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DEVELOPMENT REPORT

**MONTE CARLO SIMULATION USING
THE METER SYSTEM WITH APPLICATIONS
RELATED TO LWBR
(LWBR Development Program)**

B. R. BEAUDOIN

FEBRUARY 1977

CONTRACT EY-76-C-11-0014

BETTIS ATOMIC POWER LABORATORY, WEST MIFFLIN, PA.,
OPERATED FOR THE U.S. ENERGY RESEARCH
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METER is a Monte Carlo computer program which can be used to simulate the interaction between independent random variables and their effects on one or more dependent random variables. The program is easy to use for simple simulations but is capable of accommodating complex simulations. METER processes input, generates random numbers from several common frequency distributions under user control, performs the simulation which the user has coded in FORTRAN, and displays results.

MONTE CARLO SIMULATION USING THE METER SYSTEM
WITH APPLICATIONS RELATED TO LWBR

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B. R. Beaudoin

I. INTRODUCTION

The design and manufacture of a nuclear plant and a reliable assessment of performance characteristics must take into account effects of design models, projected plant operating conditions, uncertainties in physical properties, and variations in as-manufactured components. Design models can be tried, tested, and perhaps compared to experiments. Operating conditions, physical properties, and component dimensions can be varied in the computer codes used to calculate plant performance, thereby producing sensitivities to important variables. This method of applying all uncertainties and tolerances multiplicatively will produce estimates of ranges of expected performance, for example, minimum and maximum expected core lifetime. In many instances such estimates will be overly pessimistic or optimistic, especially where many variables are involved, since they do not account for the random

behavior of variables. To make probabilistic statements about performance-- for example, the probability that core lifetime will be at least some given value-- requires a statistical approach.

The statistical approach to assessing the effects on dependent variables of various independent random variables generally assumes that the random variables are normally distributed. For example, if $C = A + B$ where the two random variables A and B are normally distributed with means A and B and variances v_A and v_B (standard deviation $\sigma = \sqrt{v}$), we would conclude that the dependent variable C is normally distributed with mean $C = A + B$ and variance $v_C = v_A + v_B$. Suppose, however, that only part of the A population went into producing C ; for example, suppose that values less than A_1 and greater than A_2 were discarded as is frequently done by tolerancing. Further, suppose that the distribution of B was skewed. In this case, how would we characterize the distribution of C in simple analytical terms?

In order to evaluate the effects of nonnormal distributions and to evaluate complex interactions between and among many variables influencing the design, manufacture, and operation of the Light Water Breeder Reactor (LWBR) the METER (Monte-Carlo Employed To Evaluate Responses) program was developed. METER began as a multi-option program to deal with specific problems related to LWBR. Each Monte Carlo simulation was executed by requesting a particular option in the program. As more uses were identified for the concept of Monte Carlo simulation, METER became cumbersome to maintain. The multi-option system was dropped in favor of a general purpose system. This report describes a tool called METER which processes input, generates random numbers, and displays results. How the random numbers interact to form a Monte Carlo simulation is supplied by the user in the form of a FORTRAN subroutine. The FORTRAN subroutine can be as simple as:


```

SUBROUTINE SIM(X,Y)
DIMENSION X(2)
Y = X(1)+ X(2)  Note: A = B + C
RETURN
END

```

or as complex as needed to produce the desired Monte Carlo simulation. Examples are presented which explain examples of the use of METER and its application to the LWBR development effort and suggestions are given on methods for verifying METER Monte Carlo simulations.

II. DESCRIPTION OF METER SYSTEM

METER is a system of subroutines and functions which is almost a complete computer program. One subroutine, SIM, is referenced in METER by the FORTRAN statement

```
CALL SIM(arg1,arg2)
```

and is supplied by the user. The user must write his own version of SIM in such a way that the subroutine accepts one or more independent variables referenced by arg₁ and computes one or more dependent variables referenced by arg₂. METER calls SIM repeatedly, supplying random values for the independent variables, and saves the resulting dependent variable values for later evaluation. Thus, by providing the SIM subroutine, the user completes the METER program allowing it to perform a specific Monte Carlo simulation.

II. A. General Purpose Routines in METER

To perform a Monte Carlo simulation using METER one need only supply computer control cards for running a METER job, a SIM subroutine (in FORTRAN), input cards describing the independent variable distributions and input cards

labeling output. METER's general purpose routines will process the input, generate random independent and dependent values, and display output distributions.

II. A. 1. Input Routines

During the execution of METER, input is processed using the Bettis Input Package (reference 1) which assumes numbered cards containing data fields separated by commas; for example,

101,6,ABC,1.0

Input cards describing the distributions needed by a METER simulation are read by a subroutine in METER called DATA1. METER calls DATA1 at the start of each simulation to read cards in the ISS series. The format of the ISS cards will be described in detail in section II.C.1.

While typical uses of METER will not require calls on DATA1 in the user's SIM subroutine, DATA1 will be described here in the event it is required for particular applications.

Each call on DATA1 results in the reading of a specified input card. The arguments of DATA1 in their required order are

- C - on entry, the floating point number of the card to be read.
- N3 - on return, the starting location in blank common for the data on card C. METER uses blank common starting at the first location for storage of input card data; that is, the array L1 needed by the subroutine INP (ref. 1) is declared as blank common.
- N4 - on return, the number of entries found on card C.

- IND1 - on entry, the starting location in blank common for the distribution parameters required by METER's random number generator (described in more detail in section II.A.2).
- XNOM - on return, nominal value for the random variable whose distribution is described on card C.
- NER - on return, unchanged if card C was correct; set to 1 if card C was in error.

As stated previously, the typical user will not need to program direct calls on DATA1 in his SIM subroutine provided input card series 1SS is used for describing input distributions.

II. A. 2. Random Number Generator Routines

The random number generator in METER consists of five FORTRAN functions and subroutines and permits random numbers to be selected from six types of distributions. These are:

1. Flat or uniform - all random values of x between x_1 and x_2 are equally probable.
2. Line - frequency distribution for the random values is a straight line (note: the flat distribution is equivalent to a line distribution with zero slope).
3. Normal - frequency distribution for the random values is the Gaussian or bell shaped curve with specified mean and standard deviation and possibly biased and/or truncated.
4. Point - all random values are set to a specified constant (useful when setting random variables to constants without re-programming SIM or for verifying a simulation).

5. Chi-square - frequency distribution for the random values is skewed either toward low values or toward high values.
6. Histogram - frequency distribution for the random values is a histogram or step function with any specified shape.

Exactly how these distributions are specified on input cards in a METER simulation is described in section II.C.1.

The five functions and subroutines which comprise the random number generators are named INITRV, RV, RANVAR, FUNCTN, and NEWSEQ. Typical METER Monte Carlo simulations will not require the user to program direct calls on the random number routines. METER performs that function automatically during each repetition. The five routines will be described here in case the user finds a need to call them directly.

SUBROUTINE INITRV(IA,RA)

INITRV initializes the parameters for a distribution; that is, INITRV uses the input which specified the particular distribution to compute constants needed when RANVAR is requested to supply the next random number from that distribution. IA and RA are equivalenced arrays containing the input and the constants for the distribution. When reading the ISS cards METER makes sequential calls on DATA1 (section II.A.1) and INITRV. For example the statements

```
C = 101
CALL DATA1(C,N3,N4,I,XNOM,XTOL,NER)
CALL INITRV(IA(I),RA(I))
```

would result in initialization of the distribution for the first independent random variable in a METER run.

FUNCTION RV(I)

RV returns the next random value from the I^{th} distribution provided DATA1 and INITRV have been called for the I^{th} distribution. For example the statement

$$X = RV(1)$$

would place the next random value for the first distribution (described on input card 101) into the FORTRAN variable X.

FUNCTION RANVAR(IA,RA)

RANVAR computes the next random number for the distribution whose parameters are stored in the equivalenced arrays IA and RA. The function RV uses RANVAR.

FUNCTION FUNCTN(IA,RA,NOP,X)

Given the distribution parameters stored in equivalenced arrays IA and RA, NOP --the type of distribution (1 through 6 as defined earlier)-- and X--an independent variable value--FUNCTN computes the value of the dependent variable -- $y = f(x)$. FUNCTN is used by INITRV and RANVAR.

SUBROUTINE NEWSEQ

RANVAR uses the function RANDOM in the FORTRAN library when generating its random variables. RANDOM generates values between 0 and 1 with equal probability (flat distribution between 0 and 1). Given a

starting number, RANDOM will always generate the same set of random numbers between 0 and 1. Each call on METER's subroutine NEWSEQ initiates a new start in RANDOM; that is, a new set of random numbers. This capability is important for correlated sampling when testing the effects of distributions on results.

The routines discussed above constitute the random number generator in METER which provides random numbers from several types of distributions. The typical user should have no need to make direct calls on these routines; however, the above descriptions should suffice for more sophisticated simulations where direct calls might be required.

II. A. 3. Output Routine

Output from a METER Monte Carlo simulation is displayed in tabular form and in graphical form by a subroutine called DISPLA. As is the case with the input and random number routines, DISPLA need not be called in the typical user's SIM subroutine. METER automatically calls DISPLA to compute the mean, variance, and skewness, to tabulate a histogram and to plot the histogram for each output or dependent variable distribution or array of results. The arguments of DISPLA are:

NOP - on entry, must be set to 0 to indicate that DISPLA is being called from METER.

NDATA - on entry, the size of the population being displayed.

DATA - on entry, the array containing the data being displayed.

NCLASS - on entry, the number of classes or steps in the output histogram.

STEP - on entry, step size for histogram if NCLASS = 0.

A - working array of size NCLASS + 1.

B - working array of size NCLASS.

C - working array of size NCLASS.

OTITLE - on entry, 6-word array for display title (taken from 2SS cards in METER).

UNITS - on entry, 1-word containing the units for the output distribution (taken from 3SS cards in METER).

PTITLE - on entry, 3-word array for the plot title (taken from 4SS cards when DISPLA is called from METER).

COMMT - on entry, 1-word plot comment (not used when DISPLA is called from METER).

XLABEL - on entry, 3-word X-axis plot label (set to the character string in UNITS (above) when DISPLA is called from METER).

YLABEL - on entry, 3 word Y-axis plot label (set to the character string RELATIVE FREQUENCY in METER).

VALNOM - on entry, nominal value of the dependent variable whose distribution is being displayed. Computed in METER using the nominal values for the independent variables and the user's SIM routine which defines how to compute the variable.

SIGMA - on entry, number of standard deviations at which to truncate the output plot (read from input card 0 or set to 4.0 if card 0 is not input).

IO - on entry, unit number for WRITE statements (METER executes CALL OUTTAP(IO) to obtain IO).

XMIN - on return, smallest value in DATA.

XMAX - on return, largest value in DATA.

XMEAN - on return, mean value of the NDATA values in DATA.

VAR - on return, variance of the population.

STD - on return, standard deviation of the population ($STD = \sqrt{VAR}$).

SKEW - on return, coefficient of skewness of the population.

Use of input card 0 and of input card series 2SS, 3SS, and 4SS is described in detail in section II.C.1. Each plotted histogram will include a superimposed normal distribution based on the mean and variance of the data processed by DISPLA.

II. B. Testing the Random Number Generator in METER

As discussed in section II.A.2, the METER program contains a random number generator capable of producing random numbers from five types of frequency distributions. The distributions available in METER are flat or uniform, line, normal, chisquare, and histogram. If a random variable is to be treated as a constant in certain cases, a point or constant option is available. The random number generator in METER permits great flexibility for defining random variables in Monte Carlo simulations. The capability to truncate or to bias normal distributions is especially useful in sensitivity studies. To demonstrate that METER's random number generator produces the requested distributions, a testing routine was programmed and executed. The test results are displayed in the tables and figures on pages 12 through 25.

In each of the seven examples METER generated 100,000 random numbers and displayed the results in a histogram. The first example requested a flat distribution of random numbers between 0.95 and 1.05 ($1.0 \pm .05$). The input cards for defining the distributions using the Bettis Input Package are discussed in detail in section II.C. Table II.B.1 contains the resulting histogram (21 classes) for the first example. The columns labeled "MINIMUM" and "MAXIMUM" define boundaries of each class. The column labeled "COUNTS" identifies the number of random values which fell into each class. For example, of the 100,000 random values generated, 4739 fell into class 12 (1.00238 to 1.00714). Note that a true flat or uniform frequency distribution should have 4762 ($100,000/21$) values in each of the 21 classes. Class 6 has the fewest counts, (4682) and is low by 1.68%. Class 14 with the most counts (4898) is high by 2.86%. The column labeled "FRACTION" lists the fraction of total counts in each class. The columns labeled "X", "P(X)", and "F(X)" relate to the values plotted in Figure II.B.1. "X" is the mid-point of the class. "P(X)" is the plotted relative number of counts or relative frequency for the class normalized to unit area under the histogram. "F(X)" is the true value of the requested frequency distribution function at "X" also normalized to unit area. Thus, Figure II.B.1 graphically displays METER's frequency distribution for the 100,000 random numbers along with the requested frequency distribution.

Tables II.B.2 through II.B.7 and figures II.B.2 through II.B.7 display results for examples 2 through 7. The tables and figures for these examples are similar to those for the first example. Each example produces random

TEST OF RANDOM NUMBER GENERATOR IN METER

EXAMPLE 1: 101, FLAT, 1.0, 0.05

CLASS	MINIMUM	MAXIMUM	COUNTS	FRACTION	X	P(X)	F(X)
1	950000+00	954762+00	4712	471200-01	952381+00	989520+01	100000+02
2	954762+00	959524+00	4721	472100-01	957143+00	991410+01	100000+02
3	959524+00	964286+00	4815	481500-01	961905+00	101115+02	100000+02
4	964286+00	969048+00	4724	472400-01	966667+00	992040+01	100000+02
5	969048+00	973810+00	4771	477100-01	971429+00	100191+02	100000+02
6	973810+00	978571+00	4682	458200-01	976190+00	983220+01	100000+02
7	978571+00	983333+00	4697	459700-01	980952+00	986370+01	100000+02
8	983333+00	988095+00	4722	472200-01	985714+00	991620+01	100000+02
9	988095+00	992857+00	4782	478200-01	990476+00	100422+02	100000+02
10	992857+00	997619+00	4866	436600-01	995238+00	102186+02	100000+02
11	997619+00	100238+01	4696	459600-01	100000+01	986160+01	100000+02
12	100238+01	100714+01	4739	473900-01	100476+01	995190+01	100000+02
13	100714+01	101190+01	4768	476800-01	100952+01	100128+02	100000+02
14	101190+01	101667+01	4898	489800-01	101429+01	102858+02	100000+02
15	101667+01	102143+01	4747	474700-01	101905+01	996870+01	100000+02
16	102143+01	102619+01	4712	471200-01	102381+01	989520+01	100000+02
17	102619+01	103095+01	4714	471400-01	102857+01	989940+01	100000+02
18	103095+01	103571+01	4866	486600-01	103333+01	102136+02	100000+02
19	103571+01	104048+01	4782	478200-01	103810+01	100422+02	100000+02
20	104048+01	104524+01	4858	485800-01	104286+01	102018+02	100000+02
21	104524+01	105000+01	4728	472800-01	104762+01	992830+01	100000+02
ALL	950000+00	105000+01	100000	100000+01			

Table II.B.1

INRAN = 88290595182968

USER = BEAUD GRAIL JOB YHBB014 RUN 75/11/21 AT 09.50.46 ON B MACH. AT BAPL. PLOTTED 21 NOV 75 AT 10:41:54 FRAME 001

Figure II.B.1

TEST OF RANDOM NUMBER GENERATOR IN METER

EXAMPLE 2: 101,LINE,200.0,-189.9,1.0,0.05

CLASS	MINIMUM	MAXIMUM	COUNTS	FRACTION	X	P(X)	F(X)
1	950000+00	954762+00	274	274000-02	952381+00	575400+00	570486+00
2	954762+00	959524+00	779	779000-02	957143+00	163590+01	151344+01
3	959524+00	964286+00	1125	112500-01	961905+00	236250+01	245639+01
4	964286+00	969048+00	1602	160200-01	966667+00	336420+01	339934+01
5	969048+00	973810+00	2031	203100-01	971429+00	426510+01	434229+01
6	973810+00	978571+00	2463	246300-01	976190+00	517230+01	528524+01
7	978571+00	983333+00	3021	302100-01	980952+00	634410+01	622819+01
8	983333+00	988095+00	3389	338900-01	985714+00	711690+01	717115+01
9	988095+00	992857+00	3835	383500-01	990476+00	805350+01	811410+01
10	992857+00	997619+00	4330	433000-01	995238+00	909300+01	905705+01
11	997619+00	100238+01	4719	471900-01	100000+01	990990+01	100000+02
12	100238+01	100714+01	5111	511100-01	100476+01	107331+02	109430+02
13	100714+01	101190+01	5617	561700-01	100952+01	117957+02	118859+02
14	101190+01	101667+01	6186	618600-01	101429+01	129906+02	128289+02
15	101667+01	102143+01	6572	657200-01	101905+01	138012+02	137718+02
16	102143+01	102619+01	6961	696100-01	102381+01	146181+02	147148+02
17	102619+01	103095+01	7575	757500-01	102857+01	159075+02	156577+02
18	103095+01	103571+01	7825	782500-01	103333+01	164325+02	166007+02
19	103571+01	104048+01	8360	836000-01	103810+01	175560+02	175436+02
20	104048+01	104524+01	8919	891900-01	104286+01	187299+02	184866+02
21	104524+01	105000+01	9306	930600-01	104762+01	195426+02	194295+02
ALL	950000+00	105000+01	100000	100000+01			

Table II.B.2

INRAN = 88290595182968

USER * BEAUD CRAIL JOB YHBB014 RUN 75/11/21 AT 09.50.46 ON B MACH. AT BAPL.. PLOTTED 21 NOV 75 AT 10:43:3 FRAME 002

DISTRIBUTION FOR N = 100000

Figure II.B.2

TEST OF RANDOM NUMBER GENERATOR IN METER

EXAMPLE 3: 101,NORMAL,1.0,0.0125,1.0,0.05

CLASS	MINIMUM	MAXIMUM	COUNTS	FRACTION	X	P(X)	F(X)
1	950000+00	954762+00	8	800000-04	952381+00	168000-01	225260-01
2	954762+00	959524+00	43	430000-03	957143+00	903000-01	894210-01
3	959524+00	964286+00	169	169000-02	961905+00	354900+00	307021+00
4	964286+00	969048+00	435	435000-02	966667+00	913500+00	911737+00
5	969048+00	973810+00	1252	125200-01	971429+00	262920+01	234177+01
6	973810+00	978571+00	2443	244300-01	976190+00	513030-01	520226+01
7	978571+00	983333+00	4740	474000-01	980952+00	995400-01	999569+01
8	983333+00	988095+00	7965	796500-01	985714+00	167265+02	166114+02
9	988095+00	992857+00	11268	112680+00	990476+00	236628+02	238767+02
10	992857+00	997619+00	14160	141600+00	995238+00	297369+02	296834+02
11	997619+00	100238+01	15033	150330+00	100000+01	315693+02	319174+02
12	100238+01	100714+01	13981	139810+00	100476+01	293601+02	296834+02
13	100714+01	101190+01	11378	113780+00	100952+01	238933+02	238767+02
14	101190+01	101667+01	8001	800100-01	101429+01	168021+02	166114+02
15	101667+01	102143+01	4799	479900-01	101905+01	100779+02	999569+01
16	102143+01	102619+01	2568	256800-01	102381+01	539289+01	520226+01
17	102619+01	103095+01	1131	113100-01	102857+01	237519+01	234177+01
18	103095+01	103571+01	427	427000-02	103333+01	896709+00	911737+00
19	103571+01	104048+01	139	139000-02	103810+01	291500+00	307021+00
20	104048+01	104524+01	48	480000-03	104286+01	100800+00	894210-01
21	104524+01	105000+01	12	120000-03	104762+01	252000-01	225260-01
ALL	950000+00	105000+01	100000	100000+01			

Table II.B.3

INRAN = 197596862640678

USER # BEAUD

GRAIL JOB YHBB014 RUN 75/11/21 AT 09.50.46 ON B MACH. AT BAPL. PLOTTED 21 NOV 75 AT 10:44:19 FRAME 003

Figure II.B.3

TEST OF RANDOM NUMBER GENERATOR IN METER

EXAMPLE 4: 101,NORMAL,1.025,0.025,1.0,0.05

CLASS	MINIMUM	MAXIMUM	COUNTS	FRACTION	X	P(X)	F(X)
1	950000+00	954762+00	119	119000-02	952381+00	249900+00	279565+00
2	954762+00	959524+00	251	251000-02	957143+00	527100+00	477413+00
3	959524+00	964286+00	383	383000-02	961905+00	804300+00	786229+00
4	964286+00	969048+00	615	615000-02	966667+00	129150+01	124867+01
5	969048+00	973810+00	957	957000-02	971429+00	200970+01	191244+01
6	973810+00	978571+00	1312	131200-01	976190+00	275520+01	282471+01
7	978571+00	983333+00	1843	184300-01	980952+00	387030+01	402348+01
8	983333+00	988095+00	2608	260800-01	985714+00	547680+01	552679+01
9	988095+00	992857+00	3508	350800-01	990476+00	736680+01	732128+01
10	992857+00	997619+00	4519	451900-01	995238+00	948990+01	935287+01
11	997619+00	100238+01	5317	531700-01	100000+01	111657-02	115225+02
12	100238+01	100714+01	6501	650100-01	100476+01	136521-02	136896+02
13	100714+01	101190+01	7433	743300-01	100952+01	156093-02	156848+02
14	101190+01	101667+01	8373	837300-01	101429+01	175833-02	173304+02
15	101667+01	102143+01	8878	887800-01	101905+01	186438-02	184665+02
16	102143+01	102619+01	8968	896800-01	102381+01	188328+02	189758+02
17	102619+01	103095+01	8714	871400-01	102857+01	182994+02	188045+02
18	103095+01	103571+01	8607	860700-01	103333+01	180747+02	179707+02
19	103571+01	104048+01	8000	800000-01	103810+01	168000+02	165620+02
20	104048+01	104524+01	7147	714700-01	104286+01	150087+02	147199+02
21	104524+01	105000+01	5947	594700-01	104762+01	124887+02	126165+02
ALL	950000+00	105000+01	100000	100000+01			

Table II.B.4

INRAN = 197596862640678

USER # BEAUD GRAIL JOB YHBB014 RUN 75/11/21 AT 09.50.46 ON B MACH. AT BAPL. PLOTTED 21 NOV 75 AT 10:45:22 FRAME 004

Figure II.B.4

TEST OF RANDOM NUMBER GENERATOR IN METER

EXAMPLE 5: 101, CHISQUARE, 0.95, 0.96, 3, 1.0, 0.05

CLASS	MINIMUM	MAXIMUM	COUNTS	FRACTION	X	P(X)	F(X)
1	950000+00	954762+00	7502	760200-01	952381+00	159642+02	176271+02
2	954762+00	959524+00	11485	114850+00	957143+00	241185+02	240623+02
3	959524+00	964286+00	11780	117800+00	961905+00	247330+02	244826+02
4	964286+00	969048+00	10834	108340+00	966667+00	227514+02	228307+02
5	969048+00	973810+00	9817	981700-01	971429+00	206157+02	204027+02
6	973810+00	978571+00	8388	838800-01	976190+00	176138+02	177770+02
7	978571+00	983333+00	7167	716700-01	980952+00	150597+02	152311+02
8	983333+00	988095+00	6134	613400-01	985714+00	128814+02	128944+02
9	988095+00	992857+00	5115	511500-01	990476+00	107415+02	108187+02
10	992857+00	997619+00	4333	433300-01	995238+00	909930+01	901417+01
11	997619+00	100238+01	3478	347800-01	100000+01	730330+01	746888+01
12	100238+01	100714+01	2885	288500-01	100476+01	605850+01	616036+01
13	100714+01	101190+01	2378	237800-01	100952+01	495380+01	506184+01
14	101190+01	101667+01	2065	206500-01	101429+01	435650+01	414588+01
15	101667+01	102143+01	1574	157400-01	101905+01	336540+01	338634+01
16	102143+01	102619+01	1355	135500-01	102381+01	284550+01	275937+01
17	102619+01	103095+01	1048	104800-01	102857+01	224080+01	224379+01
18	103095+01	103571+01	835	835000-02	103333+01	175350+01	182119+01
19	103571+01	104048+01	711	711000-02	103810+01	149310+01	147577+01
20	104048+01	104524+01	516	516000-02	104286+01	108360+01	119412+01
21	104524+01	105000+01	500	500000-02	104762+01	105000+01	964946+00
ALL	950000+00	105000+01	100000	100000+01			

Table II.B.5

INRAN = 99622405486466

USER * BEAUD GRAIL JOB YHBB014 RUN 75/11/21 AT 09.50.46 ON B MACH. AT BAPL. PLOTTED 21 NOV 75 AT 10:46:31 FRAME 005

Figure II.B.5

TEST OF RANDOM NUMBER GENERATOR IN METER

EXAMPLE 6: 101, HISTOGRAM, 3, 0.95, 0.03333, 10.0, 30.0, 60.0, 1.0, 0.05

CLASS	MINIMUM	MAXIMUM	COUNTS	FRACTION	X	PCX	F(X)
1	950000+00	954762+00	1415	141500-01	952381+00	297150+01	300030+01
2	954762+00	959524+00	1424	142400-01	957143+00	299040+01	300030+01
3	959524+00	964286+00	1493	149300-01	961905+00	313530+01	300030+01
4	964286+00	969048+00	1452	145200-01	966667+00	304920+01	300030+01
5	969048+00	973810+00	1474	147400-01	971429+00	309540+01	300030+01
6	973810+00	978571+00	1343	134300-01	976190+00	282030+01	300030+01
7	978571+00	983333+00	1403	140300-01	980952+00	294630+01	300030+01
8	983333+00	988095+00	4248	424800-01	985714+00	892080+01	900090+01
9	988095+00	992857+00	4262	426200-01	990476+00	895020+01	900090+01
10	992857+00	997619+00	4312	431200-01	995238+00	905520+01	900090+01
11	997619+00	100238+01	4136	413600-01	100000+01	868560+01	900090+01
12	100238+01	100714+01	4299	429900-01	100476+01	902790+01	900090+01
13	100714+01	101190+01	4312	431200-01	100952+01	905520+01	900090+01
14	101190+01	101667+01	4372	437200-01	101429+01	918120+01	900090+01
15	101667+01	102143+01	8608	860800-01	101905+01	180763+02	180018+02
16	102143+01	102619+01	8608	860800-01	102381+01	180763+02	180018+02
17	102619+01	103095+01	8465	840500-01	102857+01	176505+02	180018+02
18	103095+01	103571+01	8597	859700-01	103333+01	180537+02	180018+02
19	103571+01	104048+01	8613	861300-01	103810+01	180873+02	180018+02
20	104048+01	104524+01	8660	866000-01	104286+01	181860+02	180018+02
21	104524+01	105000+01	8564	856400-01	104762+01	179844+02	180018+02
ALL	950000+00	105000+01	100000	100000+01			

Table II.B.6

INRAN = 197596862640678

USER BEAUD

GRAIL JOB YHBB014 RUN 75/11/21 AT 09.50.46 ON B MACH. AT BAPL. PLOTTED 21 NOV 75 AT 10:47:29 FRAME 006

DISTRIBUTION FOR N = 100000

2250+02

EXAMPLE 6: 101.HISTOGRAM.3.0.95.0.03333.10.0.30.0.60.0.1.0.0.05

RELATIVE FREQUENCY
23

DY= 2500+01

0000+00

9000+00

DX= 1000-01

X

1050+01

Figure II.B.6

TEST OF RANDOM NUMBER GENERATOR IN METER

EXAMPLE 7: 101, POINT, 1.0, 1.0, 0.05

CLASS	MINIMUM	MAXIMUM	COUNTS	FRACTION	X	P(X)	F(X)
1	959000+00	954762+00	0	000000+00	952381+00	000000+00	000000+00
2	954762+00	959524+00	0	000000+00	957143+00	000000+00	000000+00
3	959524+00	964286+00	0	000000+00	961905+00	000000+00	000000+00
4	964286+00	969048+00	0	000000+00	966667+00	000000+00	000000+00
5	969048+00	973810+00	0	000000+00	971429+00	000000+00	000000+00
6	973810+00	978571+00	0	000000+00	976190+00	000000+00	000000+00
7	978571+00	983333+00	0	000000+00	980952+00	000000+00	000000+00
8	983333+00	988095+00	0	000000+00	985714+00	000000+00	000000+00
9	988095+00	992857+00	0	000000+00	990476+00	000000+00	000000+00
10	992857+00	997619+00	0	000000+00	995238+00	000000+00	000000+00
11	997619+00	100238+01	100000	100000+01	100000+01	210000+03	950000+02
12	100238+01	100714+01	0	000000+00	100476+01	000000+00	000000+00
13	100714+01	101190+01	0	000000+00	100952+01	000000+00	000000+00
14	101190+01	101667+01	0	000000+00	101429+01	000000+00	000000+00
15	101667+01	102143+01	0	000000+00	101905+01	000000+00	000000+00
16	102143+01	102619+01	0	000000+00	102381+01	000000+00	000000+00
17	102619+01	103095+01	0	000000+00	102857+01	000000+00	000000+00
18	103095+01	103571+01	0	000000+00	103333+01	000000+00	000000+00
19	103571+01	104048+01	0	000000+00	103810+01	000000+00	000000+00
20	104048+01	104524+01	0	000000+00	104286+01	000000+00	000000+00
21	104524+01	105000+01	0	000000+00	104762+01	000000+00	000000+00
ALL	950000+00	105000+01	100000	100000+01			

Table II.B.7

INRAN = 144591991545034

USER = BEAUD

GRAIL JOB YHBB014 RUN 75/11/21 AT 09.50.46 ON B MACH. AT BAPL. PLOTTED 21 NOV 75 AT 10:48:28 FRAME 007

DISTRIBUTION FOR N = 100000

2500+03

EXAMPLE 7: 101.F0INT,1.0.1.0.0.05

25

RELATIVE FREQUENCY

DY= 2500+02

0000+00

9400+00

DX= 1000-01

1050+01

X

Figure 11.B.7

values in the range of 0.95 to 1.05. Example 2 samples from a line distribution having a slope of 200.0 and a y-intercept of -189.9. Example 3 samples from a normal distribution having a mean of 1.0 and a standard deviation of 0.0125. Example 4 samples from a biased and truncated normal distribution having a mean of 1.025 and a standard deviation of 0.025. Example 5 samples from a chisquare distribution which goes to 0 at 0.95, peaks at 0.96 and has a degree of skewness (4) equal to 3. Example 6 samples from a histogram distribution having 10% of its population between 0.95 and 0.98333, 30% between 0.98333 and 1.01666 and 40% between 1.01666 and 1.04999. Example 7 tests the constant option for $x = 1$. The results from these seven examples displayed in the referenced tables and figures demonstrate the use of METER's random number generator and verify that the random number generator performs as it was designed.

II. C. Use of METER to Program a Simulation

This section contains all of the detailed information needed to program and execute a METER Monte Carlo simulation. The instructions in II.C.1 show how to construct a METER job input deck. Sections II.C.2 through II.C.4 present examples of the use of METER for fuel pellet volumes, fuel thermal conductivity, and fuel stack lengths.

II. C. 1. Operational Procedure

The input deck for a METER job consists of three sections separated in such a way that each section becomes a record in the computer input file. The three sections or input records are:

1. Control cards for retrieving required files, compiling the user's SIM routine, appending to METER, and executing METER.
2. SIM subroutine and any other FORTRAN subroutines or functions referenced in SIM and written by the user.
3. Input cards for executing the simulation.

The first record of input must contain the computer cards required to retrieve the METER program, the system's FORTRAN library, compiler, and loader; the cards required to compile the user's SIM subroutine and append it to METER; and the cards required to load and execute METER. These cards depend on the computer installation and will not be described in detail. The sample problems in section II.C show the control cards used at Bettis.

The second record of input must contain the user's SIM subroutine plus other routines as needed. Key punching must start in column seven and the cards must be organized according to standard FORTRAN as follows:

```

SUBROUTINE SIM(XIN,XOUT)
  DIMENSION XIN(1),XOUT(1)
  COMMON/SIM/NIN,NOUT,NREPS,NOP,INDOUT,IAVAIL (optional)
    :
    :
Any number of FORTRAN statements
    :
    :
RETURN
END
    :
    :
Other routines needed by SIM
    :
    :
End of record card

```

The XIN array contains the 1 or more (up to 99) independent random variables; the XOUT array contains the 1 or more (up to 99) dependent random variables. the FORTRAN statements must define each XOUT(i) as functions of the XIN(j). During each repetition or history, METER will use its random number generator (II.A.2) and the distribution parameters obtained from the input cards LSS (II.A.1) to compute the XIN(j). METER will then call SIM to compute the XOUT(i). After completing the requested number of histories, METER will call DISPLA (II.A.3) to display the XOUT distributions.

Some useful information about the simulation in progress is stored in a labeled common block called SIM. The variables stored in the common block SIM are:

- NIN - number of independent random variables.
- NOUT - number of dependent random variables.
- NREPS - number of repetitions or histories being performed.
- NOP - option number (defined later in description of card 100)
- INDOUT - starting location in blank common for output distributions.
First dependent variable distribution starts at INDOUT, second at INDOUT + NREPS, third at INDOUT + 2*NREPS, etc.
- IAVAIL - next available location in blank common. The user is free to use blank common starting at IAVAIL but must not use blank common locations below IAVAIL.

The above variables can be made available in the user's SIM subroutine by including the statement

```
COMMON/SIM/NIN, NOUT, NREPS, NOP, INDOUT, IAVAIL
```

at the front of the subroutine.

The third record of the METER input deck must contain Bettis Input Package cards for controlling the execution of the simulation. These input cards are described below:

- a. Title Card, optional: = followed by character string

The Bettis Input Package assumes that a card beginning with an equal sign (=) is a title card. The character string on a title card will be printed at the top of each page of output.

- b. Card 0, optional: 0,SIGMA,ICARRY,INIT

SIGMA = number of standard deviations at which to truncate all input (independent variable) normal distributions; default is 4.0.

ICARRY = 1 if input cards are to be carried over from case to case, 0 otherwise; default is 1.

INIT = 1 if parameters of the input distributions are to be printed (debug aid), 0 otherwise; default is 0.

- c. Card 100, required: 100,ISTART,NIN,NOUT,NREPS,NOP

ISTART ≤ 0 to generate the random numbers with a random start, 0 to use the standard start in RANDOM, > 0 to begin the random numbers with a specified start based on ISTART.

NIN = number of independent random variables ($0 < NIN \leq 99$)

NOUT = number of dependent random variables to be displayed ($0 \leq NOUT \leq 99$).

NREPS= number of repetitions or histories being performed.

NOP = 1 if the user's SIM subroutine simply defines the dependent variables; that is, random values for the independent variables are generated by METER, SIM computes the dependent variable values, METER displays results (normal use of METER). SIM is executed during each repetition.

NOP = 2 if the user's SIM will handle the entire simulation by generating the independent random values using direct calls on RANVAR, RV or a user supplied random number generator. SIM is called once. Output results will be displayed by METER using DISPLA if NOUT > 0.

d. Cards lss, required: lss,(DIST),XNOM,XTOL

The lss cards are used to describe the frequency distributions to be used when generating the independent random variable values. A card is needed for each independent variable in the simulation.

ss = 01, 02, 03, ..., NIN.

Six types of distributions are allowed in METER; they are:

1. flat
2. line
3. normal
4. point
5. chi square
6. histogram

Whenever an input distribution is requested by METER for a random variable, one of the above six distributions may be selected by specifying the distribution to be used and the parameters of that

distribution. In the METER input card description the term (DIST) is used to instruct the user to supply an option number or name and a list of parameters next on a card. The following describes what (DIST) means for the various distributions:

1. Flat Distribution

$$(DIST) = I_1$$

$$I_1 = 1 \text{ or FLAT.}$$

2. Line Distribution

$$(DIST) = I_1, X_1, X_2$$

$$I_1 = 2 \text{ or LINE.}$$

$$X_1 = \text{slope of the line.}$$

$$X_2 = \text{y intercept of the line.}$$

3. Normal Distribution

$$(DIST) = I_1, X_1, X_2$$

$$I_1 = 3 \text{ or NORMAL.}$$

$$X_1 = \text{mean of the normal distribution.}$$

$$X_2 = \text{standard deviation of the normal distribution.}$$

4. Point Distribution (no randomness or variability)

$$(DIST) = I_1, X_1$$

$$I_1 = 4 \text{ or POINT.}$$

$$X_1 = \text{value to be used.}$$

5. Chi Square Distribution (skewed)

(DIST) = I_1, X_1, X_2, I_2

I_1 = 5 or CHISQUARE.

X_1 = X_0 - location where the value of the function is zero opposite from the tail.

X_2 = X_p - location where the function peaks ($X_1 \neq X_2$). If $X_1 < X_2$, the tail of the distribution is to the right. If $X_1 > X_2$, the tail of the distribution is to the left.

I_2 = the parameter ν (≥ 3) indicating the degree of skewness. The larger of the value of ν , the more closely the distribution approximates a normal distribution.

6. Histogram Distribution

(DIST) = $I_1, I_2, X_1, X_2, X_3, X_4, \dots, X_k$

I_1 = 6 or HISTOGRAM.

I_2 = the number of classes or steps in the histogram.

X_1 = left boundary of the first class.

X_2 = width of each class.

X_3 through X_k = y value for each class ($k = I_2 + 2$).

XNOM = nominal value of the random variable.

XTOL = tolerance on the random variable. Values of the variable will be taken from the specified distribution over the range $XNOM + XTOL$.

e. Cards 2ss, optional: 2ss, (string)

This card series is used to supply titles for the tabular output from METER.

ss = 01, 02, 03, ..., NOUT

string = up to 60 characters (enclosed in parentheses) used by METER to title the tabular output for the ss^{th} dependent variable distribution.

f. Cards 3ss, optional: 3ss, (string)

This card series is used to supply titles for the graphical output from METER.

ss = 01, 02, 03, ..., NOUT

string = up to 30 characters (enclosed in parentheses) used by METER to title the graphical output for the ssth dependent variable distribution.

g. Cards 4ss, optional: 4ss, (string)

This card series is used to supply the units of the dependent variables for the tabular and graphical output.

ss = 01, 02, 03, ..., NOUT

string = up to 10 characters used by METER to label the units of the ssth dependent variable.

h. Cards 5ss, optional: 5ss,X

This card series is used to control the histograms generated by METER. If not supplied, each output histogram will contain 19 classes or steps.

ss = 01, 02, 03, ..., NOUT

X = if fixed point, the number of classes or steps in the histogram for the ssth dependent variable; if floating point, X is used as the step size. In either case, the maximum number of classes allowed is 101.

i. End Case Terminator, required

Each case of input (except the last) must be terminated by a card with a slash (/) as the first non-blank character.

j. End Input Terminator, required

The last case of input must be terminated by a card with a period (.) as the first non-blank character.

The next three sections of this report will present examples of METER input and output. All input values in the sample problems were chosen strictly for the purpose of illustration.

II. C. 2. Sample Problem 1

For the first example, we will simulate the distributions of fuel pellet cross sectional area and volume given the distributions for pellet diameter and length. We will ask METER to display the distributions for diameter, length, area, and volume. (Even though diameter and length are independent variables in this simulation, they can be displayed as dependent variables.

Page 37 contains a listing of the input deck for Sample Problem 1, showing the three records of input: (a) the control cards, (b) the SIM subroutine, and (c) the variable input. The control cards will depend on the installation (the Bettis control cards are shown). The SIM subroutine has two incoming variables XIN(1) and XIN(2) which are diameter and length respectively and returns four computed variables XOUT(1), XOUT(2), XOUT(3), and XOUT(4) which are diameter, length, area, and volume respectively. During execution, the values in the XIN array will be

supplied by METER's random number generator for each repetition. SIM will compute the values for the XOUT array and return them to METER to be displayed at the end of the job.

The third record of input contains one case of input for the simulation. Card 100 requests the following:

- a. The standard start (ISTART=0)
- b. 2 input variables (NIN=2)
- c. 4 output variables (NOUT=4)
- d. 1,000 histories or repetitions (NREPS=1000)
- e. The standard METER run (NOP=1)

Card 101 defines the distribution for pellet diameter (card 1ss is for XIN(ss)) to be a normal distribution with a mean of .252 and a standard deviation of .00012. The specified range on diameter is $.252 \pm .0005$. Note that the requested range is $\pm 4.25\sigma (.0005/.00012)$; however, this will be truncated to $\pm 4\sigma$ or $.252 \pm .00048$ because card 0 was not input to override the built-in $\pm 4\sigma$ truncation. Card 102 specifies the distribution of pellet length to be normal with mean .615 and standard deviation .00165 over the range $.615 \pm .02$ which will be changed to $.615 \pm .0066$ by the 4σ truncation. The 200, 300, and 400 series of cards supply the appropriate labels for the output distribution.

Pages 38 through 46 contain the output from the METER run showing the histograms and statistics for the output distributions. Note that the actual pellet diameters and lengths fell within the requested ranges. Since the diameter and length distributions were specified to be unbiased

(mean = nominal on cards 101 and 102), the means of the dependent variable distributions (area and volume) are close to the nominal values.

This would not be the case had biased or skewed distributions been specified. The novice user might find it beneficial to experiment with this simple simulation of pellet area and volume by running several cases varying the input distributions.

Input for Sample Problem 1

YHBB001,6,001,140,1546.METER,BEAUD,U.P.
MERGE(I=METER)
CCREAD(METERCC,PLOTTER=GRAVER)

SUBROUTINE SIM(XIN,XOUT)
DIMENSION XIN(1),XOUT(1)
DATA F/0.785398163/
XOUT(1)=XIN(1)
XOUT(2)=XIN(2)
XOUT(3)=F*XIN(1)**2
XOUT(4)=XIN(2)*XOUT(3)
RETURN
END

=METER SIMULATION FOR PELLET AREA AND VOLUME (SAMPLE PROBLEM 1)
100,0,2,4,1000,1
101,NORMAL,0.252,0.00012,0.252,0.0005 \$ PELLET DIAMETER DISTRIBUTION
102,NORMAL,0.615,0.00165,0.615,0.0200 \$ PELLET LENGTH DISTRIBUTION
201,(PELLET DIAMETER DISTRIBUTION)
202,(PELLET LENGTH DISTRIBUTION)
203,(PELLET AREA DISTRIBUTION)
204,(PELLET VOLUME DISTRIBUTION)
301,(PELLET DIAMETER)
302,(PELLET LENGTH)
303,(PELLET AREA)
304,(PELLET VOLUME)
401,(INCHES)
402,(INCHES)
403,(SQUARE IN.)
404,(CUBIC IN.)

LISTING OF INPUT DATA FOR CASE 1

METER U BEAUD P 10/08/76 YHBB001 PAGE 1

=METER SIMULATION FOR PELLET AREA AND VOLUME (SAMPLE PROBLEM 1)
0001 100,0,2,4,1000,1
0002 101,NORMAL,0.252,0.00012,0.252,0.0005 \$ PELLET DIAMETER DISTRIBUTION
0003 102,NORMAL,0.615,0.00165,0.615,0.0200 \$ PELLET LENGTH DISTRIBUTION
0004 201,(PELLET DIAMETER DISTRIBUTION)
0005 202,(PELLET LENGTH DISTRIBUTION)
0006 203,(PELLET AREA DISTRIBUTION)
0007 204,(PELLET VOLUME DISTRIBUTION)
0008 301,(PELLET DIAMETER)
0009 302,(PELLET LENGTH)
0010 303,(PELLET AREA)
0011 304,(PELLET VOLUME)
0012 401,(INCHES)
0013 402,(INCHES)
0014 403,(SQUARE IN.)
0015 404,(CUBIC IN.)

KEY VARIABLES

SIGMA = 4.0000
ICARRY = 0
INIT = 0
INRAN = 1525878906250
NCASE = -1
NDATA = 70
CLASES = 19
IND1 = 71
IND2 = 73
IND3 = 77
IND4 = 101
IND5 = 105
IND6 = 4105
IAVAIL = 4163
AMOUNT = 31954
IT = OUTPUT
NER = 0
DISPAR = 12
NIN = 2
NOUT = 4
NREPS = 1000
NOP = 1

Output From Sample Problem 1

CASE 1

PELLET DIAMETER DISTRIBUTION

CLASS	(UNITS ARE INCHES)		COUNTS	P(X)
	MINIMUM	MAXIMUM		
1	251628+00	251669+00	6	600000-02
2	251669+00	251710+00	2	200000-02
3	251710+00	251750+00	6	600000-02
4	251750+00	251791+00	22	220000-01
5	251791+00	251832+00	39	390000-01
6	251832+00	251873+00	59	590000-01
7	251873+00	251914+00	90	900000-01
8	251914+00	251954+00	105	105000+00
9	251954+00	251995+00	140	140000+00
10	251995+00	252036+00	153	153000+00
11	252036+00	252077+00	130	130000+00
12	252077+00	252117+00	90	900000-01
13	252117+00	252158+00	75	750000-01
14	252158+00	252199+00	31	310000-01
15	252199+00	252240+00	26	260000-01
16	252240+00	252281+00	17	170000-01
17	252281+00	252321+00	6	600000-02
18	252321+00	252362+00	1	100000-02
19	252362+00	252403+00	2	200000-02

N = 1000

MINIMUM = 251628+00

MAXIMUM = 252403+00

MEAN = 252001+00

VARIANCE = 137087-07

STANDARD DEVIATION = 117084-03

COEFFICIENT OF SKEWNESS = -292544-02

***** NOMINAL VALUE = 252000+00

CASE 1

PELLET LENGTH DISTRIBUTION

CLASS	(UNITS ARE INCHES)		COUNTS	POX
	MINIMUM	MAXIMUM		
1	610273+00	610807+00	5	500000-02
2	610807+00	611340+00	8	800000-02
3	611340+00	611874+00	11	110000-01
4	611874+00	612407+00	23	230000-01
5	612407+00	612941+00	47	470000-01
6	612941+00	613475+00	75	750000-01
7	613475+00	614008+00	88	880000-01
8	614008+00	614542+00	114	114000+00
9	614542+00	615075+00	126	126000+00
10	615075+00	615609+00	142	142000+00
11	615609+00	616142+00	100	100000+00
12	616142+00	616675+00	95	950000-01
13	616675+00	617210+00	66	660000-01
14	617210+00	617743+00	47	470000-01
15	617743+00	618277+00	26	260000-01
16	618277+00	618810+00	15	150000-01
17	618810+00	619344+00	5	500000-02
18	619344+00	619877+00	4	400000-02
19	619877+00	620411+00	3	300000-02

N = 1000

MINIMUM = 610273+00

MAXIMUM = 620411+00

MEAN = 615080+00

VARIANCE = 269E53-05

STANDARD DEVIATION = 164272-02

COEFFICIENT OF SKEWNESS = 518544-01

***** NOMINAL VALUE = 615000+00

Output From Sample Problem 1 (Continued)

CASE 1

PELLET AREA DISTRIBUTION

CLASS	(UNITS ARE SQUARE IN.)		COUNTS	P(X)
	MINIMUM	MAXIMUM		
1	497288-01	497450-01	6	600000-02
2	497450-01	497611-01	2	200000-02
3	497611-01	497773-01	6	600000-02
4	497773-01	497934-01	22	220000-01
5	497934-01	498095-01	40	400000-01
6	498095-01	498257-01	58	580000-01
7	498257-01	498418-01	90	900000-01
8	498418-01	498580-01	108	108000+00
9	498580-01	498741-01	137	137000+00
10	498741-01	498903-01	153	153000+00
11	498903-01	499064-01	131	131000+00
12	499064-01	499225-01	90	900000-01
13	499225-01	499387-01	74	740000-01
14	499387-01	499548-01	32	320000-01
15	499548-01	499710-01	25	250000-01
16	499710-01	499871-01	17	170000-01
17	499871-01	500032-01	6	600000-02
18	500032-01	500194-01	1	100000-02
19	500194-01	500355-01	2	200000-02

N = 1000

MINIMUM = 497288-01

MAXIMUM = 500355-01

MEAN = 498764-01

VARIANCE = 214803-08

STANDARD DEVIATION = 463468-04

COEFFICIENT OF SKEWNESS = -138123-02

***** NOMINAL VALUE = 498759-01

Output From Sample Problem 1 (Continued)

CASE 1

PELLET VOLUME DISTRIBUTION

CLASS	(UNITS ARE CUBIC IN.)		COUNTS	P(X)
	MINIMUM	MAXIMUM		
1	304239-01	304528-01	5	500000-02
2	304528-01	304817-01	8	800000-02
3	304817-01	305106-01	9	900000-02
4	305106-01	305395-01	31	310000-01
5	305395-01	305684-01	49	490000-01
6	305684-01	305973-01	73	730000-01
7	305973-01	306262-01	100	100000-00
8	306262-01	306551-01	119	119000-00
9	306551-01	306840-01	139	139000-00
10	306840-01	307129-01	129	129000-00
11	307129-01	307418-01	104	104000-00
12	307418-01	307707-01	90	900000-01
13	307707-01	307996-01	49	490000-01
14	307996-01	308285-01	49	490000-01
15	308285-01	308574-01	33	330000-01
16	308574-01	308862-01	6	600000-02
17	308862-01	309151-01	3	300000-02
18	309151-01	309440-01	1	100000-02
19	309440-01	309729-01	3	300000-02

N = 1000

MINIMUM = 304239-01

MAXIMUM = 309729-01

MEAN = 306780-01

VARIANCE = 763502-08

STANDARD DEVIATION = 873786-04

COEFFICIENT OF SKEWNESS = 596654-01

***** NOMINAL VALUE = 306737-01

INRAN =2651046790

Output From Sample Problem 1 (Continued)

USER # BEAUD

METER JOB YHBB

(04U) RUN

76/10/08

AT 08.42.23

ON A MACH.

AT BAPL.

PLOTTED 8 OCT 76 AT 8:46:12 FRAME 001

Output From Sample Problem 1 (Continued)

USER = BEAUD

METER JOB YHBB

(04U) RUN 76/10/08

AT 08.42.23

ON A MACH. AT BAPL.

PLOTTED 8 OCT 76 AT 8:49:24 FRAME 003

Output From Sample Problem 1 (Continued)

II. C. 3. Sample Problem 2

The second sample problem deals with fuel thermal conductivity.

Suppose we have a model which predicts fuel thermal conductivity - K in units of BTU/Hr-Ft- $^{\circ}$ F as a function of fuel fractional porosity - P , fuel depletion - F in units of 10^{20} fissions/cc, fuel temperature - T in degrees Kelvin, and weight fraction UO_2 - U as follows:

$$K = \alpha \frac{1 - P}{1 + \beta P} \left[A_0 + A_1 U + A_2 U^2 + (B_0 + B_1 U + B_2 U^2) T + \frac{C + DF}{T} \right]^{-1}$$

where:

$$\alpha = 57.78$$

$$\beta = 1.15$$

$$C = 1,800$$

$$D = 616$$

We wish to evaluate fuel thermal conductivity under various conditions given estimates of the coefficients A_i and B_i and given uncertainties in the estimates. The input for such a Monte Carlo calculation is shown on page 49. The SIM subroutine assumes six input random variables $X(1)$ through $X(6)$ which represent A_0 , A_1 , A_2 , B_0 , B_1 , and B_2 respectively. The listed problem assumes a fuel porosity of 0.03, a fuel depletion of 0 (beginning of life), a fuel temperature of 1000° K and a UO_2 weight fraction of 0.05. These four variables are treated as constants whose values are assigned by FORTRAN "DATA" statements. Card 0 is supplied in the input to change the normal distribution truncation from $\pm 4\sigma$ to $\pm 6\sigma$. Card 100 requests a random start, six input or independent random variables, one output or dependent random variable, 10,000 repetitions.

and option 1. Distributions for the coefficients are defined on cards 101 through 106. Cards 201, 301, and 401 supply output labels and card 501 requests that the output histogram be generated with a step size of 0.05.

The output from sample problem 2 is presented on pages 50 through 52. The mean thermal conductivity for 10,000 repetitions was 2.33191; the expected value based on the nominal values on cards 101 through 106 was 2.32942. The uncertainty in fuel thermal conductivity predicted by METER for the sample problem is 0.0920 at the 1σ level.

Input For Sample Problem 2

YHBB002,6,001,140,1546.METER,BEAUD,U,P.
 MERCE(I=METER)
 CCREAD(METERCC,PLOTTER=GRAVER)

```

SUBROUTINE SIM(X,Y)
FUEL THERMAL CONDUCTIVITY
RANDOM VARIABLES --
X(1) -- A0
X(2) -- A1
X(3) -- A2
X(4) -- B0
X(5) -- B1
X(6) -- B2
DIMENSION X(1)
DATA C/1800./
DATA D/616./
DATA ALPHA/57.78/
DATA BETA/1.15/
DATA P/0.03/
DATA F/0./
DATA T/1000./
DATA U/.05/
XK0 = ALPHA * (1.-P) / (1.+BETA*P)
AT = X(1) + X(2)*U + X(3)*U**2
BT = (X(4) + X(5)*U + X(6)*U**2) * T
CT = (C + D*F) / T
Y = XK0 / (AT + BT + CT)
RETURN
END

```

=METER SIMULATION FOR FUEL THERMAL CONDUCTIVITY (SAMPLE PROBLEM 2)
 0,6.0,1,0
 100,-1.6,1,10000,1
 101,NORMAL,0.931370,0.046568,0.931370,.3 \$ COEFFICIENT A0
 102,NORMAL,20.83000,1.041500,20.83000,7. \$ COEFFICIENT A1
 103,NORMAL,-281.018,14.05090,-281.018,85. \$ COEFFICIENT A2
 104,NORMAL,0.018220,0.000911,0.018220,.006 \$ COEFFICIENT B0
 105,NORMAL,0.034136,0.001707,0.034136,.011 \$ COEFFICIENT B1
 106,NORMAL,0.104320,0.005216,0.104320,.032 \$ COEFFICIENT B2
 201,(FUEL THERMAL CONDUCTIVITY AT P=0.03 F=0 T=1000K U=5 0/0)
 301,(FUEL THERMAL CONDUCTIVITY)
 401,(BTU/HRFT0F)
 501,0.05

LISTING OF INPUT DATA FOR CASE 1

METER U 3BAUD P 06/16/76 YHBB002 PAGE 1

```

=METER SIMULATION FOR FUEL THERMAL CONDUCTIVITY (SAMPLE PROBLEM 2)
0001 0.6.0.1.0
0002 100,-1.6.1.10000.1
0003 101,NORMAL,0.931370.0.046558,0.931370.3 S COEFFICIENT A0
0004 102,NORMAL,20.83000.1.041590,20.83000.7. S COEFFICIENT A1
0005 103,NORMAL,-281.018.14.05050,-281.018.85. S COEFFICIENT A2
0006 104,NORMAL,0.018220.0.000911,0.018220.006 S COEFFICIENT B0
0007 105,NORMAL,0.034136.0.001767,0.034136.011 S COEFFICIENT B1
0008 106,NORMAL,0.104320.0.005216,0.104320.032 S COEFFICIENT B2
0009 201,(FUEL THERMAL CONDUCTIVITY AT P=0.03 F=0 T=1000K U=5 0/0)
0010 301,(FUEL THERMAL CONDUCTIVITY)
0011 401,(BTU/HRFT0F)
0012 501,0.05

```

KEY VARIABLES

```

SIGMA " 6.0000
ICARRY " 1
INIT " 0
INRAN " 245073
NCASE " -1
NDATA " 74
CLASES " 101
IND1 " 75
IND2 " 81
IND3 " 82
IND4 " 154
IND5 " 155
IND6 " 10155
IAVAIL " 10459
AMOUNT " 31909
IT " OUTPUT
NER " 0
DISPAR " 12
NIN " 6
NOUT " 1
NREPS " 10000
NOP " 1

```

Output From Sample Problem 2

CASE 1

FUEL THERMAL CONDUCTIVITY AT P=0.03 F=0 T=1000K U=5 0/0

(UNITS ARE BTU/HRFT ² F)				
CLASS	MINIMUM	MAXIMUM	COUNTS	P(X)
1	200000+01	205000+01	1	100000-03
2	205000+01	210000+01	26	260000-02
3	210000+01	215000+01	134	134000-01
4	215000+01	220000+01	599	509000-01
5	220000+01	225000+01	1230	123000+00
6	225000+01	230000+01	1922	192200+00
7	230000+01	235000+01	2196	210600+00
8	235000+01	240000+01	1812	181200+00
9	240000+01	245000+01	1194	119400+00
10	245000+01	250000+01	670	670000-01
11	250000+01	255000+01	276	276000-01
12	255000+01	260000+01	82	820000-02
13	260000+01	265000+01	28	280000-02
14	265000+01	270000+01	7	700000-03
15	270000+01	275000+01	3	300000-03

N = 10000

MINIMUM = 203855+01

MAXIMUM = 272373+01

MEAN = 233191+01

VARIANCE = 846935-02

STANDARD DEVIATION = 920291-01

COEFFICIENT OF SKEWNESS = 245121+00

***** NOMINAL VALUE = 232942+01

INRAN =2017058874

Output From Sample Problem 2 (Continued)

II. C. 4. Sample Problem 3

The third sample problem uses METER to simulate a relatively simple manufacturing process--stacking fuel pellets of random length to form fuel stacks of specified tolerances. This simulation utilizes option 2 (see description of card 100 in II.C.1) because the entire simulation must be programmed in the SIM subroutine. The coding requires more FORTRAN proficiency than the two prior examples and the author has chosen to use the Bettis Input Package to process an additional card of input rather than set certain variables directly within the SIM subroutine.

The steps in the simulation are as follows:

- a. determine minimum and maximum allowable stack lengths.
- b. since pellet length distributions and the stack length requirements could conflict and make it difficult to complete stacks, determine the maximum attempts at completing a stack and set the failure counter to 0.
- c. initialize a new stack by setting its try counter to 0 and its length to 0.
- d. select a random pellet for the stack; its length will be a random variable.
- e. add the new pellet's length to the length of the stack.
- f. repeat (d) and (e) until the stack length equals or is greater than the minimum required stack length determined at step (a).

- g. if the stack length is less than or equal to the maximum required stack length, save its value for the output distribution and return to step (c). If the desired number of stacks have been produced, terminate the simulation and display the results.
- h. if the stack length is greater than the maximum required length, up the try counter by 1. If the try counter is greater than the maximum attempts set at step (b), up the failure counter by 1, discard this stack and return to step (c).
- i. if allowed to try again, remove the last pellet (subtract its length from the stack length) and return to step (d) in hope of finding a shorter pellet.

The input deck for sample problem 3 is listed on pages 56 and 57. Each FORTRAN statement in SIM is preceeded by a comment which explains that statement. Note that when option 2 of METER is used (NOP=2), SIM must be prepared for 2 passes--pass 1 to return nominal values for all dependent random variables (second argument) and pass 2 to perform the simulation. Pass 1 for our sample problem has been programmed to read card 1 to obtain the nominal stack length, the stack length tolerance and the maximum number of attempts at finishing a stack. Since card 1 in the example contains 84.0, 0.368, and 5 respectively for the constants, the pass 1 coding could have been

```

SLNOM=84.
SLTOL=.368
NTRIES=5
Y=SLNOM
NPASS=2
RETURN

```

The constants could have been changed within SIM for each run. The advantages in coding SIM the author's way are (a) the variable input is centralized in record 3 (card input) and (b) the user's own version of METER can be saved on line for the duration of his application without further need to compile and recompile SIM during each run. At Bettis this would be accomplished by including

```
PROGM(FM)
STORE(I=METER, T=62, V=nnn, F=S, S=METER)
```

(where $1 \leq nnn \leq 999$) after the MERGE card and by including

```
FM(STORE, METER)
```

after the CCREAD card.

Subsequent runs would require the following simplified input deck

```
Job Card
FETCH(I=METER, T=62, V=nnn, F=S, S=METER)
METER.
end record
Bettis Input Package Cards
```

The output results from sample problem 3 are shown on pages 58 through 60. Note that no stack failed to be completed but that the resulting stack length distribution is somewhat peculiar. No stacks were "made" by METER with the nominal stack length and we observe 2 peaks in the distribution. The combination of the stack length requirements (84.0 ± 0.368) and the pellet length distribution ($\eta = 0.615$, $\sigma = 0.002$, between 0.615 ± 0.020) produces stacks containing either 136 or 137 pellets. It must be emphasized that this simulation does not describe all aspects of an actual stacking operation and was simplified for the purpose of demonstrating the use of METER.

Input for Sample Problem 3

YHBB003,6,001,140,1546.METER,BEAUD,U,P.
MERGE(I=METER)
CCREAD(METERCC,PLOTTER=GRAVER)

```
      SUBROUTINE SIM(X,Y)
C-----METER SIMULATION OF PELLET STACKING
C      FIRST PASS (NPASS=1) -- READ CARD 1, CHECK ENTRIES, RETURN
C                                RETURNS NOMINAL STACK LENGTH (SLNOM)
C      SECOND PASS (NPASS=2) -- PERFORM SIMULATION
C
C-----KEY VARIABLES FROM METER BASED ON CARD INPUT
COMMON /SIM/NIN,NOUT,NREPS,NOP,INDOUT,IAVAIL
C-----FILENAME FOR OUTPUT
COMMON /IT/IT
C-----BLANK COMMON LOCATION 1 IS START OF BETTIS INPUT PACKAGE TABLE
COMMON A1
EQUIVALENCE (A1(1),L1(1),A(1))
DIMENSION A1(1),L1(1),A(1)
C-----INITIALIZE PASS COUNTER
DATA NPASS/1/
C-----INITIALIZE ERROR FLAG
DATA NER/0/
C
C-----CHECK NOP (MUST BE 2)
IF (NOP.NE.2) CALL CRDERR(100,5,NER)
C-----IF PASS 2, SKIP READING CARD 1
IF (NPASS.EQ.2) GO TO 20
C
C-----START OF PASS 1
C-----INITIALIZE CARD NUMBER
IC=1
C=IC
C-----READ CARD 1, NOMINAL STACK LENGTH, STACK LENGTH TOLERANCE, TRIES
C      SEE WAPD-TM-1181 FOR DESCRIPTION OF BETTIS INPUT PACKAGE ROUTINES
CALL LINK(C,D,N3,N4,L1)
C-----CHECK NUMBER OF ENTRIES ON CARD 1
IF (N4.EQ.3) GO TO 10
C-----NUMBER OF ENTRIES WAS NOT 3, PRINT ERROR MESSAGE ...
CALL CRDERR(IC,0,NER)
C-----... THEN ABORT
CALL SUBERR
10 CONTINUE
C-----OBTAIN AND CHECK NOMINAL STACK LENGTH (SLNOM)
SLNOM=A1(N3)
C-----IF NOT GREATER THAN 0.0, PRINT ERROR MESSAGE
IF (SLNOM.LE.0.0) CALL CRDERR(IC,1,NER)
C-----OBTAIN AND CHECK STACK LENGTH TOLERANCE (SLTOL)
SLTOL=A1(N3+1)
C-----IF NOT GREATER THAN 0.0, PRINT ERROR MESSAGE
IF (SLTOL.LE.0.0) CALL CRDERR(IC,2,NER)
C-----OBTAIN AND CHECK NTRIES (NUMBER OF ATTEMPTS AT COMPLETING A STACK)
NTRIES=L1(N3+2)
C-----IF NOT GREATER THAN 0, PRINT ERROR MESSAGE
IF (NTRIES.LE.0) CALL CRDERR(IC,3,NER)
C-----ABORT IF CARD 1 WAS IN ERROR
IF (NER.NE.0) CALL SUBERR
C-----SET Y TO SLNOM, NPASS TO 2 AND RETURN
Y=SLNOM
NPASS=2
C-----END OF PASS 1
C
      RETURN
C
C-----START OF PASS 2
C-----COMPUTE MIN AND MAX STACK LENGTHS
20 SLMIN=SLNOM-SLTOL
   SLMAX=SLNOM+SLTOL
C-----INITIALIZE FAILURE COUNTER
NFAIL=0
C-----INITIALIZE RESULT (STACK LENGTH DISTRIBUTION) INDEX
I1=INDOUT-1
C-----PERFORM SIMULATION FOR REQUESTED NUMBER OF REPETITIONS (NREPS)
DO 60 I=1,NREPS
```

Input for Sample Problem 3 (Continued)

```
C-----INCREMENT RESULT INDEX BY 1
      I1=I1+1
C-----INITIALIZE COUNTER ON NUMBER OF ATTEMPTS TO COMPLETE THE STACK
30  NTRY=0
C-----INITIALIZE STACK LENGTH TO 0.0 (NEW STACK)
      SL=0.
C-----OBTAIN NEXT RANDOM PELLET LENGTH USING FUNCTION RV
40  PL=RV(1)
C-----ADD NEW PELLET LENGTH TO CURRENT STACK LENGTH
      SL=SL+PL
C-----CHECK CURRENT STACK LENGTH AGAINST LOWER LIMIT.
C      IF SHORT, GET ANOTHER PELLET
      IF (SL.LT.SLMIN) GO TO 40
C-----CHECK CURRENT STACK LENGTH AGAINST UPPER LIMIT
C      IF WITHIN TOLERANCE, STACK IS COMPLETED
      IF (SL.LE.SLMAX) GO TO 60
C-----STACK IS TOO LONG
C      DETERMINE THE NUMBER OF TRIES AT COMPLETING THE STACK
      NTRY=NTRY+1
      IF (NTRY.GT.NTRIES) GO TO 50
C-----SUBTRACT LAST PELLET AND GET A NEW ONE
      SL=SL-PL
      GO TO 40
C-----EXCEEDED THE MAXIMUM NUMBER OF ATTEMPTS
C      INCREMENT THE FAILURE COUNTER BY ONE AND START A NEW STACK
50  NFAIL=NFAIL+1
      GO TO 30
C-----SAVE THE RESULTING STACK LENGTH IN THE A ARRAY AT INDEX I1
60  A(I1)=SL
C-----PRINT THE NUMBER OF FAILURES
      WRITE(IT,70) NFAIL
70  FORMAT(/,1X,I10,31H STACKS FAILED TO BE COMPLETED.)
C-----END OF PASS 2
C
      RETURN
      END
.
=METER SIMULATION FOR STACKING PELLETS      (SAMPLE PROBLEM 3)
100,0,1,1,1000,2
1,84,0,0.368,5
101,NORMAL,0.615,0.002,0.615,0.020 $ PELLET LENGTH DISTRIBUTION
201,(STACK LENGTH DISTRIBUTION)
301,(STACK LENGTH)
401,(INCHES)
501,0.05 .
```

LISTING OF INPUT DATA FOR CASE 1

METER U BEAUD P 10/08/76 YHBB003 PAGE 1

=METER SIMULATION FOR STACKING PELLETS (SAMPLE PROBLEM 3)
 0001 100,0,1,1,1000,2
 0002 1,84.0,0.368,5
 0003 101,NORMAL,0.615,0.002,0.615,0.020 * PELLET LENGTH DISTRIBUTION
 0004 201,(STACK LENGTH DISTRIBUTION)
 0005 301,(STACK LENGTH)
 0006 401,(INCHES)
 0007 501,0.05

KEY VARIABLES

SIGMA = 4.0000
 ICARRY = 0
 INIT = 0
 INRAN = 1525878906250
 NCASE = -1
 NDATA = 35
 CLASES = 101
 IND1 = 36
 IND2 = 37
 IND3 = 38
 IND4 = 50
 IND5 = 51
 IND6 = 1051
 IAVAIL = 1355
 AMOUNT = 31841
 IT = OUTPUT
 NER = 0
 DISPAR = 12
 NIN = 1
 NOUT = 1
 NREPS = 1000
 NOP = 2

0 STACKS FAILED TO BE COMPLETED.

Output From Sample Problem 3

METER SIMULATION FOR STACKING PELLETS

(SAMPLE PROBLEM 3)

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CASE 1

STACK LENGTH DISTRIBUTION

CLASS	(UNITS ARE INCHES)		COUNTS	P(X)
	MINIMUM	MAXIMUM		
1	836000+02	836500+02	298	298000+00
2	836500+02	837000+02	344	344000+00
3	837000+02	837500+02	7	700000-02
4	837500+02	838000+02	0	000000+00
5	838000+02	838500+02	0	000000+00
6	838500+02	839000+02	0	000000+00
7	839000+02	839500+02	0	000000+00
8	839500+02	840000+02	0	000000+00
9	840000+02	840500+02	0	000000+00
10	840500+02	841000+02	0	000000+00
11	841000+02	841500+02	0	000000+00
12	841500+02	842000+02	9	900000-02
13	842000+02	842500+02	340	340000+00
14	842500+02	843000+02	2	200000-02

N = 1000

MINIMUM = 836320+02

MAXIMUM = 842506+02

MEAN = 838573+02

VARIANCE = 761311-01

STANDARD DEVIATION = 275919+00

COEFFICIENT OF SKEWNESS = 620096+00

***** NOMINAL VALUE = 840000+02

INRAN = 7802381922

Output From Sample Problem 3 (Continued)

Output From Sample Problem 3 (continued)

II. D. Suggestions for Verifying Simulations

Since the use of METER requires some new and untested programming for each application, the user must be aware of his obligation to verify his coding through sufficient testing before running actual problems. This is a serious and often difficult task, for how does one proceed to verify a computer program which by its very design is intended to produce random results? The sub-routines and functions which form the METER package have been extensively tested and are judged to operate as intended. The user's programming can be verified in two ways.

Test the programming outside of METER if possible. By writing a small driver program to supply input to the SIM subroutine and print values of variables computed by SIM, results can be compared to hand calculations. Occasionally, a verified computer program might be used as the SIM subroutine and the verification of that program would be valid.

To test the SIM subroutine within METER, make use of the point distribution; that is, specify on the distribution input cards (lss) that all input distributions consist of constant values. Run a few histories and verify that METER always produces identical and correct answers at each history. This will ensure that the user's coding has not interfered with the coding in the METER package. By all means be thorough in the verification process. Once METER is used to generate supposedly meaningful results, it may be impossible to distinguish coding errors from the variability of the results.

III. SOME METER APPLICATIONS RELATED TO LWBR

The METER program was developed for the LWBR program when assessments of design and manufacturing uncertainties were needed. Several of

the Monte Carlo simulations programmed for LWBR were intended to test the feasibility of proposed fuel rod assembly procedures. Some of the METER applications related to LWBR will be summarized to provide a feel for the types of problems which can be dealt with using Monte Carlo techniques.

III. A. Fuel Rod Binary (UO_2 - ThO_2) Stack Lengths

The first use of METER in the LWBR program involved the simulation of the stacking of binary (uranium oxide-thorium oxide mixture) fuel pellets to form the binary portion of a fuel rod. Sample problem 3 in section III.C.4 demonstrates the pellet stacking simulation. These first Monte Carlo simulations demonstrated the feasibility of meeting the binary stack length tolerances given expected pellet length distributions and provided insight into the expected binary stack length distributions. It was observed, for example, that relatively few high zone seed fuel stacks would be manufactured at the design nominal of 84 inches. Since the nominal high zone seed pellet length is 0.615 ± 0.020 inches, the stacks will contain either 136 or 137 pellets and the stack length distribution should peak near 83.640 inches and 84.255 inches with a valley near 84 inches. The METER simulation of sample problem 3 showed peaks at histogram class 2 (83.65 - 83.70) and at class 13 (84.20 - 84.25).

III. B. Fuel Rod Fissile Content

The initial binary stack simulation was soon expanded to permit the independent random variables to include all of the pellet parameters (length, diameter, end dishes, tapers, chips, density, and uranium isotopic content) so that the resulting distributions of rod fissile content and fissile linear

density (fissile grams per unit length) could be estimated. At the time that this simulation was programmed, the fissile content of the LWBR core was controlled by specifications on the fissile content (grams) in each of the various fuel rod types in the core. Because of thermal and hydraulic considerations it was decided that a control on fissile content per unit length would be more appropriate. METER was used to examine the fissile grams per unit length distributions as functions of the distributions of the pellet properties. It was demonstrated that the tolerances in relative percent which had been specified on rod fissile content could be applied to fissile content per unit length with a high degree of assurance that the new requirements could be satisfied at a high yield rate (few rejects).

III. C. Thoria Shim Pellets

A simulation was programmed to examine the procedure for assembling fuel rods. In this case the independent random variables were tubing length, bottom end cap insert length, binary pellet length, and thoria pellet lengths. Each fuel rod contains both regular thoria pellets and thoria shim pellets to precisely position the binary stack within a fuel rod and to control the size of the plenum region. This simulation was used to test the concept of shim pellets and to provide some insight into categories of shim pellet lengths needed to successfully load fuel rods.

III. D. Flow Area Between Fuel Rods

METER was used to study the allowances on LWBR thermal capability for blanket fuel rod ovality, shrinkage (collapse of the cladding against the fuel pellets), grooving (additional collapse of the cladding at pellet interfaces because of pellets with tapered ends) and wear (at points where the rods

contact the grids influencing the rod locations). The functional relationship between the subchannel flow area and the ovality, shrinkage, grooving, and wear of fuel rods for constant rod outer diameter and rod-to-rod spacing was programmed into a subroutine and used in METER. METER generated a distribution, a mean, and a standard deviation for the flow area based on input distributions for the independent variables. The minimum flow area was then computed to be the mean minus two standard deviations (95% confidence interval). This use of METER produced a more realistic estimate of the effect on thermal performance of ovality, shrinkage, grooving, and wear than would have been obtained from worst case values of the independent variables.

IV. SUMMARY

METER is a system of computer subroutines and functions which by itself is an incomplete computer program. The METER user must describe the functional relationship between one or more independent random variables and one or more dependent random variables in a subroutine (SIM) which when appended to the METER package produces a working program. METER will process input, generate random numbers, calculate random results, and display the results.

This Monte Carlo tool has found numerous applications related to LWBR at the Bettis Atomic Power Laboratory. It has the potential for dealing with statistical and probabilistic problems which are difficult to solve through analytical methods. METER can be used to compute the frequency distribution of a simple algebraic expression or it can be used to simulate a complex manufacturing process. As an exercise, it can be used to demonstrate and test theories of statistics. In its practical use, METER can compare "worst case" evaluations to statistical evaluations with associated confidence statements.

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REFERENCE

W. R. Cadwell, "Reference Manual - Bettis Programming Environment," WAPD-TM-1181, September 1974.

COMPUTER PROGRAM ABSTRACT

1. Program Name (and Title): METER, A Monte Carlo Simulation System
2. Computer and Language(s): CDC-6600, FORTRAN
3. Problem Solved: METER is a Monte Carlo computer program which can be used to simulate the interaction between independent random variables and their effects on dependent random variables. The program generates random values for independent variables according to input instructions, computes the dependent variable values given the users subroutine (SIM) for computing the dependent variables, and displays results.
4. Restrictions on Complexity of Problem: Depends on size of SIM subroutine, number of variables, and number of histories.
5. Related and Auxiliary Programs: None
6. Typical Running Time: Variable - a few seconds for simple simulations with 1,000 - 10,000 histories.
7. References:
 - (a) W. R. Cadwell, "Reference Manual - Bettis Programming Environment," WAPD-TM-1181, September 1974.
 - (b) B. R. Beaudoin, "Monte-Carlo Simulation Using the METER System - With Applications Related to LWBR," WAPD-TM-1288, October 1976.
8. Unusual Features of the Program: User programs the computation of dependent variables given independent variables into his own subroutine, appends the subroutine to METER, then executes METER.
9. Status: Production
10. Machine Requirements: CDC-6600 or equivalent.
11. Operating System or Monitor: SCOPE
12. Other Programming, Restrictions, or Operating Information: Uses the Bettis Input Package described in Reference (a).
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