JAN 26 1968

OAK RIDGE NATIONAL LABORATORY
operated by

UNION CARBIDE CORPORATION
NUCLEAR DIVISION

for the
U.S. ATOMIC ENERGY COMMISSION

ORNL - TM - 1909

COPY NO. -

34

DATE - November 15, 1967

A RANDOM PULSE GENERATOR FOR TESTING NUCLEAR INSTRUMENTATION

R. H. Baldry

ABSTRACT

When testing nuclear instruments, such as a pulse-height analyzer or a time-of-flight analyzer, it is useful to have a source of pulses that are random in time, but have a fixed amplitude, and whose mean rate is stable, yet can be adjusted easily. Random pulses for this purpose are usually obtained from a radioactive source, detector, amplifier, and discriminator; the output rate is thus dependent upon the gain and threshold of the system.

A Random Pulse Generator (ORNL model Q-3029A-1) was developed in which the radioactive source is replaced by a noisy avalanche diode. The output rate is determined by the number of amplified noise pulses exceeding a discriminator threshold, and the mean rate is stabilized by observing the output with a rate meter and controlling the avalanche diode standing current.

The measured time distribution of output pulses from the pulse generator closely matched the calculated Poisson distribution, using a computer program to analyze the results. Output mean rates from 100 Hz to 10 kHz can be selected; the mean-rate stability exceeds most measurement requirements.

The unit is constructed in a 5-1/4 in. high, single-width nuclear instrument module (NIM).

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

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.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PAGES 1 to 2
WERE INTENTIONALLY
LEFT BLANK

CONTENTS

	Page
1. INTRODUCTION	4
2. CIRCUIT DESCRIPTION	4
2.1 Noise Source and Amplifier	5
2.2 Discriminator	6
2.3 Shaper and Gate	6
2.4 Binary and Rate Meter	8
3. PERFORMANCE	9
3.1. Pulse Generator	9
3.2 Gate	9
3.3 Current Requirements	10
4. SETUP AND TROUBLESHOOTING	10
4.1 Voltages and Waveforms	10
4.2 Test Equipment and Procedure	12
4.3 Sources of Trouble in the Integrator	12
5. APPENDIX	14
5.1 Measurement of Randomness	14
5.2 Fortran-63 Program to Determine Randomness	15
5.3 Measurement of Mean-Rate Temperature Stability	18

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

1. INTRODUCTION

A random pulse generator (ORNL model Q-3029A) was designed and built for testing nuclear instruments, such as a pulse-height analyzer or a time-of-flight analyzer. The generator produces pulses random in time, with a fixed amplitude, and at a stable, but adjustable, mean rate. The unit is lightweight and portable, being built in the smallest size (5-1/4 in.) of a NIM¹ module. This pulse generator was designed to overcome two main disadvantages of the usual source of pulses for testing purposes: a radioactive source, detector, amplifier and discriminator whose output rate is dependent on the gain and threshold of the system and which is physically unwieldy.

The basic circuit for this random pulse generator was published by White² in 1964. The source of pulses is the amplified noise generated by an avalanche diode biased at a point close to breakdown. The actual output rate is determined by the number of noise pulses exceeding a discriminator threshold; the mean rate is stabilized by observing the output with a rate meter and feeding back an appropriate signal to control the avalanche diode bias current. Either positive or negative pulses can be generated at a mean rate over the range of 100 Hz to 10 kHz, a range satisfactory for most testing requirements.

The author wishes to thank J. W. Woody, Jr., for his encouragement and advice and E. McDaniel who wrote the PDP-8 programs to improve the speed and accuracy of the calculations.

2. CIRCUIT DESCRIPTION

Small current pulses from the noise source (an avalanche diode) are amplified and fed to a discriminator and shaper (Fig. 1). The shaper drives a rate meter whose output is compared with a reference voltage; the error is amplified and fed to an integrator. This controls the diode mean current and thus the mean rate. The mean rate is selected by changing the rate meter constant.

Pulses from the shaper also pass through a gate to the output.

¹Louis Costrell, Standard Nuclear Instrument Modules, TID-20893 (Rev. Jan. 1966).

²G. White, "The Generation of Random-Time Pulses at an Accurately Known Mean Rate and Having a Nearly Perfect Poisson Distribution," J. Sci. Instr. 41, 361 (1964).

Fig. 1. Basic Pulse Generator.

2.1 Noise Source and Amplifier

In the early stages of avalanche breakdown in a reverse-biased p-n junction diode, individual high-energy electrons produce short avalanche current pulses many times the mean reverse current.³ These pulses are the "prebreakdown noise"; their amplitude and frequency and the mean current at which they occur vary considerably from diode to diode. Small changes in the mean current strongly influence the rate at which noise pulses are produced (Fig. 2).

In this circuit (Fig. 3) the reverse-biased emitter base diode of a 2N3694 transistor (Q14) is the noise source. As a noise source, the 2N3694 transistor is more constant from unit to unit than avalanche diodes. The current for Q14, a few microamperes, is supplied by Q13 whose base potential is about -15 v at the lowest mean rate (100 Hz). R30 is adjusted on test to correct for noise source variations.

The sawtooth-shaped pulses across Q14 are fed through C16 to the amplifier Q15-Q16 and inverter Q17, from which they are ac coupled through emitter-follower Q18 to the discriminator. The amplitude of the pulses at Q18 emitter is about -1 v.

³W. B. Burford and H. G. Verner, Semiconductor Junctions and Devices, p. 74, McGraw-Hill, New York.

Fig. 2. Avalanche Breakdown Noise. Mean rate of noise pulses exceeding a discriminator threshold.

2.2 Discriminator

The discriminator is a conventional Schmitt type with catching diodes D15 and D18 to prevent outputs from the discriminator during the switching periods; this produces clean outputs with rise and fall times of 20 nsec (10-90%). The Schmitt trigger is set to trigger at about -1 v at the input (Q19).

2.3 Shaper and Gate

Emitter-follower Q2 prevents C25 from loading the discriminator output and triggers the emitter-coupled monostable multivibrator (Q22-Q23). R59 (22 ohms) ensures that the total emitter resistance remains larger than Q22 saturation resistance with no input, thus preventing oscillation.

The operation of the monostable multivibrator is as follows. In the steady state, Q22 is saturated; thus its collector voltage is steady at +50 mv or so. Q22 carries the current from R56. The loop gain is <1 , and there is zero voltage across C27. A negative input at C25 is differentiated and, through D20, causes Q22 collector voltage to fall. As this happens, Q22 collector resistance increases; at the same time Q23 (acting as an emitter follower) pulls current through C27 from Q22 emitter. When the loop gain reaches unity, the circuit regenerates, Q22 collector and Q23 emitter potentials fall to about -6 v, and Q22 emitter is reverse biased by 6 v. The current through R56 begins to charge C27, while Q21 collector potential remains at -6 v, until Q22 emitter again reaches conduction and supplies current to Q22 collector. This reverses D21 and removes current from Q23, which turns Q22 on further so that the circuit regenerates in the reverse direction and brings Q22 collector voltage quickly to zero. In this case C27 is recharged by the current through R58.

The result is a negative pulse about 6 v high and 0.7 μ sec wide. This time determines the minimum spacing between the random pulses.

The pulses are gated by Q24; a -6 v level at the gate input prevents negative or positive outputs from Q25 and Q26 respectively.

2.4 Binary and Rate Meter

To provide a rate meter input of defined amplitude essentially independent of time, a binary (Q2-Q3) follows the shaper.

The saturation voltage of Q2 and the sum of D5 and Q2 emitter-base voltages define the input to Q5 and Q6, which act as a pump to charge C4-C9 on a positive edge and to discharge C4-C9 into R14 on a negative edge. C11 and R14 provide the necessary time constant. The number of rate meter input pulses, and hence the random output rate, required to maintain a constant current in R14 is varied by switching C4-C9.

Short-term variations in voltage at R14 could cause nonrandom effects in the noise output of Q14 unless a very long integrating time constant is used. This is accomplished by the "on-off" integrator of Q7-Q13. As the voltage of Q7 source moves above or below Q9 base potential, a small current flows into or out of C15. This is a very large capacitor in the negative feedback loop of an amplifier (Q10-12) having a gain of about 30. The result is that Q13 base voltage moves at ± 10 mv/sec. Current changes in Q14 are thus kept to a very low level. Switch 2, with R16 and R20, provides an increased rate of change of voltage at Q13 base to help stabilize the output rate after switch-on or when a new rate is selected. To cover the required output pulse rates, Q13 base voltage moves between -15 and -10 v, while Q10 gate voltage moves -0.2 v from about -9 v.

The circuit is screened and decoupled to prevent spurious feedback and line effects which produce nonrandom outputs.

3. PERFORMANCE

3.1 Pulse Generator

3.1.1 Pulse Output

The pulse output of the generator, using the prebreakdown noise of an avalanche diode, is random in time (the time distribution is very close to the Poisson distribution), dc coupled, with positive and negative outputs of +8 v and -6.5 v respectively. The output resistance is 100 ohms on a negative excursion.

With 3 ft of cable on the output, the pulses are 0.7 μ sec wide at half amplitude and have a fall time of 0.2 μ sec and a rise time of 0.25 μ sec.

The nominal mean rate is 100 and 400 Hz, and 1, 2, 4, and 10 kHz.

3.1.2 Temperature Stability

The temperature stability from 100 Hz to kHz is better than -0.1%/°C, and at 10 kHz is not judged to be serious since most applications at that rate will be of short duration.

3.1.3 Power Line Stability

The change in the output rate is less than 0.1% for a ± 10 v change.

3.1.4 Long-Term Stability

Over a period of 12 hr at room temperature, the change in output rate is less than 0.1%.

3.2 Gate

An open, or short, circuit produces random outputs.

With a -6 v gate input, 1.5 ma stops the output.

3.3 Current Requirements

The current requirements for the unit from NIM power supplies are as follows: +12 v, 46 ma; -12 v, 44 ma; and -24 v, 11 ma.

4. SETUP AND TROUBLESHOOTING

4.1 Voltages and Waveforms

The following voltages and waveform (Fig. 4) information were obtained with an output of 100 Hz stabilized for 20 sec and the gate input an open circuit:

<u>Position</u>	<u>Voltage (v dc)</u>	<u>Comments</u>
Q13 collector	-5	20-100 mv noise
Q16 emitter	-5	20-100 mv noise
Q17 collector	-13	~1-v negative noise pulses
Q18 emitter	-1	~1-v negative noise pulses
Q20 emitter	-4	negative pulses -4 to -7 v variable width
D19-D20 junction	0	differentiated edges
Q22 collector	0 to +0.5	negative (7 v), 0.5-μsec pulses
Random output	0 to +0.5	negative (7 v), 0.5-μsec pulses
Q1 emitter	0 to +0.5	negative (7 v), 0.5-μsec pulses
Q5-Q6 emitter	+6	negative "square" waves to +1 v with random time intervals

It is difficult to examine Q6 collector or Q9 collector, but Q9 emitter can give some information:

<u>Position</u>	<u>Voltage (v dc)</u>	<u>Comments</u>
Q9 emitter	-6	shows -6 v when Q7 gate is up; a saw-tooth when Q7 gate is down
Q9 collector	-9	examine with tube voltmeter (high input impedance)

PHOTO 89924

a. Amplified noise pulses, Q 18 emitter.
0.5 v/cm, 0.1 usec/cm.

b. Discriminator output, Q 21 emitter.
2 v/cm. 0.2 u/sec 0.2 usec/cm.

c. Binary output, Q5-Q6 emitter. 2 v/cm,
5 msec/cm.

d. Differential amplifier, Q9 emitter.
2 v/cm, 0.1 usec/cm.

Fig. 4. Waveforms from ORNL Model Q-3029A-1 Random Pulse Generator.

<u>Position</u>	<u>Voltage (v dc)</u>	<u>Comments</u>
Q13 base	-15	very small (few mv), very slow triangular wave; amplitude changes to -10 v for 10-kHz mean rate

4.2 Test Equipment and Procedure

4.2.1 Test Equipment

The following test equipment is needed:

1. oscilloscope, Tektronix model 545, or equivalent, with X1 and X10 probes and W unit if available;
2. tube voltmeter, preferably >20 megohms input impedance;
3. frequency meter, to time for 1-sec and 10-sec intervals.

4.2.2 Test Procedure

The mean rate should be 100 Hz and gate input an open circuit.

The test procedure for the random pulse generator is as follows:

1. Turn the switch on and allow the unit to stabilize for 20 sec. After another 20 sec, the output pulse rate should be 100 ± 25 pulses/sec.
2. Examine Q9 collector with the tube voltmeter and Q13 base with any type of meter or the scope for conformance to the voltages and waveform information in Sect. 4.1.
3. Examine Q14 to determine if noise (about 20 to 100 mv) is being produced. If it is and there is no output, check the circuits through to the output.
4. Adjust R25 and R30 until the Q13 base potential remains steady at -15 v and Q9 collector potential remains steady at -9 v.
5. Change the output rate to 10 kHz and repeat steps 1 through 4. Q13 base voltage should rise to approximately -10 v. If the voltage rises too much, it might be necessary to exchange Q14 for a higher noise-to-current transistor.

4.3 Sources of Trouble in the Integrator

Since most of the troubles arise in the integrator, the following possible sources of trouble are suggested as an aid in troubleshooting.

1. The Q14 noise source must have a sufficient noise-to-current value.
2. R30 might need adjustment to suit Q14 characteristics and meet the circuit requirements.

3. C15 may have too high a leakage at 6 or 7 v. The total leakage should not exceed $0.5 \mu\text{a}$, and if it exceeds about $1.5 \mu\text{a}$, the unit is unlikely to function properly. Leakage measurements should be made with the voltage applied for about 30 min.

4. A simple aid to troubleshooting is the injection of regularly spaced pulses into either C16 or C20. Suitable chosen amplitudes and rates allow the checking of every portion except the noise transistor.

5. APPENDIX

5.1 Measurement of Randomness

If many samples are taken of the number of particles emitted by a radioactive source during unit time, the results when plotted will appear as in Fig. 5, where the abscissa indicates the number of particles (i , the sample size) occurring during one sample time and the ordinate shows the frequency with which each value of i occurred. This curve can be represented by

$$P(i) = \frac{e^{-r} r^i}{i!}, \quad (1)$$

where

r = mean number of particles emitted in the sample time
(the mean rate),

i = actual number of particles in the sample time,

$P(i)$ = probability of i particles occurring in the sample time.

Fig. 5. Poisson Distribution of the Output of the Random Pulse Generator.

This is the Poisson distribution. To simulate a radioactive source, the number of pulses per unit time produced by the model Q-3029A pulse generator should also follow a Poisson distribution.

The measurement is made as follows:

1. The number of pulses (i) occurring in a fixed sample time selects an appropriate channel in the memory of a pulse-height analyzer (the ADC is disconnected).
2. After each sample time, one count is added to the selected channel. Thus the frequency with which each sample size (i) occurs is stored in the appropriate channel, eventually producing a curve as in Fig. 5.
3. The mean sample size r , i.e., the mean number of pulses occurring in the sample time, is the centroid of the curve, which is determined by summing (channel contents times the channel number) and dividing the sum by the sum of the contents of all the channels.
4. When the value of r is known, the theoretical probability $P(i)$ of the number i occurring in a sample can be calculated from Eq. (1).
5. The total probability, i.e., 1, is equivalent to the total number of pulses counted in the experiment. Thus the number expected in each channel is $P(i)$ times the total number of pulses.

If the generator is truly random, the resulting curves should match exactly. The degree of matching can be determined by the chi-square (χ^2) test which gives the probability that some distribution other than the one measured might fit the theoretical curve. If $A(i)$ and $B(i)$ are the contents of the experimental and theoretical channels respectively, then

$$\chi^2 = \sum_{i=n1}^{i=n2} \frac{[A(i) - B(i)]^2}{B(i)}, \quad (2)$$

where $n2$ and $n1$ are the upper and lower channels of interest. From published tables the probability of fit can be determined by use of the chi-square test.

5.2 Fortran-63 Program to Determine Randomness

5.2.1 Introduction

The calculations described in Sect. 5.1 are laborious and subject to operator errors which could affect the chi-square results. Most of them [to determine the mean r and the probability distribution $P(i)$] have been done with the help of two programs written for the DEC PDP-8 computer⁴.

⁴These programs were written by E. McDaniel, ORNL.

To save time and provide more certain results, a Fortran-63 program was written for the CDC 1604A. This program goes through the same steps described in Sect. 5.1, including choosing the region of interest in the curve, printing out the mean, chi-square, and the practical and theoretical distributions. The program has been made fairly general so that it might be useful in applications other than the random pulse generator.

The data are copied from the analyzer before being punched on cards; in the future we plan to translate directly from punched paper tape to punched cards. A Calcomp plot routine could also be added to provide an "eyeball" check of the two distributions.

5.2.2 Notes on the Program

Storage space is allocated for up to 150 events per sample; this may easily be modified to a large value. If so, the first IF statement should also be modified [If (I1.GE. 150. OR. K. NE. 0) 12, 10].

The format for input data is eight channels per card, each occupying eight columns, right adjusted. On the last card, in column 49, there should be a nonzero character. The level of interest Y is specified on a single card following the last data card and is a three-digit integer.

When the computer reads in the data, it advances the channel number by 1. Allowance has been made for this in calculating r and the distribution, but the printed TEST RESULTS and CALC RESULTS are one channel higher than their true positions; r is correctly printed.

5.2.3 Program

```

C      TEST OF RANDOMNESS USING CHI SQUARED TEST ON POISSON DISTRIBUTION
      DIMENSION A(150),B(150)
      A=0.
      B=0.
      I1 = 1
      I2 = 8
C      READ IN TEST RESULTS AND LEVEL OF INTEREST
10 READ I1,(A(I),I=I1,I2),K
11 FORMAT (8F6.,I1)
      I1 = I2+1
      I2 = I1+7
      IF(I1.GE.150.OR.K.NE.0)12,10
12 READ I3,Y
13 FORMAT (F3,)
C      DATA IS IN,CALC THE MEAN VALUE R
C      CHMULT IS THE ARRAY CONTENT TIMES CHANNEL NUMBER

```

```

C      SUMULT IS SUM OF ALL CHMULTS, SUMCON SUMS CHANNEL CONTENTS
      I=1
      CHMULT=0.
      SUMULT=0.
      SUMCON=0.
      N1=0
      N2=0
C      DOES THE CHANNEL HAVE COUNTS
19 IF(A(I) = 1.)18,21,21
18 I=I+1
   GO TO 19
C      CHECK IF ARRAY CONTENT IS ABOVE A USEFUL VALUE,Y
21 J=I+1
   IF(A(I).LE.Y.AND.Y.LE.A(J))22,27
27 IF(A(I).GE.Y.AND.Y.GE.A(J))23,24
22 N1 = I
25 GO TO 24
23 N2 = I
C      NOW SUM CHANNEL CONTENTS AND CALC INTEGRAL
24 SUMCON = SUMCON + A(I)
   CHMULT = A(I) * I
   SUMULT = SUMULT + CHMULT
C      ARE WE PAST THE PEAK
   IF(CHMULT.EQ.0.,AND,N2.EQ.0)20,28
28 IF(CHMULT.EQ.0.,AND,N2.NE.0)26,20
20 I=I+1
   GO TO 21
26 R= SUMULT/SUMCON
   R=R+1.
   PRINT60,R,N1,N2,SUMCON
60 FORMAT(1H R=,F6.2,1H N1=,I4,1H N2=,I4,1H SUMCON=,F(5,))
C      CALC POISSON DISTRIBUTION FROM R:
C      CALC IFACTORIAL TO N1 THEN PI FROM N1 TO N2
      I=1
      SUMLON = 0.
      Z=LOGF(R)
30 T=I
   SUMLON = SUMLON + LOGF(T)
   IF(N1.LE.I)31,32
32 I=I+1
   GO TO 30
31 W=EXPF(I*Z)
   X=EXPF(R)
   V=EXPF(SUMLON)
   PI=W/(X*V)
   M=I+1
   B(M) = PI * SUMCON
   IF(I.GE.N2)40,42
42 I=I+1
   GO TO 30

```



```

C
C   ARRAYS A AND B CONTAIN THE TESTED AND CALCULATED DISTRIBUTIONS
C   NOW DO THE CHI SQUARED TEST
40  I=N1+1
    CHISQD=0.
    DEGFR=N2-N1-3
41  DIFF = A(I) - B(I)
    SQUARE = DIFF*DIFF
    CHISQD = CHISQD + SQUARE/B(I)
    IF(I,GE,N2)50,54
54  I=I+1
    GO TO 41
C   PRINT THE ARRAYS, THE MEAN AND CHISQUARED
50  PRINT51,A
51  FORMAT(1H ,TEST RESULTS,/(8F8.0))
    PRINT52,B
52  FORMAT(1H ,CALC RESULTS,/(8F8.0))
    PRINT 53,R,CHISQD,DEGFR
53  FORMAT(1H ,R=,F6.2,CHISQD=,F10.2,DEGREES OF FREEDOM=,F5.0)
END

```

5.3 Measurement of Mean-Rate Temperature Stability

A pulse-height analyzer used in the multiscaler mode provides a convenient instrument to measure the temperature stability of the model Q-3029A-1 pulse generator.

The channel-contents-scaler counts the random pulses for a fixed time (sufficient to give the required measurement accuracy), after which the count is stored and the analyzer steps to the next channel. While this proceeds, the ambient temperature is slowly changed. Thus, if the mean rate changes, the counts per channel will change, and the final result will be a profile of the mean-rate change with temperature.

INTERNAL DISTRIBUTION

- 1-5. R. H. Baldry
- 6. C. J. Borkowski
- 7. W. R. Burrus
- 8. R. A. Dandl
- 9. J. B. Davidson
- 10. C. S. Harrill
- 11. R. W. Ingle
- 12. W. H. Jordan
- 13. E. Madden
- 14. F. W. Manning
- 15-19. E. McDaniel
- 20. R. W. Peelle
- 21. J. W. Reynolds
- 22. R. T. Roseberry
- 23. G. S. Sadowski
- 24. F. W. Snodgrass
- 25. R. E. Wintenberg
- 26. F. W. Woody
- 27-28. Central Research Library
- 29. Document Reference Section
- 30-32. Laboratory Records Department
- 33. Laboratory Records, ORNL R. C.
- 34. ORNL Patent Office
- 35-49. Division of Technical Information Extension
- 50. Laboratory and University Div., ORO

EXTERNAL DISTRIBUTION

- 51. E. H. Cooke-Yarborough, Electronics Div.,
AERE, Harwell, England
- 52. J. B. H. Kuper, BNL
- 53. E. Siddall, AECL, Chalk River, Ontario