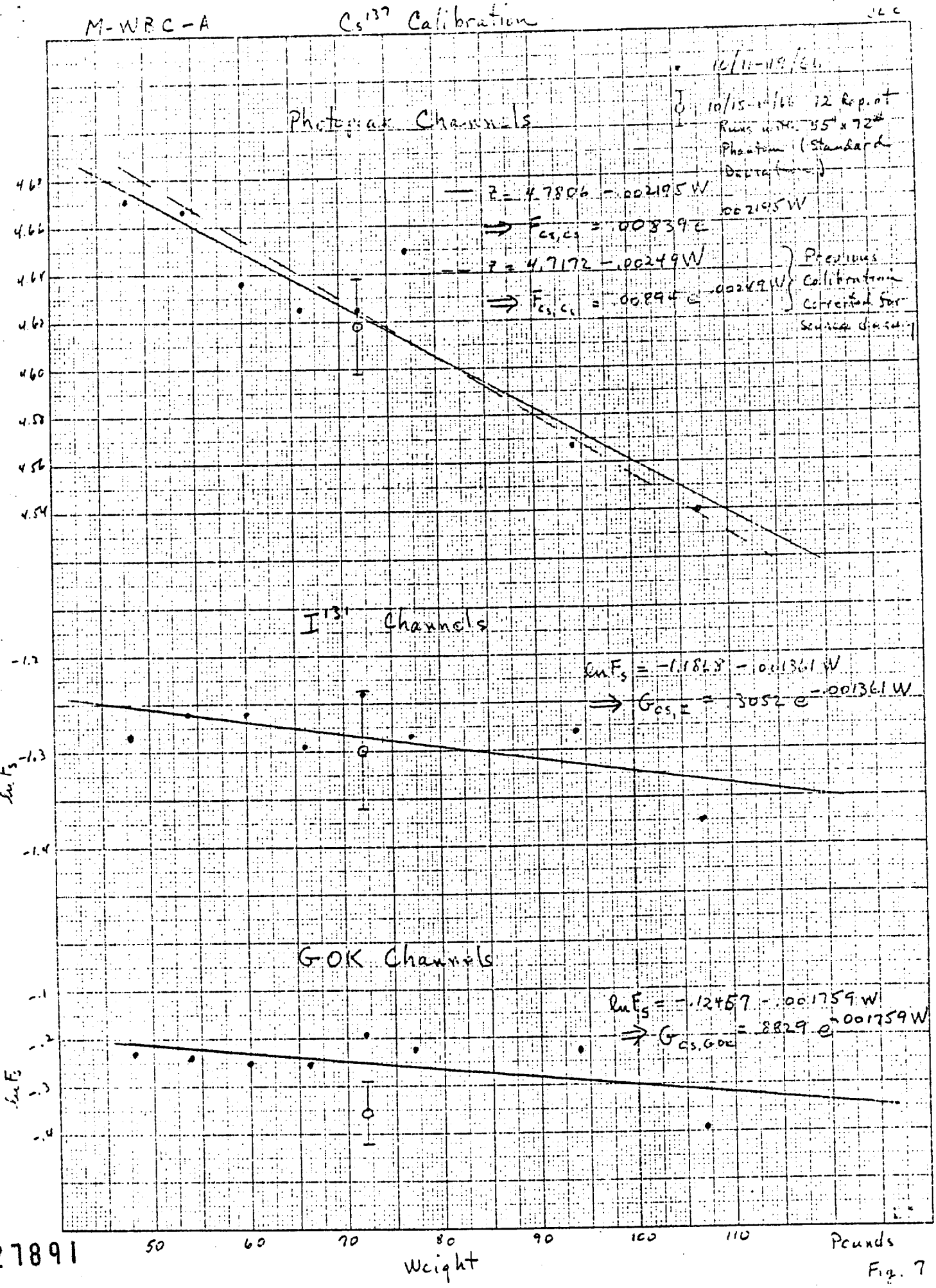


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Fig. 7

M-WBC-B $Na^{24}$ Calibration

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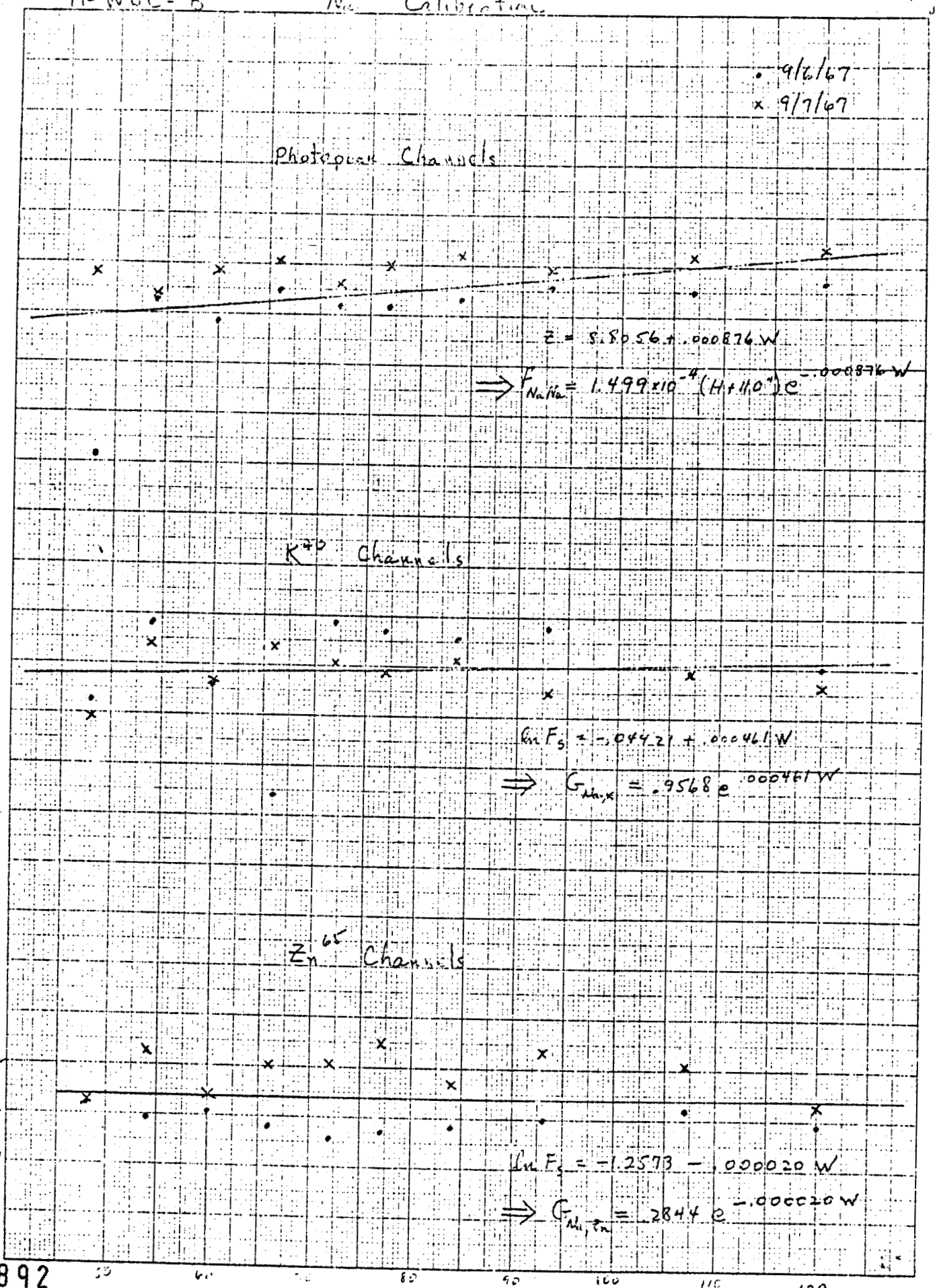


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Fig 3

M-WBC-B $Na^{24}$ Calibration

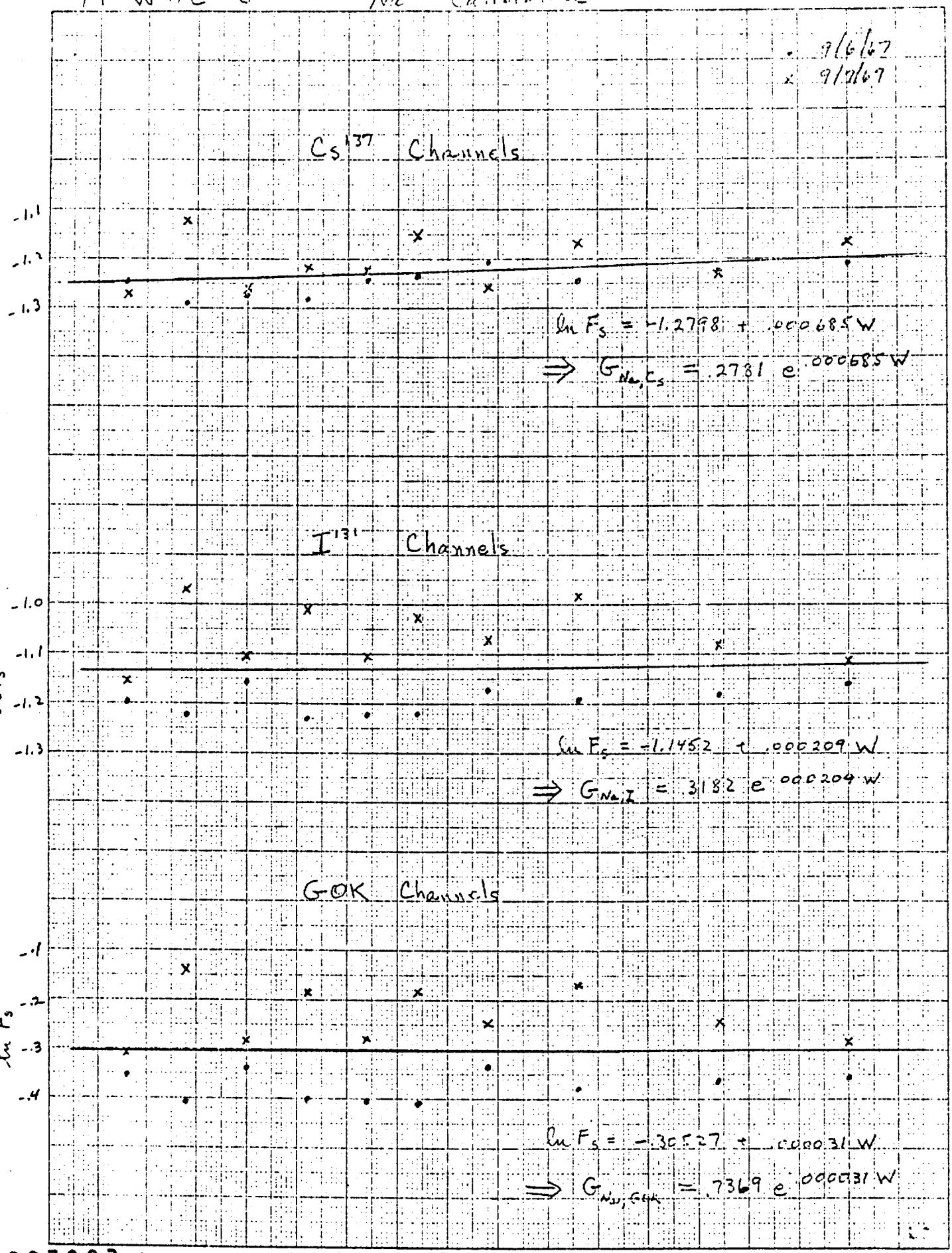


Fig 9

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M-WBC-B $K^{40}$ Calibration

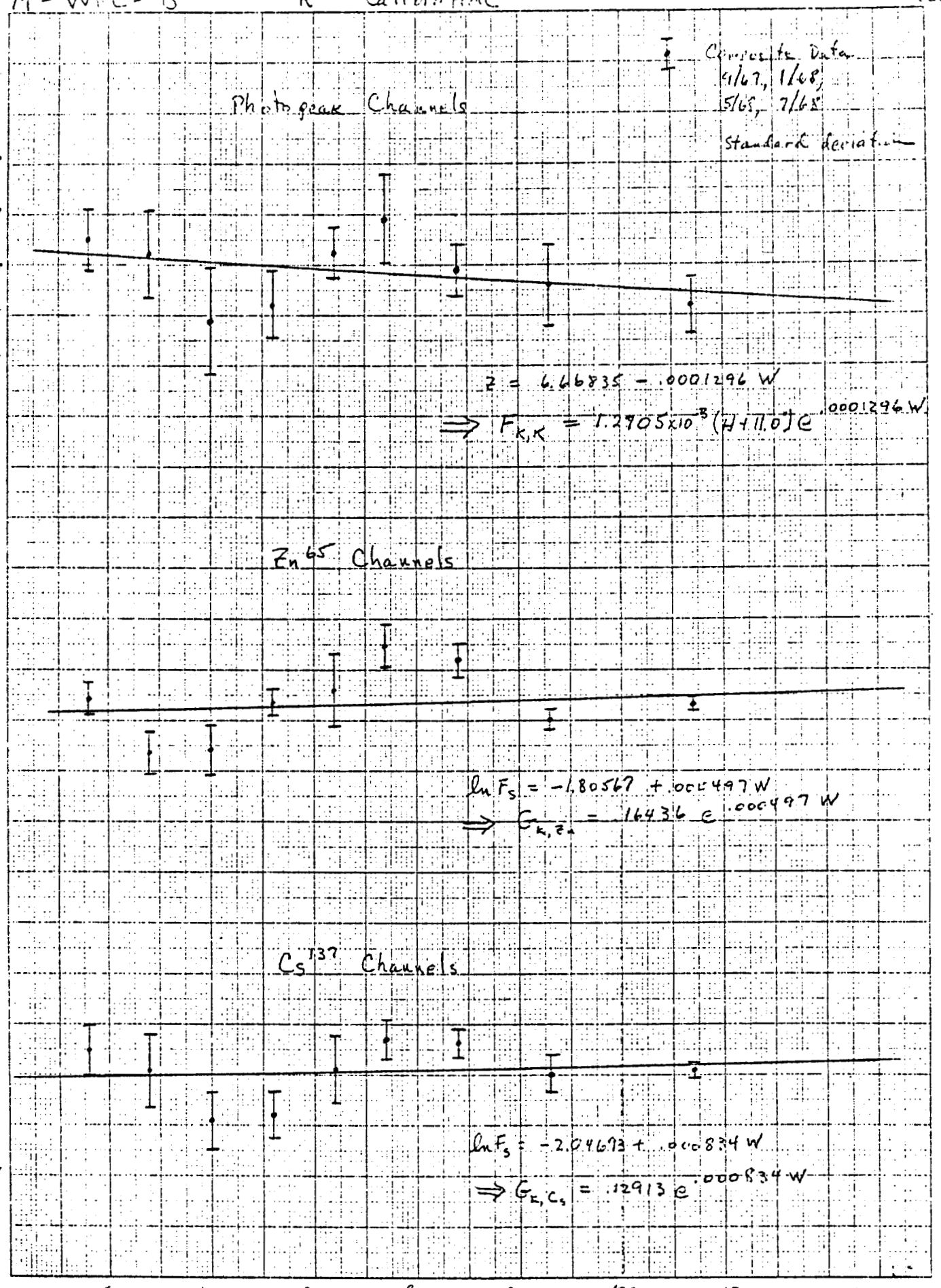


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Fig. 10

M-WBC-B $K^{40}$ Calibration

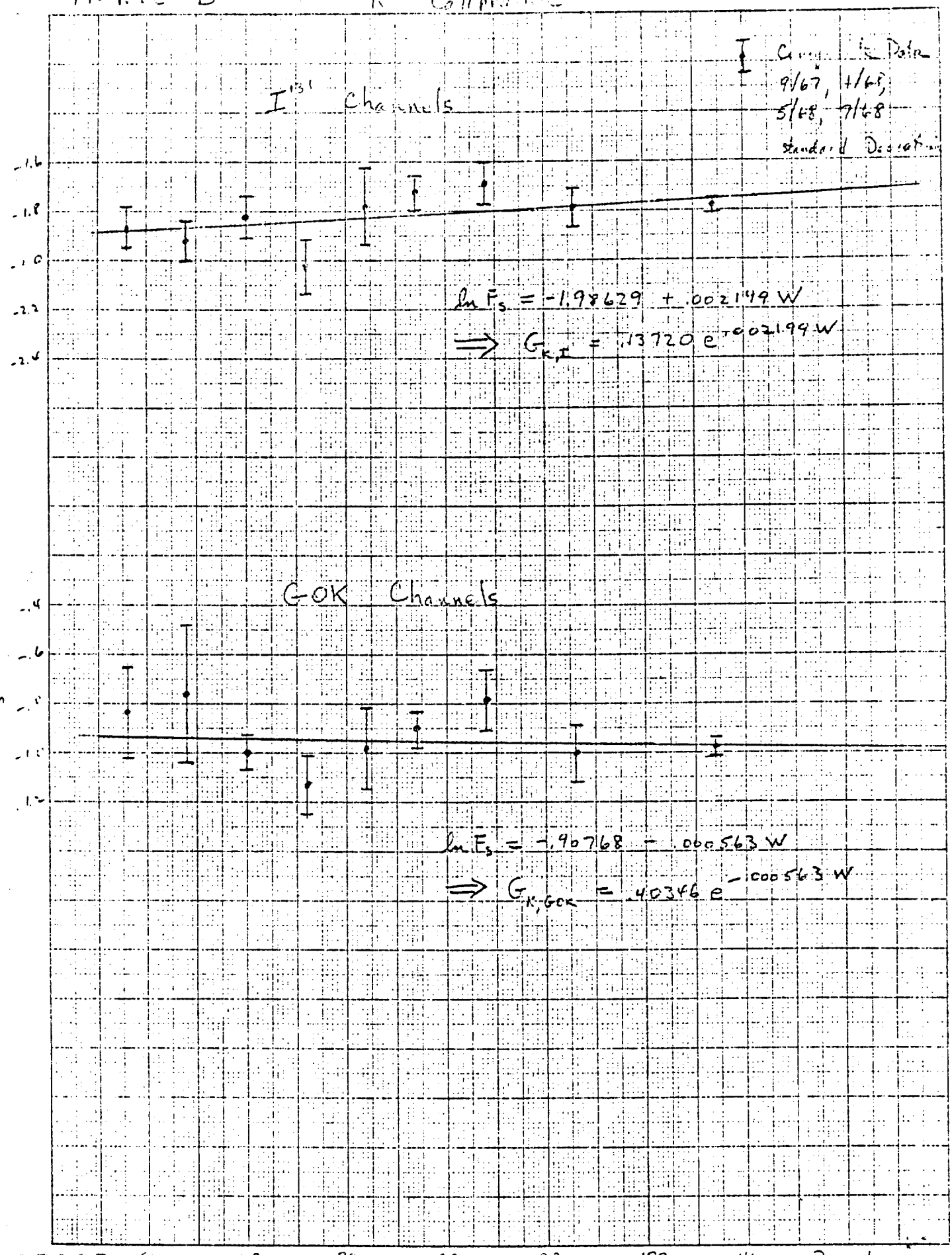


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Fig. 11

M. WBC-B

$Zn^{65}$ Calibration

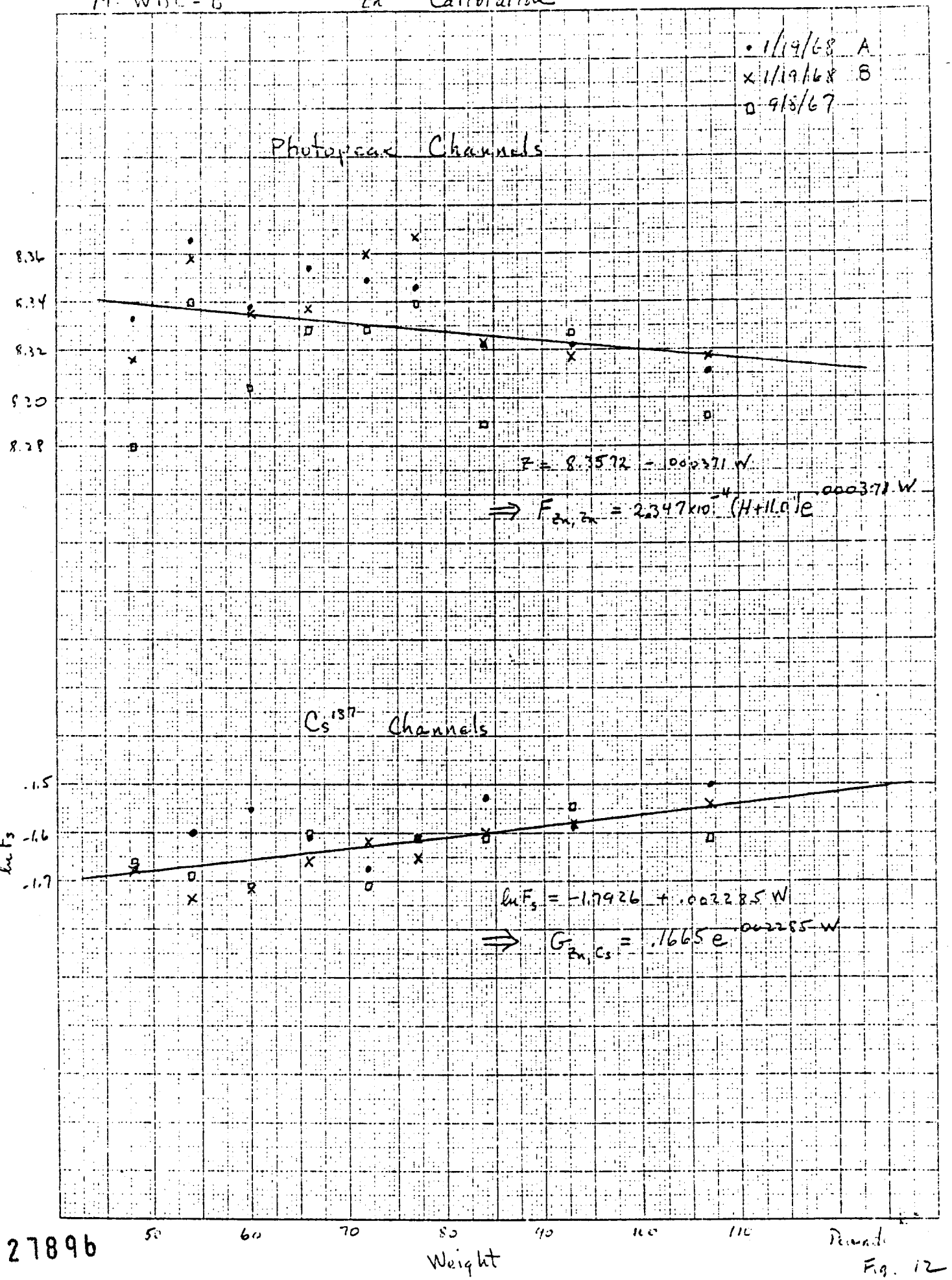


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Fig. 12

1/21/69
JLC

M-NPL-B

$Zn^{65}$ Calibration

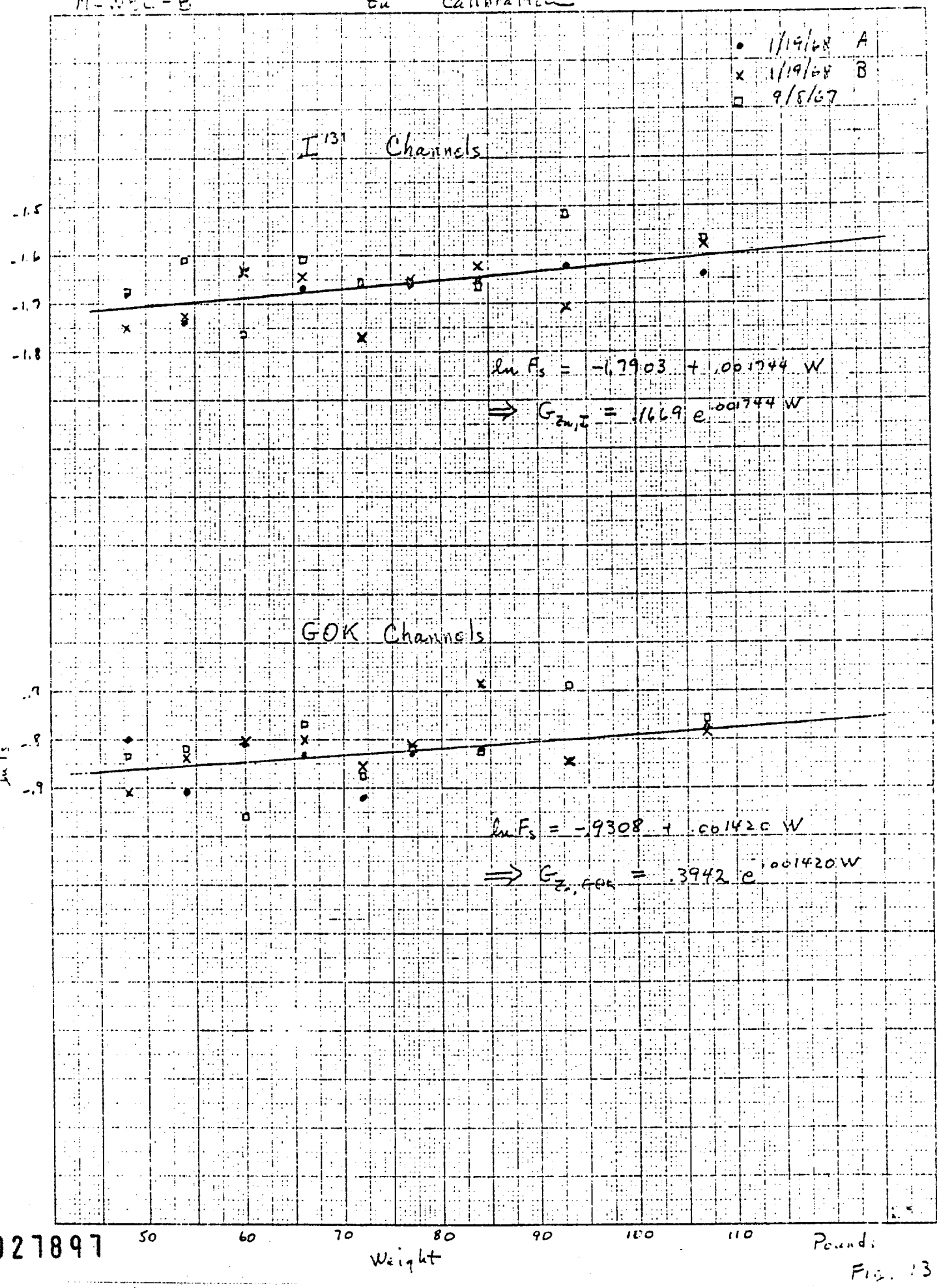


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Fig. 13

1/2/69

M-WBC-B $Cs^{137}$ Calibration

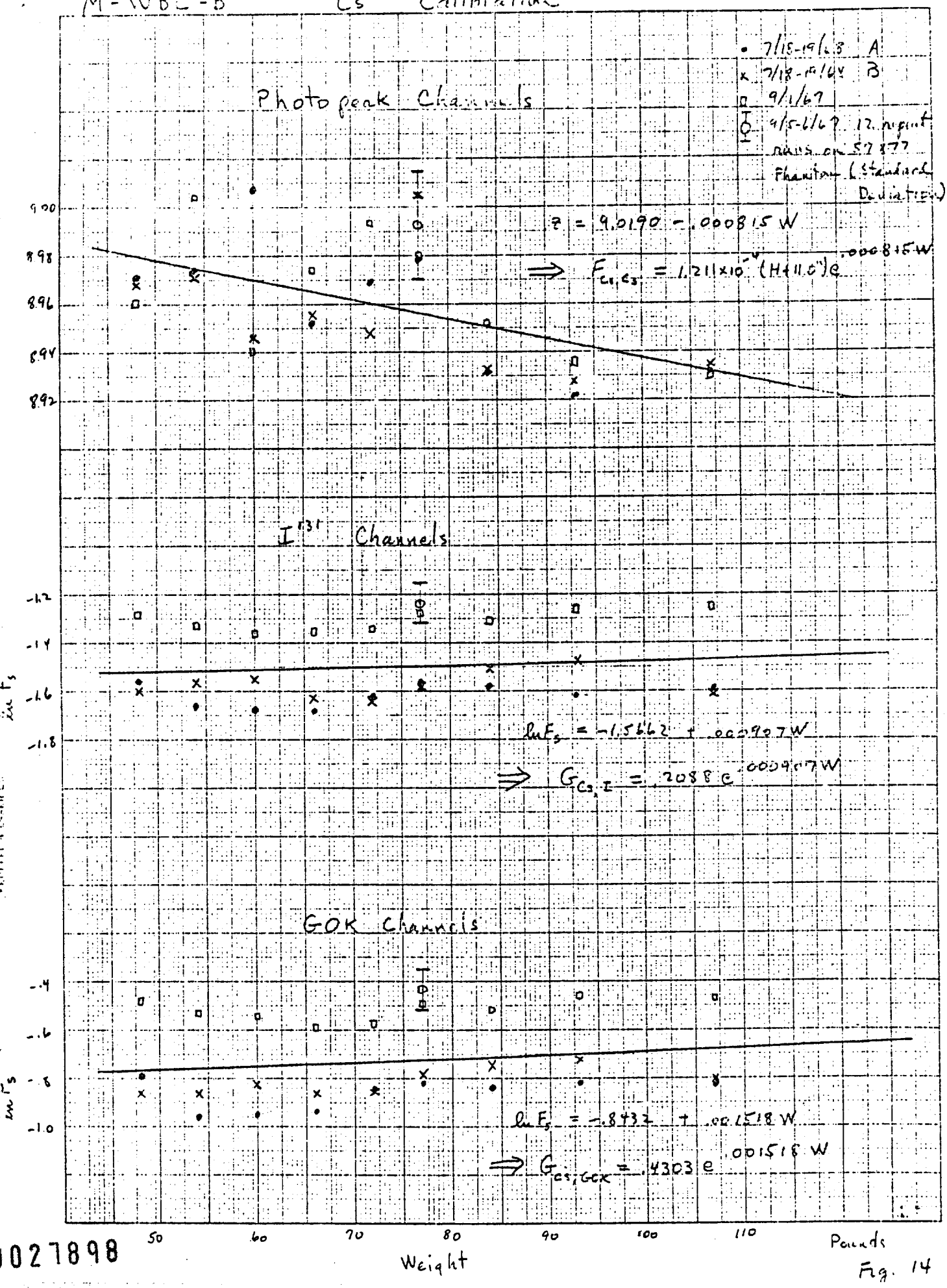


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Fig. 14