PRECISION GAMMA SCANNER

by

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ABSTRACT

A precision gamma scanner (PGS) is used in the air cell of Hot Fuel Examination Facility/South at the EBR-II site to support the LMFBR irradiation programs. The PGS consists of an in-cell element-positioning stage, a variable-slit collimator, and a germanium-lithium gamma-detector system. Gamma scanning is supervised by a Datacraft 6024/3 computer, which operates the PGS on a 24-hr basis without operator attention. Full automation of the PGS functions has made it possible to collect vast amounts of data that could not be collected manually. No multichannel analyzer is used in the system; instead, the nuclear analog-to-digital converter and other instruments are interfaced directly to the computer through the CAMAC standard.

The PGS has not only fulfilled the normal uses of a gamma scanner, such as measurements of dimensions, flux profiles, and isotope migrations, but has proven to be a sensitive device for the detection of microscopic cladding failures in irradiated fuel elements or capsules. The technique is based on identification of fission products such as ^{133}Xe , $^{140}\text{Ba/La}$, or ^{137}Cs in abnormal quantities and locations in an element or capsule.

The flexibility of the in-cell positioning stage and computer-control system has made it possible to scan a variety of subjects without making hardware changes to the equipment. Operation of the PGS has shown that a computer can safely and efficiently control hot-cell examinations.

I. INTRODUCTION

Gamma scanning is a nondestructive radiochemical analysis of a gamma-emitting sample relative to position on the sample. Gamma-ray spectra are taken as a function of position, and the relative abundances of individual isotopes that make up the complex gamma-ray spectra are determined. Gamma scanning is not a newcomer to the hot-cell examination field; this technique has aided the study of radioactive subjects in hot cells for the past 15 years. However, scanning techniques are continually being refined, opening the door to new applications.

At the HFEF complex, gamma scanning has proven to be an invaluable tool for interim, nondestructive examinations of irradiated reactor-fuel elements. The elements examined are mainly experimental fuel elements that are under study as part of the AEC's Liquid Metal Fast Breeder Reactor (LMFBR) Program. The interim examinations are conducted at intervals during the irradiation program for an experimental fuel, and the elements remain intact for further irradiation. Most of the fuels now being examined have been irradiated in EBR-II, but as the LMFBR Program proceeds, the HFEF complex will be increasingly called on to examine fuels from other facilities.

The precision gamma scanner described in this report was designed and built by Argonne National Laboratory, and has been in operation since May 1971. Gamma scanning is a time-consuming operation; therefore, the HFEF scanner has been put under computerized control to handle the large number of examinations required. This report briefly discusses the extension of the computer-control system to a variety of hot-cell examination equipment; it also presents recommendations for the design of future precision gamma scanners.

II. GENERAL DESCRIPTION OF PRECISION GAMMA SCANNER

A. Layout of Hot Fuel Examination Facility (HFEF)

The HFEF complex is equipped to do both interim and final examinations on irradiated fuel elements. The complex now comprises two buildings, called HFEF/N and HFEF/S (where N and S stand for north and south). HFEF/S, which was formerly the Fuel Cycle Facility for EBR-II, has an air cell with nine work stations and an argon-atmosphere cell with 15 work stations. HFEF/N, which was completed in 1972, has an air-atmosphere decon cell with five workstations and an argon-atmosphere main cell with 15 workstations. HFEF/N will be used primarily to disassemble and examine alpha-contaminated reactor experiments that cannot be handled in the HFEF/S air cell,

The interim-examination equipment available in the HFEF complex now includes neutron-radiography equipment, a stereomacroscopic, a contact profilometer, Model DK-25 optical micrometers, equipment for measuring bow, length, and weight of irradiated elements¹, a vent-tube sampler, fission-gas measuring devices, reencapsulation equipment, and the precision gamma scanner.

B. Layout and Operation of Precision Gamma Scanner (PGS)

The PGS is located in the air cell of HFEF/S. In designing and building the PGS, Argonne National Laboratory has assembled the newest concepts in gamma-ray detection, programmed digital controllers, positioning devices, and data-reduction services to provide a versatile gamma-scanning system for serving experimenters in the LMFBR Program. The PGS has been designed to collect the required experimental data with a minimum of setup time, operator attention, and manual data reduction, thus reducing the costs of interim examinations.

In the PGS, gamma-ray spectra are taken as a function of static position for a predetermined time, and the relative abundances of individual gamma-emitting isotopes that make up the complex gamma-ray spectra are determined. The distribution of the individual isotopes is then compared to the sampling position on the sample. From the distribution of the radioactive isotopes within a sample, it is possible to directly measure the physical results of irradiation, such as failure of an element or capsule, diameter of cladding of an element within a capsule, fuel-column height, sodium-bond height, relative burnup, migration of uranium-plutonium fission products, gas

evolution, and power distribution. Other quantities not so directly measured may be inferred from the distribution of isotopes when this is compared with other nondestructive-test results. Examples of these inferred quantities are temperature, solubility, mass transfer, melting, phase change, and neutron energy.

Because irradiated subassemblies can be removed from EBR-II and disassembled in the HFEF/S air cell in less than 15 days, the 0.081-MeV gamma rays from the decay of ^{133}Xe (5.27-day half-life) are quite prevalent, and are easily identified with the PGS. The combination of the short cycle and the PGS accuracy makes the PGS an ideal remote tool for nondestructive identification of failed capsules and elements containing nuclear fuels.

The PGS consists of the following subsystems, all of which are fully integrated to produce a fully automated gamma-scanning system:

- Precision element-positioning stage
- Variable-slit rotatable gamma-ray collimator
- Electrical-service feedthru
- Germanium-lithium gamma-detector system
- Programmed digital controller (computer)
- CAMAC control systems
- Data-acquisition systems
- Control software
- Gamma-spectrum reduction software

Figure 1 is a cutaway view of the HFEF/S air cell where the PGS is positioned. The placement of the positioning stage in the corner of the cell makes it possible to view the collimator and stage from shielding window A4. This situation also facilitates easy loading of the precision positioning stage with the two master-slave manipulators at that window.

The PGS was designed to operate in two gamma-scanning modes: axial scanning and diametral scanning. The purpose of an axial gamma scan (see Fig. 2) is to produce distribution plots of isotopes in the axial direction. The axial direction is usually taken to be the same direction as the axis of the gamma source (the up-and-down direction for a vertical capsule or element). Axial gamma scans are usually made with the collimator slit in the horizontal plane. All axial gamma scanning is done statically; i.e., the positioning stage is stopped and a complete spectrum taken at each location.

Fig. 1. Arrangement of Precision Gamma Scanner in Air Cell of HFEF/S

Fig. 2. Example of an Axial Gamma Scan

The purpose of a diametral gamma scan (see Fig. 3) is to produce distribution plots of isotopes perpendicular to the axis of the capsule or element. Diametral gamma scans are made with the collimator slit in the vertical position, and again, all scanning is done statically.

If the fuel elements have been irradiated in EBR-II, requests for gamma scanning are made by experiment sponsors through the EBR-II Irradiations Office. The purpose of the scan and the identity of the capsule, element, or stainless steel flat are designated by the experiment sponsor. The Irradiations Office representative notifies the Cognizant Engineer at HFEF that a gamma scan has been requested on subjects coming out of EBR-II. After the Cognizant Engineer has been informed of the purpose of the gamma scan, he outlines a scan technique that will satisfy the experimenter's needs. This can vary from a simple 5-minute gross gamma scan to a 3-week detailed scan.

The Cognizant Engineer's plan is presented to the HFEF Assistant Operations Manager for incorporation in the HFEF/S examination schedule. When the subassembly reaches the HFEF/S air cell and is dismantled, the designated capsule, element, or hex tube is loaded into the gamma-scanner positioning stage. The operator enters the proper scan parameters into the programmed digital controller (PDC) through a teletype. After the PDC has been initialized, it performs the following automatic functions in succession:

- (1) The collimator slit is rotated to the proper plane (horizontal or vertical)
- (2) The collimator slit is closed
- (3) The subject is moved remotely to the initial scan position
- (4) The germanium-lithium detector counts a ^{228}Th calibration source manually placed between the detector and the out-of-cell surface of the collimator.

After the calibration count is complete, the PDC writes the calibration data on a high-density magnetic data tape and halts. The operator acknowledges the PDC if he accepts the calibration data; if not, the PDC repeats the calibration. Following acknowledgment, the PDC opens the collimator slit to the proper width, collects a gamma spectrum at the preestablished position on the subject for a preset live time (see Section IV. F for a definition of live time), and writes the spectral data, subject identification, and irradiation-history parameters on magnetic tape. The cycle continues until the PGS has scanned the surface of the subject in the fixed increments specified by the

Fig. 3. Example of a Diametral Gamma Scan

Cognizant Engineer. When the scan is completed, the PDC closes the slit and moves the subject to an unload position, where the operator remotely removes it from the precision positioning stage.

The magnetic data tape is removed from the PDC and shipped to the NRTS computer center for reduction on the IBM-360 scientific computer. A nonlinear least-squares program for the determination of photopeaks by the use of a modified Gaussian function² is used to reduce the complex spectrum. The results are returned to the HFEF in the form of isotope-distribution listings and distribution plots. The Cognizant Engineer incorporates the gamma-scan results into the experimental-subassembly interim-examination report, which is transmitted to the experiment sponsor.

C. Practical Applications of the Precision Gamma Scanner

This section discusses some of the practical applications of the PGS during an interim examination. These applications involve the measurement or determination of the following:

- Capsule or element failure*
- Cladding diameter and length
- Axial fuel length
- Sodium-bond voids
- Sodium-bond height
- Relative burnup
- Migration of uranium-plutonium fission products
- Evolution of fission-product gas
- Activation-product profiles.

The PGS can be used to rapidly, and therefore inexpensively, locate failed capsules or elements containing irradiated fuel. Three spectra are required to examine a capsule for a failure of the internal experiment. The collimator slit is horizontal for all three. The first spectrum is taken

*In the nomenclature used at HFEF, a "fuel element" consists of a fuel pin within a metallic cladding or jacket. A "capsule" consists of a fuel element within a second sealed jacket (usually with a sodium heat-transfer bond between the two jackets); i.e., the fuel is doubly contained.

with the slit looking across the experiment's gas plenum (see Fig. 4); the second is taken above the experiment's cladding but below the top of the sodium bond in the capsule's gas-plenum area. The first spectrum is analyzed for ^{133}Xe , ^{22}Na , $^{140}\text{Ba/La}$, ^{137}Cs , and ^{58}Co ; the second for ^{22}Na , ^{137}Cs , $^{140}\text{Ba/La}$, and ^{58}Co ; the third for ^{133}Xe and ^{58}Co . Detection of the activation product ^{58}Co assures the Cognizant Engineer that the collimator slit was looking at the capsule in all three scans, because ^{58}Co is an activation product of stainless steel capsule hardware. Detection of ^{22}Na assures the Cognizant Engineer that the scanner was looking at the capsule's sodium bond. The fission products ^{137}Cs , $^{140}\text{Ba/La}$, and ^{133}Xe (gas) should not be present in the capsule's sodium bond or gas plenum if the cladding of the internal experiment is intact. If the capsule is examined between 15 and 50 days after its last irradiation of 100 hr or more, the photopeak resulting from the 0.081-MeV gammas from ^{133}Xe is easily identified on the PGS display scope. Thus, a complex gamma-spectrum analysis is not required for detection of failure in capsules.

The examination technique for determination of element cladding failure differs because of the different hardware configuration. One spectrum is taken for 15 min of live time with the slit horizontal at the element's gas plenum. All elements from the same subassembly are scanned in the same position. Each spectrum is analyzed for ^{22}Na , ^{133}Xe , ^{58}Co , and ^{54}Mn . The two stainless steel activation products, ^{58}Co and ^{54}Mn , are used to assure that the slit was looking at the element. The photopeaks from the four isotopes listed above are analyzed by a complex gamma-reduction program and the results normalized to reactor shutdown.

The concentration of ^{133}Xe in the gas plenum of each element will vary according to the element's location in the subassembly. Fission-gas release from the fuel to the gas plenum is a function of operating temperature and fuel burnup. A one-scan analysis of an element will not be conclusive unless the element has lost all of its fission gas, which is highly unlikely for small microcrack failures.

Another failure-detection device called the pressure leak-off device (PLOD) is used to aid in the PGS analysis of suspect elements. The PLOD is a vacuum furnace that has a gas-collection chamber in which fission gas is collected and detected with a germanium-lithium detector. One suspect element at a time is placed in the furnace and heated under a vacuum or reduced

Fig. 4. Detection of Failure in Encapsulated Fueled Experiments with the PGS

pressure. Attempts are made to drive out the fission gas through the cladding failure and collect it in the chamber. Small releases are usually not detected because of the large volume in the gas-sampling system.

After the PLOD test, the elements are returned to the PGS and counted in the same position as before the PLOD test. The same collimator slit width and live time are used for the second count as for the first. The total number of gamma rays per live-time count is determined for the ^{133}Xe peak for both counts. The ratio of the first total to the second total is equal to the ratio of gram atoms of ^{133}Xe gas present in the plenum during the first count to those present during the second count. The total should be less for the second count because of the natural decay of ^{133}Xe (5.27-day half-life). If the ratio is larger than the natural-decay ratio, the element has lost gas other than by natural decay. This method is sensitive to small releases.

Oxide-fuel elements are not sodium-bonded; therefore, the detection of ^{22}Na anywhere in the fuel element will flag the element as a failure, since sodium is used as the reactor coolant in the LMFBR program.

The PGS can be used to map the outside diameter, inside diameter, and length of irradiated capsules, elements, and internal experiments by plotting the distribution of the stainless steel activation products. Figure 5 is a typical example of the results. The accuracy of the measurement depends on the positioning-stage precision and the scanning increment. The accuracy is seldom less than 1 mil.

Figure 6 illustrates the use of the PGS to determine axial fission-product distribution. Axial fuel growth, voids, and pellet interfaces can be determined from this information.

The PGS can be used to measure a capsule's or element's sodium-bond height and voids by plotting the distribution of ^{22}Na or ^{137}Cs (1.28- or 0.511-MeV gammas) (see Fig. 7). The accuracy again depends on the positioning-stage precision and the scanning increment. The sensitivity of this application increases with the diameter of the sodium bond.

Migration of uranium-plutonium fission products, activation-product profiles, and relative-burnup profiles are all obtained by axial or diametral scans of the subject in closely spaced increments. Gamma scans of this type require long counts and small increments to obtain a high degree of accuracy, and can require up to 3 weeks for completion of a scan on one subject. Experiment sponsors are advised to weigh the cost of such an examination against its

Fig. 5. Diametral Distribution Plot for the Stainless Steel Activation Product ^{58}Co

Fig. 6. Axial Distribution Plot of the Fission Product ^{95}Nb in a Fuel Element

Fig. 7. Measurement of Sodium-bond Height in Fuel Element with the PGS

value before directing the project to produce scans of this type. Table V at the end of Section VII gives the charges for various types of scans.

Fission-product gas evolution can be measured with the PGS by counting a known standard of the same geometry before the experiment. Such parameters as gas pressure and gram atoms of ^{85}Kr and ^{133}Xe gas per sample cross section can be determined. The accuracy of this technique has yet to be statistically established, but predictions are that the accuracy will be within $\pm 1\%$ of the real gram-atom value.³

D. Design Criteria for Precision Gamma Scanner

The primary design criteria are listed below:

- Complete flexibility of all systems to handle a wide range of gamma sources
- Full automation of all functions except loading; i.e., automation of control, data acquisition, and reduction of data
- Precise positioning for all degrees of freedom
- Precise control of slit width
- Automatic slit rotation ($0^\circ - 90^\circ$)
- Accurate live time (2 ppm)
- Precise resolution from germanium-lithium detector
- Control by digital computer.

The subjects examined with the PGS at the HFEF complex range from 18-in.-long EBR-II driver-fuel elements to 61-in.-long experimental capsules and elements. The structural subjects range from hex-can flats to control-rod thimbles. Subject diameters range from 0.174 to 3.000 in. Subject activity ranges from a few R to 10^5 R. Thus, one of the most important design criteria for the PGS is the flexibility to accommodate subjects of a wide variety of physical sizes and conditions.

The above criteria all require precision in stage positioning, slit width, and gamma-detection systems. Four degrees of freedom in positioning are required: vertical (Z), sideways (X), forward and back (Y), and rotational (ϕ). The positioning device has to scan 65-in.-long subjects weighing up to 10 lb and having a maximum diameter of 3 in.

The design-basis work load for the PGS is 200 elements, capsules, or structural subjects per year. The real time required to scan these subjects

is approximately 2400 hr. Automation is therefore a necessary design criterion, as it allows the PGS to collect data on night shifts without operator attention.

Approximately 80% of the information obtainable from a gamma scanner cannot be collected without a precision positioning device, variable slit, and high-resolution detector. With the aid of these features, the HFEF precision gamma scanner can be used in the following analyses and measurements:

- (1) Detection of failures in elements and capsules
- (2) Length of fuel columns (± 0.01 in.)
- (3) Inside and outside diameters of cladding and fuel (± 0.0001 in.)
- (4) Isotope migration (both plutonium and uranium)
- (5) Location of suspected cracks and voids in fuel
- (6) Location of oxide-pellet interfaces
- (7) Mill-wire failure
- (8) Sodium levels
- (9) Flux-wire scans
- (10) Fission-product concentrations
- (11) Relative gross gamma profiles.

III. MECHANICAL DESIGN CHARACTERISTICS

A. Element-positioning Stage

The major in-cell component of the PGS is the element-positioning stage (EPS) (see Fig. 8). The EPS holds an individual fuel element or capsule in a vertical orientation and translates it in an X, Y, Z, and rotational motion (θ) relative to the collimator slit. The X and Y axes have 9 in. of travel. The Z motion has 66 in. of travel and can lift 50 lb. These three axes have positioning and readout capability of 0.001 in. The rotational motion about the longitudinal axis of a vertical element has positioning and readout capability of 0.1° .

The base of the EPS utilizes a Superior Electric Company Slo-Syn X-Y positioning table, marketed for use in numerically controlled machining operations. This table utilizes Slo-Syn stepping-motor-actuated ball screws to drive cross-slides supported on linear ball bushings. The X-Y table is mounted on a 30-in.-square by 2-in.-thick steel plate, which is the base for the whole EPS.

Fig. 8. PGS Element-positioning Stage

The Z-motion column is fabricated of two 8-in. aluminum channels facing each other. Between the channels are mounted two 2-in. steel rods on which a carriage travels, supported on linear ball bushings. The carriage is raised and lowered by a ball screw mounted between the rods and powered by a Slo-Syn stepping motor. The Z-motion column is clamped onto the X-Y table and is removable as a separate subassembly.

A collet-holder assembly is mounted on the Z-motion carriage (see Figs. 9a and 9c). Several interchangeable collets, required to accommodate the variety of fuel-element and capsule tip configurations, fit into the collet holder. The collet holder is rotated by a Slo-Syn stepping motor. A Northern Precision Laboratories rotary encoder indicates the rotational position of the collets. The collets are locked into the collet holder and are opened and closed, for insertion of fuel elements or capsules, by a pneumatic actuator inside the collet-holder subassembly.

The orthogonal axes of the EPS utilize ball screws with thread leads of 0.200 in. per revolution. These are directly coupled to double-ended Slo-Syn stepping motors having 200 steps per revolution. This results in 0.001 in. of linear motion per stepped pulse imparted to the stepping motor. The other end of the motor shaft is directly coupled to a Northern Precision Laboratories absolute encoder, which provides a discrete position signal for each 0.001 in. of linear movement, over the entire range of each axis, for computer control and visual position readout. Absolute encoders are utilized to operate the EPS in a closed-loop control mode. Electrical power outages or inadvertent movement of the various axes cannot cause loss of position registration or orientation.

In the gamma-scanning operation, two modes of positioning the fuel element or capsule relative to the collimator slit are utilized: restrained and unrestrained. In the restrained mode, a pair of fixed guides are mounted on the Z-motion column so that they straddle the collimator's scanning area. The fuel element or capsule, its bottom tip held in a collet, is passed vertically through the guides (see Fig. 9a). The guides position the fuel element or capsule within a few thousandths of an inch of an optimum position relative to the collimator slit. The guides have clusters of ball bearings spaced 120° apart, through which the fuel element or capsule passes. The bearings roll on the outside diameter of the fuel-element or capsule cladding. Each guide accommodates only one diameter of fuel element or capsule.

a. Gamma Source Held in Restrained Mode

b. Empty Stage, Showing Fixed Guides and Tip Guide

c. Gamma Source Held in Unrestrained Mode

Fig. 9. Fixtures of Element-positioning Stage

Several interchangeable guides are thus utilized (see Figs. 9a and 9b) for the various diameters of fuel elements and capsules routinely scanned.

In the unrestrained mode, the fuel element or capsule is held only at the bottom end in a collet, and the top end is retained in a spring-loaded conical socket called a tip guide (see Fig. 9c). The fuel element or capsule is free to assume its normal shape - straight or distorted. A relatively distorted fuel element or capsule cannot pass through the fixed guides without risking surface damage to the cladding.

The various motions and functions of the EPS may be controlled from a caster-mounted control console adjacent to the cell viewing window that services the EPS. This manual control console is utilized for all loading, unloading, setting up, and maintenance operations. Automatic gamma-scanning operations are controlled from the control room, which contains the computer. When the EPS is under computer control, the manual controls are electronically locked out and inadvertent actuation of any control on the console will not activate any EPS motion or function.

The manual control console has Nixie-tube position readouts, in thousandths of an inch, for each of the X, Y, and Z motions, and a readout in 0.1° for the collet rotation. It also has controls for speed and direction for the various motions. The motors may be operated at a fixed fast or slow speed or may be stepped, one pulse at a time, to produce a 0.001-in. motion per pulse. The fast and slow speeds can be adjusted by an internal control inside the manual console. Other controls are collet openers and closers, guide positioners, travel-limit indicators, control-mode indicators, and override switches.

B. Variable-slit Gamma-ray Collimator

The purpose of the collimator assembly of the PGS is to deliver undeflected, clean, sharp, controlled-intensity gamma-radiation beams to the detector.

The collimator assembly is made up of three major components: the wall-liner tube, the collimator casing, and the collimator plug. The plug rotation and the variable slit are remotely operated, either under computer control or manually from the PGS panel in the control room. Rotation of the plug is indicated by lights, and movement of the slit is measured by an encoder.

Figure 10 is a cutaway view of the collimator assembly and associated parts.

The collimator assembly is housed in a wall-liner tube adjacent to window A3 in HFEF/S. Figure 11 is a plan view of the PGS equipment in the air cell. The wall-liner tube is constructed of 12-in.-dia steel pipe and is leveled and grouted into the air-cell wall for a permanent PGS installation. The liner tube is designed to allow the removal of the collimator casing and plug.

The collimator casing is the housing for the collimator plug. The casing has an aluminum-capped inner end and two large-diameter bearings on which the collimator plug is rotated. The plug must be rotated when changing the collimator slit from horizontal to vertical orientation (0° to 90°). The capping of the inner end prevents contamination of the plug during operation and allows for simple maintenance procedures after removal of the plug.

The collimator plug is the major component of the collimator assembly. It is constructed with a variable slit and an interchangeable beam scraper. The 0.500-in.-long variable slit is adjustable in opening width from 0.000 to 0.054 in. The variable slit controls the amount of gamma radiation passing into the collimator's beam channel. The jaws of the variable slit are made of Kennertium, a 97% tungsten alloy that has almost the density of depleted uranium. This dense material in the jaws provides a very sharp, clean collimated beam to the detector. Less dense material would allow fuzzy, unpredictable, erratic edges on the collimated beam. The plug body is constructed of carbon steel and is approximately 60 in. long. It is built in two matching halves, with lead gaskets between the offset joints to eliminate streaming of the gamma radiation through the joints. The interchangeable-beam-scraper holes are of various sizes to control the gamma-exposure area at the face of the detector. The beam scrapers are also fabricated from Kennertium.

When the collimator slit is rotated, the top of the slit is used as the reference plane passing through the axis of rotation. The ideal condition would be to have the centerline of the slit exactly on this axis, but this would require two moving jaws. Where only one movable jaw is used, the other side of the slit must be the reference plane. When the collimator plug is rotated, the runout of the collimator slit must be compensated for. One half of the slit opening becomes the runout difference from the true center (see Fig. 12).

Fig. 10. Cutaway View of Collimator Assembly

Fig. 11. Plan View of PGS Equipment in Air Cell

Fig. 12. Runout of Collimator Slit

When collimator plug is out of the casing, it is handled with a nylon sling that supports it at two points symmetrical to the center of gravity. A roller is provided in the top of the collimator plug, and during installation, the collimator plug is rotated 180° and started into the casing with the roller in a down position. As the roller begins to contact the reduced-diameter section of the casing, it is used as an inner-end support roller, with the nylon sling supporting the other end. As the plug reaches the rear support bearing in the casing, the plug is again rotated 180° so that the roller is located at the top. The plug is then pushed the rest of the way in until it is seated in the support bearings. The plug is then bolted securely to the flange of the casing.

The slit width is varied by a lead-screw wedge, driven by a stepping motor. The stepping motor is actuated manually from the PGS control-room panel or by computer control. The slit width is indicated in 0.1-mil increments by a direct-driven encoder attached to the motor. The slit width is read on the control-room panel. The encoder and drive are reset to zero for each reading so that system slack is always on the same side. The horizontal or vertical orientation of the slit is also displayed in the control room. Collimator-plug rotation is accomplished by a stepping motor and a chain drive attached to the periphery of the plug. The rotational drive may be actuated manually from the control room or by computer control.

C. Electrical-service Feedthru

A special feedthru in the cell wall provides control and data-transmission wiring for the element-positioning stage inside the air cell. The feedthru was installed in an existing 8-in. pipe port adjacent to air-cell window A3 (see Fig. 13). The feedthru is fabricated of 8-in.-OD, 1/4-in.-wall steel tubing. It has welded caps on both ends and contains four 1-in.-dia cable tubes, which are helically wound with one turn in 30 in. to prevent radiation streaming. The remaining space in the main tube is filled with high-density concrete for shielding. At the out-of-cell end is a junction box with four 52-pin connectors. The connectors are wired to 52-conductor cables that extend inside the air cell and connect with the element-positioning stage.

Fig. 13. Electrical-service Feedthru for PGS

Fig. 14. Detector-support Stand

D. Detector-support Stand

An out-of-cell detector-support stand (see Fig. 14) positions the gamma-detector crystal, preamplifier, cryostat, and dewar relative to the collimator assembly. The stand, fabricated on carbon steel, is located at window A3 directly in back of the collimator. The stand positions the detector crystal in the optimal position with respect to the collimator slit. The vertical positioning is accomplished by four simultaneously driven screw jacks. A small lead personnel shield behind the detector head stops any stray gamma radiation that might penetrate the detector.

IV. DESIGN CHARACTERISTICS OF GAMMA-RAY-DETECTOR SYSTEM

A. Germanium-Lithium Detector and Cryostat

Figure 15 is a diagram of the germanium-lithium detector.

Fig. 15. Diagram of Germanium-Lithium Detector

The detector is made from a crystal of germanium, which has been doped with gallium or boron to create an excess of holes (positive charges). Since lithium acts as a donor of electrons, the germanium is made into an N-type material. A PN junction is created where the number of donors and acceptors are equal. Within this junction exists an electrically neutral region, which is called the intrinsic material.

Three geometrical types of detectors are available: the planar detector, the true coaxial detector, and the five-sided coaxial detector. The PGS detector is of the true coaxial (circular) type.

The solid-state gamma-ray detector requires cryostatic cooling for proper performance. At room temperature the electronic noise generated within the junction is great enough to mask the electronic pulses generated by a gamma ray. Therefore, the detector is maintained at 77°K by cooling in liquid nitrogen. This cooling is provided by a liquid-nitrogen cryostat with an operating period of approximately 22 days between refillings (at 5000 ft altitude). The cryostat is a Union Carbide Model LD-31.

In Fig. 15, a gamma ray is symbolically shown entering the junction (intrinsic) area. The gamma ray interacts with the intrinsic material to produce hole-electron pairs by the photoelectric effect. Through this effect, many electrons and holes are produced from both primary and secondary electrons as they lose energy. This production takes place at a rate of approximately one electron-hole pair per 3 eV of gamma-ray energy. The free electrons and holes migrate through the junction, so that the electrons collect at the positive terminal and the holes at the negative terminal. The total charge collected of either sign is a measure of the total energy of the incident gamma ray.

To collect this charge and present it in a meaningful manner, the system shown in Fig. 16 is used.

Fig. 16. Block Diagram of Gamma-ray-detector System

The PGS gamma-ray detector is a Nuclear Diodes Model LG CC 5.0-2.5.

B. Preamplifier

The preamplifier is located near the detector but not in the gamma-radiation field. It has a threefold purpose (a) to collect the charge liberated by the gamma rays, (b) to convert this charge to a voltage pulse, and (c) to provide the capability of driving up to 70 ft of cable. For convenience in connecting and ease in handling, the high voltage is fed to the detector through the preamplifier case.

The preamplifier for the gamma-ray detector is a Nuclear Diodes Model 101A.

C. High-voltage Power Supply

The high-voltage power supply is used to bias the gamma-ray detector diode in a reversed-bias condition. With this condition existing, the electrons that are liberated by the gamma ray migrate to the positive terminal of the bias voltage. The amplitude of the bias voltage varies with manufacturing technique and with the width of the diode junction. The optimum voltage amplitude is determined empirically by the manufacturer, and in the case of the PGS detector was found to be 2850 V.

The stability of the system is directly proportional to the stability of the high-voltage power supply. It is necessary that the long-term stability of the power supply be better than $\pm 0.05\%$.

The PGS high-voltage power supply is a Hewlett-Packard, HVB Series, Model 6516A.

D. Amplifier

The amplifier shown in Fig. 16 serves two purposes. One purpose is to provide impedance matching and proper cable termination for the preamplifier and amplifier cable run. Proper cable matching is necessary to prevent "ringing" and pulse-shape distortion. The second purpose of the amplifier is to amplify the voltage pulse to a level compatible with the analog-to-digital converter.

As with the high-voltage power supply and preamplifier, the amplifier must be very stable to prevent drifting of pulse amplitudes. The long-term stability should be better than $\pm 0.1\%$ in the operating range.

The PGS amplifier is a Tennelec Model TC 202.

E. Analog-to-Digital Converter and CAMAC Interface Module

Up to this point in the detector system the pulse created by the gamma ray has been massaged by analog methods. Next, to put the data in the desired, digital form, an analog-to-digital converter (ADC) is used. Each of the pulses that is fed to the ADC is converted from a peak analog voltage amplitude to a digital binary number. While the ADC is busy processing a pulse, the succeeding pulses must be locked out so they cannot interfere with the conversion.

Two features of an ADC especially affect its suitability for use with a gamma-detector system. One of these features is the conversion time or rate, which determines the maximum gamma-counting rate. The conversion rate of the ADC selected for the PGS is 100 MHz. The second feature is the resolution, or number of binary bits in the output. The output of the selected ADC is 13 bits, implying that the peak input voltage can be divided into 8192 binary amplitudes ($2^{13} = 8192$). The selected ADC has conversion control, and for the PGS system, is set to provide a conversion gain of 4096 (12 binary bits).

The CAMAC-ADC interface module was designed and fabricated by Argonne National Laboratory. It primarily provides gating between the ADC and the CAMAC dataway, which is described in Section V.E, of this report. It also provides signals such as "busy," "status," etc., as required by the CAMAC standard.⁴ The interface module is described in Section V.F, and a detailed drawing is given in Fig. 28, Appendix A.

F. Live Timer

In statistical counting such as gamma-ray counting, time is divided into real time, dead time, and live time. Live time is defined as the time that the system is not processing a pulse and is available to receive a pulse. The dead time is the time that passes while the system is processing a pulse. The real time is the actual passage of time and is the sum of dead time and

live time. Ideally, a system should have zero dead time, but this of course is not possible, so the next best system is one that can keep track of either dead time or live time as well as the real time.

The PGS system uses live-time control for counting gamma rays. The live timer is shown in Fig. 29 of Appendix A. The live timer communicates with both the ADC and the CAMAC-ADC interface through the optional 36-pin connector. The communication essentially amounts to determining when the ADC is processing a pulse or when a count is in the CAMAC-ADC interface waiting to be picked up by the PDC. In both cases, the live timer is not timing. When the processing has been completed, the live timer tells the ADC that the live timer is set and timing and that any pulse that comes along should be accepted. The live timer is described in detail in Section V.F.

V. DESIGN CHARACTERISTICS OF PGS INSTRUMENTATION AND CONTROL

A. Basic Features

Two important considerations were kept in mind while designing the PGS instrumentation (see Fig. 17). One was the need to meet the design requirements within the budgeted money and allotted time. The other was the need to provide for future expansion and changes.

The PGS was the first of its kind and consequently many of the control circuits were the first of their kind. The tight schedule did not permit the prototyping and testing of these components, so it was necessary to design so that field changes would be easy to perform. Since the HFEF complex was serving a number of customers, it was anticipated that the customers' requirements might necessitate changes also.

The constantly increasing workload at the HFEF complex made it apparent that a system for digital control and data acquisition should be capable of expansion. The HFEF staff believed that a wider application of automatic control and data acquisition was the way to meet this increasing workload.

Because of the very tight schedule, it was apparent that EBR-II Engineering Section III did not have the manpower to complete all of the design in time. A study was immediately undertaken to find a standard that would be of value in farming out components of the PGS control system and would also provide for future additions and changes. The only promising digital-interfacing standard was CAMAC, and this standard was selected.^{4,5}

Fig. 17. Block Diagram of PGS Instrumentation and Control System

PGS CONTROL - ROOM PANEL

2

The CAMAC standard is basically a universal set of interfacing criteria for digital computers. It designates mechanical dimensions of modules, electronic loading, connectors, timing, and signal utilization. Figure 18 is a basic block diagram of a CAMAC system. It should be noted that this is only one configuration of a CAMAC system and there are numerous variations; however, all of the CAMAC systems meet the CAMAC standard and the components have maximum interchangeability.

Fig. 18. Block Diagram of a CAMAC System

For further information on the CAMAC standard, see Refs. 4 and 5.

Reference 5 covers the requirements of the branch drivers and branch highway in relation to characteristics of the digital computer such as word size, distinguishability between data word and command word, and ability to operate asynchronously (commonly referred to as "hand shaking"). The CAMAC standard is designed to assist the computer manufacturer in interfacing to peripherals and doesn't require the computer to be designed around the CAMAC standard. Once a specific computer has been interfaced to the CAMAC branch driver, then all CAMAC modules will be able to communicate with the computer. This concept avoids repeated peripheral interfacing.

B. Power-supply System

The following discussion covers first the ac power source and then the dc sources for the PGS.

The primary source for ac power at the National Reactor Testing Station is commercial power for a sitewide power-transmission loop. Although voltage and frequency regulation are good, pulses with amplitudes up to 15 V and time widths up to 1 μ sec have been observed. Pulses of this nature are detrimental to digital logic operation and are difficult to filter out electronically. Considerable study led to the conclusion that a synchronous motor-generator would be the best and the least expensive method of eliminating these voltage spikes. All ac power for the PGS system is obtained from a motor-generator, and single-point grounding⁷ is used throughout the system. The single-point grounding prevents electrical-noise generation from ground loops.

The design of the PGS involves two standards. One is the CAMAC standard; the other is the Nuclear Instrument Module (NIM) standard.⁶ Both standards specify certain optional and mandatory voltages, as follows:

<u>Voltage</u>	<u>CAMAC</u>	<u>NIM</u>
± 3 dc		Optional
± 6 dc	Mandatory	Optional
± 12 dc	Optional	Mandatory
± 24 dc	Mandatory	Mandatory
117 ac	Optional	Optional
+200 dc	Optional	

As this listing shows, the CAMAC and NIM standards are very compatible from the standpoint of voltage levels. The basic difference between the two standards is that the NIM standard is used for analog-parameter design, whereas the CAMAC standard is used for digital-parameter design. Where possible, common voltage sources have been used for both the NIM and CAMAC subsystems.

The +6 Vdc supply is the main voltage source for the CAMAC-module digital integrated circuits (IC's). A simple voltage-dropping network (Fig. 19) is used to drop the +6 to ± 5 Vdc.

Fig. 19. Transistorized Voltage-dropping Network

The use of +6 Vdc with the droppage to approximately +5 Vdc on each module serves to prevent cross talk between modules. The 0.01-μf distributed capacitors prevent cross talk between IC packages. The design limits for loading and for distributed capacitors were arbitrarily set at ten IC packages for each voltage-dropping network and five IC packages for each 0.01-μf capacitor. This was not necessarily a firm rule, and some variation was allowed on the CAMAC modules.

The CAMAC-PDC interface has a separate +5 Vdc power supply, and the PDC has its own dc power-supply system.

C. Programmed Digital Controller (PDC)

The PDC (see Fig. 20) is the heart of the precision-gamma-scanner system. It provides control commands to the stage and other equipment as required and accepts and stores data from the gamma-ray-detector subsystem.

The PDC is a Datacraft Series 6024 Model 3 digital computer with a word length of 24 bits plus parity. The cycle time of the PDC is 1 μsec and it has a memory capacity of 8K words (expandable to 65K words). The PDC is equipped with eight external interrupts (expandable to 24), of which one is used for the magnetic tape, two are used for the teletype, three are used for the CAMAC peripherals, and one is a spare.

Fig. 20. Programmed Digital Controller and PGS Control System

Besides the CAMAC peripherals, the PDC has two other peripherals. One is a nine-bit magnetic-tape transport, Peripheral Equipment Corporation Model 6840-9-25, with a speed of 25 ips. The magnetic tape is used for storing both programs and data. The other peripheral is a teletype/punch/reader, Teletype Corporation Model ASR-33. The teletype is the main communication between the operator and the computer.

The input-output (I/O) structure of the PDC consists of both 8- and 24-bit channels, including a special type of 24-bit channel that has automatic block-transfer capability (ABC). For the PGS, an 8-bit I/O channel is used for the teletype, and a 24-bit ABC I/O channel is shared by the magnetic-tape transport and the CAMAC peripherals.

The PDC has an instruction-word set of more than 582 words. All programming is done in assembly language. The existing PGS program is described in Section VI.B.

The general requirement that the PGS be an expandable system was applied also to the PDC. The selected PDC will accept other peripherals, such as a disk memory, a card reader, a second magnetic-tape transport, and a line printer. The memory can be expanded to 65K words, and the external priority-interrupts can be increased to 24.

D. CAMAC-PDC Interface

Before the CAMAC-PDC interface is discussed, a brief explanation should be given of the CAMAC command- and data-word structure. The CAMAC standard defines a command word as being composed of three binary bits for crate address (CR), five binary bits for station number (N), four binary bits for subaddress (A), five binary bits for the function (F), one binary bit for initialize (Z), and one binary bit for G, the "graded-L request" (see Ref. 5). The function F has certain codes that have been defined by the CAMAC standard for read, write, etc., and the logic in the PGS does not deviate from these designated codes. If special commands are ever required, undesignated codes are available for that purpose.

Although the arrangement of the specific bits within the CR, N, A, F, Z, and G fields is somewhat delegated, the arrangement of the fields is arbitrary as far as the interface is concerned. For the PGS system, the field arrangement is as follows:

23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Not used					G	Z	16	8	4	2	1	8	4	2	1	16	8	4	2	1	4	2	1
					F				A				N				CR						

The data word is a 24-bit word, and the least significant bit was selected as the rightmost bit or bit No. 0, as shown above. Although the command word is 19 binary digits in length and the data word is 24 digits, the computer word length does not have to be 24 bits or greater in length. Because of the manner in which the interface organizes the fields, many computers with word lengths of 16 bits have been interfaced to the CAMAC standard.⁸

The CAMAC-PDC interface is composed of essentially three parts: the general interface or buffer circuitry, supplied by Datacraft;⁹ the storage registers and timing circuits; and the branch drivers. The latter two parts are shown in Fig. 30 of Appendix A.

The branch-driver electronic characteristics, such as voltage levels and current sinking, are well defined in the CAMAC standard.⁴ The standard also describes the branch highway, which is the 66-twisted-pair transmission path for all signals between the CAMAC interface and the Type-A branch controller.

The branch controller uses the command and data words simultaneously, so both words are transmitted together. Since the PDC can only output either a command word or a data word at one time, the storage point is in the CAMAC-PDC interface. As shown in Fig. 30 of Appendix A, this storage is provided by 12 four-bit registers, half of them for command words and half for data words.

When a data word is output by the PDC, it is first stored in the data registers; next, a command word is output and stored in the command-word registers; then the logic gates are opened to the branch highway, and the data and command words are transmitted together to the branch controller. The information processing from this point on is described in Section E below.

The programming sequence is data word first, followed by a command word. If the instruction to the CAMAC system does not require a data word, then the outputting of the command word only will cause the information to be transmitted to the Type-A branch controller.

The inputting of a data word is performed under the command of the PDC. A command word to "read" is output by the PDC, and the CAMAC system responds by presenting the information from a particular module to the dataway and hence to

the branch highway. The input data are loaded into the input storage registers, and are then read from these registers by the PDC.

The CAMAC-PDC interface was constructed on printed-circuit boards that were physically compatible with the Datacraft buffer boards and card file. Five boards were used for the interface, with three of them (1B, 2B, and 3B) being identical boards to minimize the number of different boards required in the system. (see Fig. 30 of Appendix A.)

E. CAMAC Crate, Dataway, Branch Controller, and Branch-termination Unit

The CAMAC standard of Ref. 4 defines the CAMAC crate, giving the physical dimensions and tolerances of the crate and modules.

The standard CAMAC crate has 25 positions for modules, numbered consecutively from left to right starting with position 1. Positions 24 and 25 are reserved for the Type-A branch controller. For wider branch controllers more positions are used. Fig. 21 shows front and rear views of a CAMAC crate, and for comparison, a NIM bin.

The CAMAC dataway is the communications path between the branch controller and the other modules in the crate. It also provides a communications path between modules in the same crate. The dataway holds the same importance within the crate as the branch highway does between the branch drivers and the crates. The dataway is composed of 86 signal or voltage lines. Included in this array are 79 bus lines: 14 for the required and optional voltages of the CAMAC standard; 24 for write lines; 24 for read lines; 5 for the function code; 4 for the address code; 2 for signal strobes; and 1 each for initialization, response, busy signal, clear, inhibit, and command accepted. The signals "station number" and "look-at-me" (an interrupt signal) are not bussed, and run from each module station back to the branch controller. The five remaining signal lines are not bussed and may be used by the designer as he chooses. The dataway is shown in the rear view of the CAMAC crate in Fig. 21b; it consists of a multilayer printed-circuit board with the signal lines etched as indicated above.

Various branch controllers can be used in a CAMAC system, but if the CAMAC standard as given in both Refs. 4 and 5 is followed, then the Type-A branch controller is used. The Type-A controller is described in Ref. 5. The Type-A controller completes the "handshake" between the PDC and the CAMAC

a. Front View of CAMAC Crate and Module

b. Rear View of CAMAC Crate and Module

c. Front View of NIM Bin and Module

d. Rear View of NIM Bin and Module

Fig. 21. Comparative Views of CAMAC Crate and NIM Bin

system by signaling the PDC when a command word and data word have been accepted by the CAMAC branch system. The controller decodes the CR (crate address) and N (module position) of the command word and puts the proper module on line to receive the rest of the command word.

Another function of the branch controller is to correct for skew and reshape the digital signals as required, to keep them within the electrical characteristics required by the standard.

The branch-termination unit is a simple module composed of a set of termination resistors, as shown in Fig. 22. There is a resistor network for each of the branch-highway twisted pairs.

Fig. 22. Resistor Network in Branch-Termination Unit

The resultant parallel impedance of each resistor network is 100 ohms, which is the characteristic impedance of the branch-highway twisted pair. The branch-termination unit is located at the end of the branch highway, as shown in Fig. 23.

Fig. 23. Location of Branch-termination Unit in CAMAC System

The termination unit aids in preventing signal reflection and noise generation by "antenna" action.

The termination unit is fabricated to the CAMAC standard and utilizes two positions in the crate. The unit is conveniently positioned next to the Type-A controller in the last crate in the series. (A CAMAC system can have up to seven crates, although only one is now being used for the PGS.) No communication can take place between the PDC and the branch-termination unit.

F. CAMAC Interface Module for Analog-to-Digital Converter

The CAMAC-ADC interface module is one of the simpler modules of the PGS CAMAC system. It serves mainly to interface the ADC to the CAMAC dataway. As shown in Fig. 28 of Appendix A, the module has the necessary logic gates to gate the 13-bit ADC word onto the dataway. It also provides front-panel readout of the ADC word. The module provides for an interrupt to the PDC when it has received data from the ADC.

The ADC interface module responds to the following CAMAC words:

$CR \cdot N \cdot A_0 \cdot F_0$ Read and reset ADC and ADC interface.

The ADC interface is a single-width CAMAC module. It was designed and fabricated by Argonne National Laboratory.

G. CAMAC Live-timer Module

The live-timer module is shown in Fig. 29 of Appendix A. As discussed in Section IV.F, the live timer is used to keep track of the time that the ADC is available for processing pulses. All pulses are locked out of the ADC until the live timer is started by a command from the PDC. The counting mechanism is a clocked-up/down 24-bit binary counter. When the live timer is started, the counter will start to count down at the rate determined by the clock pulse, which is at a 10-kHz rate for the PGS system. A pulse is received by the ADC, which begins processing the pulse. Simultaneously, the live-timer clock pulse is locked out of the counter and the countdown stops. The gamma pulse is converted to a binary number and read by the PDC. When the PDC reads the ADC interface, it resets the ADC, and in so doing opens the clock gate to the live-timer counter. The counter then continues to count down until another pulse is received. This process is repeated until the counter reaches zero. When the counter reaches zero the ADC is shut down and will not accept any more pulses. An "L" signal is also generated, which interrupts the PDC from resetting the ADC.

The CAMAC live-timer module responds to the following CAMAC command words:

CR·N·A ₀ ·F ₀	Read live timer
CR·N·A ₀ ·F ₉	Reset live timer
CR·N·A ₁ ·F ₁₆	Write live time from PDC to live timer
CR·N·A ₀ ·F ₁₂	Start live timer
CR·N·A ₀ ·F ₁₄	Stop live timer
CR·N·A ₀ ·F ₁₀	Reset look-at-me module (which sends interrupt signals to the PDC).

The live timer is a single-width CAMAC module. It was designed and fabricated by Argonne National Laboratory.

H. CAMAC Clock Module

The clock module provides a precision clock pulse for the CAMAC system. At present the live-timer module is the only module using the clock pulse.

The clock module has a 10-MHz precision oscillator as the fundamental clock. The fundamental frequency is divided down to provide outputs of 10^7 ,

10^6 , 10^5 , 10^4 , 10^3 , 10^2 , 10^1 , and 10^0 Hz. The outputs are provided on the auxiliary 36-pin connector on the back of the crate.

This module does not respond to any CAMAC command words. It is a single-width CAMAC module, which was designed and fabricated by Argonne National Laboratory.

I. CAMAC Stage-position Controllers and Display System

The PGS stage has four degrees of motion: the X, Y, and Z directions; and rotation, ϕ . Other driven mechanisms are the tip guide and the fixed guides. All electrical drives on the PGS stage are stepping motors with various torque ratings. Stepping motors were selected as the drivers because they would be compatible with digital equipment and would minimize the electrical-noise generation. For further noise abatement, since there were only four 50-pin electrical wall penetrations, the signal leads were separated from the motor leads to prevent transformer action. All the stepping motors were supplied by the Superior Electric Company and are of the bifilar type with 200 steps per revolution. The motor characteristics are listed below:

<u>PGS Service</u>	<u>Manufacturer's No.</u>	<u>Approximate Torque, oz-in.</u>	<u>Approximate Speed, steps/sec</u>
X motion	HS50L	180	60
Y motion	HS50L	180	60
Z motion	SS250-1002	240	40
ϕ motion	SS25-1001	20	60
Tip guide	SS25-1001	20	40
Tip-guide assembly	SS250-1002	240	40

The motors are powered from solid-state power supplies manufactured by Northern Precision Laboratories, Model 800863. Each power supply can accommodate four stepping motors and has an adjustable series resistor to set the proper voltage for each motor. It also has a variable speed adjustment for speed control on all the motors. The power supply accepts signals for both manual control and computer control. The mode of control is selected by a key-operated switch on the PGS control-room panel.

Since the tip-guide and fixed-guide motors are used for loading only, these motors operate on manual control and do not have any computer-control features. The four stage motors (X, Y, Z and Ø) are required to operate under both computer and manual control. Each motor is interfaced through an identical CAMAC control module. The control module operates on a closed control loop that is implemented by hardware rather than software. This feature permits the PDC to write out to the control module the desired position and then start the motor via the control module. Without further monitoring by the PDC, the motor drives the stage to the new position. On arrival, the stage is stopped automatically, generating a look-at-me signal to the look-at-me module, which in turn generates an interrupt to the PDC. (The look-at-me module is described in Section V.P.)

The position-display information is stored in the control module in binary-coded-digital (BCD) form. On command from the PDC, this information is read to a converter module for BCD-to-binary conversion, before transmission to the PDC.

When the PDC transmits binary position information to a control module, the path is again through the converter module. The PDC commands the converter module to accept the binary position data and convert it to BCD. Following this command, the PDC commands the control module to read the BCD data from the converter module. The hardware conversion process is described in detail in Section V.N.

The control modules are designed to operate simultaneously under computer control but only singly when under manual control. Should any limit switch be activated, all motors are stopped by a signal from the stall module to each of the control modules (see Section V.O. for a description of the stall module) and an interrupt is sent to the computer.

The stage-position control modules were designed and fabricated by Northern Precision Laboratories. The model number is PN 800865. Each of the modules responds to the following CAMAC command words:

CR·N·A ₀ ·F ₀	Read position from module to computer in BCD
CR·N·A ₀ ·F ₁₆	Write position from computer to module in BCD
CR·N·A ₀ ·F ₁₀	Reset look-at-me signal
CR·N·A ₀ ·F ₁₂	Start motor
CR·N·A ₀ ·F ₄	Write BCD position from control module to converter module for conversion to binary (control module first generates dataway signal Pl, as explained on p. 61).

CR-N-A₀-F₂₀

Read BCD position information from converter module to control module (control module generates dataway signal P2)

The display system is an integral part of the control system and will now be discussed. The display system is composed of digital encoders, decoders, and display units. The encoders are absolute contact-type encoders. The code generated by the encoders is basically the reflected binary code (also called the gray code), but with the additional features of a carry code. The encoder gray code is transmitted to the position-display units, where it is decoded from the modified gray code to BCD 8421 code and displayed. The decoder display units are located on the FGS control-room panel, with slave readouts located on the manual control console at air-cell window A4. The BCD information is also transmitted to the control modules for control and for reading by the PDC. The entire display system is manufactured by Northern Precision Laboratories. The model numbers are:

Four-axis position display/decoder	PN800883
X-axis encoder	PN800809
Y-axis encoder	PN800809-1
Z-axis encoder	PN800809-2
θ-axis encoder	PN800809-3

The readout on each axis is:

X and Y	0-9.999 in.
Z	0-9.999 in.
θ	0-359.9°

The encoders were specifically selected to have 200 counts per turn to be compatible with the stepping motors, which have 200 steps per turn. This prevents "hunting" by the control system and ensures that for each position of the motor there exists a number on the encoder. The encoders are attached directly to the shafts of the double-ended stepping motors.

J. CAMAC Controller for Collimator Slit Position

The slit-position controller is identical to the controllers used for the X, Y, Z, and $\emptyset$ motions. The drive motor is a Superior Electric Model SS25-1001. The characteristics of the motor are described in the preceding section.

The control and display system for collimator slit position differs in two ways from that for stage position: (a) the drive motor and encoder are outside the air cell, and (b) the display system is a single unit rather than a combination of four units. The slit position is displayed on the PGS control-room panel and not at the manual control console. The readout range is 0 to 9999 mils, although the actual opening of the slit is a maximum of 55 mils.

The CAMAC slit-position control module and the encoder-display unit were manufactured by Northern Precision Laboratories. The control module is a Model PN-800865, and the encoder/display unit consists of Models 800914 and 800915 respectively.

K. CAMAC Module for Collimator Rotation

The collimator is rotated with a stepping motor. As with the tip-guide and tip-guide-assembly drives, the stepping motor was selected because of compatibility with digital equipment and avoidance of generation of 60-Hz noise. The drive motor is a Superior Electric Model SS250-1002.

The motor is controlled by a two-position CAMAC control module, which receives its signals from two limit switches, one for horizontal position and one for vertical position (see Fig. 31 in Appendix A). On command from the PDC, the control module starts the motor, which rotates the collimator until a limit switch is activated. The control module automatically stops the motor and generates a look-at-me when either of the limit switches is activated. Hence, the PDC does not need to monitor the rotation once it has requested the rotation to start.

The module for collimator rotation is a single-width CAMAC module, designed and fabricated by Argonne National Laboratory. The module responds to the following CAMAC command words:

CR·N·A₀·F₁₂ Move to position 1 (slit in the vertical position)

CR·N·A ₁ ·F ₁₂	Move to position 2 (slit in the horizontal position)
CR·N·A ₀ ·F ₀	Read slit position
CR·N·A ₀ ·F ₁₀	Reset look-at-me signal.

L. Display Scope and CAMAC Interface Module

The display unit is a storage scope with a raster area of 21 x 16.2 cm. The raster is composed of 300 lines by 400 lines, or a total of 1200,000 dots. The storage scope is a Tektronix Model 611.

The interface to the scope is a single-width CAMAC module with graphic capabilities. The scope is controlled from the PDC by outputting a CAMAC command word and data word. The module is capable of generating a look-at-me at the end of either "scope erased" or "spot written". However, this feature is not used in the PGS system, but instead a software delay is provided in the program to prevent interference by the PDC during either the erasing or writing process.

The scope module contains not only the necessary timing circuits and logic for response to the CAMAC commands listed below, but also an X- and Y-axis digital-to-analog converter. The converter converts the digital data from the PDC to a 0- to 1-V analog signal, which is compatible with the input circuitry of the storage scope. All signals between the scope and the module pass through the 36-pin J1A connector (see Fig. 32 of Appendix A).

The CAMAC scope module was designed and fabricated by Argonne National Laboratory. It responds to the following CAMAC command words:

CR·N·A ₀ ·F ₁₂	Erase display
CR·N·A ₁ ·F ₁₆	Load gain and select store or nonstore mode
CR·N·A ₁ ·F ₁₆	Store data word in X-axis register
CR·N·A ₁ ·F ₁₇	Store data word in Y-axis register and write after 80- μsec delay
CR·N·A ₁₅ ·F ₁	Read module characteristic word
CR·N·A ₀ ·F ₈	Test "erase completed" look-at-me
CR·N·A ₁ ·F ₈	Test "spot written" look-at-me
CR·N·A ₀ ·F ₁₀	Reset both look-at-me's.

The gain word is an eight-bit word, as shown below:

23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
																S	Y ₃	Y ₂	Y ₁	Y ₀	X ₂	X ₁	X ₀

where the gain codes are defined as follows:

<u>X Axis</u>			<u>Y Axis</u>		
<u>Channels</u>	<u>Full Scale</u>	<u>Code</u>	<u>Channels</u>	<u>Full Scale</u>	<u>Code</u>
		X ₂ X ₁ X ₀			Y ₃ Y ₂ Y ₁ Y ₀
2 ¹²		0 0 1	2 ¹²		0 0 0 1
2 ¹¹		0 1 0	2 ¹³		0 0 1 0
2 ¹⁰		0 1 1	2 ¹⁴		0 0 1 1
2 ⁹		1 0 0	2 ¹⁵		0 1 0 0
2 ⁸		1 0 1	2 ¹⁶		0 1 0 1
			2 ¹⁷		0 1 1 0
			2 ¹⁸		0 1 1 1
			2 ¹⁹		1 0 0 0
			2 ²⁰		1 0 0 1

The store mode is written as follows:

Store 1

Nonstore 0

The X data word is 12 bits in length, with the bit arrangement shown

23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
												MSB	X	X	X	X	X	X	X	X	X	X	LSB

where MSB and LSB are the most and least significant bits. The Y data word is a 24-bit word and must be received from the PDC last, since the scope writes after receiving this word.

M. Real-time Clock and CAMAC Interface Module

The real-time clock is a calendar clock manufactured by Monsanto Electronics, Series MIDAS 1816-316. The clock has three digits for the date and six digits for the time of day. The resolution of the time of day is 1 sec, and the time of day is registered on a 24-hr basis. Visual readout is provided by 1-in. Nixie tubes. The clock is set by means of thumbwheel switches on the front of the chassis.

The real-clock time is read out to the PDC through the CAMAC calendar-clock interface (see Fig. 33 in Appendix A). This interface, which is one of the simpler units in the PGS system, provides a means of dropping the 15-V BCD logic signals of the calendar clock down to the 5-V logic levels compatible with the CAMAC standard. The interface provides the necessary logic to respond to the following CAMAC words:

$CR \cdot N \cdot A_1 \cdot F_0$	Read real-time days in BCD
$CR \cdot N \cdot A_0 \cdot F_0$	Read real-time hours, minutes, and seconds in BCD
$CR \cdot N \cdot A_1 \cdot F_4^*$	Write BCD days from interface module to converter module and convert to binary
$CR \cdot N \cdot A_2 \cdot F_4^*$	Write BCD hours from interface module to converter module and convert to binary
$CR \cdot N \cdot A_3 \cdot F_4^*$	Write BCD minutes from interface module to converter module and convert to binary
$CR \cdot N \cdot A_4 \cdot F_4^*$	Write BCD seconds from interface module to converter module and convert to binary.

The calendar-clock interface is a single-width CAMAC module. It was designed and fabricated by Argonne National Laboratory.

N. BCD-to-Binary and Binary-to-BCD Converter

Both of these code conversions can be done by either software or hardware. Since the PDC was purchased with a limited amount of core, and since its primary purpose was control and acquisition of data from the gamma scanner, hardware conversion was selected as the most economical.

*Used in conjunction with converter module. Calendar-clock interface module generates dataway signal P1.

The conversion from BCD to binary and binary to BCD uses standard logic methods and is described in the literature.¹⁰ The conversion module is unique in the PGS system in using the dataway to communicate with other modules. This method of communication does not violate the CAMAC standard and saves computer time by not using the computer as a transfer path between modules.

As discussed in Section V.D, both a data word and a command word are transmitted from the PDC-CAMAC interface to the CAMAC system. The data word contains the binary information to be converted to BCD, and the command word contains the command to convert from binary to BCD. Timing circuits are contained in the conversion module to prevent interference on the dataway and to ensure waiting for completion of conversion before transferring. The transfer is accomplished by addressing the receiving module with the command word $CR \cdot N \cdot A_0 \cdot F_{20}$. The receiving module responds by generating a P2 signal (see signal listing below) and by latching to the write lines for information transfer. The converter module receives the P2 signal and places the converted-to-BCD data on the write lines. The data are then transferred automatically.

The transfer of BCD data from another module to the converter module is accomplished in the following manner: The BCD data are read from the other module with the command word $CR \cdot N \cdot A_0 \cdot F_4$. The response to this command is to place the BCD data on the read lines and generate a P1 signal. The P1 signal is received by the converter, which responds to this signal by receiving the BCD data from the dataway read lines and converting it to binary. The binary data are transferred to the PDC by addressing the converter module with the command word $CR \cdot N \cdot A_1 \cdot F_0$.

The binary-to-BCD and BCD-to-binary converter module responds to the following CAMAC command words:

$CR \cdot N \cdot A_0 \cdot F_{20}$	Write binary and convert to BCD
$CR \cdot N \cdot A_2 \cdot F_0$	Read BCD to computer from converter
$CR \cdot N \cdot A_0 \cdot F_{22}$	Write BCD and convert to binary
$CR \cdot N \cdot A_1 \cdot F_0$	Read binary to computer from converter module.

The converter module also responds to the following dataway signals:

P1	Accept BCD information from either read or write lines and convert to binary
----	--

- P2 Place BCD data that has already been converted from binary on the write lines
- P3 Accept binary information from either the read or write lines and convert to BCD
- P4 Stop conversion and clear L
- P5 Stop conversion and clear L
- Z Initialize all registers and flip-flops
- B Gate the L off the dataway.

This module generates the following dataway signals:

- L Signal produced at the end of either conversion process
- Q Signal to produce status bit when addressed with any of the functions F_0 , F_{10} , F_{20} , F_{22} .

The converter module was designed and fabricated to Argonne National Laboratory specifications by Northern Precision Laboratories. The model number is PN-800865.

0. CAMAC Stall Module

The stall module accepts 12 inputs from limit switches and provides the necessary logic to register the abnormal condition, provide a motor-shut-down signal to the motors, and provide an interrupt signal to the computer. An abnormal condition exists when any one of the 12 inputs is open-circuited. The inputs pass through the 36-pin connector, as shown in Fig. 34 of Appendix A. The abnormal condition is registered in an integrated-circuit bistable multivibrator. The stall module is reset by a manual switch located in the PDC control room. The stepping motors are shut down when the stall module generates a P4 CAMAC signal. All stepping-motor control modules accept the P4 signal and use it for a hardware shutdown signal. The PDC receives a priority-interrupt signal from the module and can also do a software shut-down if desired.

The following inputs on the stall module are used:

<u>Input No.</u>	<u>Limit</u>
1	Z-motion down limit
2	Z-motion up limit
3	X-motion forward limit
4	X-motion middle limit

<u>Input No.</u>	<u>Limit</u>
5	X-motion back limit
6	Y-motion left limit
7	Y-motion right limit
8	Guide assembly jam up
9	Guide assembly jam down
10	Guide travel up
11	Guide travel down
12	Spare

These inputs are shown in Figs. 35 and 36 of Appendix A.

The stall module is a single-width CAMAC module. It was designed and fabricated by Argonne National Laboratory. The module responds only to the CAMAC command word read:

CR·N·A₀·F₀ Read stall module.

P. CAMAC Look-at-me Module

The look-at-me (LAM) module can accommodate 23 look-at-me (L) signals. The number of signals was selected to accommodate the maximum number of L inputs from a single CAMAC crate. The basic purpose of the module is to provide a priority basis for the L signals from other modules and generate a single interrupt to the PDC. Each of the L signals is assigned a priority on the printed-circuit board by jumpering the input, as shown in Fig. 40 in Appendix A. For each priority of input a distinct code is generated, which the PDC can read as required. An additional feature of the LAM module is that four L inputs can be wired together to provide the logical operator OR, permitting a single code for four different look-at-me signals.

For the PGS system the priorities selected were as follows:

<u>Priority</u>	<u>Binary Code</u>	<u>Crate Position</u>	<u>L Generation</u>
1	0 0 0 0 1 OR'ed	3	X-position home
2	0 0 0 1 0	4	Y-position home
3	0 0 0 1 1	5	Z-position home
4	0 0 1 0 0	6	Ø-position home
5	0 0 1 0 1	7	Slit position home
6	0 0 1 1 0	8	Collimator position home
7-23	0 0 1 1 1-1 0 1 1 1	Not used on PGS	

The look-at-me module is a single-width CAMAC module. It was designed and fabricated by Argonne National Laboratory.

The LAM module responds to the following CAMAC command words:

$CR \cdot N \cdot A_0 \cdot F_0$	Read priority code
$CR \cdot N \cdot A_0 \cdot F_{10}$	Reset look-at-me.

Q. Manual Control Console

The manual control console is located at window A4 of the air cell. The console is used mainly for manual loading of fuel pins and capsules into the PGS stage. For this operation, there are push-button controls for each stepping motor; i.e., X, Y, Z, and $\emptyset$ position, plus the tip-guide and fixed-guide motors. The console also contains displays for X, Y, Z, and $\emptyset$ position. No position-display information is provided for the tip guide and fixed guides, since the operator uses these drives only when loading and it is required that the stage be viewed through the window (see Appendix C.3 for a description of the loading procedure).

All of the limit-switch actuations are indicated on the manual control console, because it is an administrative requirement that whenever a limit switch is actuated, the operator must deactuate it from this console while observing the stage. This requirement prevents damage to the element or capsule.

The two stepping-motor power supplies are conveniently located in the manual control console. This location places the power supplies as near as possible to the stepping motors, which keeps the line-voltage drop and power loss to a minimum.

Since the slit position and collimator rotation do not affect the manual loading operation, these two PGS functions are not indicated or controlled at the manual control console.

The console is mounted on wheels to provide for easy movement, which is required for viewing of the stage. The console cabinet is a standard 19-in. electronic cabinet with sloping front for location of pushbutton controls and position displays. The interconnecting cabling between the stage, manual control console, and PDC control room is shown in Figs. 35 - 39 of Appendix A.

VI. SYSTEM SOFTWARE*

A. Operating System

The programmed digital controller (PDC) operates under a real-time, hardware-interrupt-oriented operating system, which is designed for flexibility and efficiency. This operating system is bootstrapped into the PDC core from the magnetic-tape unit, and is thus called the tape operating system (TOS). The TOS will function with one or more tape transports. Tape transport number zero contains the TOS tape, and other tape transports can be used for general storage. The TOS tape consists of the following files: processor file at the load point (end of file zero, or EOF 0), library file at EOF 1, and scratch file at EOF 2. The processor file contains the following processors:

Record 1. Absolute magnetic-tape loader at load point in bootstrap format.

Record 2. Resident TOS in absolute magnetic-tape-loader format.

Records 3 and 4. Job control and link loader in load-module format (these are routines that control the loading and execution of other routines and subroutines).

Records 5, 6, 7 and 8. Basic assembler, nonresident debug program, utility program, and cross-reference program in load-module format.

The library file consists of the standard support-library and user-library subroutines. The scratch file serves as a temporary file for binary output or as a source file for pass two of an assembly. During PGS operation, the scratch file serves as the data file for spectral and gamma-scan information. The TOS is loaded from the magnetic tape via the following bootstrap program:

*For an explanation of the computer jargon that appears in this section, the reader is referred to the Series 6000 Computer System Reference Manual, Datacraft Corp. Fort Lauderdale, Fla., RM61305-00, and to standard reference works such as Standard Dictionary of Computers and Information Processing, Martin H. Weik, Hayden Book Company, Inc., New York (1969).

<u>Core Location</u> <u>(octal code)</u>	<u>Octal</u> <u>Instruction</u>	<u>Mnemonic</u> <u>Instruction^a</u>	<u>Description</u>
0	62500406	TOA '406	Transfer operand to A register
1	00700700	OCW '700	Output command word
2	62500015	TOA WC	Transfer operand to A register
3	00714700	OAW '700	Output address word
4	22600003	BNZ *-1	Branch on not zero (wait if busy)
5	05000014	TMA CW	Transfer memory to A register
6	00700700	OCW '700	Output command word
7	00730700	ISW '700	Input status word
10	22600007	BNZ *-1	Branch on not zero (wait if busy)
11	00110200	QBB B7	Query bits of byte
12	22600007	BNZ *-3	Branch on not zero (wait if busy)
13	21000020	BUC '20	Branch unconditionally
14	40034506	CW DATA '40034506	Execute memory
15	00000100	WC DAC'100	Word count
16	00000200	BA DAC '20	Block address
17	01000000	TMI	Transfer memory to I register

^aThis column is merely a mnemonic aid to the operator. The numbers led by primes are in octal code.

After loading of the resident TOS from magnetic tape is completed, the control-room teletype will print the message ABORT. Statements can then be read in from the teletype. The operator can manually control the job stream of the TOS by using two keys of the teletype, X-OFF and BELL. To unconditionally terminate a current job, the operator must actuate the keys CTRL (control) and X-OFF. This will cause the message ABORT to be printed on the teletype, and job-stream control will then be assigned to the teletype.

A hold condition can result from program-control or job-control statements. Generally, a message is printed on the teletype when a hold is encountered. The message informs the operator of action required; however, before the PDC releases the hold condition, the operator must actuate the keys CTRL and BELL on the teletype.

The TOS job-control and link-loader routines are used to load the binary format of the PGS control program into the PDC core. This program remains resident in the core during operation of the PGS. The following control statements are written on the teletype to load the PGS control program from the teletype paper-tape reader:

<u>Operator Action</u>	<u>Function</u>										
1. X-OFF	Initializes TOS and types ABORT										
2. \$JOB PGS	The \$JOB statement opens a new job and saves the 6-character name PGSXXX. The abort flag is reset and the restrict flag is set.										
3. \$ASSIGN 4, 2	This statement causes physical device 2 (teletype paper-tape reader) to be assigned to logical file 4 (binary input)										
4. \$OPTION .7	This statement sets the specified bits of a memory word; i.e., 7 places a 1 in the selected bit position. The leading dot (.), if present, enters zeros in all bits of the word prior to the specified bits. The 7 also causes the link loader to output an external map on the teletype.										
5. \$LINK 5634, 17777	Parameters 5634 and 17777 octal define a "link area" of memory in which the core image of an executable program is built from all load modules read from the binary-input device (teletype paper-tape reader), plus any library routines required from the TOS library file (logical file 12). The upper portion of the link area is used by the link loader as temporary storage for developing an external linkage table, which links the PGS program to the TOS processors. The TOS processors occupy core area 0 to 5633 octal; the PGS program occupies core area 5634 to 17744 octal.										
6. Press halt switch on PDC console (at this time, the operator manually inputs the proper interrupt branch locations into the TOS priority-interrupt linkage table).	<table> <tr> <th><u>Core Location (octal code)</u></th><th><u>Octal Instruction</u></th></tr> <tr> <td>103</td><td>25006557</td></tr> <tr> <td>104</td><td>25006607</td></tr> <tr> <td>105</td><td>25006713</td></tr> <tr> <td>106</td><td>25006770</td></tr> </table> <p>The above instructions are interrupt branch instructions to designate the absolute core locations</p>	<u>Core Location (octal code)</u>	<u>Octal Instruction</u>	103	25006557	104	25006607	105	25006713	106	25006770
<u>Core Location (octal code)</u>	<u>Octal Instruction</u>										
103	25006557										
104	25006607										
105	25006713										
106	25006770										

Operator Action

of the jam alarm, live timer, ADC, and look-at-me subroutines. These locations may change with program revisions.

7. X-OFF

8. \$JOB PGS

9. \$GO

The PGS program will begin processing at core location 5634 octal.

External definition (external address defined during program execution) can be defined for the interrupt routines and placed in the resident TOS. This will eliminate steps 6 and 7 above. Refinements of this type will be completed when a new disk monitoring system is implemented. This system will replace the TOS, but the TOS will always be held as a backup operating system.

B. Control Software

The gamma-scanning functions are ordered and controlled by a program named PGS. This program is loaded under TOS in a binary format as described above. Once initialized by the \$GO statement, the PGS program will disarm the system interrupts and reset all the look-at-me lines in the CAMAC crate. The magnetic tape will advance to the head of the scratch file (file 13) and halt. GSI RDY FOR INF will be typed on the teletype, which tells the operator that the gamma scanner is ready for information. The operator acknowledges the message with the CTRL and BELL keys. This releases the PDC from a hold state and starts the sequential input of the control parameters listed in Table I on p. 71.

Before the operator pushes the carriage RETURN key for step 43 of Table I, he should set the PDC control switches and sense switches. The functions of these switches are given in Tables II and III. When the desired switches are set, a RETURN will initialize the program. If control switch 20 is set, the PDC will assume that the first spectrum is a calibration spectrum. A ²²⁸Th source is placed 4 in. in front of the germanium-lithium detector and counted for the same real time as specified for the gamma scan. When the count is completed, the PDC will halt without indexing the stage to a new position. If control switch 17 is set, the operator can request to look at certain areas of the calibration spectrum to ensure that it is correct. If it is not satisfactory, the magnetic tape is rewound and the source is again counted. After a satisfactory spectrum is obtained, switch 20 is reset and

a new slit width and live time are requested according to steps 41 and 44 of Table I.

The PDC will now direct the gamma scan automatically without operator attention. The spectrum will be written on magnetic tape and the stage incremented to the next static scanning position. The tape record will begin with the following data files:

1.	<u>Calibration File</u>	<u>Number of Words</u>
	Spectrum number (0 for calibration spectrum)	1
	X, Y, Z, and $\emptyset$ positions	4
	Time spectrum count started (day, hour, min, sec)	4
	Slit width	1
	Spectrum	4096
	Time spectrum count ended (day, hour, min, sec)	4
	End of file	(EOF)
2.	<u>Information File</u>	
	Title	20
	Pin number	2
	Subassembly number	2
	Core position	2
	Fluence	2
	Type of scan	2
	Last irradiation	1
	Live time	1
	Length of irradiation	1
	X, Y, Z, $\emptyset$ scan parameters	12
		EOF
3.	<u>Spectrum File</u>	
	Spectrum number (1 - 1500)	1
	X, Y, Z, and $\emptyset$ positions	4
	Time spectrum count started	4
	Slit width	1
	Spectrum	4096
	Time spectrum count ended (day, hour, min, sec)	4
		EOF

Any number of calibration and spectrum files up to a maximum of 300 follow the three initial files, depending on the gamma-scan parameters.

The PGS program can process four real-time interrupts. The highest-priority interrupt is from the stall-alarm module. If a limit switch on the stage is triggered, the stall-alarm module will initialize both a hardware and software shutdown of all stage stepping motors. The time of the jam or stall (day, hour, minute, second) will be printed on the teletype with an operator message JAM ALARM. The operator will clear the jam manually and release the PDC by pushing CTRL and BELL.

The second-priority interrupt is an interrupt initiated by the live timer when the preset live-time register is clocked down to zero. This activates a subroutine in which the position and spectral data are written on magnetic tape. The subroutine then branches to the main body of the program, which sets up the new parameters.

As the third priority, the ADC is also handled on an interrupt basis. An interrupt is initiated from the CAMAC-ADC interface every time a count is loaded into the ADC module. The interrupt routine addresses the PDC-CAMAC interface and inputs the count address to the PDC. A base address is added to the ADC address, and the resultant memory location is incremented by one. If sense switch 9 is set, the channel and address total counts are output to the CAMAC display-scope module, and the data are written as one point on the display screen. Displaying the data on the scope will increase the dead time.

The lowest-priority real-time interrupt comes from the look-at-me module. The look-at-me module is an interrupt structure within the CAMAC crate. The PGS program uses look-at-me signals from the position drives and collimator-rotation drive to start each motor when the stage is being positioned. If a look-at-me signal is not received from a position module, the PDC will go into a wait mode until the operator clears the malfunction.

The PGS control program contains different subroutines to handle data to and from the teletype and pack and unpack numerical characters to and from one binary-word location. A listing of the PGS program is given in Appendix B. Table IV lists the CAMAC control-word instructions and their functions.

TABLE I. PGS Operational Control Functions

Operator Action	Computer Action	Description
1. None	Types TITLE on teletype	Computer requests job title from operator
2. CTRL-BELL	Advances teletype carriage two lines	
3. Types in 60 or less characters giving title, then presses carriage RETURN	Prints and stores 60 characters in 20-word block called TITLE	If a carriage RETURN is transmitted from the teletype before the block is full, the computer fills the remainder of the block with blanks and continues the program
4. None	Types PIN NO on teletype	Computer requests pin number of subject to be gamma scanned (e.g., 014)
5. CTRL-BELL	Advances carriage two lines	
6. Types in six or less characters giving pin number, then RETURN	Prints and stores six characters in two-word block called PINO	Same as 3
7. None	Types SUB NO on teletype	Computer requests subassembly number (e.g., X071A)
8. CTRL-BELL	Advances carriage two lines	
9. Types in six or less characters giving subassembly name, then RETURN	Prints and stores six characters in two-word block called SUBNO	
10. None	Types CORE on teletype	Computer requests irradiation core position (e.g., 4D5)
11. CTRL-BELL	Advances carriage two lines	
12. Types in three-character core position, then RETURN	Prints and stores in two-word block called COREP	
13. None	Types FLU on teletype	Computer requests fluence
14. CTRL-BELL	Advances carriage two lines	

TABLE I (continued)

Operator Action	Computer Action	Description
15. Types in six or less characters giving fluence, then RETURN	Prints and stores fluence in two-word block called FLUEN	
16. None	Types POS on teletype	Computer requests the initial, final, and incremental steps for the four degrees of motion X, Y, Z and $\emptyset$
17. CTRL-BELL	Advances carriage two lines	
18. Inputs final X position, then RETURN	Prints, packs, and stores in one word block called POS, then advances carriage two lines	The six or less digits are stored as one binary number instead of six or less ASCII characters. The number represents mil units.
19. Inputs final Y position, then RETURN	Prints, packs, and stores in one word block called POS + 1, then advances carriage two lines	
20. Inputs final Z position, then RETURN	Prints, packs, and stores in one word block called POS + 2, then advances carriage two lines	
21. Inputs final $\emptyset$ position, then RETURN	Prints, packs, and stores in one word block called POS + 3, then advances carriage two lines	
22. Inputs X increment, then RETURN	Prints, packs, and stores in one word block called POS + 4, then advances carriage two lines	An increment is the distance the drive will move from one scan to the next. Six or less characters are entered; the number represents mil units.
23. Inputs Y increment, then RETURN	Prints, packs, and stores in one word block called POS + 5, then advances carriage two lines	

TABLE I (continued)

Operator Action	Computer Action	Description
24. Inputs Z increment, then RETURN	Prints, packs, and stores in one word block called POS + 6, then advances carriage two lines	
25. Inputs Ø increment, the RETURN	Prints, packs, and stores in one word block called POS + 7, then advances carriage two lines	
26. Inputs initial X position, then RETURN	Prints, packs, and stores in one word block called POS + 8, then advances carriage two lines	The scan will start at the X, Y, Z, and Ø position specified in the initial position. Six or less characters are entered; the number represents mil units.
27. Inputs initial Y position, then RETURN	Prints, packs, and stores in one word block called POS + 9, then advances carriage two lines	
28. Inputs initial Z position, then RETURN	Prints, packs, and stores in one word block called POS + 10, then advances carriage two lines	
29. Inputs Ø position, then RETURN	Prints, packs, and stores in one word block called POS + 11, then advances carriage two lines	
30. None	Types IRRA TIME on teletype	Computer requests number of hours of irradiation the subject has received.
31. CTRL-BELL	Advances carriage two lines	
32. Types in six or less characters giving irradiation time in hours, then RETURN	Prints, packs, and stores in one block called RTIME	

TABLE I (continued)

Operator Action	Computer Action	Description
33. None	Types LAST IRRRA on teletype	Computer requests number of hours to last irradiation of 100 hours or more (e.g., 2400 = 10 days)
34. CTRL-BELL	Advances carriage two lines	
35. Inputs six or less characters giving time to last irradiation in hours, then RETURN	Prints, packs and stores in one block called LTIRR	
36. None	Types TYPE SCAN on teletype	Computer requests type of scan (AXIAL or DIAMET)
37. CTRL-BELL	Advances carriage two lines	
38. Types AXIAL or DIAMET	Prints and stores in two-word block called TYPSCAN	This word tells the program which way to rotate the collimator and how to set up the positioning functions.
39. None	Types SLT WD on teletype	Computer requests slit width in ten thousands of an inch (e.g., 501 = 50.1 mils)
40. CTRL-BELL	Advances carriage two lines	
41. Types in six or less characters giving desired slit width, then RETURN	Prints, packs and stores in one block called SLTWD	
42. None	Types LIVE TIME on teletype	Computer requests live time in seconds (e.g., 600 = 10 minutes).
43. CTRL-BELL	Advances carriage two lines	
44. Types in six or less characters giving desired live time, then RETURN	Prints, packs and stores in one word block called LTIME. When a RETURN is received, advances carriage two lines and initializes program	

TABLE II. Control-switch Settings for the PGS

Switch No.	Function
23	Display-scope test
22	ADC and live-timer test
21	X, Y, Z, and $\emptyset$ motor and encoder test
20	Calibration spectrum
19	Printout of spectrum number, X, Y, Z, and $\emptyset$ positions, and day, hour, minute, and second of real time when the spectrum was started and ended
18	Printout of day, hour, minute, and second when all motors stopped at the next scan position
17	Printout of total counts in requested channel range
16	Automatic spectrum printout every two spectral cycles
15	Automatic spectrum printout every four spectral cycles
14	Automatic spectrum printout every eight spectral cycles
13	Saves scope display from last spectrum
12	Halts computer after completing count in progress
11	Returns positioning stage to initial starting position after completing count in progress, and reinitializes
10	Returns stage to load/unload position after completing count in progress, and reinitializes
9	Live-time display of 4096-channel spectrum on display scope
8	End-of-count display of last 4096-channel spectrum on display scope
7	Puts scope in storage mode
6	Sets a gain of 2^{-19} counts full scale to the Y axis on display scope
5	Sets a gain of 2^{-15} counts full scale to the Y axis on display scope
4	Sets a gain of 2^{-13} counts full scale to the Y axis on display scope
3	Sets a gain of 2^{-12} counts full scale to the Y axis on display scope
2	Sets a gain of 2^9 channels full scale to the X axis of the display scope
1	Sets a gain of 2^{11} channels full scale to the X axis of the display scope
0	Sets a gain of 2^{12} channels full scale to the X axis of the display scope

TABLE III. Sense-switch Settings for the PGS

Switch No.	Function
1	On selected consecutive channels, types out counts/ channel on teletype
2	Types out gross gamma count. Control switch 19 must also be set
3	Not used
4	Not used

TABLE IV. CAMAC Control Words Used in the PGS Program

Label	Octal Code	Function
SX	140031	Starts X drive motor
XY	140041	Starts Y drive motor
SZ	140051	Starts Z drive motor
SØ	140061	Starts Ø drive motor
BCDX	240031	Writes BCD to X module
BCDY	240041	Writes BCD to Y module
BCDZ	240051	Writes BCD to Z module
BCDØ	240061	Writes BCD to Ø module
STOP X	160031	Stops X drive motor
STOP Y	160041	Stops Y drive motor
STOP Z	160051	Stops Z drive motor
STOP Ø	160061	Stops Ø drive motor
RXBCD	31	Reads BCD position from X encoder to computer
RYBCD	41	Reads BCD position from Y encoder to computer
RZBCD	51	Reads BCD position from Z encoder to computer
RØBCD	61	Reads BCD position from Ø encoder to computer
WXBCD	200031	Writes BCD position from computer to X module
WYBCD	200041	Writes BCD position from computer to Y module
WZBCD	200051	Writes BCD position from computer to Z module
WØBCD	200061	Writes BCD position from computer to Ø module

TABLE IV (continued)

Label	Octal Code	Function
RSBCD	71	Reads BCD position from slit encoder to computer
WSBCD	20071	Writes BCD position from computer to slit module
SS	140071	Starts slit-drive motor
STOPS	160071	Stops slit-drive motor
LIVE 5	61021	Reads status of live timer
LIVE 6	340021	Inhibits dead time
LIVE 7	120021	Clears look-at-me
RDLM	141	Reads CAMAC look-at-me module
RLX	120031	Resets X-module look-at-me
RLY	120041	Resets Y-module look-at-me
RLZ	120051	Resets Z-module look-at-me
RLØ	120061	Resets Ø-module look-at-me
RLS	120071	Resets slit-module look-at-me
RLC	12101	Resets collimator look-at-me
RLSC	120121	Resets scope-module look-at-me
RLAM	120141	Resets look-at-me module
RDAY	40551	Reads days from real-time clock
RHR	41151	Reads hours from real-time clock
RMIN	41551	Reads minutes from real-time clock
RSEC	42151	Reads seconds from real-time clock
DY	210521	Transfers Y data only to display scope

C. Software for Reduction of Gamma Spectra

The Experimental Physics Section, Physics Branch, Nuclear Technology Division of Aerojet Nuclear Corporation analyzes the gamma-ray spectra obtained from irradiated experiments measured by Argonne at the HFEF complex.

These spectra are measured with a germanium-lithium detector system. The efficiency of this system for the detection of a gamma ray has been measured at a variety of gamma-ray energies for one geometric configuration.

The deviation of the system from a linear energy-vs-channel relation has also been measured. As noted below, these two sets of information are necessary for the analysis of the spectral data.

A gamma scan generally consists of a series of 50 to 300 spectra taken at different positions along the capsule or element. These spectra are recorded sequentially on a magnetic tape, with an information record at the front of the tape to describe the experiment. When this tape is received by the Experimental Physics Section, the personnel prepare the necessary computer-input information to carry out the analysis.

The analysis consists of the following operations: The first data on the tape are for a ^{228}Th spectrum. Five particularly strong gamma-ray peaks are located and analyzed. Then the program determines the approximate energy-vs-channel relation ($E = a + bx + cx^2$) and the peak-width-vs-channel relation ($W = \sigma + Bx$). Throughout the analysis of the succeeding fuel-sample spectra, this width function is used without change to determine the parameters of the peak-locating routine and the range of data to be used in fitting each peak. The $E(x)$ function is used only in the initial analysis and is updated for each spectrum.

After the ^{228}Th spectrum has been processed, each fuel spectrum is analyzed as follows: A peak-locating routine searches through the data to locate all of the peaks. Each peak is fitted with a Gaussian function (plus a background line) to determine its area and position. An important part of this computation is the determination of the background. At present this is done by extrapolating the background from the high-energy side of the peak. However, if there is a second peak in this region, the spectrum on both sides of the peak in question is used to determine the background.

From the positions and energies of a set of 5 to 10 calibration lines in the spectrum, the $E(x)$ function is computed and the energies of all of the peaks are determined. From these energies, the associated peak efficiencies and thereby the gamma-ray intensities are determined.

After the gamma-ray energies and intensities are known, these energies are compared with those in a library of energies and intensities of gamma rays associated with fission-product isotopes of interest and isotopes produced by irradiation of common structural materials. From this comparison, the observable isotopes of interest are identified. The amount of each isotope is computed.

This process is repeated for each of the 50 to 300 spectra of the gamma scan. The analysis time is about 15 sec per spectrum. After all of the spectra have been analyzed a summary list is made of the intensity of each (of up to 10 specified isotopes) for each of the spectra. These 10 intensity distributions may be plotted as a function of the position along the pin or plate. The information in this final summary can be made available for further computer processing if desired.

Several features have been added to the program to minimize the chance that once the analysis is initiated it will fail before completion. For example, the function $E(x)$ is not allowed to change drastically from one run to another. This means that if any spectrum is "bad", the $E(x)$ function will not be changed enough to cause subsequent analyses to fail. This check is especially useful when a set of data includes spectra at the ends of the pin or plate where there is no fuel. Also certain computer-system checks (e.g., overflows) are overridden so that the job will not be terminated.

VII. OPERATIONAL CHARACTERISTICS

A. Operating Personnel

Operation of the PGS requires a hot-cell floor technician (a person qualified to operate master-slave electromechanical manipulators) for loading the gamma source in the element-positioning stage. A computer operator is also required for entering the scanning information into the PDC. Once the gamma scan is begun, both the floor technician and the computer operator are free to do other jobs.

Summary procedures for the operation of PGS are included in Appendix C. As a quick review of these procedures will indicate, automatic computer control reduces manual procedures, thus reducing the manpower to both prepare and execute the procedures.

B. Data Presentation

Data from the PGS can be presented to the experimenter in two forms, raw and reduced. Raw gamma-ray spectral data are contained on a nine-track high-density 800-bits-per-inch magnetic tape in the format described in Section

VI.B. These data can be copied from the HFEF magnetic tape to the experimenter's magnetic tape and sent to the experimenter for reduction by his own techniques.

Reduced data are delivered to the experimenter in the form of isotope-distribution plots and computer line-printer listings. Plots for each isotope distribution requested are produced both in log and linear format on 35-mm microfilm. This film is filed at HFEF for one year then sent to the experimenter if he so requests. Copies of pertinent plots are sent to the experimenter in the HFEF Cognizant Engineer's report. Copies of the computer line-printer listing are also in the Cognizant Engineer's report, and the original is filed at HFEF with the microfilm. Gross gamma-scan data are presented in the form of computer listings. The data are not filed at HFEF but are delivered to the experimenter. Examples of reduced PGS data are given in Appendix D.

C. Charges for Gamma-scanning Services

The charges for gross scanning, precision gamma scanning, and failure detection with the PGS are given in Table V.

TABLE V. Charges for Gamma-scanning Services^a

PGS Function	Operational Charge	Data Reduction
Detection of failure in encapsulated fuel experiment	\$10.00/capsule	No charge
Detection of failure in fuel element	\$25.00/element	\$1.00/element
Axial gross gamma scan	\$5.00/subject + \$1.00/in.	\$0.10/in.
Diametral gross gamma scan	\$5.00/subject + \$20.00/in.	\$2.00/in.
Precision axial gamma scan (static scan)	\$5.00/subject + 25¢/spectrum	\$1.10/spectrum
Precision diametral gamma scan (static scan)	\$5.00/subject + 25¢/spectrum	\$1.10/spectrum

^a These charges are tabulated to aid experimenters in estimating the costs of examinations. Since these charges can change without notice, experimenters should contact the HFEF staff to obtain firm costs.

VIII. RECOMMENDATIONS

A. Mechanical Design

Listed below are recommendations that would be worthwhile improvements in the mechanical design of future gamma-scanning equipment:

- (1) A more robust positioning stage for increased accuracy and versatility.
- (2) A collimator with better provision for slit adjustment, including a slit adjustable in two dimensions and a fixed-area reference slit. These would increase counting accuracy, permitting more efficient identification of isotopes and quantitative analysis of the isotope.
- (3) An improved slit-opening indication system that would read out the slit dimension with better accuracy, to within ± 0.0001 in.
- (4) Additional features such as an anticoincidence system to allow the possibility of being able to determine the actual burnup rate in percent in fuel elements or capsules. This application would be well worth the effort.

B. Instrumentation and Control

With control systems that are the first of a kind, there is always room for improvement. Several minor improvements would increase the capabilities and efficiency of the PGS control system; and recommendations are given below for the next such system. The reader is cautioned not to take these recommendations as the ultimate system, but to weigh them and place them in the new design if they appear to fit or improve the system. The recommendations are not necessarily listed in their order of importance, which is left up to the user and designer of the next system.

1. Electrical Isolation

The system uses single-point grounding and obtains its power from a single motor-generator. Single-point grounding was used because of the ground loops that would have been created in the nuclear-detection system if

the facility ground was used. The motor-generator was used to filter out the voltage spikes that sometimes occur in the NRTS site power.

It is felt that electrical isolation, both digital and analog, would remove the need for supplying power to remote cabinets from the motor-generator and also remove the need to keep the nuclear detector ungrounded from the facility ground. A preliminary study has been performed on this system, with the results indicating that light-emitting diodes (LED's) could be used for the digital isolation between the CAMAC system and the remote cabinet. Numerous commercial amplifiers are available that provide good isolation between input and output. A conceptual design has been completed for an analog isolation amplifier using LED's.

2. Independence of CAMAC Modules

The CAMAC system is set up to provide for maximum independence of modules. In keeping with this independence, it is recommended that the clock module (Section V.H) not be used and each CAMAC module have incorporated in it a clock oscillator where required. For the PGS system, this would only require incorporating a precision oscillator in the live-timer module (Section V.G). If desired, the clock frequency could be made software selectable.

3. Expansion of Hardware-closed-loop Control

The hardware-closed-loop concept for stage control has worked extremely well. It is recommended that this concept be utilized in future PGS control systems and be expanded to other devices as described in the next paragraph.

4. Digital Storage Unit

With the advent of integrated-circuit solid-state memories, it appears feasible that a digital storage unit could economically be fabricated. This storage unit could be designed to the CAMAC standard, and would be used basically for taking and storing a gamma-ray spectrum. A secondary use could be for temporary storage for the programmed digital controller (PDC).

A conceptual design has been completed for provision of a 4K memory with a word length of 24 binary bits. The memory will interface to the Northern Scientific ADC and will be randomly addressed by the ADC. When an address is received from the ADC, the memory will automatically read into a counter register. One count will be added, and the result will be written back into the memory. Thus, a complete spectrum can be stored in the memory without monitoring by the PDC. Note that this digital storage is basically an extension of the hardware-closed-loop concept to the nuclear-detector system.

A second use of the digital storage would be for either random access or sequential storage for the PDC. To completely read into or write out of all 4096 words of such a CAMAC storage unit would require 10 to 20 msec.

5. Utilization of Binary Code

As discussed in Section V.N, a hardware BCD-to-binary converter was provided. The conversion unit was necessary, since the decoded information from the encoders was in BCD form. It is recommended that consideration be given to binary-output encoders, and then all the control modules could be designed around the binary code.

6. Remote CAMAC Crates

For remotely located CAMAC crates it is recommended that integrated-circuit line drivers and line receivers be used to extend the branch highway. A conceptual design has been done for a branch driver for the CAMAC-PDC interface. This design incorporates line driver/receiver circuits and also LED isolation. Although the portion of the branch highway between the line driver and receiver does not meet the CAMAC standard, the circuitry before the line driver and after the line receiver does fully meet this standard. The non-compliance with the CAMAC standard should not create any real problem, since connecting circuits between the line driver and receiver would significantly reduce the noise immunity of the system and thus are not recommended by the integrated-circuit manufacturers.

7. Integrated Circuits

Part of the design approach for the PGS system was to use integrated circuits wherever possible and economically feasible. It is recommended that this approach be used for the next gamma scanner.

One area that may very well utilize integrated circuits more fully is the BCD-to-binary and binary-to-BCD converter. At the time this module was designed and fabricated, available integrated circuits were used, but since then, new completely integrated BCD-to-binary and binary-to-BCD converters have been marketed. These units should be investigated for use in this module.

C. Optimization of Data Reduction

The PDC does not presently have enough core memory to contain programs that could process the gamma spectra by simple methods. The PGS real-time control program and the tape-operating system require all but 7 of the 8192 core locations. Therefore, it is recommended that an additional 8K of core be added to the system to handle reduction programs for jobs that do not require complex reductions such as those involving the Gaussian program.

The ASR-33 teletype will not handle the heavy input and output required by the PGS without constant adjustment and repair. Therefore, it is recommended that a heavier-duty input-output device be used for future systems.

A nuclear-detector system containing a stabilization circuit that automatically corrects for ADC gain and zero shifts during long counts is recommended for future systems. A high-speed fixed-dead-time ADC would also help decrease the time required to precision-gamma-scan a subject.

IX. EXPANDING THE USE OF THE PROGRAMMED DIGITAL CONTROLLER

The PGS was the first hot-cell examination process in the HFEF complex to use closed-loop digital control. This piece of equipment was the first step in a three-phase development program to implement an overall HFEF automation plan that would accomplish the following objectives:

- (1) Provide remote automatic control of selected hot-cell equipment to increase experiment throughput and decrease handling damage

- (2) Optimize the acquisition, analysis, and reporting of HFEF examination data
- (3) Aid in accounting for fissionable material in the HFEF complex
- (4) Aid in HFEF scheduling and accounting.

Phase I of the HFEF automation plan has been completed. The use of a programmed digital controller (PDC) to control the PGS 24 hours a day without operator attention has been very successful and without incident. Experience has been gained in both real-time digital control and the use of the CAMAC-standard interface. Figure 24 illustrates Phase I of the HFEF automation plan, where the PDC is dedicated to the control of the PGS. Although this is true at present, Phase II of the HFEF automation plan will connect two more hot-cell examination devices to the digital control system: the optical profilometer and the fission-gas-detection system (see Fig. 25).

Phase II will provide experience in the simultaneous digital control of hot-cell examination processes and establish the limits of digital data accumulation by the PDC. A sophisticated computer-operating system will be used to govern the computer and verify the correct operation of real-time programs. The operational efficiency of Phase II will dictate whether the HFEF will move into the final design and installation of Phase III, a fully automatic hot-cell inspection line (see Fig. 26). The proposed digital control system for the automatic examination line is shown in Fig. 27. The key to the examination line is the moving storage belt for capsules and elements (also shown in Fig. 27), which automatically loads capsules and elements into the examination device. This eliminates master-slave handling of capsules and elements and the piecemeal examination that results from basket storage of capsules and elements.

The PDC presently being used for the PGS will be field-modified into the supervisory PDC shown in Fig. 27. This PDC will control operations in both HFEF/S and HFEF/N from a central control room.

X. CONCLUSION

The PGS has proven to be a key examination device at the HFEF complex. Its success is due to the flexibility and automation of the PGS components. The initial design and fabrication cost (\$230,000) has long been recovered in the value of the data provided, especially in detection of cladding

Fig. 24. Phase I of HFEF Automation Plan

MOTOR
GENERATOR

AIR-23
TELETYPE

2

Fig. 25. Phase II of HFEF Automation Plan

2

Fig. 26. Phase III of HFEF Automation Plan

Fig. 27. Proposed Digital Control System for Automatic Examination Line

HFEF / S

2

failure in fueled capsules and elements. Maintenance and operational costs have been minimal compared to those of other examination devices at the HFEF. The decision to eliminate the expense of the multichannel analyzer and produce a system that is operated under full computer control both in equipment operation and alarm monitoring has proven to be successful and economical.

In conclusion, our experience has shown that the following equipment is a minimum for precision gamma scanners:

- (1) Automated precision element-positioning stage
- (2) Fixturing for supporting the subject both in the restrained and unrestrained modes (see Section III.A)
- (3) Automatic control of ADC gain and zero shift
- (4) Variable-slit collimator
- (5) CAMAC instrument-module system.

APPENDIX A

Electrical Drawings

The drawings contained in this appendix show the electrical circuits for the CAMAC modules, the PDC/CAMAC interface, and the cabling arrangement of the PGS system.

ID-7D-1B379

CONNECTOR ON
BACK OF ADC
(MEMORY UNIT)

Fig. 28. CAMAC-ADC Interface Module

21. 2000

[illegible]

NOTE:
1. * INDICATES PIN ON AUGUST 1968-1970 BIO-ACID
2. OTHER CDS ARE CONTAINING CARBONATES IN GLASS
3. CDS CDS ARE THROUGHOUT THE FIELD NUMBER 142
4. 142 COMPONENTS CARBON-25% 142-142
5. 142 COMPONENTS WITHOUT ID NUMBERS
6. ALL FIELD MODIFICATIONS

ID-7D-18379

947462

1. <u>LEAD</u> <u>ROZIN</u> <u>70%</u> <u>52</u> <u>2nd</u> <u>10/10/70</u> <u>BOISE</u> <u>1/10</u> <u>CE 7</u> <u>10/10/70</u> <u>L. MARILL</u> <u>10/10</u> 2. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 3. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 4. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 5. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 6. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 7. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 8. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 9. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 10. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 11. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 12. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 13. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 14. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 15. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 16. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 17. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 18. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 19. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 20. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 21. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 22. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 23. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 24. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 25. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 26. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 27. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 28. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 29. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 30. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 31. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 32. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 33. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 34. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 35. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 36. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 37. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 38. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 39. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 40. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 41. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 42. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 43. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 44. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 45. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 46. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 47. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 48. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 49. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 50. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 51. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 52. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 53. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 54. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 55. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 56. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 57. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 58. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 59. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 60. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 61. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 62. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 63. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 64. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 65. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 66. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 67. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 68. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 69. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 70. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 71. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 72. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 73. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 74. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 75. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 76. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 77. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 78. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 79. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 80. <u>10/10/70</u> <u>10/10/70</u> <u>10/10/70</u> 81. <u>10/1</u>	
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ID-7E-10315

Fig. 29. CAMAC Live Timer

[illegible]

1D-7D-18312

- 21, 22 SN7400
- 23 SN7400
- 24 SN7402
- 25, 212 SN7403
- 26, 210, 213 SN7404
- 27 SN9311
- 28, 214, 216 SN74121
- 211, 213 SN7474
- C1-C3 01-74
- C4-C9 02-74
- C21-101-74
- R1-24 100K
- R5-27 500K
- R6 250K
- Q1-2N2219
- Q2-2N2219
- SOCKET ASSEMBLY

1. COMPONENTS WITHOUT ID NUMBERS ARE FIELD MODIFICATIONS

SEE CABLE DRAWING
1D-7E-18316 AND 3-5

2

1D-7D-18312

APPROVE NATIONAL LABORATORY		DATE	
FOR TESTING IN THE DIVISION OF AIRCRAFT RESEARCH, LABORATORY		DATE	
FEE		DATE	
COLLIMATOR ROTATE IND 4		DATE	
CONTROL MODULE (3CR-02-1)		DATE	
FOR ASSOCIATED QWES		DATE	
SEE B/M 1D-7D-15259		DATE	
1D-7D-18312		DATE

Fig. 32. CAMAC Display-scope Module

Fig. 33. CAMAC Clock Module

ID-7D-18179

SEE CABLE DWG.
ID-7E-181516 SER. 1-8

SEE CABLE DWG.
ID-7E-181516 SER. 2

Fig. 34. CAMAC Stall Module

ID-7D-18179

POWER SUPPLY AND LOGIC ONE CIRCUIT

COMPONENTS WITHOUT ID NUMBERS
ARE FIELD MODIFICATIONS

R1-R12 270Ω 1/4 WATT
R13-R28 500Ω 1/4 WATT
R29-R30 1KΩ 1/4 WATT
R31-R32 10KΩ 1/4 WATT
R33-R34 100KΩ 1/4 WATT
R35-R36 1MΩ 1/4 WATT
R37-R38 10MΩ 1/4 WATT
R39-R40 100MΩ 1/4 WATT
R41-R42 1GΩ 1/4 WATT
R43-R44 10GΩ 1/4 WATT
R45-R46 100GΩ 1/4 WATT
R47-R48 1TΩ 1/4 WATT
R49-R50 10TΩ 1/4 WATT
R51-R52 100TΩ 1/4 WATT
R53-R54 1PTΩ 1/4 WATT
R55-R56 10PTΩ 1/4 WATT
R57-R58 100PTΩ 1/4 WATT
R59-R60 1MΩ 1/4 WATT
R61-R62 10MΩ 1/4 WATT
R63-R64 100MΩ 1/4 WATT
R65-R66 1GΩ 1/4 WATT
R67-R68 10GΩ 1/4 WATT
R69-R70 100GΩ 1/4 WATT
R71-R72 1TΩ 1/4 WATT
R73-R74 10TΩ 1/4 WATT
R75-R76 100TΩ 1/4 WATT
R77-R78 1MΩ 1/4 WATT
R79-R80 10MΩ 1/4 WATT
R81-R82 100MΩ 1/4 WATT
R83-R84 1GΩ 1/4 WATT
R85-R86 10GΩ 1/4 WATT
R87-R88 100GΩ 1/4 WATT
R89-R90 1TΩ 1/4 WATT
R91-R92 10TΩ 1/4 WATT
R93-R94 100TΩ 1/4 WATT
R95-R96 1MΩ 1/4 WATT
R97-R98 10MΩ 1/4 WATT
R99-R100 100MΩ 1/4 WATT

ID-7D-18179

DESIGNER		CHECKED		DATE		REVISED		DATE	
J. L. R. 1/10/79		J. L. R. 1/10/79		1/10/79		1/10/79		1/10/79	
TITLE		SUBTITLE		SCALE		SHEET NO.		TOTAL SHEETS	
FEE		CANAL		STALL MODULE		(BSCM-02-1)		ID-7D-18179	
DATE		BY		FOR ASSOCIATED DWG		SEE B/M ID-7D-18299			

ID-7E-18316 27

2

NOTE:

1. LAMP CONNECTIONS INDICATED FOR
DISTRICT AND SERIAL NO.
2. 0 = AIR CELL SHALL BE INSTALLED

ID-7E-18316 27

PRECISION GAMMA SCANS	
CALL CHARTER	
ID-7E-18316 27

Fig. 36. PGS Cable Diagram, Part 2

ID-7E-15516 SET 2 OF 2

ID-7E-15516 SET 2 OF 2

PRECISION GAMMA SCANNER
CABLE DIAGRAM
ID-7E-15516 SET 2 OF 2

Fig. 38. PGS Cable Diagram, Part 4

20-TE-10316 INT 4
P 2

50 71681-21-0
7 Dec 73

[illegible]

NOTE:

1. COUNT COLUMNAR, ROTARY MODULE
 2. SMALL - 20-10-1831
 3. LAM - LOGIC AND ME INTERFACE
 4. ADC - A/D CONVERTER
 5. LIVE TIME - LIVE TIME
 6. 2. PA NUMBERS - 2. PA NUMBERS
 7. 8. SUGGESTED B. - 8. SUGGESTED B. PA 800643

<p>ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED</p>		<p>DATE 10-10-80 BY 1045</p>	
<p>FOR ASSOCIATED DICS SEE BUN 20-10-18249</p>		<p>ARMOR NATIONAL LABORATORY FEF REGION GAMMA SCANNER CABLE DIAGRAM ID-7E-18316 1478 OF 8</p>	

ID-7E-18316 1478 OF 8

ID-7D-18177

Fig. 40. CAMAC Look-at-me Module

IDENT. NO.
ID-7D-18177

[illegible]

APPENDIX B

PGS Control Program

This appendix contains the control-program flow diagram, the control-program listing, and a software map of the tape operating system.

1. Flow Diagram of PGS Control Program

LIVE-TIMER INTERRUPT ROUTINE

ADC INTERRUPT ROUTINE

2. Listing of PGS Control Program

```
*THIS PROGRAM WILL SCAN AN EBR-II IRRADIATED CAPSULE OR
*ELEMENT USING PRECISION GAMMA SCANNER STAGE AS THE
*POSITIONING DEVICE
*THE SYSTEM IS BASED ON THE CAMAC TYPE INTERFACE
*PRIORITY INTERRUPT LEVELS 11,12,13,14 OF GROUP 1
*OR DEDICATED TO CORE POSITIONS 103,104,105,106,AND
*CØNTRØL THE JAM SUBRØUTINE,LIVE-TIMER SUBRØUTINE,
*ADC SUBRØUTINE AND THE LØØK-AT-ME SUBRØUTINE
*THE MAIN CØNTRØL PROGRAM IS NØT UNDER CØNTRØL
*ØF A PRIORITY INTERRUPT
*THE TELETYPE IS PRIORITY 8 ØF GROUP 1
*
*
*****GAMMA SCAN CØNTRØL SWITCH SETTINGS*****
*SET SWITCH 23 FØR SCØPE TEST
*SET SWITCH 22 FØR ADC TEST & LIVE TIMER TEST
*SET SWITCH 21 FØR MØTØR & ENCØDER TEST
*SET SWITCH 20 FØR CALIBRATIØN SPECTRUM
*SET SWITCH 19 FØR PRINT ØUT ØF SPEC NØ,TIME, PØS, SLIT WT
*SET SWITCH 18 FØR PRINT ØUT ØF TIME WHEN MØTTØRS ARE HØME
*SET SWITCH 17 FØR PRINT ØUT ØF CHANNELS VERSUS SPEC
*SET SWITCH 16 FØR EVERY 2 SPEC
*SET SWITCH 15 FØR EVERY 4 SPEC
*SET SWITCH 14 FØR EVERY 8 SPEC
*SET SWITCH 13 TØ SAVE END ØF CØUNT DISPLAY
*SET SWITCH 12 FØR HLT AFTER CØMPLETING CØUNT IN PRØGRESS
*SET SWITCH 11 TØ RETURN TØ INTIAL SCAN POSITIØN AND RE-INITIALIZE
*SET SWITCH 10 TØ RETURN STAGE TØ LØAD POSITIØN AFTER CØMPLETING SPECTRUM
*****SCØPE DISPLAY AND GAIN CØNTRØL SWITCHES*****
*SET SWITCH 9 FØR LIVE TIME DISPLAY
*SET SWITCH 8 FØR END ØF CØUNT DISPLAY
*SET SWITCH 7 TØ PUT SCØPE IN STØRAGE MØDE
*SET SWITCH 6 FØR GAIN ØF 2-19PØWER FULL SCALE
*SET SWITCH 5 FØR GAIN ØF 2-15PØWER FULL SCALE
*SET SWITCH 4 FØR GAIN ØF 2-13PØWER FULL SCALE
*SET SWITCH 3 FØR GAIN ØF 2-12PØWER FULL SCALE
*SET SWITCH 2 FØR GAIN ØF 512 CHANNELS FULL SCALE
*SET SWITCH 1 FØR GAIN ØF 2048 CHANNELS FULL SCALE
*SET SWITCH 0 FØR GAIN ØF 4096 CHANNELS FULL SCALE
*THE SENSE SWITCHES CAN BE USED TØ ESTABLISH
*NEW CØNTRØL PARAMETERS FØR FUTURE PRØGRAM
*ADDITIØNS LIKE THE PRØFILØMETER
*
*
*
*THE AUTHOR ØF THIS PRØGRAM IS J.W. RIZZIE
*EBR-II FEF
*
*
*
*
*
*
*
*
*
*
*
```

```

*
      IDEN  GAMMA SCAN
      NAME  PGS
      TNI   8
Z2     TMA  RLX+8,I
      OCW   '0701
      BNZ   *-1
      BWI   Z2
RP      T0A  '47400
      T0E   '47400
*ARM TTY & MAG TAP INTERRUPTS
      TD1
      TNK   '1316
      BLU   $I/0
      B0N   *-2
      TNK   '1300
      BLU   $I/0
      B0N   *-1
*
*
RI      TZA
CLEAR   TNI   4096
      TAM   SPEC+4096,I      ZERO CORE SPECTRUM AREA
      BWI   CLEAR
      TAM   INDEX
      TAM   SPECNO          SPECTRUM NUMBER
      TAM   H0LD            LOOK-AT-ME 8BIT CORE WORD
      TAM   INT0            INITIAL TAPE OUTPUT
      TAM   WAIT            WAIT SIGNAL
      TAM   D0
      TAM   D1
      TAM   D2
      TAM   D3
      TAM   CT
      TAM   C0UNT
      TAM   FINISH
      TAM   SPECST
      TMK   M1
M1      BLU   $H0LD
      '05    ="GS1 RDY FOR INF"
      TMK   M2
M2      BLU   $H0LD
      '02    ="TITLE?"
      BLK   LINF D
A        TL0   B
      BLU   $I/0
      B0N   A
C        TNK   '0100
      BLU   $I/0
      B0N   C
      TMK   M3
M3      BLU   $H0LD
      '02    ="PIN N0"
      BLK   LINF D
      BLJ   INP6
      TDM   PIN0
      TMK   MS
      BLU   $H0LD

```

MS	'02	="SUBN0 "	
	BLK	LINF0	
	BLJ	INP6	
	TDM	SUBN0	
	TMK	M4	
	BLU	\$H0LD	
M4	'02	="C0RE "	
	BLK	LINF0	
	BLJ	INP6	
	TDM	C0REP	
	TMK	M5	
	BLU	\$H0LD	
M5	'01	="FLU"	
	BLK	LINF0	
	BLJ	INP6	
	TDM	FLUEN	
SKIP	TMK	M10	
	BLU	\$H0LD	
M10	'01	="P0S"	
	TNI	12	
C2	BLK	LINF0	
	BLJ	INP6	
	BLJ	NUM1	
	TAM	P0S+12,I	
	BWI	C2	
	TNJ	4	
C0NVT	TMA	P0S+12,J	
	TAM	G0P0S+4,J	
	BWJ	C0NVT	
	TMK	M7	
	BLU	\$H0LD	
M7	'03	="IRRA TIME"	
	BLK	LINF0	
	BLJ	INP6	
	BLJ	NUM1	
	TAM	RTIME	
	TMK	M11	
	BLU	\$H0LD	
M11	'03	="LAST IRRA"	
	BLK	LINF0	
	BLJ	INP6	
	BLJ	NUM1	
	TAM	LTIRR	
	TMK	M12	
	BLU	\$H0LD	
M12	'03	="TYPE SCAN"	AXIAL,DIAMET
	BLK	LINF0	
	BLJ	INP6	
	TDM	TYPSCAN	
CHSLIT	TMK	M55	
	BLU	\$H0LD	
M55	'02	="SLT WD"	
	BLK	LINF0	
	BLJ	INP6	
	BLJ	NUM1	
	TAM	SLTWD	
	TMK	M6	
	BLU	\$H0LD	

```

M6      '03      ="LIVE TIME"
        BLK      LINFD
        BLJ      INP6
        BLJ      NUMI
        TAM      LTIME
        BLK      LINFD
        TMA      SCANCD
        CMA      TYPSCAN
        BNZ      CØLRT
        TMA      RH
        TAM      RØT
        TØA      '4
        TAM      CØLL
        BUC      START
CØLRT   TMA      RV
        TAM      RØT
        TØA      '1
        TAM      CØLL

```

*ARM AND ENABLE GAMMA SCANNER INTERRUPTS

```

*
START   NØP
R       TZA
        TAM      CT
        TNI      4096
C45     TAM      SPEC+4096,1
        BWI      C45
TST     TSA
        RLA      23
        QBB      B0
        BNZ      TESTSCP
TST1    TSA
        RLA      22
        QBB      B0
        BNZ      TESTADC
TST2    TSA
        RLA      21
        QBB      B0
        BNZ      TESTMØT
        TSA
        RLA      13
        QBB      B0
        BNZ      LL1
        TMA      ERASE
        ØCH      '0701
        BNZ      *-1
LL1     TMA      RCØLL
        ØCW      '0701
        BNZ      *-1
        IDW      '0701
        BNZ      *-1
        CØB      '2
        BØZ      RØTAT
        CMA      CØLL
        BØZ      GT1
RØTAT   TMA      RØT
        ØCW      '0701
        BNZ      *-1
Q2      TMB      HØLD

```

	QBB	B2
	B0Z	Q2
	S0B	'4
	TBM	H0LD
GT1	TMA	DS
	BLK	DEC0DE
	CMA	SLTWD
	B0Z	GT2
	TMA	SLTWD
	0DW	'0701
	BNZ	*-1
	TMA	BBCD
	0CW	'0701
	BNZ	*-1
	TNI	10
WT55	N0P	
	BWI	WT55
	TMA	BCDS
	0CW	'0701
	BNZ	*-1
	TMA	SS
	0CW	'0701
	BNZ	*-1
Q1	TMB	H0LD
	QBB	B1
	B0Z	Q1
	S0B	'2
	TBM	H0LD
GT2	BLJ	STRTM0T
	TSA	
	RLA	18
	QBB	B0
	B0Z	SLTM
	BLJ	TIMYEAR
	TNI	4
BUST	TMA	TIME+4,I
	BLK	NUM0UT
	BLK	SPACE
	BWI	BUST
	BLK	LINF0
SLTM	TMA	LIVE1
	0CW	'0701
	BNZ	*-1
	TMA	LTIME
	MYM	MPYFT
	0DW	'0701
	BNZ	*-1
	TMA	LIVE2
	0CW	'0701
	BNZ	*-1
* START	LIVE	TIMER
	TMA	ADC
	0CW	'0701
	BNZ	*-1
	T0A	'77400
	T0E	'77400
	TD1	
	BLJ	TIMYEAR

PRINT 0UT TIME

```

BUST1  TNI  4
        TMA  TIME+4,I
        TAM  TIME1+4,I
        BWI  BUST1
        TMA  LIVE3
        ØCW  '0701
        BNZ  *-1
WTINT   C2M  WAIT
        BØZ  WTINT/
        TZA
        TAM  WAIT
        TØA  '47400
        TAE
        TD1
* ØUT PUT SPEC ØN SCOPE
        TSA
        RLA  8
        QBB  B0
        BØZ  CØNT
        TSA
        ØDW  '0701
        BNZ  *-1
        TMA  GAIN
        ØCW  '0701
        BNZ  *-1
DSPLY   TNI  4096
        TMA  SPEC+4096,I
        ØDW  '0701
        BNZ  *-1
        TMA  DY
        ØCW  '0701
        BNZ  *-1
        TNK  65
        NØP
        BWK  *-1
CØNT    TSA
        RLA  19
        QBB  B0
        BØZ  NØPT
        BLK  LINFØ
        BLJ  TIMYEAR
        TNI  4
BUST2   TMA  TIME1+4,I
        BLK  NUMØUT
        BLK  SPACE
        BWI  BUST2
        BLK  SPACE
        BLK  SPACE
        BLK  SPACE
        TMA  SPECNØ
        BLK  NUMØUT
        BLK  LINFØ
        TNI  4
BUST3   TMA  TIME2+4,I
        BLK  NUMØUT
        BLK  SPACE
        BWI  BUST3
        BLK  LINFØ

```


PØSØUT	TNI	4
	TMA	GØPØS+4,I
	BLK	NUMØUT
	BLK	SPACE
	BLK	SPACE
	BWI	PØSØUT
	TMA	SLTWD
	BLK	NUMØUT
	BLK	LINFØ
* * *		
NØPT	TSA	
	RLA	17
	QBB	BØ
	BØZ	NØPRINT
	TØA	'123
	ØCW	'ØØØØ
	BNZ	*-1
	TMK	M8
M8	BLU	SHØLD
	'Ø2	= "FST CH"
	BLK	LINFØ
	BLJ	INP6
	BLJ	NUMI
	TAM	SPECST
	TMK	M9
M9	BLU	SHØLD
	'Ø2	= "LAST C"
	BLK	LINFØ
	BLJ	INP6
	BLJ	NUMI
	TAM	FINISH
	BLK	LINFØ
	AUM	CT
	TØA	1
X1	TAM	DØ
	TSA	
	RLA	16
	QBB	BØ
	BØZ	X2
	TØA	2
X2	TAM	D1
	TSA	
	RLA	15
	QBB	BØ
	BØZ	X3
	TØA	4
X3	TAM	D2
	TSA	
	RLA	14
	QBB	BØ
	BØZ	X5
	TØA	8
X5	TAM	D3
	TZA	
	AMA	DØ
	AMA	D1

	AMA	D2
	AMA	D3
	TAM	PTINDEX
	TMA	CT
	CMA	PTINDEX
	BNZ	NØPRINT
	TZA	
	TAM	CT
FULLPT	TMI	SPECST
SPECØUT	TIA	
	BLK	NUMØUT
	BLK	SPACE
	TMA	SPEC,I
	BLK	NUMØUT
	BLK	SPACE
	AØI	1
	AUM	CØUNT
	TØE	4
	TMA	CØUNT
	CEA	
	BNZ	CT1
	BLK	LINFØ
	TZA	
CT1	TAM	CØUNT
	CMi	FINISH
	BNZ	SPECØUT
	BLK	LINFØ
	QSS	B1
	BØP	NØPT
NØPRINT	NØP	

NØ ØF CHANNEL TØ ØE PRINTED

*
*
*
*
*

	TSA	
	RLA	20
	QBB	BØ
	BØZ	GØ
	HLT	
	TMA	SAVSPEC
	TAM	SPECNØ
	TSA	
	RLA	20
	QBB	BØ
	BØZ	SHI
	TNK	'1312
	BLU	\$1/Ø
	BØN	*-2
	TNK	'1311
	BLU	\$1/Ø
	BØN	*-2
SHI	BUC	CHSLIT
GØ	CZM	INDEX
	BNZ	CØNT1
	TMA	PØS
	CMA	PØS+8
	BØZ	AXIAL

	SMA	P0S+8
	ESA	
	DVM	P0S+4
	A0A	1
	NAA	
	TAM	SI
	TAM	SIN
AXIAL	TMA	P0S+2
	SMA	P0S+10
	ESA	
	DVM	P0S+6
	A0A	1
	NAA	
	TAM	SK
	T0A	1
	TAM	INDEX
C0NT1	TMK	SK
	TMA	P0S
	CMA	P0S+8
	B0Z	CUNT
	TM1	SI
	TMA	G0P0S
	AMA	P0S+4
	TAM	G0P0S
	BW1	C0NT2
	TM1	SIN
CUNT	TMA	P0S+8
	TAM	G0P0S
	TMA	G0P0S+2
	AMA	P0S+6
	TAM	G0P0S+2
	TMA	G0P0S+3
	AMA	P0S+7
	T0E	3590
	CEA	
	BNP	N360
	S0A	3600
N360	TAM	G0P0S+3
	TAM	G0P0S+3
	BWK	C0NT2
	BUC	ST0P2
C0NT-2	TKM	SK
	TIM	SI
	TSA	
	RLA	12
	QBB	B0
	B0Z	TA1
	HLT	
	BUC	CHSLIT
TA1	TSA	
	RLA	11
	QBB	B0
	B0Z	TA2
	BUC	RP
TA2	TSA	
	RLA	10
	QBB	B0
	B0Z	START

```

STOP2  BLK  UNLOAD
        TNK  '1306
        BLU  $I/0
        B0N  *-2
        TNK  '1300
        BLU  $I/0
        B0N  *-2
        BLJ  TIMYEAR
        TNI  4
BUST6   TMA  TIME+4,I
        BLK  NUMOUT
        BLK  SPACE
        BWI  BUST6
        TMK  M13
        BLU  $HOLD
M13     '02  ="UNLOAD"
        BUC  RI
B       DATA '0101
        DATA 20
        DAC  TITLE
SCANCD  DATA '20254111
*INTERRUPT ROUTINE TO PROCESS JAM ALARM INTERRUPT
*

```

```

E1      ***
        TRM  SE1
        TNI  4
TX      TMA  ST0PX+4,I
        0CW  '0701
        BNZ  *-1
        BWI  TX
        TMK  M14
        BLU  $HOLD
        BLK  LINF0
        BLJ  TIMYEAR
        TNI  4
BUST5   TMA  TIME+4,I
        BLK  NUMOUT
        BLK  SPACE
        BWI  BUST5
M14     '03  ="JAM ALARM"
        TMR  SE1
        BRL* E1
SE1     BL0K 5

```

* THIS ROUTINE WILL PROCESS THE LIVE TIMER INTERRUPT ROUTINE

```

E2      ***
        TRM  SE2
        BLJ  TIMYEAR
        TNI  4
BUST4   TMA  TIME+4,I
        TAM  TIME2+4,I
        BWI  BUST4
        TMA  LIVE1
        0CW  '0701
        BNZ  *-1
        TMA  ADC

```

```

      0CW      '0701
      BNZ      *-1
      IDW      '0701
      BNZ      *-1
      TSA
      RLA      20
      QBB      80
      BNZ      C0T
      TZA
      CMA      INT0
      BNZ      C0T1
A8      TL0     TAP0UT
      BLU      $I/0
      B0N      A8
      TNK      '1300
      BLU      $I/0
      B0N      *-2
      TNK      '1306      WRITE EOF
      BLU      $I/0
      B0N      *-2
      TNK      '1300
      BLU      $I/0
      B0N      *-2
      AUM      INT0
C0T      BUC     C0T1
      TMA      SPECN0
      TAM      SAVSPEC
      TZA
      TAM      SPECN0
      BUC      A9
C0T1     AUM     SPECN0
A9      TL0     TP0UT
      BLU      $I/0
      B0N      A9
      TNK      '1300
      BLU      $I/0
      B0N      *-2
      TNK      '1306
      BLU      $I/0
      B0N      *-2
      TNK      '1300
      BLU      $I/0
      B0N      *-2
      AUM      WAIT
      TMR      SE2
      BRL*     E2
TAP0UT   DATA  '1304
      DATA    45
      DAC      TITLE
TP0UT    DATA  '1304
      DATA    4110
      DAC      SPECN0
SE2      BL0K   5
*
*THIS SUBROUTINE WILL PROCESS THE ADC
*INTERRUPT
E3      ***
      TRM      SE3

```

```

TMA    ADC
ØCW    '0701
BNZ     *-1
IDW     '0701
BNZ     *-1
LLA     12
RLA     12
TAM     SAVADD
TAI
AUM     SPEC,I
NØF    TSA
RLA     9
QBB     B0
BØZ     NØDP
TSA
ØDW     '0701
BNZ     *-1
TMA     GAIN
ØCW     '0701
BNZ     *-1
TMA     SAVADD
ØDW     '0701
BNZ     *-1
TMA     XD
ØCW     '0701
BNZ     *-1
TMI     SAVADD
TMA     SPEC,I
ØCW     '0701
BNZ     *-1
TMA     YD
ØCW     '0701
BNZ     *-1
TNI     65
NØP
NØDP   BWI     *-1
TMR     SE3
BRL*    E3
SE3     BLØK  5

```

* THIS INTERRUPT ROUTINE PROCESS THE LOOK-AT-ME
 * INTERRUPT

```

E4     ***
TRM     SE4
TMA     RDLM
ØCW     '0701
BNZ     *-1
IDW     '0701
BNZ     *-1
CØB     '1
BNZ     S1
TMB     HØLD
AØB     '1
TØM     HØLD
TMK     DTY1
NKK
REST3  TMA     RLX+4,I
ØCW     '0701

```

X,Y,Z,Ø LOOK-AT-ME

	BNZ	*-1
	BWK	REST3
S1	BUC	RESET
	CØB	'2
	BNZ	S2
	TMB	HØLD
	AØB	'2
	TBM	HØLD
	TMI	DTY1
	NII	
REST1	TMA	RLS
	ØCW	'0701
	BNZ	*-1
	BWI	REST1
S2	BUC	RESET
	CØB	'4
	BNZ	RESET
	TMB	HØLD
	AØB	'4
	TBM	HØLD
	TMI	DTY1
	NII	
REST	TMA	RLC
	ØCW	'0701
	BNZ	*-1
	BWI	REST
RESET	TMI	DTY1
	NII	
RT1	TMA	RLAM
	ØCW	'0701
	BNZ	*-1
	BWI	RT1
	TMR	SE4
	BRL*	E4
SE4	BLØK	5
TESTSCP	BUC	TST
TESTADC	BUC	TST1
TESTMØT	BUC	TST2

```

*PROGRAM TO CONVERT 6 CHARACTERS IN THE AGE
*ACCUMULATOR TO A BINARY NUMBER IN A REGISTER
NUMI      TAM      BUF3
          TIM      SAVI
          TJM      SAVJ
          TKM      SAVK

```

	TZA	
	TAM	ACCUM
	TMA	BUF3
	TNI	6
AGN	LRD	8
	CØB	" "
	BØZ	BLNK
	BWI	AGN
SAME	TAM	BUF3
	TNI	3
AGN2	TZA	
	RRD	8
	RLA	16
	TEK	
	SØB	'60
	MYM	TBL2+3,I
	AAM	ACCUM
	TKE	
	BWI	AGN2
	TNI	3
	TME	BUF3
AGN3	TZA	
	RRD	8
	RLA	16
	TEK	
	SØB	'60
	MYM	TBL1+3,I
	AAM	ACCUM
	TKE	
	BWI	AGN3
	TMA	ACCUM
	TMI	SAVI
	TMK	SAVK
	TMJ	SAVJ
	BUC	0,J
BLNK	TNK	1
	TØB	"0"
	BWI	NØTE
	RRD	8
	BWK	*-1
	BUC	SAME
NØTE	LRD	8
	AMK	*-1
	BUC	BLNK+1
TBL1	DATA	1
	DATA	10
	DATA	100
TBL2	DATA	1000
	DATA	10000
	DATA	100000
BUF3	BLØK	1
ACCUM	BLØK	1

* INPUT SIX OR LESS DIGIT NUMBER IN THE
* A ACCUMULATOR

INF6	TIM	S1I
	TKM	S1K
	TJM	S1J


```

ENTER  TLØ  B1
        BLU  $I/Ø
        BØN  ENTER
A1      TNK  '0100
        BLU  $I/Ø
        BØN  A1
        TMD  BF
        TMI  S1I
        TMJ  S1J
        TMK  S1K
        BUC  0,J
S1I     BLØK 1
S1K     BLØK 1
S1J     BLØK 1
B1      DATA '0101
        DATA 2
        DAC  BF
BF      BLØK 2
* THIS ROUTINE WILL READ THE TIME OF YEAR IN
* DAYS,HOURS,MINS,SEC,AND OUT-PUT IT ON THE TTY
*
TIMYEAR TIM  XSVI
        TJM  XSVJ
        TKM  XSVK
        TNI  4
TMY     TMA  RDAY+4,I
        ØCW  '0701
        ØNZ  *-1
        TNK  10
WT1     NØP
        BWK  WT1
        TMA  RBIN
        ØCW  '0701
        ØNZ  *-1
        IDW  '0701
        ØNZ  *-1
        TAM  TIME+4,I
        BWI  TMY
        TMI  XSVI
        TMK  XSVK
        TMJ  XSVJ
        BUC  0,J
XSVK    BLØK 1
XSVJ    BLØK 1
XSVI    BLØK 1
* THIS ROUTINE WILL OUTPUT A 23 BIT NUMBER
* IN THE A ACCUMULATOR ON THE TTY
*
NUMØUT  TIM  SAVI1
        TJM  SAVJ1
        TKM  SAVK1
* LARGEST NUMBER 8,366,407
        TNI  7
CATTLE  ESA
        DVM  TAB1+7,I
        TEM  SAVRM
        TAM  NUM+7,I
        TMA  SAVRM

```

```

      BHI  CATTLE
      TNI  7
CATTLE1 T0A  '123
      0CW  '0000
      BNZ  *-1
      ISW  '0000
      QBB  B0
      B0Z  *-2
      TMA  NUM+7,1
      A0A  '260
      0DW  '0000
      BNZ  *-1
      BHI  CATTLE1
      TMI  SAVI1
      TMJ  SAVJ1
      TMK  SAVK1
      BUC  0,K
TAB1    DATA 1000000
      DATA 100000
      DATA 10000
      DATA 1000
      DATA 100
      DATA 10
      DATA 1
SAVRM   BL0K 1
NUM      BL0K 7
SAVI1    BL0K 1
SAVJ1    BL0K 1
SAVK1    BL0K 1
*THIS SUB-ROUTINE WILL SPACE THE
*TTY TWO SPACES
*
SPACE    TKM    STK
      TJM    STJ
      TIM    STI
      T0A    '123
      0CW    '0000
      BNZ    *-1
      ISW    '0000
      BNZ    *-1
      QBB    B0
      B0Z    *-3
      T0A    '240
      0DW    '0000
      BNZ    *-1
      0DW    '0000
      BNZ    *-1
      TMI    STI
      TMJ    STJ
      TMK    STK
      BUC    0,K
*THIS PROGRAM WILL GIVE ONE LINE FEED
*AND A CARRIAGE RETURN
*
LINF0    TKM    STK
      TJM    STJ
      TIM    STI
      T0A    '123

```

```

      ØCW      '0000
      BNZ      *-1
      ISW      '0000
      BNZ      *-1
      QBB      B0
      BØZ      *-3
      TØA      '215
      ØDW      '0000
      BNZ      *-1
      TØA      '212
      ØDW      '0000
      BNZ      *-1
      TMK      STK
      TMJ      STJ
      TMI      STI
      BUC      0,K
STK      BLØK  1
STJ      BLØK  1
STI      BLØK  1
*THIS SUBROUTINE WILL START THE X,Y,Z,Ø
*STEPPING MOTØRS AND DRIVE THEM TO
*THE POSITIONS IN PØS,PØS+1,PØS+2,PØS+3
*
STRTMØT  TNI      4
MØT      TMA      DX+4,I
          BLK      DECØDE
          CMA      GØPØS+4,I
          BØZ      GØTØ
          TMA      GØPØS+4,I
          ØDW      '0701
          BNZ      *-1
          TMA      BBCD
          ØCH      '0701
          BNZ      *-1
          TNK      10
WT5      NØP
          BWK      WT5
          TMA      BCDX+4,I
          ØCH      '0701
          BNZ      *-1
          TMA      SX+4,I
          ØCW      '0701
          BNZ      *-1
QUERY     TMB      HØLD
          QBB      B0
          BØZ      QUERY
          SØB      '1
          TBM      HØLD
GØTØ      BWI      MØT
          BUC      0,J
*
*
*
*
*
*
*

```

*
*
*
*
*
*
*

*THIS SUBROUTINE DRIVES THE STAGE TO THE
*UNLOAD POSITION

*

```

UNLOAD  T0A    8000
        TKM    STK
        TAM    G0P0S
        T0A    2000
        TAM    G0P0S+1
        TMA    XPS
        TAM    G0P0S+2
        T0A    0000
        TAM    G0P0S+3
        BLJ    STRTM0T
        TMK    STK
        BUC    0,K
DEC0DE  0CW    '0701
        BNZ    *-1
        TIM    SAVI
        TNI    10
        NOP
        BWI    *-1
        TMI    SAVI
        TMA    RBIN
        0CW    '0701
        BNZ    *-1
        IDW    '0701
        BNZ    *-1
        BUC    0,K
XPS     DATA  30000
*CAMAC CONTROL WORDS
SX      DATA  '140031
SY      DATA  '140041
SZ      DATA  '140051
S0      DATA  '140061
BCDX    DATA  '240031
BCDY    DATA  '240041
BCDZ    DATA  '240051
BCD0    DATA  '240061
ST0PX   DATA  '160031
ST0PY   DATA  '160041
ST0PZ   DATA  '160051
ST0P0   DATA  '160061
RXBCD   DATA  '31
RYBCD   DATA  '41
RZBCD   DATA  '51
R0BCD   DATA  '61
WXBCD   DATA  '200031
WYBCD   DATA  '200041
WZBCD   DATA  '200051
W0BCD   DATA  '200061
RSBCD   DATA  '71

```

WSBCD	DATA	'20071
SS	DATA	'140071
STOPS	DATA	'160071
BCDS	DATA	'240071
DX	DATA	'40031
DY1	DATA	'40041
DZ	DATA	'40051
DØ	DATA	'40061
DS	DATA	'40071
RV	DATA	'140101
RH	DATA	'140501
ØBCD	DATA	'240111
BCDB	DATA	'260111
RBCD	DATA	'1111
RBIN	DATA	'511
ERASE	DATA	'140121
GAIN	DATA	'200121
XD	DATA	'200521
YD	DATA	'210521
ADC	DATA	'11
LIVE	DATA	'21
LIVE1	DATA	'110021
LIVE2	DATA	'200421
LIVE3	DATA	'140021
LIVE4	DATA	'160021
LIVE5	DATA	'61021
LIVE6	DATA	'340021
LIVE7	DATA	'120021
RDLH	DATA	'141
RLX	DATA	'120031
RLY	DATA	'120041
RLZ	DATA	'120051
RLØ	DATA	'120061
RLS	DATA	'120071
RLC	DATA	'120101
RLSC	DATA	'120121
RLAM	DATA	'120141
RDAY	DATA	'40551
RHR	DATA	'41151
RMIN	DATA	'41551
RSEC	DATA	'42151
DY	DATA	'210521
DTY1	DATA	'100000

*
*
*
MPYFT DATA 10000
RCØLL DATA '101
*
*
*

*STORAGE AREA FOR BLOCK DATA
TITLE BLØK 20
PINØ BLØK 2
SUBNØ BLØK 2
CØREP BLØK 2
FLUEN BLØK 2

READ
RESET
WRITE
START
STØP
READ STATUS
INHIBIT DEAD TIME
CLEAR LØØK-AT-ME

TYPSCAN	BLØK	2
LTIRR	BLØK	1
LTIME	BLØK	1
RTIME	BLØK	1
PØS	BLØK	12
FINISH	BLØK	1
SPECST	BLØK	1
SPECNØ	BLØK	1
GØPØS	BLØK	4
TIME1	BLØK	4
SLTWD	BLØK	1
SPEC	BLØK	4096
TIME2	BLØK	4
RØT	BLØK	1
HØLD	BLØK	1
SI	BLØK	1
SK	BLØK	1
INDEX	BLØK	1
STØP1	BLØK	1
SAVADC	BLØK	1
ØVF	BLØK	1
TIME	BLØK	4
INTØ	BLØK	1
CØUNT	BLØK	1
WAIT	BLØK	1
DØ	BLØK	1
D1	BLØK	1
D2	BLØK	1
D3	BLØK	1
CT	BLØK	1
SIN	BLØK	1
PTINDEX	BLØK	1
SAVADD	BLØK	1
SAVI	BLØK	1
SAVJ	BLØK	1
SAVK	BLØK	1
CØLL	BLØK	1
SAVSPEC	BLØK	1
*		
*		
*		
ENDS		
SEØF		

3. Map of Tape Operating System

ABORT
\$JOB SYSGEN
\$ASSIGN 4,2,5,11,6,1
\$OPTION .7
\$XXYY 0516
\$LINK 10000,17777,20
AML 00020 00062 00020

\$DUMPF
\$LINK 10000,17777,0
LNK 04
LNK 04
LNK 04
LNK 04

TOS	00000	05560	00000	
START	00000	ABORT	00000	EXIT 00002
SLM	00000	BG.LOW	00134	BG.HI 00135
S.HLT	00040	S.PAT	00110	S.SPIL 00137
S.SSD	00124	S.SSDE	00133	INFO 00005
S.OPTS	00133	DELTIM	00165	S.TOT 00147
S.CHA	00142	S.CBA	00143	S.CAB 00144
S.CAE	00146	LPCU	00000	TRCU 00100
RTCU	00200	CRCU	00300	CRCU 00400
MTCU	00700	S.IOC	00350	S.JCR 03115
S.CLDR	02634	S.INFO	02511	OPMESS 00702
S.CT	00455	S.CTR	00455	S.CTP 00455
S.LFH	01716	S.SFH	01726	POWERD 00166
PREST	00277	ITRAP	00303	STALL 00307
S.TIP	01026	S.TOP	01331	S.MTIP 02225
C02629	01476	TIME	02572	S.BORT 03211
S.RBG	02622	JCB	03143	S.CP 03200
FRFLAG	03016	S.MT0	02005	S.MT1 02006
S.MT3	02010	SSM	02511	ENDSSM 04377
POW	03422	GDW	03452	GDAW 03321
G8BB	03272	P.LOW	02774	P.HI 02775
P.NAME	02772	S.IRH	03247	J.C.R 03265
LINKLO	04377	ENDJCR	05557	LNKEND 05560

\$DUMPF
\$DUMP J.C.R.,3265,5557,3265,13265
\$LINK 10000,17777,3265
LNK 03
BSR 02

DEBUG 03265 04265 03265

\$DUMP
\$LINK 10000,17777,5560
ASSEMB 05560 14067 05560

\$DUMP
\$LINK 10000,17777,5560
XREF 05560 07445 05560

\$DUMP
\$LINK 10000,17777,5560
UTILIT 05560 11600 05560

\$DUMP
\$LINK 10000,17777,5560
SOLID 05560 06057 05560

\$DUMP
\$LINK 10000,17777,5560
SCOPE 05560 06250 05560

APPENDIX C

PGS Operating Procedures

This appendix gives the following:

- (1) Procedures for applying power to the PGS and PDC
- (2) Procedures for loading the magnetic-tape transport and bootstrap program
- (3) Procedure for loading the PGS stage
- (4) Initial conditions for PGS operation
- (5) Procedures for operating the PGS.

1. Applying Power to the PGS and PDC

a. Power to PGS

This procedure assumes that a complete PGS startup is required, with all components initially de-energized.

- (1) Check that the switches and knobs on the instrument racks on the right side of the PGS control-room panel (room 12) are in the following positions:

Tennelec TC 202 Linear Amplifier

Coarse gain -- 100

Fine gain -- 0.751

Shaping -- unipolar

Rate -- low

Polarity -- inverted

Input B connected to leftmost jack on the rack second from the top

Output C connected to the ADC 0-10-V input on the Northern

Scientific ADC

Northern Scientific Analog-to-digital Converter (ADC)

Discriminator -- 0 to 100%

Lower-level pot -- 0.23

Upper-level pot -- 10.0

Group size -- 4096

Zero-level pot -- 110

Zero-level switch - 0 to 10%

Conversion gain -- 4096

Coupling -- ac

Baseline restorer -- active

Coin/Anticoin in anticoin(cidence)

Off/Analyze to analyze

Note: The Tennelec Baseline Restorer TC 202 BLR is not interconnected with the PGS/PDC system at this time. The Model 70 Branch Controller is switched ON LINE and is connected by the branch-highway cabling to the Model 50 branch-termination unit.

- (2) Locate the Hewlett-Packard high-voltage power supply on the right side of the NIM bin (gray cabinet) in room 12. On the front of this unit disconnect the high-voltage coax cable to the detector. Next, set all thumb wheels on the power-supply switches to 0. This prevents inadvertent application of high voltage to the detector and possible damage to it.
- (3) Place the safety switch on the fuse box located in the northwest corner of room 12 in the OFF position.
- (4) At the motor-generator (MG) set in the basement of HFEF/S, push the START button on the control box. After the MG set has attained stable operation as indicated by the voltage and current meters, throw the safety switch on the fuse box located next to the control box to the ON position.
- (5) In room 12, place the safety switch on the fuse box to the ON position.
- (6) The calendar-clock POWER FAILURE indication light should be lit. The calendar clock is set by following the operating instructions in Section 2 of the instruction manual for the Mansanto Digital Clock/Calendar, document No. 1816-316M.
- (7) Apply power to the four-axis position-display module by activating the POWER ON/OFF switch in the lower left-hand corner of the Northern Precision Laboratories position-display module. The position displays will come on and indicate the position of the stage.

- (8) Apply power to the Type 611 storage-display scope by pushing the POWER ON/OFF toggle switch behind the front-panel access door.
- (9) Apply power to the NIM bin by pushing the POWER ON/OFF toggle switch in the upper right-hand module of the bin above the voltage jacks. The associated POWER light will energize.
- (10) Reconnect the detector high-voltage coax cable disconnected in step 2, and apply power by pressing the LINE/PUSH ON indicator switch. This switch should light, indicating the application of power. Voltage can now be applied to the detector by the thumb wheel.

CAUTION: To prevent damage to the detector by applying voltage too rapidly, the voltage must be increased in 100-V increments on the thumb wheel up to 800 V, and then increased in 1000-V increments up to 2800 V. Allow a minimum 15 sec between each voltage increment. The final setting for the detector high voltage is 2820 V.

b. Power to PDC

- (1) Apply power to the Datacraft 6024 by placing the circuit breaker of the central processor unit (CPU) in the ON position. This circuit breaker is located on the front lower right-hand side of the CPU cabinet. Next place the circuit breaker of the peripheral cabinet in the ON position. This circuit breaker is located below the magnetic-tape transport. Apply power to the magnetic-tape transport by depressing the POWER indicator switch on the top right-hand side of the transport and note that the switch lights.
- (2) Apply power to the ASR-33 Teletype by pushing the POWER ON/OFF toggle switch on the lower rear panel. Allow a minimum of 1 hr for the electronic circuitry in the PGS and PDC systems to stabilize.

2. Loading the Magnetic-tape Transport and Bootstrap Program

Loading the magnetic-tape transport is accomplished by following the procedure in the technical manual, "MODEL GX40 Synchronous Read After Write Transport" by Peripheral Equipment Corporation, Section III, paragraphs 3-1 through 3-4. Select only those tapes that have a yellow or white holder and an identification tag stating "TOS copy". The TOS is the tape operating system, a supervisory program that sets up the computer to process subsequent programs.

Having loaded the tape, and noting that the LOAD light is energized on the magnetic-tape transport, manually load the magnetic-tape-bootstrap program. This operation sets up the computer to accept the TOS program. The loading of the bootstrap program is accomplished as follows:

- (1) Note that the HALT light is lit on the Datacraft PDC console. If not, depress the HALT/RUN pushbutton and note that the HALT light energizes.
- (2) Depress the CLEAR OR tab and note that the OPERAND REGISTER display has no lights energized.
- (3) Depress the ENTER PA tab and note that no lights are lit on the PROGRAM ADDRESS display. The computer is set up to load information in the core memory starting at core location 0.
- (4) Note the magnetic-tape-bootstrap card posted above PDC console. The right-hand column is the core location in octal notation. The left-hand column is the corresponding information to be manually "thumbed" in via the console entry switches, in octal notation. Note in the left-hand column that each listed number has eight digits between 0 and 7. The PDC console has 24 entry switches (tabs) in eight groups of three, with alternating groups of white and blue tabs. By momentarily depressing any combination of three tabs in a group, any number from 0 to 7 can be generated in octal notation, as follows:

No Tabs Depressed	= 0
- - *	= 1
- * -	= 2
- * *	= 3
* - -	= 4
* - *	= 5
* * -	= 6
* * *	= 7

where - means that the tab switch is not depressed and * means the switch is depressed. Repeat step 2 as necessary to clear the OPERAND REGISTER.

- (5) Read the left-hand digit listed as core location 0 from the magnetic-tape-bootstrap card and depress the proper tabs for that digit, using the three blue tabs on the extreme left of the 24 tabs described in

step 4. Note that corresponding lights will light on the OPERAND REGISTER. Read the next digit to the right for core location 0 and enter in the same fashion using the group of white tabs to the immediate right. Continue in this manner, working from left to right until all eight digits for core location 0 are entered and displayed on the OPERAND REGISTER. If a mistake in "thumbing in" a number is made, depress the CLEAR OR tab and start over.

Example: 6 2 5 0 0 4 0 6
 * * - - * - * - * - - - - - * - - - - * * -

- (6) After confirming that the number on the OPERAND REGISTER is correct, depress the ENTER REG tab and note that the information entered in the previous step is now displayed on the DISPLAY REGISTER.
- (7) Depress the ADV PA (advance program address) tab and note that the DISPLAY REGISTER is cleared. Observe that a light in the 0 position is now present on the PROGRAM ADDRESS display. Note that this ADV PA tab also advances the program to the next core location.
- (8) Repeat step 2, CLEAR OR.
- (9) For each succeeding core location listed on the magnetic-tape-bootstrap card repeat steps 5 through 8.
- (10) After inserting in the memory bank the last core location on the magnetic-tape-bootstrap card, depress MASTER CLEAR. All light displays should be off except M, HALT, and MAN. Depress the ENTER PA (enter program address) tab, thus returning the program to core location 0. Note that no lights are lit on the PROGRAM ADDRESS display.
- (11) Ensure that the LINE-OFF-LOCAL switch on the front of the teletype console is in the LINE position.
- (12) Depress the ON LINE indicator switch on the magnetic-tape transport and note that the switch light energizes.
- (13) Depress the HALT/RUN tab. The RUN light should energize, and the teletype should print ABORT. If ABORT is not typed out, some error has been made, and can be corrected by performing the following steps:
 - (a) Depress the HALT/RUN tab and note that the HALT light is lit.
 - (b) Depress the CLEAR OR tab and note that there are no lights on the OPERAND REGISTER display.

- (c) Depress the ENTER PA tab and note the following: no lights lit on the PROGRAM ADDRESS display; and the information for core location 0 will be displayed on DISPLAY REGISTER. Compare the information from the magnetic-tape-bootstrap card with that on DISPLAY REGISTER.
 - (d) If the DISPLAY REGISTER and the bootstrap card agree, then depress the ADV PA tab. This advances the program to the next core location and displays it on the DISPLAY REGISTER.
 - (e) Repeat steps 13 b, c, and d.
 - (f) Repeat step d until an error is found in the information loaded into the computer compared with that on the bootstrap card. If an error is found, repeat steps 2, 5, 6, 7, and 8 for "thumbing in" the correct information on the bootstrap card.
- (14) Repeat steps 10, 11, and 13. If no ABORT is printed on the teletype there is the possibility that the TOS magnetic tape is causing the malfunction. Replace the tape with a different tape and perform the procedure again.

3. Loading the PGS Stage

a. Initial Conditions

- (1) The stage's element or capsule guides are empty as determined by visual observation from window A4.
- (2) The PGS manual control console is energized with the power-indicator lights lit on the control panel and the two stepping-motor power supplies. No BLOW FUSE indicator lights or alarm lights are energized.

b. Loading of Capsules or Elements

- (1) Check with the computer operator in room 12 to confirm that control of the stage can be transferred to the manual control console.
- (2) After confirmation that operation with the manual control console is permitted, switch the keyswitch on the PGS control-room panel (room 12) to the MANUAL CONTROL position and conform the energizing of the corresponding indicator light.

- (3) Confirm that the MANUAL CONTROL light on the manual control console is energized.
- (4) Check the X, Y, Z, and $\emptyset$ indicators on the manual control console. To facilitate loading and avoid mechanical interferences, the load/unload positions must conform to the following indications on the console:
 - X = 8000 (equal to a X position of 8.000 in.)
 - Y = 7500 (equal to a Y position of 7.500 in.)
 - Z = 30000 (equal to a Z position of 30.000 in.)
 - $\emptyset$ = 0000 (equal to an $\emptyset$ of zero degrees)
- (5) If the indicators are as required above, proceed to step 7; if not, perform step 6.
- (6) To maneuver the stage into the required position to facilitate loading, a definite sequence must be followed with Z operated first, then Y, X, and $\emptyset$ in that order.
 - (a) If Z motion is required, depress the Z-motion UP or DOWN indicator switches first as required to get to an indicated 30000.
 - (b) If Y motion is required, depress the Y-motion LEFT or RIGHT indicator switches next (after the Z switches) to get an indicated 7500.
 - (c) If X motion is required, depress the X-motion AWAY or FORWARD indicator switches next (after the Z and Y) to get an indicated 8000.
 - (d) If $\emptyset$ motion is required, depress the $\emptyset$ motion ROTATE CW (clockwise) or ROTATE CCW (counterclockwise) indicator switches as required to get an indicated 0000.
- (7) With the stage at the initial position tabulated in step 4, stage motion in the Z direction to facilitate the loading of a longer or shorter element or capsule will be performed by depressing the Z-motion UP or DOWN switches as required. Gamma scanning will commence from this Z indication.
- (8) If scanning is to be done in the restrained mode, install a guide fixture of the appropriate size for the element or capsule to be gamma scanned.
- (9) Install a collet of the appropriate size.

- (10) Open the outlet valve on the argon-gas bottle in the basement (under window position A3). Set the regulator output pressure to 400 psig (minimum) to 500 psig (maximum). This pressurizes the line to the solenoid that operates the T-bar actuating system.
- (11) Depress the CK OPEN indicator switch on the console, which raises the T-bar to its load position.
- (12) Using the master-slave manipulator at window A4, feed the capsule or element to be scanned into the bottom guide, then the top guide. Move the capsule or element with the manipulator to assure that the guides are not binding.
- (13) Visually confirm that the spacer wire (if present) is through the top guide.
- (14) Actuate the Z-motion UP button until the T-bar contacts the bottom of the capsule or element.
- (15) Release the manipulator so that the capsule or element rests on the top of the T-bar.
- (16) Ensure that the spacer wire on the capsule or element is oriented toward the slide on the T-bar. Slide the capsule's or element's spade onto the T-bar until the spade contacts the raised part of the T-bar.
- (17) Depress the CK CLOSE indicator switch to actuate the T-bar to the down position, which clamps the spade in the collet.
- (18) Secure the argon supply for the T-bar actuating system.
- (19) Inform the computer operator in room 12 that loading is complete, and ensure that the keyswitch on the PGS control-room panel is returned to the COMPUTER CONTROL position, with the corresponding energization of the indicator light.

c. Unloading the Stage

- (1) To unload the stage, confirm with the computer operator in room 12 that scanning is complete and that operation at the manual control console is permitted.
- (2) Confirm that the keyswitch on the PGS control-room panel is in the MANUAL CONTROL position and the corresponding indicator light is energized.

- (3) Confirm that the MANUAL CONTROL light on the manual control console is energized, the three POWER lights are energized, and no alarm lights are energized.
- (4) To avoid mechanical interferences and facilitate unloading, the stage should be in the following indicated positions:

X = 8000

Y = 7500

Z = 30000 (or in the initial Z position achieved in step 3.b.(7))

$\emptyset$ = 0000 degrees.

If the stage is not at these indications, operate, in the following order, the Z, Y, X, and $\emptyset$ indicator switches until the required indications are achieved.

- (5) With the required indications achieved, energize the Z-motion switch as required to facilitate unloading of the capsule or element. Grip the capsule or element with the manipulator to prevent inadvertent premature unloading.
- (6) Ensure that 400-500 psig argon gas is supplied to the collet.
- (7) Depress the CK OPEN indicator switch to raise the T-bar and unclamp the spade. Slide the spade off the T-bar and carefully slide the capsule or element out of the top and then the bottom guides.
- (8) After disposition of the capsule or element according to the instruction of the Cognizant Engineer or Zone Engineer, secure the argon-gas supply.

4. Initial Conditions for PGS Operation

- (1) The PGS has had power applied to the entire system for a minimum of 1 hr. (The procedure for applying power is given above in Section 1 of this appendix.)
- (2) The capsule or element has been loaded into the PGS in-cell stage in accordance with the procedure in Section 3 of this appendix.
- (3) The COMPUTER CONTROL/MANUAL CONTROL keyswitch located below the position-display power switch on the PGS control-room panel is in the COMPUTER CONTROL position.

- (4) The calendar clock is indicating the correct day and time.
- (5) The linear amplifier and ADC for the nuclear detector are connected properly with all switches and control pots properly set (see Section 1.a.(1) of this appendix).
- (6) The high-voltage power supply is indicating 2820 V.
- (7) The CAMAC crate has all 14 of its PGS modules inserted in the proper places.
- (8) The branch-controller module, on the extreme right of the CAMAC crate, has its control switch in the ON LINE position.
- (9) The PDC magnetic-tape transport has been loaded and initialized according to the procedure in Section 2 of this appendix.
- (10) The teletype selector switch is in the ON LINE position.
- (11) A Scanning Request Form has been received from the Cognizant Engineer and approved by the Zone Engineer for the capsules or elements to be scanned.

5. Operating the PGS

- (1) Get the PGS binary paper tape from storage. This tape contains the current PGS gamma-scanning program translated into binary notation.
- (2) To load the binary paper tape, note that on the left side of the teletype there is a free-turning spindle. Place the tape on the spindle so that it will unwind in a clockwise manner. The paper-tape reader is on the immediate left of the teletype keyboard. Release the clear plastic cover, which uncovers eight slots and a drive wheel. This area and the underside of the plastic cover should be free of dirt and oil. Take the leader of the PGS binary paper tape and position it so that the perforated holes line up with the drive wheel. Ensure that all the fingers of the drive wheel protrude through the tape. Holding the tape in this manner, close the clear plastic cover.
- (3) On the teletype keyboard, type \$JOB and actuate a carriage return by pressing the RETURN key. NOTE: It is important that all instructions to the machine be typed exactly as depicted herein, including the spacing between letters and words.

- (4) Next, type \$ASSIGN 4, 2 and press RETURN. Then type \$OPTION .7 and press RETURN.
- (5) Finally, type \$LINK 5634, 17777 and press RETURN. The paper tape will then start and read the information into the computer. The typed instruction tells the computer to load the PGS program in core locations 5634 through 17777 (octal notation). The tape operating system (TOS) has previously been loaded in core locations 0-5633 by means of the bootstrap program given in Section 2 of this appendix.
- (6) If the teletype prints out a LNK 03 before the end of the paper tape is reached, this means that the PDC has encountered a checksum error in an input record. An input record to the link loader is 55 words long, consisting of six 9-word subfields and a 1-word, hash-total checksum as the 55th word of the record. If the link-loader checksum does not agree with the checksum on the paper tape, the message LNK 03 will be typed on the teletype and the PDC will go into a hold state.
 - (a) The hold state is released by a CTRL and BELL command from the teletype keyboard. The PDC causes the message BSR 02 to be printed on the teletype and again goes into a hold state. This message tells the operator that he must manually back-space one record on the paper tape. Each record starts with a line advance (USASCII Code B₂, B₄, and B₈) and ends with a carriage return (USASCII Code B₁, B₃, B₄, and B₈). When a LNK 03 occurs, the tape will stop on the line advance for the upcoming record. The operator should open the plastic paper-tape guide on the teletype paper-tape reader and back up the tape until the punch for the preceding line advance is over the reader head. The plastic guide should now be closed. The hold state is released with CTRL and BELL, and the PDC makes another attempt to read the record correctly. If another LNK 03 occurs, repeat the above procedure. Continuing LNK 03 messages indicate a faulty paper tape or a problem with the teletype paper-tape reader.

- (b) After the tape has been completely read in, the teletype will type out the message PGS 05634 17745 05634.* If this message is not typed out, the PGS program was loaded improperly.
- (7) Next, it is required to make changes to the core memory in order to set up the supervisory interrupts in the PGS program. The procedure for thumbing in these changes is the same as for thumbing in the magnetic-tape-bootstrap program, the only difference being the core location.
- (a) To make these changes, first initiate computer HALT and note that the HALT light is lit.
- (b) Depress the CLEAR OR tab.
- (c) Using the three groups of three tabs on the right, thumb in the octal number 103. The OPERAND REGISTER display should then look like this:

```

      0      0      0      0      0      1      0      3
  - - - - - * - - - - *

```

- (d) Depress the ENTER PA tab and note that this display is on the PROGRAM ADDRESS. Information can now be loaded at core location 103. Again, perform CLEAR OR.
- (e) Now thumb in the core changes listed below, using the entry-switch tabs.

<u>Core Location</u> <u>(octal code)</u>	<u>Core Change</u> <u>(octal code)</u>	<u>Supervisory</u> <u>Interrupt</u>
103	25006557	Jam alarm
104	25006607	Live timer
105	25006713	ADC
106	25006770	Look-at-me
7543	00001750	Live-timer conversion factor

(These changes are used in the current PGS program, but may be altered at the discretion of the Zone or Cognizant Engineer.) The loading procedure is similar to that used in loading the bootstrap program. Depress the ENTER REG, ENTER PA, and CLEAR OR tabs in that order. Information can now be loaded at core

* This number may be changed at the discretion of the Zone or Cognizant Engineer.

location 104 as shown on the PROGRAM ADDRESS display. Thumb in the appropriate core change, and repeat in this manner until all changes listed above except the last one have been made to core locations.

- (f) The OPERAND REGISTER display should be clear. If not, depress CLEAR OR.
 - (g) To make the last core change, use the four groups of three tabs on the right. Thumb in the last number and note the corresponding display on the OPERAND REGISTER. Depress the ENTER PA tab and note the same display on the PROGRAM ADDRESS. Information can now be loaded at core location 7543.[†] Depress CLEAR OR and thumb in the core change in the same manner as previously.
 - (h) After the last core change is thumbed in, the computer must be returned to core position 0. This is accomplished by performing steps 2 and 3 of the bootstrap loading (Section 2 of this appendix) and then actuating the HALT RUN tab.
 - (i) The teletype should type out ABORT.
- (8) With the core correction made, the computer is ready to accept a job.
- (a) Type \$JOB and press RETURN.
 - (b) Type \$GO and press RETURN.
 - (c) Teletype will type GSI RDY INFO.
 - (d) Using the following format for an axial scan, type in the required information from the Scanning Request Form:

Operator Action	Teletype Action*
1. Actuate CTRL and BELL keys.	Teletype types TITLE.
2. Actuate CTRL and BELL keys. Type in the title from the scanning request and press RETURN.	After RETURN, teletype types PIN NO.

[†] This number may be changed at the discretion of the Zone or Cognizant Engineer.

Operator Action	Teletype Action*
3. Actuate CTRL and BELL keys, then type in the pin number and press RETURN.	Teletype types SUB NO.
4. Actuate CTRL and BELL keys. Type in the subassembly number and press RETURN.	Teletype types CORE.
5. Actuate CTRL and BELL keys. Type in the core-loading position and press RETURN.	Teletype types FLU.
6. Actuate CTRL and BELL keys. Type in the fluence and press RETURN.	Teletype types POS.
7. Actuate CTRL and BELL keys. Type in X-axis final position in mils** and press RETURN.	
8. Type in the Y-axis final position in mils*** and press RETURN.	
9. Type in the Z-axis final position in mils*** and press RETURN.	
10. Type in the $\emptyset$ final position in tenths of degrees and press RETURN.	
11. Type in the X incremental movement in mils and press RETURN.	
12. Type in the Y incremental movement in mils and press RETURN.	

* The carriage advances one line after each CTRL-BELL and each RETURN; thus, each of the titles and data items listed below is typed on a separate line.

** If Scanning Request states "centered", type in the number specified in the current PGS program (7850). This number may be changed at the discretion of the Zone or Cognizant Engineer.

*** If Scanning Request states, "normal", type in the number specified in the current PGS program (9000). This number can be changed at the discretion of the Zone or Cognizant Engineer.

Operator Action	Teletype Action
13. Type in the Z incremental movement in mils and press RETURN.	
14. Type in the Ø incremental movement in tenths of degrees and press RETURN.	
15. Type in the X start position in mils and press RETURN	
16. Type in the Y start position in mils and press RETURN.	
17. Type in the Z start position in mils† and press RETURN.	
18. Type in the Ø start position in tenths of degrees and press RETURN.	Teletype types IRRA TIME.
19. Actuate CTRL and BELL keys. Type in the duration of last irradiation (from the Scanning Request) in hours, and press RETURN.	Teletype types LAST IRRA.
20. Actuate CTRL and BELL keys. Type in hours since the last irradiation, and press RETURN.	Teletype types TYPE SCAN.
21. Actuate CTRL and BELL keys. Type in AXIAL and press RETURN.	Teletype types SLT WD.
22. Actuate CTRL and BELL keys. Type in 0, and press RETURN.	Teletype types LIVE TIME.
23. Actuate CTRL and BELL keys. Type in 600 (this is the live or operating time in seconds), but <u>do not</u> <u>press RETURN</u> .	

† 3250 mils must be added to the "start" and "end" positions stated in the Scanning Request, because of the height of the holding chuck.

- (e) On the PGS console, set the rocker-type control switches 7, 9, 17, 18, 19, and 20 to their actuated position.
- (9) The computer is now set up for a calibration scan. To perform the scan, do the following:
 - (a) Obtain the ^{228}Th source from the Radiation Safety office and tape it to the collimator slit on the wall, in front of the detector to the left of window A3. The detector stand must be moved back so that the red mark on the angle iron on the left side is $5\text{-}1/4 \pm 1/4$ in. from the shield of the collimator-rotation motor.
 - (b) Return to room 12 and press RETURN on the teletype keyboard. This sets in motion the PGS program
 - (c) The collimator will rotate to the axial or diametral position, the slit will close to zero, and the X, Y, Z, and ϕ motions will go to their start positions, in that order.
 - (d) When ϕ reaches its start position, the teletype will type out the day and time, and then the calibration scan will begin.
- (10) If the teletype types JAM ALARM while the stage is going to the start position, or during a scan, the computer will go into a hold state until the problem is manually cleared. To clear the problem, observe the stall-control module in the CAMAC crate. There should be one or more lights lit. To check the validity of the jam alarm, locate the push-button switch around the right side of the NIM bin (grey cabinet). This switch is suspended by two red wires. Depress the switch and note the red lights on the stall-control module.
 - (a) If the lights do not go out, the jam alarm is valid and indicates that the capsule or element is jamming in the stage. No attempt should be made to manually clear the jam by room-12 operations. Notify the Zone Engineer, and have the capsule or element removed from the stage.
 - (b) If the light does go out, the jam alarm is spurious and the scan can be continued.
- (11) In the event of a jam alarm, also observe the look-at-me module to the left of the stall-control module. If any lights are lit, this module must be cleared also.

- (a) Clearing is accomplished at the branch-controller module by placing the ON LINE/OFF LINE switch in the OFF LINE position.
 - (b) Depress pushbutton C located below the ON LINE/OFF LINE switch. All lights on the look-at-me module should go out.
 - (c) Then depress the HALT pushbutton at the PGS console.
 - (d) Actuate CLEAR OR and thumb in the number 6034* on the entry switches, using the four groups of three tabs to the right.
 - (e) Depress the ENTER REG, ADV PA, CLEAR OR, and HALT/RUN tabs in that order.
 - (f) If the computer does not return to the normal run mode, note the look-at-me module again. If a light is still lit, repeat the procedure. If no light is lit, rethumb in 6034*. This procedure may have to be repeated several times to clear the computer.
- (12) Once the stage has gone to the start position and the gamma-scanning operation has started, note the display scope. If the display is very bright or "blossomed", press the erase button. Now the spectrum can be visually watched. Note the lone peak in the right of the display. This is the calibration peak.
- (13) When the live-timer module has timed out and reached the end of the scanning interval, the calibration will be ended and the information printed on the magnetic tape. The actual time taken for the spectrum, the run number, the X, Y, Z, and $\emptyset$ positions, and the slit width will be printed out by the teletype. After this, the teletype will type FST CH (first channel).
- (a) Actuate the CTRL and BELL keys, type 3334,* and press RETURN. The teletype will print out LAST C (last channel).
 - (b) Actuate the CTRL and BELL keys, type 3354*, and press RETURN. The teletype will then type the channel number and the total counts per channel, starting at channel 3334 and ending at channel 3353. The peak channel for calibration should be 3345 ± 5 channels, with the peak count being 1100 ± 150 counts.
- (14) When the last channel has been typed out, the computer will halt.

* This number may be changed at the discretion of the Zone or Cognizant Engineer.

The calibration can be repeated, starting with step (8), if the results of the first scan were not satisfactory.

- (15) If a correct calibration is achieved, reset control switches 17, 19, and 20 on the PDC console and prepare for scanning a capsule or element as follows:

- (a) Remove the ²²⁸Th source from in front of the detector and move the detector toward the wall so that the detector is almost flush with the collimator. Tighten the hand screw at the base of the detector stand to prevent accidental movement away from the proper alignment.
- (b) Return to room 12 and depress the HALT/RUN button. The computer will go to the run mode and the message SLT WD will be typed on the teletype.
- (c) Actuate CTRL and BELL keys and type in the required slit width in tenth of mils from the Scanning Request Form.
- (d) Press RETURN and the PGS will start the requested scan of a capsule or element.

* This number may be changed at the discretion of the Zone or Cognizant Engineer.

APPENDIX D

Examples of PGS Data

This appendix gives a computer printout and a number of plots as examples of actual data taken with the PGS.

X056A GAMMA SCAN (F9C-36M)

PIN NUMBER = F9C-36
SUBASSEMBLY NUMBER = X056A
CORE POSITION = 6B2
FLUENCE = 5.3E22
SCAN TYPE = AXIAL

POSITION	START	FINAL	INCREMENT
X	7850	7850	0
Y	7500	7500	0
Z	21500	42500	250
Ø	50	50	0

NORMALIZED COUNTING RATE

POSITION		(141)ICE	(103)RU	(106)RUD	(137)CS	(95)ZR	(95)NB	(58)CO
RUN	X Z	NCR SIG	NCR SIG	NCR SIG	NCR SIG	NCR SIG	NCR SIG	NCR SIG
1	7850 21500	0.0 0	0.0 0	0.0 0	49.6 9	0.0 0	0.0 0	2209.9 6
2	7850 21750	0.0 0	0.0 0	0.0 0	41.6 10	0.0 0	36.2259	2337.7 7
3	7850 22000	0.0 0	0.0 0	0.0 0	46.1 9	0.0 0	384.7 22	2639.3 6
4	7850 22250	0.0 0	1867.8 5	71.4 8	140.3 4	1006.1 5	17828.4 6	508.5 10
5	7850 22500	308.5 25	1865.5 6	50.7 17	143.8 5	1078.5 4	17950.3 6	613.4 6
6	7850 22750	0.0 0	2529.1 6	73.0 7	166.5 6	1094.1 6	20998.4 4	573.4 8
7	7850 23000	131.7 25	2515.2 4	86.7 8	163.6 4	1307.2 5	22277.7 5	667.5 5
8	7850 23250	338.4 57	2696.1 4	75.9 8	167.8 4	1419.8 3	23506.7 5	731.1 6
9	7850 23500	105.4 26	2724.9 4	94.2 12	191.2 3	1432.6 3	24481.5 3	850.2 5
10	7850 23750	0.0 0	2990.5 4	92.7 7	330.7 6	1542.6 4	26490.7 5	592.4 5
11	7850 24000	87.2 35	4196.6 3	142.9 6	878.2 3	2325.9 4	40201.9 5	1080.6 7
12	7850 24250	452.8 14	13508.5 5	463.7 5	1269.3 4	10042.4	5177451.3	4 1246.5 4
13	7850 24500	1606.6 6	32677.1 3	1089.6 5	1606.5 2	27485.1	5464434.8	4 1671.7 4
14	7850 24750	2306.4 7	35205.2 3	980.1 6	1952.3 3	29706.8	5497032.4	4 1722.4 4
15	7850 25000	2502.0 5	37846.4 3	1111.6 3	2077.8 3	30400.7	4516362.9	3 1811.7 5
16	7850 25250	2493.9 4	37171.7 3	1141.1 2	2142.5 3	30708.3	5517167.0	4 2094.1 4
17	7850 25500	2300.5 6	0.0 0	1162.0 3	2147.5 2	31867.8	4540231.9	4 2294.6 4
18	7850 25750	2940.8 4	41219.9 3	1197.3 4	2191.6 3	32973.1	5557047.4	4 2437.9 4
19	7850 26000	3148.6 10	41085.8 3	1365.2 5	2408.7 3	32928.9	5567204.8	4 2377.0 3
20	7850 26250	2765.1 6	39879.1 3	1386.3 5	2880.4 3	32395.0	5545857.3	4 2640.2 3
21	7850 26500	2659.9 8	41203.0 3	1391.7 6	2516.7 3	33716.0	5568485.1	4 2478.3 7
22	7850 26750	3100.6 5	41441.6 3	1423.8 4	2733.5 3	33705.0	4575744.9	4 2783.4 4
23	7850 27000	2582.6 4	43243.9 2	1436.7 5	2539.0 4	35064.1	5583635.3	4 2702.4 3
24	7850 27250	3052.7 9	41995.3 3	1416.6 4	2758.2 3	34412.0	5585264.9	4 2937.9 3
25	7850 27500	3197.1 7	41288.9 2	1386.3 5	2501.8 2	33849.9	5569086.5	4 2692.7 3
26	7850 27750	2161.8 12	41513.4 3	1438.5 4	2827.0 3	33791.0	5564939.6	3 2803.1 5
27	7850 28000	2809.4 5	43319.4 3	1477.8 4	2736.6 2	35108.3	5589545.9	4 2497.9 3
28	7850 28250	3271.5 5	42770.2 3	1413.7 5	2897.7 3	34387.8	5591021.7	4 2008.9 6
29	7850 28500	3054.1 4	44727.6 3	1507.8 5	2985.6 3	36478.0	5610550.3	4 2343.6 7
30	7850 28750	3149.2 5	46803.3 3	1598.7 5	2748.1 3	37511.3	5629493.8	3 2128.1 5
31	7850 29000	3704.6 8	46484.3 3	1557.3 5	2821.5 2	38233.5	4634826.4	4 2115.1 5
32	7850 29250	3066.0 4	45701.8 3	1422.7 3	3089.8 3	37396.8	5620455.1	4 2114.7 4
33	7850 29500	2796.0 4	46482.1 3	1351.2 2	2990.9 4	37532.6	4635450.4	4 2148.2 3
34	7850 29750	2896.8 5	45793.1 3	1534.7 5	2817.2 3	37634.3	5625655.8	4 2216.9 4
35	7850 30000	3174.6 4	0.0 0	1625.6 5	3045.4 3	38312.3	4634619.7	4 2226.4 6
36	7850 30250	3213.0 5	45987.9 3	1610.4 4	2976.1 3	37236.2	5633221.4	3 2676.2 5
37	7850 30500	3076.1 4	46392.1 2	1373.2 3	2829.1 3	37628.1	5641778.3	4 2851.1 5
38	7850 30750	3301.8 5	48609.3 3	1373.3 3	2941.5 2	38337.4	5645832.6	4 2639.1 3
39	7850 31000	3305.2 6	48108.7 3	1485.7 3	3023.8 3	39108.9	5649073.3	4 2728.8 3
40	7850 31250	2992.6 5	47456.4 3	1659.7 4	2758.4 3	39373.4	5644484.5	4 3247.9 5
41	7850 31500	3211.8 4	46421.2 3	1446.0 3	2774.6 3	38276.7	6640119.2	3 3145.9 4
42	7850 31750	2971.0 4	46202.2 3	1422.4 4	3213.5 4	38532.2	4641464.0	4 3232.7 5
43	7850 32000	3696.9 5	47540.3 2	1605.1 5	3393.3 3	38228.6	5652625.5	3 3260.7 3
44	7850 32250	3113.7 4	49005.3 3	1725.4 5	3852.6 3	39675.2	5664202.8	3 3015.8 3

45	7850	32500	3123.9	4	46194.6	3	1586.8	5	4263.9	3	38160.6	4631947.7	4	3223.8	6	
46	7850	32750	3303.4	4	48570.8	3	1701.2	6	2070.6	3	39556.0	4670708.1	3	2964.3	4	
47	7850	33000	3429.7	5	45464.3	3	1538.9	5	2660.0	2	36948.2	3627695.1	4	2981.1	5	
48	7850	33250	2848.6	5	47856.4	2	1613.0	5	2791.2	3	38805.9	4662383.3	3	3035.9	3	
49	7850	33500	3255.9	4	48171.5	2	1586.8	5	2776.4	2	39231.5	4678224.8	4	2947.1	3	
50	7850	33750	3427.0	7	48884.9	3	1484.9	3	2529.6	3	39768.5	4669347.9	4	2680.7	6	
51	7850	34000	3032.0	6	49240.9	3	1687.0	5	2896.4	2	39023.2	4656852.6	4	1962.5	3	
52	7850	34250	3048.0	4	47817.2	3	1660.5	4	3072.1	2	39277.8	4659694.2	4	1832.1	7	
53	7850	34500	2949.1	4	48265.6	3	1391.4	3	2509.2	3	39386.9	4662829.3	3	2085.1	3	
54	7850	34750	3654.5	8	47293.4	2	1589.8	5	2834.7	3	38739.6	3653539.7	3	2021.7	6	
55	7850	35000	3257.2	4	45495.0	3	1544.5	6	3246.9	3	37662.8	4636279.4	3	1976.2	5	
56	7850	35250	3573.4	4	46751.3	3	1275.9	3	2405.9	3	36980.7	4636332.3	3	2209.8	3	
57	7850	35500	2659.6	9	45650.7	3	1377.6	2	2961.9	3	37572.6	4645462.8	4	1982.6	6	
58	7850	35750	2758.8	4	44088.0	3	1296.2	2	2876.6	2	37375.9	5623592.9	3	2261.3	6	
59	7850	36000	2994.5	4	42558.6	3	1382.4	5	3063.5	3	35600.3	4606120.1	3	2216.7	6	
60	7850	36250	2591.2	9	44815.5	3	1518.7	5	3641.9	3	37149.0	5620441.9	4	2181.7	4	
61	7850	36500	3045.7	4	43707.5	3	1411.8	4	2768.4	3	35925.5	4602209.0	3	1994.4	3	
62	7850	36750	3324.4	6	42451.3	3	1365.8	5	3409.9	2	35152.8	4586551.8	4	2329.1	6	
63	7850	37000	2683.9	6	42600.8	2	1469.2	5	2410.7	2	35457.0	4601273.4	4	2461.9	6	
64	7850	37250	2393.6	8	41107.9	3	1374.6	6	2265.0	3	34177.0	5584427.8	4	2172.1	6	
65	7850	37500	3016.1	8	39692.5	3	1281.8	4	2376.3	3	32783.5	4550085.5	4	2209.8	5	
66	7850	37750	2872.2	5	40687.9	2	1365.0	4	2458.9	3	34639.6	5581903.4	3	1979.8	5	
67	7850	38000	214.1	24	4336.9	4	123.3	7	1293.5	3	2218.2	4	39438.5	5	1716.0	5
68	7850	38250	0.0	0	3447.0	5	104.7	9	245.6	3	1898.8	5	32918.3	4	1515.9	7
69	7850	38500	217.6	18	3407.4	5	104.3	8	222.3	4	1789.3	5	30955.5	5	1394.0	5
70	7850	38750	152.8	24	2987.8	6	99.4	7	192.0	7	1601.2	6	27859.5	6	1225.6	9
71	7850	39000	172.2	43	692.4	11	21.7	27	141.8	7	503.2	7	9348.7	5	2696.7	6
72	7850	39250	0.0	0	0.0	0	0.0	0	36.6	10	0.0	0	192.3	29	1189.5	8
73	7850	39500	0.0	0	0.0	0	0.0	0	55.2	10	0.0	0	0.0	0	1136.1	4
74	7850	39750	0.0	0	0.0	0	0.0	0	44.9	7	0.0	0	317.5	25	843.7	9
75	7850	40000	0.0	0	0.0	0	0.0	0	46.9	9	25.0	29	245.2	32	778.5	8
76	7850	40250	0.0	0	0.0	0	0.0	0	44.6	9	0.0	0	0.0	0	700.5	5
77	7850	40500	0.0	0	0.0	0	0.0	0	50.3	7	24.7	40	276.3	31	653.9	9
78	7850	40750	0.0	0	0.0	0	0.0	0	41.9	8	39.0	31	319.5	32	603.6	9
79	7850	41000	0.0	0	0.0	0	0.0	0	44.2	9	30.3	30	301.7	23	542.7	7
80	7850	41250	0.0	0	0.0	0	0.0	0	42.8	9	0.0	0	0.0	0	492.9	8
81	7850	41500	0.0	0	0.0	0	0.0	0	46.4	8	19.5	44	0.0	0	527.4	7
82	7850	41750	0.0	0	0.0	0	0.0	0	35.5	8	0.0	0	152.9	32	590.2	9
83	7850	42000	0.0	0	0.0	0	0.0	0	48.0	12	0.0	0	0.0	0	600.9	7
84	7850	42250	0.0	0	0.0	0	0.0	0	43.7	8	0.0	0	0.0	0	507.8	6
85	7850	42500	0.0	0	0.0	0	0.0	0	34.6	11	0.0	0	0.0	0	540.5	9

DETAIL SCAN OF 202

^{54}Mn

X: 7.850

SUBASSEMBLY NUMBER: X071A

FLUENCE: 9E22

PIN NUMBER: 202

LIVE TIME: 300 SEC

02/02/72

DETAIL SCAN OF 202

⁹⁵NB

X: 7.850

SUBASSEMBLY NUMBER: X071A

FLUENCE: 9E22

PIN NUMBER: 202

LIVE TIME: 300 SEC

02/02/72

DETAILED SCAN OF FAILED AREA (180 DEG. DIAMET)

⁵⁸CO

Z:31.900

SUBASSEMBLY NUMBER: X071A

FLUENCE: 9E22

PIN NUMBER: 230

LIVE TIME: 300 SEC

01/31/72

DATAILED SCAN OF FAILED AREA(60 DEG. DIAMET)

^{95}Nb

Z:29.900

SUBASSEMBLY NUMBER: X071A

FLUENCE: 9E22

PIN NUMBER: 230

LIVE TIME: 300 SEC

01/28/72

DETAILED SCAN OF FAILED AREA (180 DEG. DIAMET)

⁹⁵Zr

Z:31.900

SUBASSEMBLY NUMBER: X071A

FLUENCE: 9E22

PIN NUMBER: 230

LIVE TIME: 300 SEC

01/31/72

DETAILED SCAN OF FAILED AREA (180 DEG. DIAMET)

¹³⁷Cs

Z:29.900

SUBASSEMBLY NUMBER: X071A

FLUENCE: 9E22

PIN NUMBER: 230

LIVE TIME: 300 SEC

01/31/72

DETAILED SCAN OF FAILED AREA(DIAMET)

¹⁴¹CE

SUBASSEMBLY NUMBER: X071A

FLUENCE: 9E22

Z:31.900

PIN NUMBER: 230

LIVE TIME: 300 SEC

02/11/72

SHORT AXIAL SCAN

^{103}Ru

X: 7.820

SUBASSEMBLY NUMBER: X094

FLUENCE: 2E22

PIN NUMBER: G-3

LIVE TIME: 300 SEC

03/30/72

X094 G-4 SCAN

^{54}Mn

X: 7.820

SUBASSEMBLY NUMBER: X094

FLUENCE: 2E22

PIN NUMBER: G-4

LIVE TIME: 300 SEC

04/04/72

X094 G-4 SCAN

^{103}Ru

X: 7.820

SUBASSEMBLY NUMBER: X094

FLUENCE: 2E22

PIN NUMBER: G-4

LIVE TIME: 300 SEC

03/29/72

X094 G-4 SCAN

^{131}I

X: 7.820

SUBASSEMBLY NUMBER: X094

FLUENCE: 2E22

PIN NUMBER: G-4

LIVE TIME: 300 SEC

03/29/72

GROSS GAMMA SCAN OF CAPSULE PNL-5-15 FROM SUBASSEMBLY X116

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