Westinghouse Astronuclear Laboratory

REACTOR EXPERIMENTATION
AND THE PACKARD - BELL COMPUTER

March 1966
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
Westinghouse Astronuclear Laboratory

REACTOR EXPERIMENTATION
AND THE PACKARD - BELL COMPUTER

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared By
Reactor Analysis
Department

INFORMATION CATEGORY
Unclassified

B. B. Reck
3-10-66
AUTHORIZED CLASSIFIER
DATE
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>WANEF Sample Changer Averaging Program</td>
<td>3</td>
</tr>
<tr>
<td>Fuel Element Scanner Program</td>
<td>14</td>
</tr>
</tbody>
</table>
INTRODUCTION

This report supplements the data provided in WANL-TME-997, Reactor Experimentation and the Packard-Bell Computer, October 1964.* Information pertinent to the subject was not available at the time of the original publication; however, this new addition of material will clarify two of the computer programs. The Sample Changer Averaging Program is explained on pages 55-60 and the Fuel Element Scanner Program, on pages 61-70 of the first edition (WANL-TME-997).

A brief repetition of material is mentioned to orient the reader and to unitize the program instructions.

* The Raytheon 250 was previously known as the Packard-Bell 250 computer.
WANEF SAMPLE CHANGER AVERAGING PROGRAM 1

PURPOSE

To supplement the data analysis, of power and flux distributions in a nuclear reactor, which was performed by the WANEF Sample Changer Program 1. This program is designed to accept the output tapes of the above-mentioned program and to perform further computation on the data appearing on them. It can average together the results of multiple measurements of the same data appearing on successive cycles of the sample changer using an error-weighted averaging technique. It can also renormalize the separate cycles to any desired values and can recorrect the data for variations in the sensitivities of the different samples.

The results are output both on punched tape and typewriter in the identical format as the input tapes. This allows the corrected data to be run through the program again for any further desired corrections.

RESTRICTIONS

1) The input data must be on paper tape in the format described below.
2) A maximum of 8 cycles can be averaged together.
3) A maximum of 278 data points can appear on each tape.
4) The Octal Utility Package must be in line 01.

STORAGE

The program is written for the basic computer of 10 lines and uses essentially all of the available storage locations.

PROGRAM EQUATIONS

The program corrects the data in the following manner using the constants defined in a separate section below.

1) An error-weighted average of the input data, $S_{jm}$, is obtained at each location,
The averaged input data, \( \bar{S}_i \), is further corrected by multiplying by a constant, \( X_i \), which can differ for each location. This is used to make any additional corrections for variations in the sample sensitivities beyond those which were made in the Sample Changer Program.

4) The final correction made to the averaged input data, \( \bar{S}_i \), is division by a constant, \( Av \), to normalize them to some desired value.
The formula representing the corrections of steps 3 and 4 is:

\[
\bar{S}_i = \frac{X \bar{S}_i}{Av}
\]

where \(\bar{S}_i\) are the final results which are output.

5) The percent error, \(\bar{S}_i\), in \(\bar{S}\) are computed from the following formula which was derived using propagation-of-error techniques on the above equation:

\[
\bar{S}_i = 100 \sqrt{\Delta A + \Delta X + (s_i)^2}
\]

INPUT AND OUTPUT FORMATS

The input and output data tapes have identical formats. The data tapes are broken into sentences each one having the following format:

1) Location - A six-character alphanumeric code followed by a plus or minus sign, a six-digit integer, a decimal point and a tab.

2) Relative Power - A plus sign, one-digit integer, decimal point, four-digit decimal and a tab.

3) Percent Error - A plus sign, two-digit integer, decimal point, two-digit decimal, and a carriage return.

There can be a maximum of 278 different locations or data sentences per cycle on the input tape.

CONSTANTS

A number of constants are required by the program. These can be input either on tape or on the flexowriter keyboard or both. The format in either case is identical. The attached form has been used to facilitate the input of these data. An explanation of the constants follows:
1) N - The number of different data sentences which appear on each cycle.

2) M - The total number of cycles which will be input.

3) Av - A normalizing constant by which each output power is divided in order to scale the results to any desired value.

4) A A - The fractional root mean square error in A.

5) A E - The average fractional root mean square error in the E constants.

6) A X - The average fractional root mean square error in the X constants.

7) E_m - A table containing one multiplication constant for each input cycle. These constants are used to allow different input cycles to be normalized to each other before they are averaged together.

8) X_i - A table containing one multiplication constant for each location. These constants can be used to allow a correction of the data for any variations in the sensitivity of samples. This table can be omitted if all constants are one.

CONSTANTS FORMAT

The format of the input constants consists of the identification number, (from 1 to 8 as the constants are listed above), followed by a termination character (space, tab, or carriage return), followed by the value of the constant, followed by another termination character.

For the tables of items 7 and 8, the format is: identification number, 1st constant, termination character, 2nd constant, termination character, etc.

At the end of the constants tape there must appear a 99 followed by a termination character.

PROGRAM EXECUTION

The following is the sequence of operations used to execute the program.

1) Return to O. U. P. (located in line 01).

2) Mount the program tape and type "F" to read the tape in under control of the O. U. P.
3) Special instructions used at WANEF but not essential to program operation:
   Depress Enable and Breakpoint; punch a leader, a 2, the experiment number
   (three digits), a stop code, and a leader; punch off, raise Enable and Breakpoint.

4) Mount the constants tape and type a "T" to read the tape in under program
   control.

5) Mount the 1st data tape.

6) Type any remaining constants in the format of the constants type.

7) Type a "99" followed by a carriage return. This will start the data tape reading
   in.

8) Program halts in line 17 after end of last data tape.

9) Special instructions used at WANEF but not essential to program operation:
   Depress Enable; punch a leader, a lower case, and a leader; punch off.

   This program can be re-used without reloading into the computer. Start at Step 4
   in this case.

   Note that the first output of data occurs after the first data point of the last cycle
   has been read in.

   There are no error signals in this program.
00002
Read in constants from tape and keyboard

20202
Float constants #A, 5, 6 and 3

Compute $\Delta X + \Delta A$

25602
Initialize counter $m$ and address of $E_m$

Float $E_m$

Initialize counter $i$
and addresses of $X_i$, $S_i$, and $s_i$

Call compute routine

Read 1st, data sentence of input tape and compute

Sample Changer Averaging Program
Sample Changer Averaging Program

- **b**
  - $32102$
  - $m = M$?
  - Yes: Last cycle
  - No
  - Call Output Routine

- **e**
  - $32402$
  - $i = N$?
  - Yes: Last data sentence of cycle
  - No
  - Increment $j$ and addresses of $X_j$, $S_j$, and $s_j$
  - Call Compute Routine
  - Read next data sentence and compute
$$34003 = M?$$

Yes

No

Increment $m$ and address of $E_m$

Final HALT Line 17

Sample Changer Averaging Program
Compute Routine

Entry

00003

Read in data sentence:
\( L_1 L_2 L_3, S_j \) and \( s_j \)

Float \( S_j \)

\( \alpha = E_m S_j \)

Float \( s_j \)

\( \beta = \left( \frac{s_j}{100} \right)^2 + \Delta E \)

07608

\( m = 1? \)

Yes \( \Rightarrow \) First cycle

25303

\( \bar{S} = \alpha \)

\( \bar{s} = \sqrt{\beta} \)

g

Fix \( \bar{S} \) and \( \bar{s} \)

Exit

Sample Changer Averaging Program
Compute Routine

\[ \sum_1 = \frac{1}{\bar{s}^2} \left( \frac{s}{\bar{s}} \right)^2 + \frac{1}{\alpha^2 \beta} \]
\[ \sum_3 = \sqrt{\sum_1} \]
\[ \sum_2 = \frac{1}{\bar{s}} \left( \frac{\bar{s}}{\bar{s}} \right)^2 + \frac{1}{\alpha \beta} \]

\[ \bar{s} = \frac{\sum_2}{\sum_1} \]
\[ \bar{\bar{s}} = \frac{\sum_3}{\sum_2} = \sqrt{\frac{\sum_1}{\sum_2}} \]

Sample Changer Averaging Program
Set addresses for $S$ and $s$

Float $X$ and $\overline{S}$

Compute and fix:
$$\overline{S} = \frac{X \overline{S}}{Av}$$

Float $\overline{s}$

Compute and fix:
$$\overline{s} = 100 \sqrt{A + AX + (\overline{s})^2}$$

Punch and type output
$L_1$, $L_2$, $L_3$, tab, $\overline{S}$, tab, $\overline{s}$, C/R

Exit
FUEL ELEMENT SCANNER PROGRAM

PURPOSE

This program reduces data taken on the WANEF wire and fuel element scanners to obtain the axial flux or power distributions in the reactor. Output is obtained on both punched tape and typewriter format and consists of the normalized and corrected activities along the wires or fuel elements as a function of distance. The percent errors or statistical uncertainties for each point are also output.

A second type of output is also possible and consists of the reciprocal of the corrected activities together with percent error. This output can be used as a table of relative sensitivities of different portions of the wire or scanning apparatus if the wire has been exposed to a uniform flux.

RESTRICTIONS

1) The input data must be on paper tape in the format described below.
2) The Octal Utility Package must be in line 01.

STORAGE

The program is written for the basic computer of 10 lines and uses essentially all of the available storage locations.

PROGRAM EQUATIONS

The program corrects the data of both scanners in the following manner using the constants defined in a separate section below.

The contribution of the background is computed and subtracted from the counts using the formula:

\[ n = c - bt \]

where,

- \( c \) is the raw counts
- \( b \) is the background rate
t is the interval time

n is the corrected counts

The square of the fractional root mean square error, defined as h, is also calculated. The formula used is derived using the principles of propagation of errors, from the above equation it is:

\[ h = \frac{1}{n^2} \left[ \frac{c}{n} + (t \Delta b)^2 + (b \Delta t)^2 \right] \]

where, t is assumed to be ± 1 count on that scaler which measures internal time. If either b or t is omitted from the input, then the following formulas are used instead of the above:

\[ n = c \]
\[ h = 1/c \]

From the resolving time of the system and the interval time, the counts are further corrected for resolving time losses. Several different formulae are used according to circumstances. The most general is:

\[ N = \frac{t}{\lambda} \frac{e^{\lambda n \tau} - 1}{1 - e^{-\lambda (t-n \tau)}} \]

This is the exact expression for the resolving time correction of a sample which is decaying exponentially with time while it is being counted. If the quantity \((\lambda n \tau)\) is less than approximately 0.001, an approximation is made in which the quantity \((e^{\lambda n \tau} - 1)\) in the above expression is replaced by the quantity \((\lambda n \tau)\). Also, if the quantity \(\lambda (t-n \tau)\) is less than approximately 0.001, an approximation is used in which the quantity \(1-e^{-\lambda (t-n \tau)}\) is replaced by the quantity \(\lambda (t-n \tau)\).

If the value of \(\lambda\) is not known, as is the case in beta counting fission foils, then the above equations cannot be used and the program uses instead the formula:

\[ N = \frac{nt}{t-n \tau} \]
This equation is exact only if the sample activity is not changing while it is being counted.

The error on the counts after resolving time correction is calculated on the basis of a propagation-of-error analysis of the last-mentioned equation. The square of the fractional root mean square error, defined as \( q \), is given by the formula:

\[
q = h + \left( \frac{n}{t} \right)^2 \left[ h + \Delta + \left( \frac{\Delta t}{t} \right)^2 \right]
\]

If the interval time on the resolving time is not input, then the following equations are used:

\[
N = n, \quad q = h
\]

For all but the normalizing wire channels the analysis continues as follows.

The corrected counts are divided by the average of the corrected counts in each of the normalizer channels.

A correction is made for the relative efficiency of each segment of the sample that was scanned. This variation in efficiency can be due either to a variation in detector efficiency for different parts of the scanner cycle, a variation in the size or composition of the sample itself, or a variation due to changes in the self-shielding correction with axial position in the core. In the analysis of the PAX series of experiments only the first of these effects was corrected for in the data reduction.

The equations for these last two steps are:

\[
S = \frac{aN}{N_{\text{norm}}}
\]

where,

\[
N_{\text{norm}} = \frac{1}{n} \sum_{i=1}^{n} N_i
\]
S is the relative power
a is the efficiency for a given segment of wire
N, are the n channels of the normalizer

The percent error which is output is determined by a propagation-of-error analysis of the above equations and is given by:

$$s = 100 \sqrt{\Delta a + q + q_{\text{norm}}}$$

where,

$$q_{\text{norm}} = \frac{1}{n^2} \sum_{i=1}^{n} q_i$$

q, are the errors in the n normalizer channels

For the alternative form of the output in which the output consists of the reciprocal activities rather than the relative powers, the equation of the previous three steps are replaced by the following:

$$S = \frac{N_{\text{norm}}}{N}$$

$$s = 100 \sqrt{q + q_{\text{norm}}}$$

The channel numbers are used to compute the axial position of each segment of the sample according to the following formulae:

For the scan up the sample: \( J = \epsilon (i - \gamma) \)

For the return scan on the fuel element scanner: \( J = \epsilon (i_4 + i_5 - i - \gamma) \)

where,

j is the channel number and the constants are as defined in the section below. In the PAX experiments the constants \( \epsilon \) and \( \gamma \) were chosen such that \( J \) represented the distance in centimeters from one end of the reactor core.
INPUT DATA

The input data tape is broken into words of 10 digits followed by either a space or a carriage return. The first 4 digits represent channel number from 1 to 1024. The last 6 digits represent the number of counts stored in that channel, from 0 to 126,976.

CONSTANTS

A number of constants are required by the program. These can be input either on tape or on the Flexowriter keyboard or both. The format in either case is identical. Forms are used to facilitate the input of these data. An explanation of the constants follows:

1) $B$ - run number for identification.
2) $\Gamma$ - a factor which is 1, if the data is from the wire scanner and 2, if the data is from the fuel element scanner.
3) $Z$ - a factor which is 1, if the output is to be proportional to the reciprocal of the sample activity and which is 2, if the output is to be directly proportional to the sample activity.
4) $j_1$ - the first normalizer channel
5) $j_2$ - the last normalizer channel
6) $j_3$ - the first data channel
7) $j_4$ - the last data channel of the scan up the element
8) $j_5$ - the first data channel in the return scan for the fuel element scanner
9) $j_6$ - the last data channel in the return scan for the fuel element scanner
10) $F$ - the clock frequency in counts per minute
11) $F'$ - the ratio of the total length of 1 scan to the length of 1 channel
12) $r$ - the counter resolving time in units of $10^{-6}$ minutes. This factor can be omitted if negligible.
13) $\lambda$ - the decay constant of the sample in units of minutes$^{-1}$. This factor can be omitted if not known.
14) \( b \) - the background rate of the detector in units of counts per minute. This factor can be omitted if negligible.

15) \( \Delta \tau \) - the square of the fractional root-mean-square uncertainty in the resolving time. This factor can be omitted if negligible.

16) \( \Delta b \) - the root-mean-square uncertainty in the background rate in units of counts per minute. This factor can be omitted if negligible.

17) \( \Delta a \) - the square of the fractional root-mean-square error in the efficiency factors. This factor can be omitted if negligible.

18) \( L \) - the position of the wire in the core expressed in an alphanumeric

19) \( t' \) - the counts accumulated in an interval timer.

20) \( \varepsilon \) - the channel increment factor

21) \( j \) - channel zero correction factor

22) \( J,a \) - a table of efficiency factors versus axial position or the sample

**FORMAT**

The format of the input constants consists of the identification number (from 1 to 23 as the constants are listed above), followed by a termination character (space, tab, or carriage return), followed by the value of the constants, followed by another termination character.

For the table of item 23, the format is: identification number (23), 1st axial position, termination character, 1st sensitivity, termination character, 2nd axial position, etc. The table terminates with a 0000 followed by a termination character. The table must be ordered with increasing axial positions. This table must be used even if all sensitivities are equal to 1.00.

At the end of the constants tape there must appear a 99 followed by a termination character.
PROGRAM EXECUTION

This code is written for use with a normalizer wire technique in which a short normalizing wire is irradiated at the same time as the sample (long wire or fuel element) to be scanned and placed on the scanner so that the detector passes over it at the beginning of each cycle or revolution of the scanner. The counts from this normalizer are recorded in a separate group of channels of the analyzer. In the analysis of the data, the code corrects the counts in each channel for background contributions and resolving time losses and then divides the corrected counts in the channels of the scanned sample by the average of the corrected counts in those channels representing the normalizer wire. If no normalizer wire is used, the code can omit this step. The use of the normalizer wire, however, permits the relative activities of different samples to be compared without decay correction. The normalizer wire also affords an automatic correction for length of irradiation in comparing samples irradiated in successive reactor runs providing similar normalizers are irradiated at the same location in the reactor for each run.

The design of the scanners themselves obviates the need for a decay correction in order to compare the relative activities of different segments of the same sample due to the rapidity at which the scanners cycle over the length of the sample.

The following is the sequence of operations used to execute the program.

1) Return to OUP (located in line 01).
2) Mount Program Tape and type "F" to read-in under control of OUP.
3) When tape has read-in, mount the constants tape and type a "T" to read-in under program control.
4) Type any remaining constants in correct format.
5) Mount the data tape.
6) Type '99' followed by a carriage return. This will start the data tape reading in.
OUTPUT

The computed results are output on punched tape in the form: axial position, tab, relative power, tab, percent error, carriage return. The results are output on the typewriter in the form: core location, tab, axial position, tab, raw counts, tab, relative power, tab, percent error, carriage return.

In the mode where the reciprocal of the sample activities is called for the punched tape contains: axial position, tab, reciprocal activity, carriage return. The typewriter output is: tab, axial position, tab, raw counts, tab, reciprocal activity, tab, percent error, carriage return.
CLEAR INPUT AREA

INPUT CONSTANTS FROM TAPE AND KEYBOARD

τ = 0?

SET τ AND λ SWITCHES

b = 0?

ZERO N₁, q₁, SUM

ERROR 4 OUTPUT

ERROR 2 OUTPUT

scanning program
DO PRELIMINARY CALCULATIONS ON INPUT CONSTANTS

32003

+ # 0 ?

NO

SET + SWITCH

λ = 0 ?

NO

λ <

YES

NO

ERROR 6 OUTPUT

00010

PREPARE TO READ IN DATA
SWITCH 1 TO a₁
SWITCH 2 TO b₁
SWITCH 3 TO c₁

READ DATA WORD

SWITCH 1

a₁

SCANNER PROGRAM
Sr SWITCH 1 TO 0,

SET SWITCH 1 TO $a_2$

SET SWITCH 1 TO $a_3$
SET SWITCH 2 TO $b_2$

$N_1 = 0$?
YES $N_{\text{NORM}} = 1$
$Q_{\text{NORM}} = 0$

NO $N_{\text{NORM}} = \frac{N_1}{(i_2 - i_1 + 1)}$
$Q_{\text{NORM}} = \frac{q_1}{(i_2 - i_1 + 1)^2}$

WORD UNWANTED, READ NEXT ONE

COMPUTE NORMALIZER DATA

NORMALIZER DATA FINISHED

NO NORMALIZER DATA
NORMALIZE TO 1.0 INSTEAD

SCANNER PROGRAM
NO

SET SWITCH 1 TO $a_4$

\[ i > i_4 \]?

NO

YES

\( \Gamma = 1 ? \)

NO

HALT

WIRE SCANNER, DATA COMPLETE

YES

FUEL ELEMENT SCANNER

SET SWITCH 1 TO $a_5$
SET SWITCH 3 TO $a_2$
SET ADDRESS COMPUTE COMMANDS

Scanner Program
SET SWITCH 1 TO $a_8$

$1 < 15$ ?

YES $\rightarrow 8$

NO $\rightarrow$ WORD NOT WANTED, READ NEXT ONE

$1 > 16$ ?

YES $\rightarrow$ HALT

NO $\rightarrow$ FUEL ELEMENT DATA COMPLETE

$\rightarrow$ COMPUTE DATA

SCANNER PROGRAM
BYPASS CALCULATION OF BACKGROUND AND RESOLVING TIME CORRECTIONS

\[ n = c - b t \]

\[ h > 0 ? \]

ERROR 3 OUTPUT

\[ n > 0 ? \]

NO COUNT, READ NEXT WORD

\[ h = \frac{1}{n} \left[ c + \left( 1 + \Delta h \right) + \left( 0 + \Delta t \right) \right] \]

\[ \tau = 0 ? \]

\[ n = n \]

\[ q = h \]

\[ Y_1 = n \tau \]

\[ Y = Y_1 - Y_1 \]

\[ q = h + \left( \frac{n \tau}{\tau} \right) \left[ h + \Delta t + \left( \frac{\Delta y}{y} \right)^2 \right] \]

\[ q \text{ IS ERROR IN COUNTS WHEN CORRECTED FOR BACKGROUND AND RESOLVING TIME LOSSES} \]

\[ N = N \left( 1 \pm \sqrt{q} \right) \]

SCANNER PROGRAM
Supplement 1

1. If \( \lambda = 0 \), use approximate formula for resolving time corrections.

2. If \( y' \leq 0.05 \), use resolving time correction formula which accounts for interaction between decay of sample during counting and resolving time losses.

If excessive errors result from using approximate formula, use:

- Exact expression for \( P = e^{\lambda y'} - 1 \) if \( \lambda y' \leq 0.001 \)
- Approximate formula for \( P = \lambda y' \) if \( \lambda y' > 0.001 \)

- Exact expression for \( R = 1 - e^{-\lambda y} \) if \( \lambda y \leq 0.001 \)
- Approximate formula for \( R = \lambda y \) if \( \lambda y > 0.001 \)

3. Calculate:

\[ N = \frac{\lambda P}{T} \]
SWITCH 2

\[ b_1 \]

NORMALIZER CALCULATION

16011

\[ q = q + q_{\text{NORM}} \]

\[ N_1 = N_1 + N \]

\[ q_1 = q_1 + N^2 q \]

READ NEXT WORD

SWITCH 3

\[ s_1 \]

\[ s_2 \]

\[ s = 100 \sqrt{a} \]

z = 2?

\[ Z = 2? \]

\[ S = N_{\text{NORM}} / N \]

YES

\[ \text{LOCATE CORRECT } \alpha \]

\[ S = N_{\alpha} / N \text{ NORM} \]

\[ \text{SUM} = \text{SUM} + S \]

\[ s = 100 \sqrt{a + \Delta a} \]

NO

\[ \text{OUTPUT RESULTS} \]

READ NEXT WORD

SCANNER PROGRAM