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REACTOR EXPERIMENTATION AND THE PACKARD-BELL COMPUTER

MASTER

**Astronuclear Laboratory
Westinghouse Electric Corporation**

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INTRODUCTION

The primary purpose of this report is to provide general knowledge for computer applications to nuclear problems. It is in no way wholly encompassing. For the nuclear engineer, it should provide some ideas for increased data acquisition, reactor monitoring and general reactor experimentation, and for the computer applications engineer and programmers, the programs contained herein may provide some clever techniques to problem solutions. Even some needed basic subroutines are included to add to general field requirements.

The Westinghouse Astronuclear Experimental Facility (WANEF) is the critical experiments unit of Astronuclear, located at the Waltz Mill Site in Pennsylvania, whose task it is to perform basic research and reactor analysis on the NRX series of nuclear reactors to be used in America's first nuclear rocket engine. The report then shows some of the solutions to problems of reactor analysis using a small general purpose computer. While most of the programs discussed here are probably quite unique to WANEF, the reader may find an insight to this own specific problems.

Computer applications to WANEF research tasks have just really begun. The acquisition of a pulsed neutron generator will require computer application for complete problem analysis using this somewhat new technique. This will provide the WANEF facility with increased capability of determining reactor parameters, reduce radiation problems, obtain more data with increased safety and reduce the time required in reactor experimentation. Rapid and accurate analysis would only be possible using a computer system as is available at WANEF.

Future programs, subroutines, analysis techniques, etc., will continue to be published to provide all concerned with the latest information and program techniques that develop in the Computer/Nuclear field.

DATA ACCUMULATION SYSTEMS

The data accumulation systems and techniques described below are separated into counting room and control room systems. The counting room systems include wire and fuel element scanners which were used in flux and power distribution measurements. The section on the control room systems describes the period measurement device, control drum angle indicators, Data Acquisition System, Packard Bell 250 Computer, and a developmental on-line flux distribution detector.

Counting Room Measurement System

SCANNER, WIRE

Introduction

In an effort to establish simplicity and ease of operation in the art of nuclear measurements, a measurement system was developed for the purpose of determining the induced activity as a function of position along a wire or tape. Since this induced activity may be patterned by the flux profile of a reactor, the system provides a simple, efficient method of obtaining such profile data. The system provides the experimentalist with the ability to visually observe the flux distribution so encountered by the wire or tape only minutes after scanning begins. Figure 1 is a photograph of the instrument and figure 2 is a block diagram of the scanner. Figure 3 is a block diagram of the multi-channel analyzer which is used in conjunction with the scanner.

Principle of Operation

If the activity along a wire or tape is represented by the function $A(x, t)$, then:

$$A(x, t) = f(x) \cdot g(t)$$

where, $f(x)$ and $g(t)$ are functions, respectively, of position and time. If the wire material is uniform with respect to position along the wire, then $f(x)$ is representative of the neutron flux distribution in the reactor core at the wire position. The wire material type, of course, determines the particular neutron energy group or groups measured.

The measurement of $f(x)$ is carried out independently of the function $g(t)$. To accomplish this, a wire specimen is mounted on the periphery of a wheel. A detector is then mounted with its face in a plane perpendicular to a radius of the wheel so as to view the activity along the wire. As the wheel is revolved, the position of the wheel is synchronized to the data register and memory of a digital computer such that each particular Δx_i along the periphery of the wheel, and consequently along the wire, always corresponds to the same memory channel. Thus, all the events of radioactive disintegration that occur in Δx_i and are detected are stored in that particular memory channel.

In this instrument Δx_i is equal to 0.50 centimeter or any desired multiple thereof. Since 0.50 centimeter is equivalent to 1.2 degrees of the wheel circumference, a wire nearly 150 centimeters long may be scanned. As normally used, Δx_i is increased to 2.0 centimeters and a wire approximately 144 centimeters long is scanned. The wire is held in place on the periphery of the wheel by mylar tape approximately 2 mils thick. This tape holds the wire against the wheel along the complete length of the wire. The effect of the tape on beta shielding is negligible.

Figure 1. Wire Scanner System

Figure 2. Block Diagram of Wire Scanner

Figure 3. Block Diagram of Multichannel Analyzer

Since the wire is radioactive and has some finite half-life, a small error exists in the data due to the decay of activity between counting the first and the last Δx of the wire. This error may be made as small as possible but there are restrictions imposed by the mechanical and electronic components. Optimization may be achieved by choosing the desired error based on some knowledge of the activity level of the wire and the half-life of the wire material.

Consider the relation of activity with time. Then:

$$f(x) = \text{constant} = f_o$$

$$g(t) = g_o e^{-\lambda t} \text{ where } f(x) \text{ and } g(t) \text{ are defined below.}$$

For fission products $g(t) = g_o \sum_{k=1}^n e^{-\lambda_k t}$, but a mean half-life may be chosen such that the error will be approximately the same as if only one half-life existed. This is permissible since the time required to complete an experiment is such that the decay of fission products closely fits an exponential curve.

Let the activity along the wire be uniform, thus the activity may be expressed by:

$$A(x, t) = f_o g_o e^{-\lambda t}$$

Assuming 100 percent detection efficiency, the counts recorded in memory channel 1 are:

$$C_1 = \int_0^{t_1} A(x, t) dt = f_o g_o \frac{1 - e^{-\lambda t_1}}{\lambda}$$

and the counts recorded in memory channel 300 are:

$$C_{300} = f_o g_o \frac{e^{-\lambda t_{299}} - e^{-\lambda t_{300}}}{\lambda}$$

Then the fractional change between memory channels 1 and 300 is:

$$E = \frac{C_1 - C_{300}}{C_1} = \frac{1 - e^{-\lambda t_1} - e^{-\lambda t_{299}} + e^{-\lambda t_{300}}}{1 - e^{-\lambda t_1}}$$

Δt , the time required for the detector to pass one increment, Δx , is equal to $t_1 - t_o$ and $t_{300} - t_{299}$. Also $t_{299} = 299 \Delta t$. Therefore:

$$E = \frac{[1 - e^{-\lambda \Delta t}] - e^{-\lambda 299 \Delta t} [1 - e^{-\lambda \Delta t}]}{[1 - e^{-\lambda \Delta t}]} = 1 - e^{-\lambda 299 \Delta t}$$

If the wheel speed "v" is given in terms of revolutions per minute then:

$$\Delta t = \frac{60}{300v} \text{ seconds per channel} = \frac{0.2}{v} \text{ seconds per channel}$$

Taking the logarithm of the above expression: $\ln(1 - E) = -299 \frac{\lambda 0.2}{v} = \frac{59.8\lambda}{v}$.

As an example, if $v = 7$ revolutions per minute and $\lambda = 2.125 \times 10^{-4} \text{ sec}^{-1}$, the error between channel 1 and channel 300 is 0.180 percent.

Scanner Console

Figure 1 is a view of the scanner console. The instrument in the top of the console is an AID linear amplifier which has been replaced by a transistorized amplifier. The unit below the amplifier is a bias supply variable from 0 to 300 volts for the solid state detector. Front panel meters allow applied bias voltage and back-current to be monitored continuously. The remaining panel on the console provides master power control and a switch for the wheel drive motor. The detector probe is mounted on the right side of the console. The detector height is adjustable above the wheel although close proximity is always maintained for maximum resolution. Immediately below the probe is the wire specimen scanning wheel. The wheel and associated drive mechanism are shock mounted on the chassis frame.

Solid State Detector

The detector employed as the radiation measurement device on the wire scanner is a surface-barrier junction-type silicon diode manufactured by ORTEC. This is a standard off-the-shelf item fitted with a BNC type connector. The radiation-sensitive face is collimated by a small brass plate so that correct viewing geometry is obtained. The collimator is 1/16 inch brass with a rectangular slot 3/32 inch by 3/8 inch across the plate.

The important detector specifications are listed below. The depletion region depth available to absorb beta particle energy is of primary concern in this application.

ORTEC Detector Specifications

Alpha resolution	30.0 kev FWFM (nominal) 23.9 kev FWHM (actual*)
Noise width	17.5 kev FWHM
Depletion region depth	310 microns, obtained at 120 volts bias
Nominal Resistivity	3100 ohm-cm
The above depletion depth will totally absorb:	

- 1) Alpha particles up to 25.40 mev
- 2) Beta particles up to 0.300 mev
- 3) Protons up to 6.10 mev

* Measured with a 'thin' Am²⁴¹
5.5 mev alpha source

Indexing

The indexing of memory locations and the start (or recycle) condition for the wire scanner is accomplished electronically. The recycle or start pulse is obtained by a magnetic proximity switch which generates an output pulse. This is used to reset the address scaler and the memory advance register in the computer and to return all electronic logic to initial conditions.

Memory location indexing is accomplished by a shutter between a light source and a light sensitive diode. The shutter consists of a wheel mounted on the same rotating shaft as the wire specimen wheel and which contains 300 holes equally spaced 1.2 degrees apart around its rim. These holes provide the shutter action between diode and light source as the wheels revolve. The system generates a voltage pulse which, after shaping with a simple R-C network, is fed directly to an input on the TMC Analyzer - Computer to advance the computer memory address. Memory advance time is about 9.2 microseconds.

Use of Scanner

The operational mode of the scanner is quite simple. Since the periphery of wheel is grooved to facilitate positioning of the wires scanned, source-detector geometry is no problem.

The wire to be scanned is firmly attached to the periphery of the specimen wheel by means of mylar tape. Bias voltage is applied to the detector and the current checked. The wheel is revolved, and all clearances are checked. The TMC 1024 Analyzer-Computer is prepared by clearing the memory, resetting the time normalizer scaler, and setting a preset stop number. When all units are set for starting conditions, the start gate inhibit is disabled and, upon the next start pulse (one per revolution), the data accumulation begins. Also, all stored pulses are sent to the preset overflow scaler. This basically provides an immediate integrated count over the length of wire, and during the time this unit is counting the elapsing time is recorded on a time normalizing scaler. The time base of this scaler can be selected from the WANEF master clock.

The preset count selected is arbitrary and is chosen on the basis of experimental time available, number of wires to be scanned, etc. When this preset count is reached, the wheel continues to turn but data accumulation is stopped when that particular revolution has been completed. The time normalizing scaler is turned off simultaneously.

The data stored in the memory of the analyzer, the time normalizer number, and the location of the wire scanned are three pieces of data required for input to the scanner program for data reduction.

SCANNER, FUEL ELEMENT

Introduction

This system is quite similar to the wire scanner but is designed for counting rigid samples such as fuel elements which cannot be wrapped around the periphery of the wire scanner wheel. Figure 4 is a photograph of the fuel element scanner and figure 5 is a block diagram. Figure 3 as mentioned previously, is a block diagram of the multi-channel analyzer which is used with both scanners.

Principle of Operation

Since the mass of solid state detector (SSD) is small compared to that of a fuel element, the detector is moved and the fuel element is held in place. (Wires may also be scanned if

Figure 4. Fuel Element Scanner System

Figure 5. Block Diagram of Fuel Element Scanner

desired). The detector carriage rides on an I-beam rail and is propelled by a ball bearing lead screw. The lead screw is driven by a d-c shunt wound motor geared to a convenient maximum speed. Since the lead screw is operated at low speeds, the low momentum permits rapid reversal with little strain on the mechanics of the system. The scanning speed is considerably less than that of the wire scanner.

Indexing for memory location is accomplished by the same light-diode technique used in the wire scanner. The shutter plate is mounted directly on one end of the lead screw shaft and has only one small hole so that inaccuracies caused by errors in hole spacings are eliminated. The index rate is four pulses per inch and this can be reduced in the logic control unit by the ratios: 1, 2, 4, 8, or 16. Thus one pulse per four inches is possible.

Drive motor reversal is actuated by carriage limit switches and relays. A mechanical switch is also used to reset the address scaler to zero.

A scan is considered to be one back-and-forth pass. During this scan two data points are obtained for each Δx_i along the fuel element. The memory in the TMC-1024 will only scale in one direction, thus the memory contains two curves which if folded over and added will result in the desired scan.

The largest errors in the data from the fuel element scanner are due to speed variations of the drive motor ($\sim \pm 0.5$ percent). However, if short half life wires are scanned some errors may be introduced at low scan speeds. Since the wire or fuel element is scanned in both directions and the data combined, the error introduced is equal to the amount that the exponential decay deviates from a linear decay over a time interval equal to one scan. For a simple decay scheme:

$$N = N_0 e^{-\lambda t} = N_0 \left(1 - \lambda t + \frac{(\lambda t)^2}{2!} - \frac{(\lambda t)^3}{3!} + \dots \right).$$

A linear decay would be expressed by $N = N_0 (1 - \lambda t)$. Thus, the errors are due to the second and higher order terms.

An estimate of the error for the most pessimistic conditions may be obtained by substituting typical values in the above expressions. Scan time is normally about 60 seconds but may be as high as 100 seconds. Practically, a wire with a half life of five minutes is about

as short as can be scanned. Thus:

$$\lambda = 2.31 \times 10^{-3} \text{ sec}^{-1}$$

Then:

$$\frac{(\lambda t)^2}{2!} = \frac{(2.31 \times 10^{-3} \times 100)^2}{2} = \frac{(0.231)^2}{2} = 0.02 = 2.0\%$$

The error due to decay during the scanning of fuel elements is negligible since the half life is in excess of 30 minutes.

Scanner Console

Figure 4 is a view of the fuel element scanner. The frame construction is rigid to reduce vibration and to support the necessary hardware weight. The carriage for the detector is in the center, mounted on the rail, behind which is the lead-screw. The cabinet enclosure on the left houses the lead screw drive motor and shutter plate. The electronic units on the left in the rack below the table are the lead screw drive motor power supply and the diode bias supply. At the far right, a voltage regulator is installed to provide constant, noise-free line voltage for the electronic equipment.

The upright console next to the fuel element scanner contains the TMC-1024 multi-channel analyzer, output devices (scopes and tape punch), preset overflow scaler (at top) and time normalizing scaler (second from top), plus necessary electronic pulse logic for operation.

Solid State Detector

The same type detector is used in both the wire and fuel element scanners.

Use of Scanner

The operation of the scanner is identical to the wire scanner. It is only necessary to install the fuel element in the design trough with the correct fuel element face toward the detector. All critical spacing is previously adjusted.

AUTOMATIC COUNTING SYSTEM

Introduction

Since some measurement techniques require flux and power mapping in a reactor core and surrounding regions where the use of long irradiated wires is not compatible with the reactor geometry, a simple 2π gas-flow proportional detector system for beta counting short wires and foils is essential. The system should be completely automated in order to use personnel efficiently and to reduce the errors involved in handling large volumes of data. Such a system, using solid state circuitry, was built to WANEF specifications by the Nuclear Chicago Corporation. Figure 6 is a photograph of their NC-8010 system and a block diagram is shown in figure 7.

Principle of Operation

The NC-8010 system consists of three sample changing mechanisms, appropriate amplifiers, scalars, timers, logic and control units and output devices (printer and punch). The detector is a newly designed 2π proportional counter, an end window of aluminum-coated mylar, and uses P-10 gas (90 percent argon and 10 percent methane). The detecting chamber is $1 \frac{7}{16}$ inches inside diameter with trochoidal (curtate cycloidal) profile. The anode is made from 0.002 inch diameter tungsten wire. The resulting plateau (with end window) is 200 volts with 2 percent slope per 100 volts in the Geiger region; 350 volts with 1 percent slope per 100 volts in the alpha proportional region; and 200 volts with 2 percent slope per 100 volts in the beta proportional region.

The sample changers hold 50 samples in the loading chute and upon command (either manual from the operator or automatically from the logic control under automatic operation) the new sample is withdrawn from the bottom of the loading chute and placed in position under the radiation detector. The previous sample is discharged at the bottom of the exhaust chute. In the automatic recycle mode of operation the sample changer will transfer all counting samples from the exhaust chute back to the loading chute for recounting. Various modes of operation are available according to experimental requirements.

Figure 6. NC-8010 Counting System

Figure 7. Block Diagram of Automatic Counting System

Background radiation is reduced in the proportional detectors by the use of brass shielding around the chamber in addition to about two inches of lead around the housing. Each chamber is coupled to a transistorized charge-sensitive preamplifier with a discriminator which uses the triggered-relaxation-oscillator characteristics of a tunnel diode. The output of the discriminator drives a scaler.

The three scalers and the preset timer are located in a single unit chassis having a single display. The elapsed timer and memory storage unit provides a timer which may be used as an elapsed timer or as a time normalizer.

Two additional detectors are available for use with the NC-8010 system. One is a 4π detector for calibration purposes and the other is a 2π detector which can be used as a normalizer in the preset count mode of operation described elsewhere. The counts obtained from this 2π detector are fed to the preset timer which now acts as a scaler and is set to stop counting at some preset value. The elapsed timer now counts at a pre-selected frequency (from the master clock) under control of the preset timer.

An alternate method is to control the preset timer by fixed time gate pulses from the elapsed timer which is fed from the master clock. Thus, if the fixed time pulses are spaced one minute apart, the preset timer will start counting every minute unless it is already counting, or some other mode of operation is under way -- cycle change, readout, etc. This is known as preset time counting.

Console of NC-8010

Figure 6 provides a view of the console arrangement of the various electronic components.

Use of NC-8010

The use of the automatic counting system is described in detail under Sample Changer Program.

TAPE-TO-CARD CONVERTER

The output of the data reduction programs in the Packard Bell computer is in the form of one inch wide punched paper tape. Inasmuch as the IBM 7094 computer is not equipped to handle this tape, the tape was translated onto punched cards by means of an IBM Model 47 tape-to-card punch. This punch was modified at WANEF to enable it to read the Packard Bell punched tape code in addition to the usual IBM punched tape code.

The format of the cards produced from the output of the Sample Changer Program is as follows:

<u>Card Column</u>	<u>Format</u>	<u>Information</u>
1	x	2 punch
2-4	xxx	experiment number
11-16	xxxxxx	core position (e.g., 2J6E08)
18-23	x.xxxx	relative power
26-30	xx.xx	percent error
82	x	1 punch

The format of the cards punched from the output of the Scanner Averaging Program is as follows:

<u>Card Column</u>	<u>Format</u>	<u>Information</u>
1	x	1 punch
2-4	xxx	experiment number
5-10	xxxxxx	core position (e.g., 2J6E08)
11-17	xxx.xxx	axial position (centimeters)
19-24	x.xxxx	relative power
26-33	xx.xx	percent error
82	x	1 punch

SYSTEMS PERFORMANCE

Detector Window Thickness

The flow counters and solid state detectors used in the sample changers and scanners, respectively, are sensitive to both alpha and beta radiation. Inasmuch as both the uranium-aluminum wires and the fuel elements have a large alpha background emission rate, it was necessary to introduce an aluminum window in front of the detectors in order to reduce the background counting rate from an unirradiated sample to a reasonable value. Figure 8 shows the observed count rate from both an irradiated and an unirradiated uranium-aluminum wire in a sample changer as a function of thickness of an aluminum window. The window thickness chosen for use in the PAX experiments was 0.003 inch of aluminum. As the figure indicates, this reduced the background counting rate from 10,000 counts per minute to 1000 counts per minute while affecting the count rate from the fission products in an irradiated wire by only 2 or 3 percent.

Detector Plateaus

Figures 9 and 10 show the count rates from a standard source for a typical flow counter and a typical solid state detector, respectively, as a function of voltage applied to the detector. These were measured with the aluminum windows in place and were used as a basis for determining the proper bias voltage to be used.

Scanner Channel Length

The number of counts accumulated in any one channel of the wire scanner is proportional to the length of that channel. The channel length is controlled by the spacing of the holes in the wheel which provides the stepping pulses to the channel address advance circuits. The uniformity of channel lengths was measured by feeding a high speed pulse generator into the analyzer input while the wire scanner was controlling the channel address advance. If all channels were of equal length the same number of counts should be accumulated in each channel. The experiment indicated, however, a variation of as much as ± 3 percent from the mean channel length. Since the data reduction programs could

Figure 8. Count Rate vs Window Thickness of 2π Counter

Figure 9. Gas Flow Counter Plateau

Figure 10. Solid State Detector Plateau

compensate for this variation if it were constant, further tests were made to determine to what extent successive measurements of relative channel lengths showed correlation. The results of several such tests indicated that any one channel length remained constant within ± 0.2 percent over a period of several days.

CES Irradiations

Overall performance of the Model 8010 sample changer system was checked prior to assembly of the PAX reactor by means of test irradiations in the CES reactor at the Westinghouse Reactor Evaluation Center. Consistency of the points indicates a fairly high precision.

Control Room Systems

PERIOD PICKOFF

Reactor "on-line" data is obtainable by several modes at WANEF. The reactor operations console contains a two-pen cross-over strip chart recorder which displays continuously a running record of the logarithm of the neutron flux level and a scaled linear neutron flux level. Responses of the neutron flux to either a positive or negative reactivity change are recorded and can be utilized to determine periods or shutdown reactivities.

Another linear recorder is used to control a sweep 60 second clock by turning the clock "on" during the time required for the neutron flux to increase a factor of e , (2.718), as the reactor power level is exponentially increasing. The output consists of a clock displaying the reactor period in seconds. The period can be read to within 0.2 second. The method of measuring the slope of the log N trace to determine the reactor period is not necessary since the period clock does this.

DRUM POSITION INDICATION

The positions of the PAX control drums are indicated by Kearfott "Precision Angle Indicators" (PAI), shown in figure 11 at the center of the console. Figure 12 gives a close-up view of the resolver and Precision Angle Indicator. These are simple servo-resolver systems having excellent accuracy and tracking characteristics. The calculated accuracy is 7.8 minutes and the experimentally determined accuracy is about 6 minutes averaged over the 12 position angle indicators. A drum position can be reproduced to within 1 minute. The output of the PAIs is visual and all twelve are simultaneously displayed.

DETECTORS, BUFFER AND MULTIPLEXER

The data acquisition system (DAS) is a collection of detectors and nuclear electronic instrumentation designed primarily to collect experimental data and is not associated with the control console. The DAS is all digital and has three data channels. Any pulse generating detector may be used in any channel.

The output of the DAS may be either of two modes, manual, or fully automatic. In the auto-mode the entire system is computer controlled. The computer control is established between the DAS and itself by a parallel entry logic multiplexer and a high speed buffer. This allows the computer to scan the various units of the DAS and obtain all the binary coded decimal input data, convert it to computer language and store this data word in the computer. Refer to figure 13 for a block diagram of the DAS, multiplexer computer system. Because of the computer design, the automatic control of the DAS is affected by program (software) status and as a result, can be as varied as programs can be written. Either very simple experiments can be set up in auto-program or complex dual coincidence experiments may be performed with little more than a program rewrite to fit the requirements.

Figure 11. PAX Control Console

Figure 12. Data Acquisition System

Figure 13. DAS Block Diagram

Some examples of programs for DAS auto-control are:

- 1) Continuous DAS output as a function of time;
- 2) Output five DAS time cycles, average count calculate $1/c$ (for approach to critical);
- 3) Reactor "on-line" period measurement; and
- 4) Drum worth calculation from "rod drop" flux decay.

The output of the computer is available in three forms: Flexowriter, punched on paper tape or plotted on an incremental X-Y-Z plotter (Z-axis refers to pen modulation). While these are "on-line" computer operations, the computer may actuate the DAS and then transfer to output to efficiently use all cycle time.

PACKARD BELL 250 COMPUTER AND FLEXOWRITER

The computer used in the WANEF operation is a Packard Bell 250 (PB-250) shown in figure

14. The buffer is a PB unit, HSB-22, and the multiplex is a custom unit built by Control Logic, Incorporated.

The PB-250 specifications in abbreviated form are:

Type	-	Serial, binary, internal program
Command Structure	-	Single address with index register and next instruction location tag
Number of Commands	-	51
Operation Times	-	Add/subtract - 12 micro seconds
		Double precision add - 24 micro seconds
		Multiply - 276 micro seconds
		Divide - 252 micro seconds
		Square root - 252 micro seconds
		Access time (optimized) - 12 micro seconds
		Access time range - 12 to 3072 micro seconds
		Fast access time range - 12 to 192 micro seconds
		Maximum operation rate - 41,666 instructions per second

Figure 14. PB-250 Computer System

Word Length	-	21 bits plus sign
Memory	-	Type - Magnetostrictive delay lines Capacity - 2320 words
Power Requirement	-	115 volts, 60 cps, 110 watts
Standard Input/Output	-	Model FX-1T Flexowriter (table mount) or Model FX-1R (rack mount) with paper tape reader and punch 11 control input lines 32 control outputs on 5 lines High speed block input/output at 85,000 words/sec

ON-LINE FLUX DISTRIBUTION

Since access to the internal locations of the PAX reactor is restricted due to fuel element design, only small diameter devices can be inserted into the core. Uranium-aluminum wires inserted in long tubes were used to measure flux during this experimental program.

An on-line detector sufficiently small to be inserted in the fuel element flow channels was constructed by Oak Ridge, Technical Enterprises Corporation utilizing a silicon diode charged-particle detector. Construction of an operational right circular cylinder solid state diode required a year of development from the time of concept. Figure 15 shows the final design.

The overall diameter of the detector is 65 mils and can easily be inserted into the core. This detector is designed to detect neutrons by measuring the kinetic energy of the fission fragments produced by fissions in U^{235} . The diode surface barrier junction is cylindrical in shape and is immediately adjacent to the inside cylindrical surface of a stainless steel tube which has been coated by electro-deposition with 10,000 Å of U^{235} enriched to ~93 percent. The depletion region or sensitive volume of the diode is only a few microns deep.

Figure 15. "On-Line" Solid State Radiation Detector

The alpha particles emitted by the uranium and its daughters are also detected and produce a signal corresponding to about 4.5 mev energy loss in the diode. This is of no interest except that it provides a 4.5 mev calibration point. The fission fragments possess energies as high as 100 mev and have a very large mass. Consequently, their specific ionization is quite high and the range of the fission fragments, even at 100 mev, is very short. The junction of the diode is coated with 100 Å of gold which has very little effect on either alpha particles or fission fragments. The stopping power of silicon is approximately the same as aluminum. Thus, the one micron minimum depth of the depletion region in the detector is sufficient to completely stop the 100 mev fission fragments. Since the thickness of the U^{235} coating is also about one micron, this causes marked straggling across the U^{235} region such that a large portion of the fission fragments will lose all or a significant fraction of their initial energy before they escape from the U^{235} . Figure 16 shows oscilloscope pictures of measured alpha and fission fragment pulse height distributions as recorded with a multi channel pulse-height analyzer.

The geometry is a little less than 2π and the macroscopic cross-section is low but the detector exhibited adequate sensitivity during initial tests. The approximate sensitivity is 10^{-6} counts/nvt. For its intended application, a high sensitivity is more desirable than energy resolution. However, alpha particles are easily separated from the fission fragments and rejected and the beta and gamma sensitivity is negligible.

The detector characteristics are:

- (1) Detector size - 1.0 mm diameter by 3 mm long bare; 0.5 inch long by 0.065 inch diameter mounted. See figure 17.
- (2) Fast neutron toleration - 10^{13} nvt after which noise increases by a factor of 2 at 10^{14} nvt and increased resistivity requires more bias to establish a depletion region.
- (3) Bias - when new, zero volts required for 5 micron depletion region depth; 5 volts provides 40 micron depth.

Alpha Pulse Height

Fission Fragment Pulse Height

Figure 16. Pluse Height Distributions of Alpha Particles and Fission Fragments

- (4) Maximum bias - 5 volts, 0.09 microamperes current.
- (5) Noise - 18 KEV (FWHM) at 5 volts.
- (6) Active junction area - 9mm.
- (7) Nominal resistivity - 1500 ohm-cm.

One advantage of this detector over the uranium-aluminum wires is the fact that the flux depression across the U^{235} thickness is so small as to be negligible. Thus, there are no correction factors required when the neutron spectrum changes. The electronics required for the detector are commercially available and any manufacture of low noise solid state detector instrumentation can provide the necessary units to make up a measurements system. However, an accurate remote positioning device is required for efficient use of the detector. The method shows promise of providing a highly efficient means of flux mapping in critical experiments.

A crude positioning device was used in conjunction with the detector during one power run in an attempt to obtain an axial power distribution in a flow channel in the J row. The data obtained, (see figure 17), compare poorly with the axial power distributions measured by means of wire or fuel element scanning techniques. If one assumes, however, a constant noise background of approximately 4000 counts per minute and corrects the data accordingly, the data points fall within ± 20 percent of the measured axial distribution. The source of such a large background rate has not yet been found.

Figure 17. Axial Flux Distribution Obtained with Solid State Detector

SAMPLE CHANGER PROGRAM I

Purpose

This program processes data obtained on the WANEF automatic sample changer system to generate neutron flux and power distributions in a nuclear reactor. Output is obtained in both punched tape and typewriter format and consists of the normalized and corrected activities of the samples together with a percent error expressing the statistical uncertainties in the measurement.

A second type of output is also possible and consists of the reciprocal of the corrected activities together with the percent error. This output is used for the purpose of obtaining tables of intercalibration factors expressing the relative sensitivities of the different samples when the samples have all been exposed to an identical neutron flux.

Restrictions

- (1) The input data must be on paper tape in the format described below.
- (2) A maximum of 141 samples can be analyzed.
- (3) The program must be reloaded each time it is used.
- (4) The Octal Utility Package is located in line 01.

Storage

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

Program Equations

The program corrects the data of both the manual and automatic changers in the following manner. The contribution of the background is computed and subtracted from the counts using the formula:

$$n = c - bt$$

where,

c is the measured counts,

b is the background count rate,

t is the counting time, and

n is the corrected counts.

The square of the fractional root mean square error, h, is also calculated. The formula derived, using the principles of propagation of errors, is:

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

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

$$n = c$$

$$h = 1/c.$$

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

The most general is:

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

This is the exact expression for the resolving time correction of a sample which is decaying exponentially with time while it is being counted. If the quantity $(\lambda n \tau)$ is less than approximately 0.001 then an approximation is made in which the quantity $(e^{\lambda n \tau} - 1)$ in the above expression is replaced by the quantity $(\lambda n \tau)$. Also, if the quantity $\lambda(t - n \tau)$ is less than approximately 0.001 then an approximation is used in which the quantity $1 - e^{-\lambda(t - n\tau)}$ is replaced by the quantity $\lambda(t - n \tau)$. If the value of λ is not known, as is the case in beta counting fission foils, then the above equation cannot be used and the program uses instead the formula:

$$N = \frac{nt}{t - n \tau}$$

This equation is exact only if the sample activity is not changing while it is being counted.

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

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

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

$$N = n$$

$$q = h.$$

For all but the normalizing samples, the analysis continues as follows:

- (1) The corrected counts are divided by the corrected counts on the normalizer.
- (2) A correction is made for the relative efficiency of the different sample changers.
- (3) A correction is made for the relative efficiency of the different samples. The variation in sample efficiency can be due either to variations in sample size or to effects such as variations in the self-shielding of the samples.
- (4) A further correction factor can be applied to all the samples in an experiment in order to normalize the results to any desired value.

The equation for the last three mentioned steps is:

$$S = \frac{\alpha N \delta \text{Con}}{N_{\text{Norm}}}.$$

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

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

The symbols used in these equations, are defined under Definitions.

For the alternate form in which the output consists of the reciprocal activities rather than the relative activities, steps 3 and 4 above are omitted and the inverse of the

activity is computed. The appropriate equations for this part of the program are:

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

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

Input Data

The input data required for the program consists of the output data from the counting system and the constants defined in the following section.

The input data tape is broken into "sentences", each one having a format as follows:

- (a) A 2-digit number representing planchet number.
- (b) One space.
- (c) A 4-digit number as described below.
- (d) One space.
- (e) A 6-digit number representing counts on the sample in the first sample changer.
- (f) One space.
- (g) A 6-digit number representing counts on the sample in the second sample changer.
- (h) One space.
- (i) A 6-digit number representing counts on the sample in the third sample changer.
- (j) One space.
- (k) A 4-digit number as described below.
- (l) A carriage return.

The two 4-digit numbers can represent respectively either preset count on the manual sample changer and counting interval or else the counting interval and the elapsed time since reactor shutdown. In both cases there is a scale factor, preset to either 10 or 100, omitted from the second number. There is also a scale factor of 100 omitted from the first number when it represents preset count.

In order to convert the counting interval and the elapsed time to seconds, the clock frequency must be known. This may be any number from 100 to 600,000 pulses per minute.

Constants

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

DEFINITIONS

- (1) B - Run number for identification.
- (2) M - Counting mode, '1' for preset count and '2' for preset time.
- (3) Z - A code which determines the output. If the output is to be proportional to the reciprocal of the sample activity a '1' is used. If the output is to be directly proportional to the sample activity a '2' is used.
- (4) J - The total number of manual and automatic sample changers used. This may be either 2, 3, or 4.
- (6) F - The clock frequency or the rate at which the timing pulses are fed to the interval and elapsed timers.
- (7) F' - Scale factor of 10 or 100 determined by switches on counting system control panel.
- (8) τ - The pulse-pair resolving time for the automatic sample changers in units of 10^{-8} minutes. This factor may be omitted if negligible.
- (9) λ - The decay constant of the sample activity in units of inverse minutes. This factor may be omitted if not known.
- (10) b_i - The background counting rates for each of the sample changers used in units of counts per minute. These factors may be omitted if negligible.

- (11) δ_i - The inverse sensitivity of each of the sample changers used (other than the one containing the normalizing sample) relative to that of the sample changer which contains the normalizing sample.
- (12) $\Delta\tau$ - The square of the fractional root-mean-square uncertainty in resolving time. This factor may be omitted if negligible.
- (13) τ_N^- - The pulse-pair resolving time for the sample changer containing the normalizer foil, in units of 10^{-8} minutes. This factor may be omitted if negligible.
- (14) Δb - The root-mean-square uncertainty in the background counting rate, in units of counts/minute. This factor may be omitted if negligible.
- (15) f - The square of the fractional root-mean-square uncertainty in the product of the values of items 11, 18, and 21. This factor may be omitted if negligible.
- (16) A_N - The number of samples per sample changer. With the exception of the sample changer used for the normalizing sample, each sample changer used must have the same number of samples.
- (17) - Table of sample identification numbers versus the location at which they were irradiated, expressed in an alphanumeric code. This table is not used when $Z = 1$ in item 3 above.
- (18) - Table of sample identification numbers versus the inverse sensitivity of each sample. Those samples whose sensitivity is 1.00 may be omitted from the table.
- (19) - Table of sample identification numbers showing the order in which they were placed in the automatic sample changers.
- (20) N_R - The number of changer cycles of the samples.
- (21) Con - A multiplicative constant applied to each output datum in order to normalize the whole set of data to any desired level.

FORMAT

The format of the input constants consists of the identification number, (from 1 to 20 as the constants are listed above), a termination character (space, tab, or carriage return), the value of the constant, followed by another termination character.

For the background rate and instrument sensitivities the format is: identification number, termination character, 1st constant, termination character, 2nd constant, termination character, etc.

For item 17, the format is: identification number (17), 1st sample number (4 digits), termination character, 1st core location (6 alpha-numeric characters, dash, 6 digits), termination character, 2nd sample number, etc. The table ends with a 0000 followed by a termination character. All six alpha-numeric characters must be given for each sample number and there must be a sample number for each planchet used in those automatic sample changers which were operated in the automatic mode.

For item 18, the format is: identification number (18), 1st sample number, termination character, 1st sensitivity, termination character, 2nd sample number, etc. The table ends with a 0000 followed by a termination character. It is necessary to include in this table only those samples whose sensitivity differs from 1.00.

For item 19, the format is: identification number (19), 1st sample number, termination character, 2nd sample number, etc. The sample numbers must appear in the following order: 1st wire in 1st changer, 2nd wire in 1st changer, ..., last wire in 1st changer, 1st wire in 2nd changer, 2nd wire in 2nd changer, ..., last wire in 2nd changer, etc. The table must end with 0000 followed by a termination character. Only samples in those changers being used in the automatic operating mode should appear in this table.

The order in which the various tables and constants are inserted into the computer is subject to the following restrictions:

Item 4 must precede Items 10 and 11.

Table 17 must precede Tables 18 and 19.

The constants tape terminates with a 99 followed by a carriage return.

Program Execution

This code is written for use with the preset count technique. In this technique a normalizing sample of the same material as the other samples being counted is located either in the manual sample changer or in the first of the automatic sample changers which is then set to operate as a manual changer. The normalizer sample will be counted each time the other samples are counted. In the data analysis, the activity of each of the foils is ratioed to that of the normalizing foil. Changes in the count rate due to decay in the activity of the foils is automatically compensated for since the normalizing foil count rate is changing proportionally. In addition, if the results of two or more foil exposures in the reactor are to be compared it is merely necessary to place the same or similar normalizing foils in the same reactor position in each run and the data from the different foils will be automatically normalized to each other, after analysis, independently of differences in the total exposure.

Generally, the sample changers are set to accumulate some preset count on the normalizer; hence, the name, "preset count technique." The code herein described is sufficiently general however, that a preset time may be used to determine the length of the counting intervals.

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

- (1) Return to OUP (located in line 01).
- (2) Insert Part I of Program Tape into the tape reader.
- (3) Type "F" to read tape in under control of OUP.
- (4) When tape has been input, insert the constants tape.
- (5) Type "T" to read tape in under program control.
- (6) When tape has been input, insert Part II of the Program Tape.
- (7) Type any remaining constants in appropriate format as described above.
- (8) Type "99" followed by a carriage return. This will start the program tape.
- (9) When tape has been input insert the Data Tape.

- (10) Special instructions used at WANEF but not essential to the program:
Depress Enable and Breakpoint, punch a leader, a 2, the experiment number, a stop code, and a leader; turn punch off; raise Enable and Breakpoint.
- (11) Type "T" to start data tape read-in under program control.
- (12) Final program halt displays "37" in the operand lights.
- (13) Special instructions used at WANEF but not essential to the program:
Punch a leader, a lower case, and a leader.

Special purpose instructions which are sometimes useful are given below.

- (1) To re-start data tape: Return to OUP, do step 10 if desired, type "31006 \$ + 0000000C/R T".
- (2) To repeat last computation: Return to OUP, delete unwanted information from output tape, type "05602."
- (3) To return to step 7: Return to OUP, type "32303." This is valid only if Part II of the program tape has not yet started to read in.
- (4) To add extra digits to relative power type "25606\$ + 0703040 C/R" after Part II of program tape has read-in.
- (5) To continue to additional cycles after last one called for on constants list: Return to OUP, type "32104."

Output

DATA

The output data contains the core location, sample number, counts, relative flux (or fissions/gram) or reciprocal activity, percent error, and elapsed time, if used.

In addition, the following error callouts are provided.

- Error 1 - The interval time is zero.
- 2 - No background rate was input.
- 3 - The count was less than the background. No output is calculated for this particular sample.

- 4 - No resolving time was input.
- 5 - No decay constant was input and the quantity y was greater than approximately 0.05. This indicates that the calculation of relative power has excess errors due to the approximations used.
- 6 - A decay constant was input and the quantity λy^2 is greater than approximately 0.001. This indicates that the calculation of percent error is incorrect due to the approximations used.
- 7 - The number of sample changers was not specified. Program halts.
- 8 - A sample number specified in Table 18 or 19 was not in Table 17.
- 9 - A decay constant was input and the quantity λy was greater than approximately 0.001. This indicates that the calculation of percent error was incorrect due to the approximations used.

FORMAT

The computed results are output on the punched tape as follows: core location, tab, relative power, tab, percent error, carriage return. The results are output on the typewriter in the form: core location, tab, sample number, tab, counts, tab, relative power, tab, percent error, carriage return. In the mode where the reciprocal of the sample activities is called for, the punched tape format is: a sample number, tab, reciprocal activity, carriage return. The typewriter output is: tab, sample number, tab, count, tab, reciprocal activity, tab, percent error, carriage return.

If an elapsed time is used, this is output on the typewriter after the percent error in both of the above modes.

PART I A
EXECUTES ITSELF AS PART I OF PROGRAM TAPE IS BEING READ IN.

PART I B
IS EXECUTED WHEN CONSTANTS TAPE IS READ IN.

PART II A
EXECUTES ITSELF AS SECOND PROGRAM TAPE IS BEING READ IN.

PART II B
IS EXECUTED AS DATA TAPE IS READ IN.

PART II B CONTINUED

PART II B CONTINUED

PART II B CONTINUED

PART II B CONTINUED

Identification

WANEF Sample Changer Averaging Program I.

Purpose

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

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

Reference

WANEF Sample Changer Program.

Restrictions

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

Storage

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

Program Equations

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

1) An error-weighted average of the input data, S_i , i.e., obtained at each location, L_i , using the formula:

$$\bar{S}_i = \frac{\frac{1}{E_m S_i \beta_i}}{\frac{1}{(E_m S_i)^2 \beta_i}}$$

where the summations are carried out over all the data, at any one location, from every cycle. The E_m are separate normalizing constants for each cycle and the β_i are the squares of the fractional root-mean-square errors in $E_m S_i$ as given by the formula:

$$\beta_i = \frac{s_i^2}{100} + \Delta E$$

where the s_i are the percent errors from the input data.

2) The fractional root-mean square error in $\bar{S}_i$, defined as $\bar{s}_i$, is computer using the formula given below which was derived from propagation-of-error techniques.

$$\bar{s}_i = \frac{\frac{1}{(E_m S_i)^2 \beta_i}}{\frac{1}{E_m S_i \beta_i}}$$

where the summations are carried out as above.

3) The averaged input data, $\bar{S}_i$, are further corrected by multiplying by a constant, X_i , which can differ for each location. This is used to make any additional corrections for variations in the sample sensitivities beyond those which were made in the Sample Changer Program.

4) The final correction made to the averaged input data, $\bar{S}_i$, is division by a constant, A_v , to normalize them to some desired value.

The formula representing the corrections of steps 3 and 4 is:

$$\bar{S}_i = \frac{X_i \bar{S}_i}{A_v}$$

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

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

$$\bar{s}_i = 100 \sqrt{\Delta A + \Delta X + (s_i)^2}$$

Input and Output Formats

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

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

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

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

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

Constants

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

1. N - The number of different data sentences which appear on each cycle.
2. M - The total number of cycles which will be input.
3. Av - A normalizing constant by which each output power is divided in order to scale the results to any desired value.
4. ΔA - The fractional root mean square error in A.
5. ΔE - The average fractional root mean square error in the E constants.
6. ΔX - The average fractional root mean square error in the X constants.
7. E_m - A table containing one multiplication constant for each input cycle
These constants are used to allow different input cycles to be normalized to each other before they are averaged together.

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

Constants Format

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

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

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

Program Execution

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

1. Return to O. U. P. (located in line 01).
2. Mount the program tape and type "F" to read the tape in under control of the O. U. P.
3. Special instructions used at WANEF but not essential to program operation:
Depress Enable and Breakpoint; punch a leader, a 2, the experiment number (three digits), a stop code, and a leader; punch off, raise Enable and Breakpoint.
4. Mount the constants tape and type a "T" to read the tape in under program control.
5. Mount the 1st data tape.
6. Type any remaining constants in the format of the constants type.
7. Type a "99" followed by a carriage return. This will start the data tape reading in.
8. Program halts in line 17 after end of last data tape.
9. Special instructions used at WANEF but not essential to program operation:
Depress Enable; punch a leader, a lower case, and a leader; punch off.

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

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

There are no error signals in this program.

Program Execution

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

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

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

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

SCANNER PROGRAM

SCANNER PROGRAM

SCANNER PROGRAM

SCANNER PROGRAM

SCANNER PROGRAM

SCANNER PROGRAM

Output

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

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

SCANNER AVERAGING PROGRAM

Purpose

This program supplements the data analysis of axial power and flux distributions in a nuclear reactor, which is performed by the WANEF Scanner Program I. This program is designed to accept the output tapes of the above-mentioned program and to perform further computation on the data appearing on them. It can average the results of multiple measurements of the same data appearing on separate tapes using an error-weighted averaging technique. Using the same technique, it can also fold the data from the fuel element scanner so as to produce the average of the scan up and down the element. It can also renormalize the separate tapes to any desired values and can re-correct the data for axial variations in the sensitivity of the scanner or sample.

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

Restrictions

- (1) The input data must be on paper tape in the format described below.
- (2) A maximum of 8 tapes can be averaged.
- (3) A maximum of 297 data points (different axial locations) can appear on each tape.
- (4) The Octal Utility Package must be in line 01.

Storage

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

Program Equations

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

An error-weighted average of the input data, $\bar{S}_i$ is obtained at each axial position, i , using the formula:

$$\bar{S}_i = \frac{\sum \frac{1}{E_m S_i \beta_i}}{\sum \frac{1}{(E_m S_i)^2 \beta_i}}$$

where, the summations are carried out over all the data, at any one axial position, both from every tape and, for the fuel element data, from the two scans (up and down the element). The E_m separate normalizing constants for each tape and the β_i are the squares of the fractional root-mean-square errors in $E_m S_i$ as given by the formula:

$$\beta_i = \left(\frac{s_i}{100} \right)^2 \Delta E$$

where, the s_i are the percent errors from the input data.

The fractional root-mean-square error in $\bar{S}_i$, defined as $\bar{s}_i$, is computed using the formula given below which was derived from propagation-of-error techniques:

$$\bar{s}_i = \sqrt{\frac{\frac{1}{(E_m S_i)^2 \beta_i}}{\sum \frac{1}{E_m S_i \beta_i}}}$$

where, the summations are carried out as above.

The averaged input data, $\bar{S}_i$, are further corrected by multiplying by a constant, X_i , which is a function of axial position. This is used to make any additional corrections for variations in the axial sensitivity of instruments and samples beyond those which were made in the Scanner Program.

The final correction made to the averaged input data, $\bar{S}_i$, is division by a constant, A_v , to normalize them to some desired value. This correction is generally used to normalize the data of the axial scan to the axial average value.

The formula representing the corrections of the last two steps is:

$$\bar{S}_i = \frac{X_i \bar{S}_i}{A_v}$$

where, $\bar{S}_i$ are the final results which are output.

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

$$s_i = 100 \sqrt{\Delta A + \Delta X + (\bar{s}_i)^2}$$

Input Data

The data tapes are broken into sentences each containing the following data with the format indicated.

- (1) Axial position - a sign, three-digit integer, decimal point, three-digit decimal and a tab.

- (2) Relative Power - a plus sign, one-digit integer, decimal point, four-digit decimal and a tab.
- (3) Percent Error - a plus sign, two-digit integer, decimal point, two-digit decimal, and a carriage return.

The input data tape may contain a maximum of 297 different axial positions. This would be 297 sentences for the wire scanner or 594 sentences for the fuel element scanner.

Constants

DEFINITIONS

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

- Γ - A factor which is 1 if the program input is data from the wire scanner and which is 2 if the program input is from the fuel element scanner and hence needs to be folded.
- N - The number of different axial locations which appear on the input tape.
- M - The total number of tapes which will be input.
- Av - A normalizing constant by which each output power is divided in order to scale the results to any desired value. This is generally used to normalize the output to an average value of 1.00.
- ΔA - The fractional root mean square error in A.
- ΔE - The average fractional root mean square error in the E constants.
- ΔX - The average fractional root mean square error in the X constants.
- E_m - A table containing one multiplication constant for each input tape. These constants are used to allow different input tapes to be normalized to each other before they are averaged together.

- X_i - A table containing one multiplication constant for each axial position. These constants can be used to allow a correction of the data for any axial variations in the sensitivity of instruments or samples.

Format

The format of the input constants consists of the identification number, (from 1 to 9 as the constants are listed above), followed by a termination character (space, tab, or carriage return), followed by the value of the constant, followed by another termination character.

For the tables of items 8 and 9, the format is: identification number, 1st constant, termination character, 2nd constant, termination character, etc.

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

Program Execution

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

- (1) Return to OUP, located in line 01.
- (2) Mount the program tape and type "F" to read the tape in under control of the OUP.
- (3) Special instructions used at WANEF but not essential to program operation: Depress Enable and Breakpoint; punch a leader, a 1, the experiment number (three digits), core location (six alphanumeric), a stop code, and a leader; punch off, raise Enable and Breakpoint.
- (4) Mount the constants tape and type a "T" to read the tape in under program control.
- (5) Mount the first data tape.
- (6) Type any remaining constants in the format of the constants type.
- (7) Type a "99" followed by a carriage return. This will start the program tape reading in.
- (8) Program halts in line 30 when the tape has read in unless it is the last data tape in which case skip to item 12 below.
- (9) Mount next data tape and clear parity by depressing both Enable and Breakpoint.
- (10) Raise Enable and Breakpoint. This will start the data tape reading in under program control.
- (11) Return to step 8 for continuation of instruction sequence.
- (12) Program halts in line 17 after end of last data tape.
- (13) Special instructions used at WANEF but not essential to program operation: Depress Enable; punch a leader, a lower case, and a leader; punch off.

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

SCANNER AVERAGING PROGRAM

SCANNER AVERAGING PROGRAM

SCANNER AVERAGING PROGRAM

SCANNER AVERAGING PROGRAM

OUTPUT ROUTING

SCANNER AVERAGING PROGRAM

Note that in the case of the wire scanner data, the first output of data occurs after the first data point of the last data tape has been read in. In the case of the fuel element scanner the first output does not occur until after the first data point of the return scan on the last data tape has read in.

There are no error signals in this program.

Output

The output data is of the same type as the input data and in the same format.

If it is desired to average tapes in the normalizing format of the scanner program, carry out the following instruction:

02003 \$ 026S3703;

02004 \$ 104S3704;

DECAY CORRECTION PROGRAM

Purpose

This program enables the PB-250 to calculate decay correction factors for non-linear complex decay schemes, such as those occurring from counting mixed fission products, and to apply the decay correction factors (DCF) to later data to determine sample activity independent of decay time.

Restrictions

The program as written calculates decay correction factors relative to 90 minutes after reactor shutdown.

Decay correction factors are calculated for 30-second intervals.

Decay correction factors are calculated for decay times between 30 and 413.5 minutes.

Storage

Line 00: temporary storage

Line 01: Octal Utility Package III

Line 02: Decay Correction Program

Line 03: DC Program and alpha numeric subroutine
 Line 04: Floating point subroutine 0130B
 Line 05: open - not used
 Line 06: Decimal Input-Output subroutine
 Line 07: $\left\{ \begin{array}{l} 30 \text{ to } 157.5 \text{ minutes} \\ 158 \text{ to } 285.5 \text{ minutes} \\ 286 \text{ to } 413.5 \text{ minutes} \end{array} \right.$
 Line 10: DCF
 Line 11: Table

Program Equations

After data has been input all numbers involved are set in floating point format. The equation solved is as follows.

$$K \left[\frac{N}{t^* - N_\tau} \right] - BKG_1 = N^*$$

and $N^* \times DCF = N^1$

where,

- N^* = corrected counts -- not including time normalizer
- N^1 = corrected counts of preset time determination
- K = SNF scaler normalization factor
- t_c = Preset time
- τ = system dead time
- N = uncorrected count data
- BKG_1 = Average background count
- DCF = Decay correction factor
- T_d = elapsed time after shutdown
- f_t = time scaling factor either 10 or 100
- f_q = master clock frequency (minutes)

The first requirement is to establish a real t_c in terms of the correct units to fit the first equation. Time in four binary coded decimal (BCD) digits, is converted to octal and is in terms of thousandths of units of time. The following equation is then solved to obtain t_c in terms of minutes:

$$t_c^* = \frac{t_c}{f_q} \quad (\text{minutes})$$

and again for the elapsed time T_d

$$T_d^* = \frac{T_d f_t}{f_q}$$

After the time factors are corrected, the value of N^* is sought. Then it is necessary to determine the sector number of the memory containing the correct DCF. This is accomplished by the equation:

$$\left[T_d^* - 30 \text{ (min)} \right] \times 2 = S_T$$

and the S_T now undergoes a shift instruction that depends on the Q value of the difference between a constant and the Q of S_T . This shifting technique will adjust directly the sector number of a command to choose a correct DCF.

With the DCF obtained, the equation

$$N^* \times \text{DCF} = N^1$$

is solved and output is fed to the Flexowriter.

A special form of the program is originally used to store N^* in the DCF table until 90 minutes of T_d^* is obtained. At this point, the computer begins DCF calculation based on the following ratio.

$$\frac{N_{90}^*}{N_{T_d}^*} = \text{DCF}_{T_d}$$

This program continues until all data is input. A separate output subroutine will list the DCF table upon operator control.

Input Data

Sample number, 2 digits + space

Count time (t_c), 4 digits + space

Counts, Scaler A, 6 digits + space

Counts, Scaler B, 6 digits + space

Counts, Scaler C, 6 digits + space

Elapsed time (T_d), 4 digits carriage return

Constants

All constants required are input during program execution.

PROGRAM EXECUTION

- 1) Load OUP III
- 2) Zero all lines
- 3) Load decay correct on program
- 4) a) Set the counting system timer clock frequency (f_q) in octal form in terms of pulses per unit time at sector 10102\$.
- b) Set the elapsed timer scaling factor (f_t) at sector 10202\$. This scaling factor = +10 or +100 depending on scale setting switch. If switch is to the left, $f_t = +10$. If switch is to the right, f_t is +100.
- c) Set the system dead time factor (τ) at sector 10302\$ in octal form. This is, at present, +0000754 having a Q of -6.
- d) The daily scaler normalization factor (SNF) at
Sector 10402\$ as + 000x.xxx for scaler C
Sector 10502\$ as + 000x.xxx for scaler B
Sector 10602\$ as + 000x.xxx for scaler A
The program will correct the Q value of the SNF's
- e) Set the background counts averaged on the three scalers (BKG.) at sector 10702\$
- 5) Load data tape in reader and type "T" to enter program.
- 6) If program is halted between tape read and end of output enter 22603. to reset.

Output

The output data is in the following sequence having a format similar to input data:

Sample number, 2 digits plus tab

Elapsed Time (T_d^*), 4 digits plus tab

Counts corrected A, 6 digits plus tab

Counts corrected B, 6 digits plus tab

Counts corrected C, 6 digits plus carriage return

DATA REDUCTION PROGRAMS

Various computer programs were written for the PB-250 computer for processing and reduction of data obtained during the PAX experiments. All but one of these programs are concerned with flux and power distributions in the reactor. The one program permits the PB-250 to be used as an on-line period-reactivity computer. These computer codes are described in detail in the following paragraphs.

Period and Reactivity Measurement Program I

PURPOSE

This program is for PB-250 operation of the DAS in the auto-control mode to determine the period of a reactor which is increasing exponentially in power, and to calculate from the "in-hour" equation the reactivity in dollars. The output data is typed on the Flexowriter.

RESTRICTIONS

(1) Set preset elapsed timer pulse rate at 100 pulses/sec or greater.

(2) Preset time should be set for 0500 with an input pulse rate of 100 pulses/sec.

If other than 0500 is desired for the preset time, change 22104 to + 000xxxx)₈; e.g., 0500 corresponds in 22104 to + 0000764)₈.

(3) 25503 contains error percentage of τ_i compared to $\bar{\tau}$. The octal number here is + 7577777 which alarms on overflow if greater than 2 percent error is indicated. The octal number is scaled at a Q of zero.

(4) Start program after reactor source is withdrawn and all drum movement has ceased. Stop program prior to leveling reactor power.

(5) Do not exceed 10^6 counts/min. count rate on DAS scalars. Above this point, DAS channels approach saturation.

(6) Do not attempt to restart program unless reset tape has been filled.

(7) Flexowriter must be on during computation of $\bar{\tau}$ and \$, but need not be on during data taking.

STORAGE

Line 00: temporary storage
 Line 01: Octal Utility Package III
 Line 02: DAS auto-control program
 Line 03: DAS auto-control program
 Line 04: DAS auto-control program
 Line 05: DAS auto-control program
 Line 10: DAS auto-control program
 Line 06: Decimal Input-Output subroutine
 Line 07: Floating point subroutine
 Line 11: logarithmic subroutine

PROGRAM EQUATIONS

The data words from the DAS must be converted from binary-coded decimal (BCD) to binary to fit PB-250 language. The DAS outputs BCD in the following form:

<u>DAS/BCD Binary Form</u>					
<u>Decimal</u>	<u>4</u>	<u>2¹</u>	<u>2</u>	<u>1</u>	<u>Octal</u>
0	0	0	0	0	0
1	0	0	0	1	1
2	0	0	1	0	2
3	0	0	1	1	3
4	0	1	1	0	4
5	0	1	1	1	5
6	1	1	0	0	6
7	1	1	0	1	7
8	1	1	1	0	10
9	1	1	1	1	11

The largest decimal number is composed of six digits and a multiplier, either 1 or 100. The conversion is accomplished in the following manner. Let the least significant digit (LSD) be called D_1 , the next LSD be called D_2 , etc, and the most significant digits (MSD) be called D_6 . Let $C_1, C_2, \dots, C_6$ be coefficients in A_i in the equation, $A_m b^m + \dots + A_2 b^2 + A_1 b^1 + A_0 b^0$ which defines a given set, here a number system. If the C_i be the octal representation of decimal powers of ten and the D_i be decimal numbers, then a complete converted data word is:

$$D_6 C_6 + D_5 C_5 + \dots + D_2 C_2 + D_1 C_1$$

$$\left[\left(\left[(D_6 C_1 + D_5) C_1 + D_4 \right] C_1 + D_3 \right) C_1 + D_2 \right] C_1 + D_1 .$$

Here, the C_i of the first equation are known, but in the second equation C_i is the basic radix and this equation can only be used when this is known. The first equation is selected,

$C_1 = 1)_8 = 1)_{10}$	$D_1 = \text{units}$
$C_2 = 12)_8 = 10)_{10}$	$D_2 = \text{tens}$
$C_3 = 144)_8 = 100)_{10}$	$D_3 = \text{hundreds}$
$C_4 = 1750)_8 = 1000)_{10}$	$D_4 = \text{thousands}$
$C_5 = 23420)_8 = 10000)_{10}$	$D_5 = \text{tens of thousands}$
$C_6 = 303240)_8 = 100,000)_{10}$	$D_6 = \text{hundreds of thousands}$

and solved to convert from 42' 21 BCD to 8421 octal which is 3 bit binary. All input data undergoes this operation.

The reactor power, in the absence of a neutron source, increases exponentially as:

$$P = P_0 e^{T/\tau} \quad \text{or} \quad N = N_0 e^{T/\tau}$$

where,

P is the power,

N is neutron population

T is time

τ is the period

Let C represent the neutron events that are proportional to N and P , then

$$C = C_0 e^{T/\tau}. \text{ Normalized to } C_0, C_i = e^{t_i/\tau},$$

$$\ln C_i = \frac{T}{\tau} = \frac{t_i - a}{\tau} \quad \text{and} \quad \tau \ln C_i = t_i - a,$$

where, t_i is the time at which the measurement is made and a is a fixed time increment over which C_i is determined. For a least squares fit over all points on an exponential power increase, it follows that:

$$\sum (\tau \ln C_i - t_i + a)^2 = \text{minimum}$$

Taking the partial derivative with respect to τ :

$$\frac{\partial}{\partial \tau} \left[\sum_N (\tau \ln C_i - t_i + a)^2 \right] = \sum_N \tau (\tau \ln C_i - t_i + a) (\ln C_i) = 0$$

Also the partial derivative with respect to a :

$$\frac{\partial}{\partial a} \left[\sum_N (\tau \ln C_i - t_i + a)^2 \right] = \sum_N \tau (\tau \ln C_i - t_i + a) = 0$$

$$\text{Thus, } \tau \sum_N (\ln C_i)^2 - \sum_N t_i \ln C_i + a \sum_N \ln C_i = 0 \quad \text{and,} \quad \sum_N \ln C_i - \sum_N t_i + a \sum_N 1 = 0$$

where, $\sum_N = N$ = number of points used to determine τ

$$\text{Let } \alpha_1 = \sum_N (\ln C_i)^2, \quad \beta_1 = \sum_N \ln C_i, \quad \gamma_1 = \sum_N t_i \ln C_i$$

$$\alpha_2 = \sum_N \ln C_i, \quad \beta_2 = N, \quad \gamma_2 = \sum_N t_i, \quad \text{then,}$$

$$\alpha_1 \tau + \beta_1 a = \gamma_1 \quad \text{and} \quad \alpha_2 \tau + \beta_2 a = \gamma_2$$

Then the solution of the above equations is:

$$\tau = \frac{\begin{vmatrix} \gamma_1 & \beta_1 \\ \gamma_2 & \beta_2 \end{vmatrix}}{\begin{vmatrix} \alpha_1 & \beta_1 \\ \alpha_2 & \beta_2 \end{vmatrix}} = \frac{\gamma_1 \beta_2 - \gamma_2 \beta_1}{\alpha_1 \beta_2 - \alpha_2 \beta_1}$$

Substituting:

$$\tau = \frac{\left[N \sum_{i=1}^N t_i \ln C_i - \sum_{i=1}^N t_i \sum_{i=1}^N \ln C_i \right]}{N \sum_{i=1}^N (\ln C_i)^2 - \left[\sum_{i=1}^N \ln C_i \right]^2}$$

The program uses natural logarithms and all numbers in calculation of τ or β (for reactivity) are held in floating point so as to obtain accuracy when high count rates are involved or long periods of data collecting are encountered. The only restriction involved requires that the count rate be initially set low enough such that at higher reactor power levels, the data channels do not approach saturation.

This form of τ is the equation used to determine τ by a least squares fit to an exponential.

An error will result if the reactor power level is not exponential. Operator control is required to start the program only during the exponential rise. (The program uses natural logarithms and, due to the magnitude of the numbers after $N=10$, rounding off is required; i.e., single precision numbers are used. If the data numbers are too large (count rate too high) and $N > 5$, overflow may occur with no computer alarm - thus an error. This requires that the starting count rate be adjusted so that after data is collected, $N = 10$ or so, no log sums will have overflowed. If the period to be measured is greater than 80 seconds the "rounding off" of the logarithms will cause an error because the incremental change in the logarithm per data step is less than that portion of the logarithm rounded off. Revisions are in process which will eliminate these restrictions.)

After τ , the period, has been calculated, the program proceeds to solve the "in-hour" equation. But since there are three data channels, τ_i , is averaged. And to insure that the average $\bar{\tau}$ is correct, a rejection criteria is required. This compares each τ_i to $\bar{\tau}$. If an error in excess of two percent is found the other two τ_i are used to generate a new $\bar{\tau}$ and the error is again checked. If an error is found, the program will halt on alarm indicating no confidence in any of the three data points τ_1 , τ_2 or τ_3 .

If a $\bar{\tau}$ is established, the equation

$$\rho = \text{reactivity} = \frac{\beta - \bar{\tau}}{\beta} + \sum_{g=1}^6 \frac{\lambda_g \bar{\tau}}{1 + \lambda_g \bar{\tau}} \quad \text{is solved using}$$

Keypin's values for the A's and λ 's.

$A_1 = .038$	$\lambda_1 = 0.0127 \text{ sec}^{-1}$
$A_2 = .213$	$\lambda_2 = 0.0317$
$A_3 = .188$	$\lambda_3 = 0.115$
$A_4 = .407$	$\lambda_4 = 0.311$
$A_5 = .128$	$\lambda_5 = 1.40$
$A_6 = .026$	$\lambda_6 = 3.87$

Since the data point of each interval is actually obtained over a finite interval, the counts collected are the integration over an exponential variation. Consequently t_i at the time when the count begins introduces a slight error. If the count rate is increasing exponentially over a short time interval and integrated counts C_a are obtained, the time $(t + \Delta t)$ at which $C' \times a = C_a$, is desired.

$$C = e^{t/\tau}, \quad C' = e^{\frac{t+\Delta t}{\tau}}$$

$$C_a = \int_t^{t+a} C \, dt = \int_t^{t+a} e^{t/\tau} dt = \tau \left[e^{\frac{t+a}{\tau}} - e^{t/\tau} \right]$$

$$C_a = C \times a = a e^{\frac{t+\Delta t}{\tau}}$$

$$\text{Therefore, } \tau/a \left[e^{\frac{t+a}{\tau}} - e^{t/\tau} \right] = e^{\frac{t+\Delta t}{\tau}} \quad \text{and } t+\Delta t = a - \ln \frac{a}{\tau}$$

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τ (Sec)	Δt (Sec)
40	0.8
30	1.2
20	2.6

Since many of the reactor periods at WANEF are adjusted to approximately 30 seconds a correction factor of one second is added to t_i in determination of $\overline{\tau}$.

The program error was determined by feeding the computer a known set of data of which the period had been hand calculated. The error was consistent and has a value of $\sim \pm 0.5$ percent.

INPUT

Data

All the input data are obtained on-line from the data acquisition and master clock.

CONSTANTS

There are no program constants other than those contained in the commands for execution.

PROGRAM EXECUTION

- (1) Load OUP III in line 01 as per requirements.
- (2) Load "zero" tape and zero all lines except 01.
- (3) Load the period measurement program.
- (4) Stop and reset elapsed timer.
- (5) Push DAS manual reset button.
- (6) Push switch SW2 manual reset on multiplex test control panel.
- (7) Type "T"
- (8) Set preset timer to 0500 and input rate to 100 per second (No. 1 time selector) (extreme left hand knob) on master timer.

(9) Set elapsed timer pulse rate to 100 per second (No.2 time selector) on master timer.

(10) Start elapsed timer to begin program and depress "enable" to stop program but then only during a count. The program may also be terminated by stopping the elapsed timer.

(11) At completion of program, depress "enable" and "breakpoint" switches and type "I", lift "enable" and "breakpoint", and type I7I02. to enter $\bar{\tau}$ and \$ computation. Program output is included and program will stop with HLT (34).

(12) Alarm signals are identified as follows:

HLT 33: there is no average accurate to less than 2 percent

HLT 32: invalid or a negative period

HLT 34: program end

(13) Auto-control between PB-250 and multiplex is established by certain software commands. Use of the following commands will provide all necessary DAS control.

TES 22:	order of magnitude of Scaler	#1	}
TES 23:	order of magnitude of Scaler	#2	
TES 24:	order of magnitude of Scaler	#3	

TES 25: Data offer - intercycle ready

TES 26: Cycle start

PTU 7000: High Speed Buffer set

PTU 7001: Data Acknowledge - Multiplex advance

PTU 7002: System Reset

BSI 7300: Data input

OUTPUT

The period and associated reactivity are the only output from the program.

Format

Period π = +xxx.xx

Reactivity in \$ = +x.xxx.

Shutdown and Reactivity Measurement Program II

PURPOSE

This program is for PB-250 operation of the DAS in the auto-control mode designed to calculate count rate ratio between constant power and shutdown. From a look-up table, this ratio "R" then chooses a value of reactivity "\$" corresponding to "R".

The output is typed on the Flexowriter -- a value of "R" and "\$" for each of the three input channels.

RESTRICTIONS

1. Count rate at level power should not exceed channel saturation to 10 Kc/sec, random pulses.

STORAGE

00 : temporary storage

01 : OUP III

02 : S. & R. M. Program II

03 : S. & R. M. Program II and alphameric output

04 : S. & R. M. Program II

05 : S. & R. M. Program II and table of constants and table of \$

06 : Decimal Input-Output

07 : Table of R

10 : S. & R. M. Program II

11 : Log and exponential subroutine

INPUT

All data input to PB-250 by DAS in auto-control mode.

PROGRAM EQUATIONS

Let $\bar{n}_0$ be the average count rate of a neutron detector channel, and let n^* be the count rate at a time 15 seconds after reactor shutdown, then the ratio

$$\frac{n^*_i}{\bar{n}_{0i}} = R_i \quad \text{where } i \text{ is a subscript to}$$

denote a specific channel number. This analysis for an intermediate spectrum reactor along with the relationship between "R" and reactivity "R", easily yields "\$".

In the program, the log (base e) of the count is obtained instead of using floating point procedure. Thus

$$\ln R_i = \left[\ln n^* + \ln 10 - \frac{\sum \ln n_o}{12)_8} \right]_i$$

where $\ln_e 10 = 2.233)_8 = 2.30)_10$ which is a time correction for n^* .

PROGRAM

1. Sector 22402\$ sets the program procedure where

Case I: Computer scrams reactor

command: 22402\$ 226 7735 (TES-35)

delay: 24502R +0011001 (about 14 sec)

words: starting at 21202\$ for 10 sectors,

"PUSH BREAK POINT FOR SCRAM"

Case II: Computer senses a scram

command: 22402\$ 240 7730 (TES-30)

delay: 24502\$ +0011001 (about 14 sec)

words: starting at 21202\$ for 10 sectors

"SCRAM ONE DRUM OR ALL - SET P.T."

2. The delay determines count start 14 secons after shutdown for a two-second period. Slope from 14 to 16 secons is considered linear.

$$\begin{array}{lcl} \text{total delay} & = & \text{system} + \text{PTU} + \text{delay} + \text{scram} = 14,000 \text{ ms} \\ & & \text{reset} \quad \text{to delay} \quad \text{action} \end{array}$$

$$3.0 \text{ ms} + .124 \text{ ms} + 13832 \text{ ms} + 165 \text{ ms} = 14,000 \text{ ms}$$

3. Clock frequency to elapsed and preset timers = 100 cps

The Preset time during averaging = 20.00 seconds

The Preset time for shutdown = 02.00 seconds

The sector containing this for check is at 22104\$
with +0003720 for 20 seconds (i.e. "2000")
and with +0000310 for 2 seconds (i.e. "0200")

PROGRAM EXECUTION

- 1) Return to OUP III for keyboard control.
- 2) Load S. & R. M. Program II and type "F".
- 3) Turn on multiplex and check out data (DAS) system.
- 4) Set preset time to 2000.
- 5) Stop and reset elapsed timer and set preset timer and all data scalers on remote operation. Push manual system reset.
- 6) Reset multiplex and read 12 VDC on meter.
- 7) Type "T" to enter program.
- 8) Start elapsed timer.
- 9) After 10 count intervals have elapsed, the PB-250 will type instruction either: "Push Breakpoint for Scram" or "Scram One Drum or All - Set P.T." Set the preset timer to 0200 and comply with instruction. After the 2 second count interval starting at 14 seconds, "R" and "\$" will be output.
- 10) To reuse program, load "reset" tape and type "F".
- 11) Return to step 5.

OUTPUT

Output is typed only and has the following form:

R = + . X X X

\$ = + X . X X X

On-Line Reactivity Measurements

General purpose analog computers are programmed by hardware changes which cannot compete with the flexibility of digital computers where program changes are strictly software. Analog computers have for some time been used for the continuous measurement of reactivity of a nuclear reactor. A digital computer may be used for the same purpose by compiling an appropriate program in time for use with the next critical experiments. A program to provide continuous calculations of reactivity as a specific experiment progresses is expected to be completed at WANEF. The technique will be to measure the count rate from BF_3 proportional counter and sample the count rate over a time interval as a function of precalculated error. The output has not yet been decided but could be either a digital display, an x-y digital plot, or a typed format. The equation to be solved is

$$\frac{\Delta k}{k_{\text{eff}} \bar{\beta}} = \rho = 1 + \frac{1}{N} \left(\frac{\ell^*}{\bar{\beta}} \frac{dn}{dt} - \sum \lambda_i x_i - \frac{\ell^*}{\bar{\beta}} S \right)$$

where,

$$\frac{\ell^*}{\bar{\beta}} \frac{dC_i}{dt} = \frac{d x_i}{dt} = m a_i - \lambda_i x_i$$

- N = total neutron population in the reactor
- $\bar{\beta}$ = effective delayed neutron fraction
- C_i = total population of delayed neutron precursors of the type i
- $A_i = \frac{B_i}{\bar{\beta}}$ = effective fraction of delayed neutrons produced by neutron precursors of the type i
- λ_i = decay constant of the delayed neutron precursors of the type i
- ℓ^* = effective neutron life time
- Δk = excess multiplication reactivity in dollars, since $k_{\text{eff}} \cong 1$
- S = source strength

In the above equation dN/Jt is measured by the DAS computer system and applied to the equation where the values for the precursor groups are taken from LASL's data of Dr. Keepin.

DATA PLOTTER PROGRAMS

The Packard Bell Model DR-1 digital recorder may be operated under computer control for plotting one variable against another as computer output. Provision for Z-axis modulation is incorporated through the use of a pen solenoid for control of pen contact with the recording surface. Capable of high speed operation, this solid state recorder utilizes a self-contained power supply.

Specifications

- Speed - X-axis - 200 increments per second maximum
Y-axis - 200 increments per second maximum
Z-axis - 10 operations per second maximum
- Recording - An increment is 0.01 inch movement of the pen or drum in either a positive or negative direction.
- Control - Under computer control, the recorder functions in any of six operating modes (+X, -Y, +Y, -Y, Pen Up, Pen Down). Front panel controls are provided to turn power on and off, to turn paper roll take-up motors on and off, to raise or lower pen, to drive the drum in either direction a single increment or at a 120 per second rate, and to drive the pen a single increment, or at a 120 increments per second rate. Limit switches are provided at each end of the chart to limit the pen-carriage excursion. The X-Y plotter is controlled by computer software and the system has unlimited versatility. Any number of marking symbols may be used with appropriate programming.

X-Y Data Plotter Program I

PURPOSE

This program inputs a fixed point decimal number from either the Flexowriter keyboard or paper tape reader and plots the point on the DR-1 X-Y Plotter.

RESTRICTIONS

- 1) The only characters which should be entered are plus (+), minus (-), 0-9, space, carriage return and tab.
- 2) The magnitude of the number, ignoring any decimal point must be less than 14400 for the X-axis and 1000 for the Y-axis.
- 3) The X-point is first entered and the Y-point is second entered.
- 4) Storage: Sectors 000-045 of Line 04
Decimal Input-Output 1A (Cat. No. 0111A) in Line 06
OUP III in Line 01
XY Plotter DR-1 subroutine in Line 07

INPUT

The input number is of the form

SI. FT

where,

S is the sign of the number,

I is the integer part of the number,

F is the fractional part of the number and,

T is the termination character.

If no sign is input, a plus is assumed; if no decimal point is input, an integer is assumed.

PROGRAM EXECUTION

The program is not line relocatable and is loaded into Line 04 by means of the OUP III (0001B). Each subroutine is located into the line number above. (See Storage.)

Sectors 007 and 027 of Line 04 locate the decimal S.R. in Line 06 through the Index Register.

Sectors 013 and 033 set Q for the decimal S.R., which is its input keyword.

Sectors 015 and 035 of Line 04 set return instruction for decimal S.R.

Sectors 016 and 036 of Line 04 should read 000S3706 for keyboard input or 005S3706 for tape input.

If an error is made while typing, the program may be reset by typing the sign (+ or -) followed by the correct number. Code deleters read from tape are ignored, as are spaces between the sign character and first digit, which may be used to represent leading zeroes.

No error alarms are provided by the input program.

Sector 04504 contains entry to X-Y plotter DR-1 subroutine.

Sector 04404 contains the return command of the X-Y plotter subroutine to this line 04 program. This appears as 000SCC04. According to the option of the operator

CC = 34 will trace a curve point to point;

CC = 35 will trace a curve point to point and mark each point;

CC = 37 will only mark each input point;

CC = 36 will move the pen but will never lower the pen;

CC = 75 reset to (0.0).

Address 00004. will enter program.

X-Y Data Plotter Program I-A

Purpose

This program resets the plotter register to zero.

Restrictions

None.

Storage

Four sectors of any line.

Input

None.

Program

```
000LL $ 001S04LL; LDC
001LL $ 003S75LL; TOF

002LL $ 000S3707; TRU (XY program No. 0123)
003LL $ 003 00AB;      (in line 07      )
                        where A&B are any two line numbers.
```

Program Execution

Manually set X-Y plotter to zero point as required for the specific plot. Enter 000LL for execution.

X-Y Data Program II

Purpose

This program inputs up to 254 X-data points and up to 254 Y-data points of BCD (8421) information into the PB 250 memory from tape, where data on one tape consists only of X- data and data on the other tape consists only of Y-data.

RESTRICTIONS

- 1) Data point magnitude for Y axis = 1000
Data point magnitude for X axis = 2000
- 2) X tape entered first.
Y tape entered second.
- 3) The data tape must be masked if data format is other than explained in X-Y

Program I. The TMC analyzer tape is discussed here.

- 4) No more than 254 points in X and Y for a single plotting procedure.

STORAGE

Sectors 374-377, 000-077 of line 04

Decimal input-output 1A No. 0111A in line 06

OUP III in line 01

X-Y Plotter DR-1 subroutine in line 07

INPUT

X data is input under tape mask with 00704\$ 000S3702. The Y data is input under tape mask with 0074\$ 000S3703.

Refer to Program I for data format.

The TMC data tape appears as:

Data required:

	data point	set	data point	set
	These are "code delete" punches:			
0	0 0 0	0	0 0 0	0
0	0 0 0	0	0 0 0	0
0	0 0 0	0	0 0 0	0
0	0 0 0	0	0 0 0	0
0	0 0 0	0	0 0 0	0
0	0 0 0	0	0 0 0	0

PROGRAM EXECUTION

- 1) The program is not line relocatable and is loaded into line 04 by means of the OUP III (0001B). The subroutines are on the same tape for lines 06 and 07.
- 2) Load OUP III.
- 3) Load Program II -- to fill, type "F"
- 4) Install mask and data tape in reader together if required
- 5) Synchronize data points and "set" command (either space, C.R. or tab)
- 6) Adjust first data point just prior to the reader head
- 7) Enter 37404. Program and tape will halt when 254 data points are entered. There is no alarm in program to stop on inconsistent data tape. Tape loading should be closely observed.
- 8) Install mask 00704\$ 000S3703; and Y data tape
- 9) Enter 37404. Program will halt when all data points are entered.
- 10) Turn on X-Y plotter and warm up for 5 minutes. Manually adjust zero to the right side of recorder chart. Execute XY Data Program IA for XY plotter zero.
- 11) Enter 04004. to plot
- 12) Install and load reset tape before loading any new data. The reset tape consist of the following:

```
02$Z00002$377S2502
03$Z00003$377S2503
01704$+0000000
02104$+0000374
W
```

X-Y Data Plotter Program III

PURPOSE

This program in conjunction with Data Plotter Program I inputs Y data from tape and generates the X data sequentially.

STORAGE

Line 01	OUP III
Line 04	Plotter Program III and I

INPUT

Y data is input from tape with a mask to locate the decimal points, if desired.

PROGRAM EXECUTION

- 1) Load OUP III line 01.
- 2) Load Plotter Program I by typing "F".
- 3) Load Plotter Program III by typing "F".
- 4) Turn on X-Y plotter and check out.
- 5) Zero X-Y plotter - raise pen. Zero plotter by Program IA
- 6) 00504 should contain first X data point required minus the value of a single increment.
(Remember, the X-axis is scaled at 1/100th inch per unit integer, e.g. $100/10 = + 0000144/8 = 1$ inch travel in plus X direction)
- 7) 00704 should contain octal value of X increment required.
- 8) 01304 should contain largest value of X required (for automatic program halt at some X-value).
- 9) enter 00004.

Control Tape III

05402\$+0043120	11702\$+0000144	T32202\$+0005400
T32202\$+0005100	32202\$+0004600	05402\$+0011300
05402\$+0045400	05402\$+0074740	T32202\$+0005360
T32202\$+0005060	T32202\$+0004500	05402\$+0013560
05402\$+0047660	5402\$+0077220	T32202\$+0005340
T32202\$+0005040	T32202\$+0004400	05402\$+0016040
05402\$+0052140	05402\$+0101500	T32202\$+0005320
T32202\$+0005020	T32202\$+0004300	05402\$+0020320
05402\$+0054420	5402\$+0103760	T32202\$+0005300
T32202\$+0005000	T32202\$+0004200	05402\$+0022600
05402\$+0056700	05402\$+0106240	T32202\$+0005260
T32202\$+0004760	TW	05402\$+0025060
05402\$+0061160	11702\$+0000764	T32202\$+0005240
T32202\$+0004740	32602\$+0000020	05402\$+0027340
05402\$+0063440	32202\$+0005500	T32202\$+0005220
T32202\$+0004720	05402\$+0000000	05402\$+0031620
05402\$+0065720	T32202\$+0005460	T32202\$+0005200
T32202\$+0004700	05402\$+0002260	05402\$+0034100
05402\$+0070200	T32202\$+0005440	T32202\$+0005160
T32202\$+0004660	05402\$+0004540	05402\$+0036360
5402\$+0072460	T32202\$+0005420	T32202\$+0005140
T32602\$+0000100	05402\$+0007020	05402\$+0040640
		T32202\$+0005120

PURPOSE

This program inputs data in the form of relative power or fissions per gram at a particular R and O location and plots at a constant O or R, as required.

In other words, this program accepts three variables of input data (U, V, W), plotting a family of curves as U vs V at various values of constant W. Here, specifically, the variables are P, O, R.

RESTRICTIONS

- 1) The data must be input as R, θ and P in the proper format.
- 2) A maximum of 141 data points may be input during one plotting execution.

STORAGE

Line 01: OUP III
 02: Plotter Program IV
 03: Data storage
 04: Data storage
 06: Decimal Input-Output IA
 07: X-Y Plotter Program 0123
 10: Plotter Program IV A

INPUT

R = XX.XX space
 θ = XX.XX space
 P = X.XXXX carriage return

PROGRAM EXECUTION

Loading the Program: Part I

- 1) Load the OUP III and check out computer.
- 2) Load the tape reader with Plotter Program IV and type "F".
- 3) Set 056 of Line 10 to last data sector in memory storage of either Line 03 or 04.

For example, if there are 141 data points (where one point is defined by an "R", " θ ", and "P"), 85 of these will be loaded into Line 03 (where Sector 377 of Line 03 is not used) and 56 of them will be loaded into Line 04. Thus, $3 \times 56 = 168$ (base 10) = 250 (base 8), but the first data point of line 04, will go into Sector 000 of Line 04 so the last sector to contain data will be 250 (base 8) - 1 = 247 (base 8). Thus, 05610 \$ 247 1104; (STA).

- 4) Load data tape in reader and type 00010. to enter data load program IV A.
- 5) Tape and program will halt with a "21" operand after 141 data points are loaded.
- 6) Set Sector 202 of Line 02 to 1 less than last data sector of memory for a program of constant θ , thus from 3 above, 202 02 \$ 246 0504. Here, 24604 contains the last value of θ to be checked.

For a program of constant R, set Sector 202 of Line 02 to 2 less than the last data sector of memory. Thus, from 2 above, 20202 \$ 245 0504.

- 7) Sector 07502 determines whether the constant value of θ to be chosen should be positive or negative. (R is always positive.) For + θ , set 07502 \$ + 0000001. For - θ , set 07502 + 0000000.

- 8) Since values of R & θ are stored at Q = 22 in LL = 03 & 04, the incremental value (Δ) and greatest upper bound (g.u.b.) are also scaled at Q = 22. Thus, Sector 32202 must be set with the octal value of the g.u.b. and Sector 32602 must be set with the octal value of Δ .
e.g., 32202 \$ + 000052.4 cm
32602 \$ + 000000.2 cm.

Decimal points in data word are for readers benefit only, not to be typed into computer as such.) In 32602, $0.2)_8$ cm indicates $= .2)_8$ cm $= .25)_{10}$ cm and in 32202, $52.4)_8$ cm indicates the g.u.b. $= 42.5)_{10}$ cm. Thus, the radius is chosen from all values from 42.25 to 42.50 cm.

- 9) Turn on X-Y plotter and allow a few minutes for warm-up.
- 10) Manually set X-Y plotter zero and adjust paper, as required and reset plotter Register.
- 11) 02702 should be set with X-axis multiplier. It is set for $10)_{10}$, normally
- 12) Either enter "T" from keyboard or load control tape III if large numbers of points repeated must be plotted. Enter by typing "F" if tape is used. If tape is not used, set 33402 \$ 334 0022.
- 13) The program is written as P vs θ constant R. The following changes are required for P vs R at constant θ and R vs θ at constant P.

A. P vs R at constant θ

000102	\$	376 0503;
01502	\$	067S3702;
33202	\$	376 0503;
17202	\$	375 0503;
17602	\$	376 0504;
20202	\$	375 0504;
02002	\$	021S1502;
04302	\$	001 0000;

B. P vs θ at constant R

00102	\$	375 0503;
01502	\$	320S3702;
33202	\$	375 0503;
17202	\$	374 0503;
17602	\$	375 0504;
20202	\$	374 0504;
02002	\$	021S1402;
04302	\$	002 0000

C. R vs θ at constant P

00102	\$	377 0403;
01502	\$	320S3702;
33202	\$	377 0503;
17202	\$	376 0503;
17602	\$	377 0504;
20202	\$	376 0504;
05402	\$	+0000000;
02002	\$	121S1502;
12102	\$	002 0000;
04202	\$	043S1502;
04302	\$	001 0000;
05102	\$	+0000144

Part II Rankin Special I & II

- 1) Load Rankin Special I or II by typing "F" to modify Program IV/IV A.
- 2) Refer to items of Part I except 6, 7, 8, 11 & 13.
- 3) Since data contains more than 141 data pieces, the program is loaded to contain factors for loading all of 03 and 04. Thus, load data tape and enter 00010. to enter IV A.
- 4) This program is meant to operate as P vs θ at constant R with

$$Y = Y_2 - Y_1$$

where,

$$Y_1 = K (R - R_o + \Delta R)$$

and

$$Y_2 = K (R - R_o + \Delta R) + P.$$

Y_1 and Y_2 are plotted and a line is drawn between them. For best results, use control tape III

where $(R_o + \Delta R)$ and ΔR along with K are set.

The scale w/05102 \$ + 0000310 $P = 1.0 \text{ } 2.0 \text{ inches}$

w/11702 \$ + 0000764 $Y = f(R), 1/\text{cm} = 5 \text{ inches}$

w/11702 \$ + 0000144 $Y = f(R), 1/\text{cm} = 1 \text{ inch}$

Thus after data tape is loaded, clear the "HALT", and load the control tape. Type "F" to begin plotting.

- 5) Before plotting, manually set zero point on x-y plotter and enter 00011. to clear x-y register. Clear "HALT" and type F.

- 6) After control tape returns control to KB, clear 03 and 04 by typing 04\$Z and 03\$Z. Reload data tape and enter 00010. Repeat plotting operation until data tape is too short to completely load 03 & 04. At this time do not clear 03 and 04 but enter 00010. directly. Depress "Enable" when data tape is finished. Type 07310. to reset IV A, which is normally self resetting load control tape and type "F" to plot remain points.

Desk Calculator Program I (DSPI)

PURPOSE

To input by the keyboard or tape, a series of numbers to be averaged, multiplied by a factor and output on the Flexowriter.

RESTRICTIONS

Since this program is single precision, be careful not to let sum overflow A register.

STORAGE

Line 01 : OUP III
 02 : Desk Cal. Program I
 06 : Decimal Input/Output IA, 0111A

INPUT

- 1) The first number is "N", the multiplier.
- 2) The next "i" numbers are the data points. The program automatically outputs when the sum is completed. The number of individual input numbers is fixed at sector 02402 \$+00000XX, Q of 22, and also at sector 03002 \$+XX00000, Q of 6
- 3) All input data has a Q of 14)g and multiplier "N" has a Q of 17)g.

OUTPUT

$\bar{D} \sim X.XXX$ change this at 06502, if desired.
 $\bar{D} \times N = Q \sim XXXXX.XX$ change this at 05002, if desired.

PROGRAM EQUATIONS

- 1) $\sum_{i=1}^k D_i / k = \bar{D}$
- 2) $\bar{D} \times N = Q$

PROGRAM EXECUTION

- 1) Load OUP III
- 2) Load DSP I with Dec. I/O 0111A.
- 3) Enter by typing T.
- 4) After program output, program resets and is ready for a new "N", etc.

00010.

00002D

000	073S3702;	TRU	+3567610	Set Multiplying Factor First
002	003S0602;	LDB	+0161410	
003	030 0000;		+1400000	
004	005S0402;	LDC	+0261010	Read Keyboard
005	000 0003;		+0000014	
006	007S1037;	STC	+0362174	
010	011S0402;	LDC	+0461010	
011	013S3702;	TRU	+0567610	
012	000S3706;	TRU	+0027630	Σ
013	014S1402;	ADD	+0623010	
015	014 1102;	STA	+0602210	
016	017S0502;	LDA	+0761210	
020	021S1402;	ADD	+1063010	
021	000 00001		+0000001	Counter - How Many data points
022	017 1102;	STA	+0742210	
023	024S5602;	CAM	+1233410	
024	000 00441		+0000023	
025	027 7502;	TOF	+1357210	
026	002S3702;	TRU	+0127610	Average
027	030S0402;	LDC	+1421010	
030	046 0000;		+2300000	
031	032S4302;	CLB	+1530610	
033	014 0502;	LDA	+0601210	
034	063 3100;	DIV	+3146200	$\times N$
035	044S3300;	SBR	+2226600	
036	037S0402;	LDC	+1761010	
037	000 6200;		+0000000 +0	
040	056 3200;	MUP	+2706400	
041	045S2110;	SLT	+2264240	
044	061S3702;	TRU	+3067610	
045	046S1102;	STA	+2322210	
046	000 6200;		+0000000	

047	050S0602;	LDB	+2421410	}	Output $\overline{D} \times N = Q$
050	036 2404;		+1705020		
051	052S0402;	LDC	+2521010		
052	054S3702;	TRU	+2627610		
053	155S3706;	TRU	+6667630	}	Reset JB - 12
054	055S4502;	CLA	+2671210		
056	014 1102;	STA	+0602210		
057	017 1102;	STA	+0742210		
060	073S3702;	TRU	+3567610	}	Output $\overline{D}$
061	062S1202;	STB	+3122410		
062	000 0400;		+0001000		
063	062 0502;	LDA	+3101210		
064	065S0602;	LDB	+3261410	}	Set up $x \times N$
065	030 0406;	LDC	+1401030		
066	067S0402;	LDC	+3361010		
067	071S3702;	TRU	+3467610		
070	155S3706	TRU	+6667630	}	Read Keyboard and Locate N
071	062 0602;	LDB	+3101410		
072	036S3702;	TRU	+1727610		
073	074S0402;	LDC	+3621010		
074	000 0003;		+0000014	}	
075	076S1037;	STC	+3722174		
077	100S0402;	LDC	+4021010		
100	106S3702;	TRU	+4327610		
101	102S0602;	LDB	+4121410	}	
102	036 0000;		+1700000		
103	104S4502;	CLA	+4231210		
105	000S3706;	TRU	+0027630		
106	037 1102;	STA	+1742210	}	
107	002S3702;	TRU	+0127610		

BCD to Octal Converter Subroutine

PURPOSE

This program will convert a binary coded decimal number in memory to its octal equivalent.

RESTRICTIONS

Since only single precision technique is used, do not exceed a five-character BCD number (four bits per character), which would be 20 bits in length.

STORAGE

The program is line relocatable using sectors 000 through 072 plus sectors 100, 120, 140, 160, 200, 220, 240, 260, 300, 320, 340, 360.

INPUT

Calling sequence: (1) Set index register with line number of subroutine.
(2) LDA with BCD argument.
(3) LDC with return instructions (TRU).
(4) Enter 001LL where LL is line of index of register.

OUTPUT

Program will exit with octal equivalent of input BCD number in the "A" register.

METHOD

There can be a large variety of coded combinations of 4 bits to identify a given set of binary coded decimal numbers.

Every 16th interval sector starting at sector 000 is reserved to hold the correspond coded identification number. The theory that follows yields an equation

$$D_n C_n + \dots + D_6 C_6 + D_5 C_5 + \dots + D_2 C_2 + D_1 C_1 = \text{converted BCD number. But}$$

indeed, this equation will translate any number system to the octal number system.

Some reserve spaces (sectors 027, 030, 031) are saved to allow for expansion.

From the above equation merely locate in the N sectors (000, 020, 040, etc.) the corresponding conversion numbers regardless of number system or combination. There are sixteen N sectors, where for a decimal number system only ten N sectors are required, while the other six have no meaning. For example, consider the BCD code 42' 21 as follows:

<u>Decimal Number</u>	<u>B C D</u>	<u>Octal Number</u>	<u>Sector Containing Octal Number</u>
	4 2' 2 1		
0	0 0 0 0	0	000
1	0 0 0 1	1	020
2	0 0 1 0	2	040
3	0 0 1 1	3	060
4	0 1 1 0	4	140
5	0 1 1 1	5	160
6	1 1 0 0	6	300
7	1 1 0 1	7	320
8	1 1 1 0	10	340
9	1 1 1 1	11	360

The program creates an instruction (LDB) where a right shift locates the above 4 bits in the 0 bit position through the third bit position. This reads as a unique sector for every possible BCD combination.

THEORY - Number System Conversion

Let the least significant digit be called D_1 and the next LSD be called D_2 , etc., and then the most significant digits be called D_6 . Let $C_1, C_2, \dots, C_6$ be coefficients in a_i in the equation,

$$a_n b^n + \dots + a_3 b^3 + a_2 b^2 + a_1 b^1 + a_0 b^0 \text{ which defines a given set --}$$

here a number system.

If the C_i be the octal representation of decimal powers of ten and the D_i be decimal numbers, then a complete converted data word is

$$D_6 C_6 + D_5 C_5 + \dots + D_2 C_2 + D_1 \quad (1)$$

$$\left(\left(\left(\left(D_6 C_1 + D_5 \right) C_1 + D_4 \right) C_1 + D_3 \right) C_1 + D_2 \right) C_1 + D_1 \quad (2)$$

Here, the C_i of (1) are known but in (2) above, C_1 is the basic radix and (2) can only be used when this is known. We shall choose (1) where

$$C_1 = 1)_i = 1)_{10}$$

$$D_1 = \text{units}$$

$$C_2 = 12)_8 = 10)_{10}$$

$$D_2 = \text{tens}$$

$$C_3 = 144)_8 = 100)_{10}$$

$$D_3 = \text{hundreds}$$

$$C_4 = 1750)_8 = 1000)_{10}$$

$$D_4 = \text{thousands}$$

$$C_5 = 23420)_8 = 10000)_{10}$$

$$D_5 = \text{tens of thousands}$$

$$C_6 = 303240)_8 = 100,000)_{10}$$

$$D_6 = \text{hundreds of thousands}$$

and solve it to convert from 42' 21 BCD to 8421 octal which is 3 bit binary. All input data undergoes this operation.