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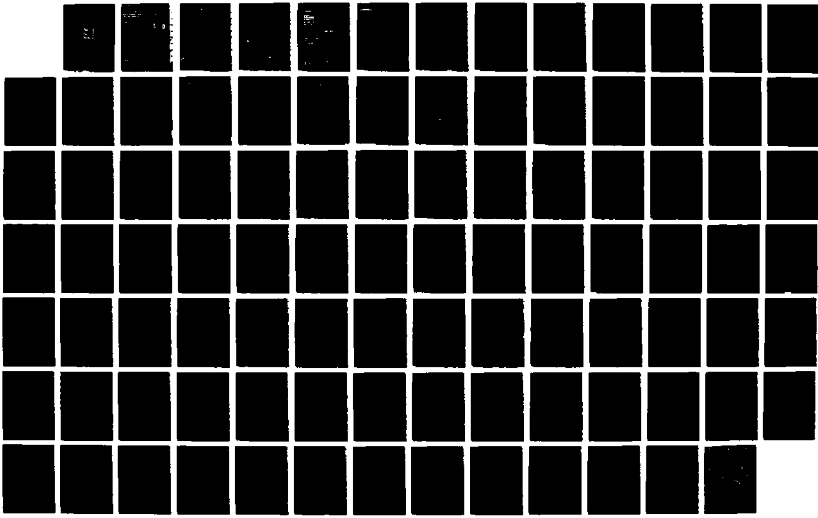

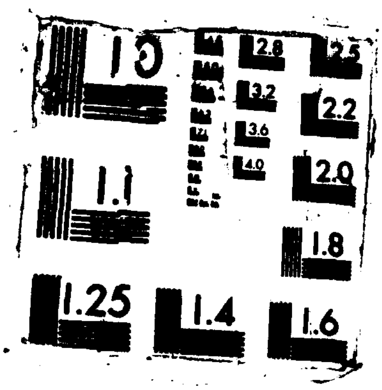
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DNA-TR-85-383

DIGITAL INTERFACE MODULES FOR ACTIVE-READOUT X-RAY SPECTROMETER

Advanced Research and Applications Corporation
425 Lakeside Drive
Sunnyvale, CA 94086-4701

1 March 1985

Technical Report

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The design of an active readout x-ray diffraction crystal spectrometer (HW-1024) for four key Pulsed Plasma Source (PRS) missions has been investigated. This active readout capability is installable into existing film-recording spectrometers, (HW-1000) and compatible with PRS facility computer resources. Three field retrofittable packages, detector, digital interface and control/DAS software, provide the active readout capability.

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PREFACE

The authors would like to acknowledge the important contributions to this effort from Jim LePage for his helpful suggestions and guidance organizing the system software; Bill Laird for his engineering layout design of the retrofittable detector and digital interface packages; and Robert H. Hamstra, Jr., Circuit Solutions, San Jose, California, who is an independent contractor to ARACOR.

SUMMARY

- This Phase I program has demonstrated the feasibility of active-readout x-ray diffraction crystal spectrometer (HW-1024).
- A key PRS diagnostic instrument, the HW-1024, can be integrated into the DNA Instrumentation Upgrade Program strategy.
- The time and labor intensive processing of film recorded spectrographic data can be eliminated.
- PRS spectrographic data will be available in minutes rather than days.
- The active-readout capability can be installed into existing HW-1000 spectrometers.
- The HW-1024 control/DAS software is compatible with existing PRS facility computer resources.
- Three packages (detector, digital interface, and software) provide the active-readout capability.
- The detector package provides the required resolution, sensitivity, and dynamic range for the four key PRS missions.
- The four PRS missions are neon K, nickel L, krypton L, and argon K lines.
- The detector package can be upgraded to other missions in the energy region 0.5 to 15 keV.
- The digital interface package provides a microprocessor-based, two-way communication link between the experimentalist and the detector package.

- The digital interface package optimizes overall system dynamic range and signal-to-noise ratio.

- The digital interface package has adequate EMP protection.

- The software package provides total instrument control from set-up and testing to data acquisition, reduction, display, and archival.

- The software package can operate in parallel with FTDAS or in a stand-alone mode for the non-DNA user.

- The software package provides x-ray spectrographic data with all instrument response factors removed.

CONVERSION TABLE

CONVERSION FACTORS FOR U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 x E -10
atmosphere (normal)	kilo pascal (kPa)	1.013 25 X E +2
bar	kilo pascal (kPa)	1.000 000 X E +2
barn	meter^2 (m^2)	1.000 000 X E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 X E +3
cal (thermochemical)/cm^2	mega joule/m^2 (MJ/m^2)	4.184 000 X E -2
calorie (thermochemical)	joule (J)	4.184 000
calorie (thermochemical)/g	joule per kilogram (J/kg)*	4.184 000 X E +3
curies	giga becquerel (GBq)†	3.700 000 X E +1
degree Celsius	degree kelvin (K)	$t_K = t°_C + 273.15$
degree (angle)	radian (rad)	1.745 329 X E -2
degree Farenheit	degree kelvin (K)	$t_K = (t°_F + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E -19
erg	joule (J)	1.000 000 X E -7
erg/second	watt (W)	1.000 000 X E -7
foot	meter (m)	3.048 000 X E -1
foot-pound-force	joule (J)	1.355 818
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 X E -3
inch	meter (m)	2.540 000 X E -2
jerk	joule (J)	1.000 000 X E +9
joule kilogram (J/kg) (radiation dose absorbed)	gray (Gy)*	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E +3
kip/inch^2 (ksi)	kilo pascal (kPa)	6.894 757 X E +3
ktap	newton-second/m^2 (N-s/m^2)	1.000 000 X E +2
micron	meter (m)	1.000 000 X E -6
mil	meter (m)	2.540 000 X E -5
mile (international)	meter (m)	1.609 344 X E +3
ounce	kilogram (kg)	2.834 952 X E -2
pound-force (lbf avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 X E -1
pound-force/inch	newton/meter (N/m)	1.751 268 X E +2
pound-force/foot^2	kilo pascal (kPa)	4.788 026 X E -2
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 X E -1
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 (kg·m^2)	4.214 011 X E -2
pound-mass/foot^3	kilogram-meter^3 (kg/m^3)	1.061 846 X E +1
rad (radiation dose absorbed)§	gray (Gy)*	1.000 000 X E -2
roentgen§	coulomb/kilogram (C/kg)	2.579 760 X E -4
shake	second (s)	1.000 000 X E -8
slug	kilogram (kg)	1.459 390 X E -1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 X E -1

*The gray (Gy) is the accepted SI unit equivalent to the energy imparted by ionizing radiation to a mass and corresponds to one joule/kilogram.

†The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

This Final Report is submitted in partial fulfillment of DNA Contract DNA001-84-C-0321, "Digital Interface Modules for Active Readout X-Ray Spectrometers." This work was sponsored as a Phase I effort under DNA's Small Business Innovative Research (SBIR) program. The work presented was performed between 5 July 1984 and 1 March 1985.

A primary mission of the Defense Nuclear Agency (DNA) is the development and operation of above-ground nuclear weapons effects (NWE) simulation facilities. These facilities provide controlled, reproducible, non-nuclear setting for the testing and evaluation of radiation threats to essential military systems and components. Evaluating such radiation threats requires a variety of specialized radiation measurement instruments to monitor and improve these radiation sources and to characterize the test-object's radiation environment. Moreover, DNA is supporting the development and deployment of digital electronic data acquisition systems (DAS) to expedite data recording and analysis.

Since 1981, the DNA has focussed on integrating all key facility instrument control, data acquisition, and data analysis tasks within facility central monitor and control computer systems. The three major objectives of this DNA Instrumentation Upgrade Program are

1. to design standard electronics hardware and computer software modules to enhance efficient use of DNA NWE simulator facilities;

2. to implement the standard designs throughout the NWE simulator community, thereby achieving uniform improvement and normalization of instrumentation capabilities; and

3. to accommodate continuing improvement of the instrumentation system based on feedback from field evaluation and on the recommendations of a government-appointed configuration management control board.

To support these objectives, an SBIR Phase I program was proposed to evaluate a design of an active readout x-ray diffraction crystal spectrometer. This new capability will allow a key Plasma Radiation Source (PRS) diagnostic instrument to be integrated into the computerized DNA Instrumentation Upgrade Program strategy.

Emitting a significant fraction of its total energy as complex series of high temperature characteristic x-ray lines, the PRS source is used for the high-fluence testing of external components such as satellite optics and sensors for material response, system generated electromagnetic pulses (EMP) and special laser weapons effects. High resolution x-ray spectrometers are a principal radiation diagnostic instrument of PRS facilities. Sponsored by the DNA, ARACOR previously has developed and deployed to the DNA's PRS facilties a standard x-ray diffraction crystal spectrometer (Model HW-1000) using photographic film as a recording media.

The complex detail within the PRS source's soft x-ray spectrum requires diagnostic instruments with high resolution. For example, a measurement spanning a photon energy range of 1 keV requires the recording of 1,000 individual signal to achieve a 1 eV resolution. Consequently, x-ray sensitive photographic film has been the preferred detector used in diffraction crystal spectrographs. Unfortunately, the handling and processing of film-recorded data are time and labor intensive operations. Often the utility and relevance of spectrograph data are significantly degraded by the delay between experiments and data analysis. Moreover, a not inconsequential fraction of the total resources available for radiation-threat experimentation is consumed by the processing and reduction of film-recorded data. The full realization of the DNA computerized DAS strategy for PRS facilities requires the development and deployment of an electronically active spectrograph detector, its associated digital hardware and instrument control/DAS software.

1.2 APPROACH.

The electro-optic radiation sensor known as the self-scanning photodiode array (SSPA) provides the basis for developing an active digital readout capability for existing spectrometers. The SSPA is a silicon-based, monolithic integrated circuit device containing a dense linear array of photosensors (1024 sensors over an active array length of 1.024 inches) and an automatic analog readout circuit. The photosensor array is sensitive to directly incident soft x-ray radiation. The device's output signal is suitable for serial analog-to-digital conversion and subsequent level storage in electronic memory. The ability of the SSPA to measure the distribution of soft x-rays along the dispersion plane of a diffraction crystal spectrograph has been demonstrated in a background radiation environment as harsh as that encountered at PRS facilities (L.N. Koppel, "Direct X-Ray Response of the Self-Scanning Photodiode Arrays," Advances in X-Ray Analysis 19). In addition, the feasibility of a microprocessor-based digital data recovery system for an SSPA-detector diffraction crystal spectrometer has been demonstrated (L.N. Koppel, "Active-Recording X-Ray Crystal Spectrometer for Laser-Induced Plasmas," Review of Scientific Instruments 47 (Sept. 1976)).

The Phase I goal was to establish the preliminary design and engineering criteria for a prototype active readout spectrometer to be built and field-evaluated during an SBIR Phase II program. To fulfill that goal, the Phase I development effort addressed three specific technical objectives:

1. to design an active readout detector package for existing DNA HW-1000 spectrometers;

2. to design a digital interface package providing two-way communication between the PRS experimentalist and the detector package; and

3. to define the PRS facility compatible-system software required by the active readout spectrometer.

1.3 PROGRAM RESULTS.

The prototype system design has met the three technical objectives. Moreover, the prototype system design has been demonstrated to satisfy additionally the needs of non-DNA facilities (Lawrence Livermore National Laboratory) and commercial concerns (x-ray source development for lithography) Following the anticipated building and evaluation of a pre-production prototype system during a Phase II program, Phase III production units will satisfy the measurement requirements throughout the DNA Nuclear Weapons Effects, special laser effects, and x-ray lithography communities, where several users have already expressed a definite interest in purchasing active readout x-ray spectrometers. Based on the results of this development effort, it is clearly feasible to automate DNA's PRS x-ray crystal spectrometer with little technical risk.

1.4 REPORT ORGANIZATION.

An overall review of the active spectrometer design approach and functional organization is presented in Section 2. Following sections present design details for the detector package (Section 3), digital interface package (Section 4), and system software (Section 5).

SECTION 2
SYSTEM DESIGN

2.1 FUNCTIONAL ORGANIZATION.

The design of the prototype system (denoted as the HM-1024 spectrometer) is schematically depicted in Figure 1. The system design can be divided into three functional sub-units.

1. **A detector package**, installable in existing HM-1000s, which includes precisely positioned concave diffraction crystal holders and two SSPAs and their analog signal processing boards mounted in an EMP shielded cage. The cage and its contents are denoted here as the sensor cassette.

2. **A digital interface package**, the heart of which is an instrument-installed digital interface module (DIM) that includes a shielded system power supply, analog-to-digital converters, array timing and control devices, data buffer, microprocessor firmware for instrument control and data transmission, shot trigger connections and fiber optic serial communication drivers. Other package components are fiber optic cables (installed between the spectrometer and the screen-room) and a screen-room signal translator box.

3. **A menu driven, instrument controlled/DAS software package** which runs on DEC RSX-11/M+ and FORTRAN 77 and requires one dedicated RS-232 port of a facility-supplied computer (CPU). This package is contained physically on a facility-compatible floppy disk.

2.2 DESIGN ISSUES.

The major spectrometer feasibility and performance design issues resolved in the Phase 1 program were the following:

1. Design of a hardware-compatible active-readout detector package that can be retrofitted into existing DNA HM-1000 spectrometers without modification.

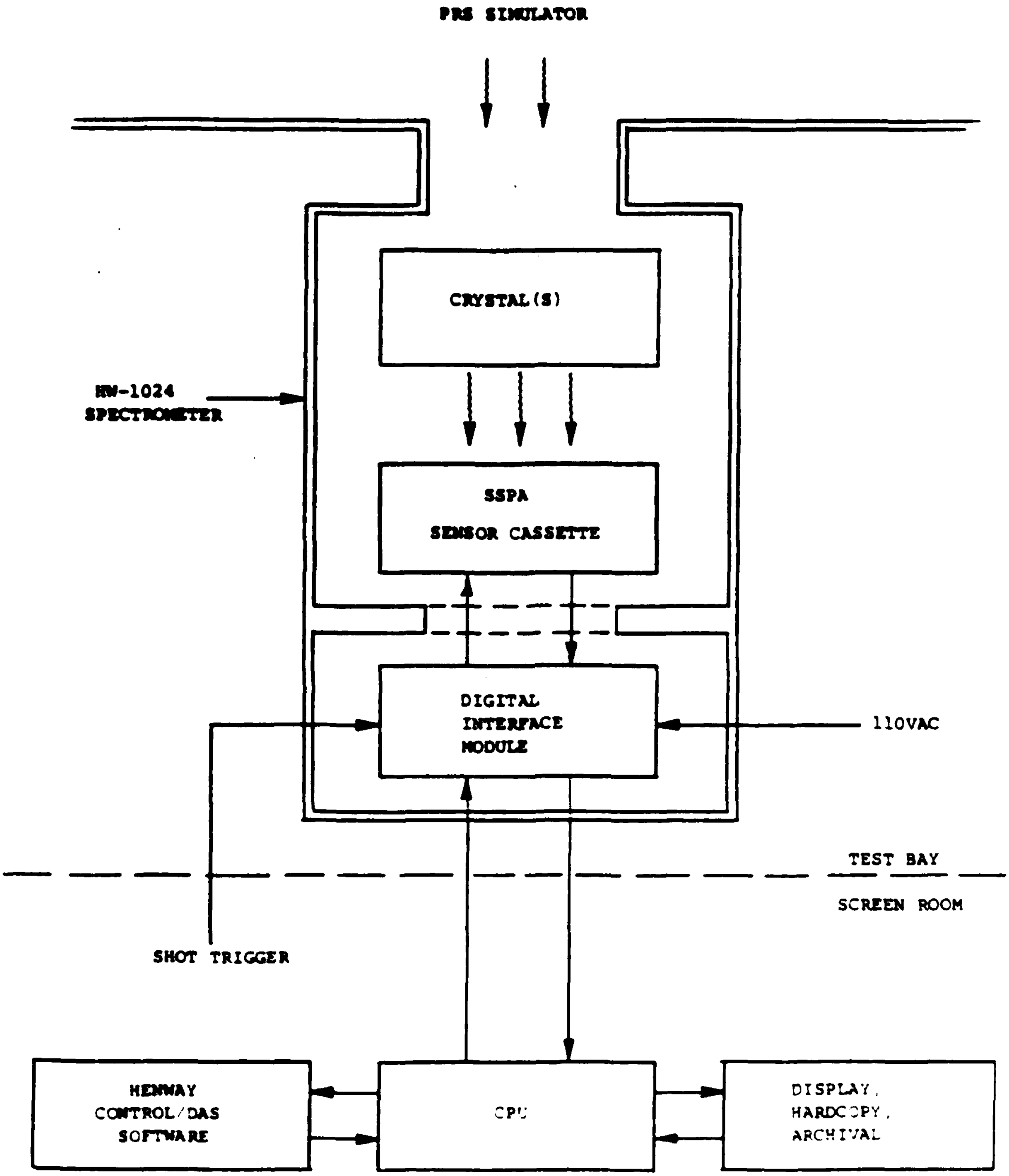

Figure 1. Active readout x-ray spectrometer system.

2. Demonstration of satisfactory PRS radiation measurement performance of the detector package from the standpoints of photon energy range coverage, spectral resolving power, and instrument sensitivity.

3. Design of a digital interface package that provides an efficient, EMP-tolerant, two-way communication link between the PRS experimentalist and the detector package and that optimizes the overall system dynamic range and signal-to-noise ratio (S/N).

4. Organization of PRS facility-compatible spectrometer control and data reduction software that provides for efficient instrument operation with minimum user intervention and that yields reduced spectrum data in a physically relevant format.

A system level approach was followed in the Phase I prototype design work to satisfy these requirements of compatibility, efficiency, and optimum performance.

2.3 DESIGN FEATURES.

The prototype active readout spectrometer system hardware design presents a straight-forward solution to the instrument compatibility issue. No modifications to the HW-1000, but merely substitution of components shown in the table below, will be required to implement the active readout capability.

HW-1000/HW-1024 HARDWARE CONFIGURATION

Existing HW-1000 Component	Replacement HW-1024 Component
1. Convex diffraction crystals	1. Concave diffraction crystals
2. Film cassette	2. Sensor cassette
3. Cassette access cover	3. DIM
4. Cassette shutter actuator	4. Blank flange

Hardware replacements between the HW-1000 and HW-1024 configurations will be reversible and will require only a small amount (about one hour) of technician time.

Measurement performance criteria for the spectrometer's detector package (containing the SSPA sensor module and specially designed x-ray diffraction crystals) were drawn from current PRS usage of the HW-1000 spectrometer. As will be demonstrated in detail in Section 3.1, the detector package provides coverage over all significant characteristic line emissions radiated by neon, nickel, krypton, and argon PRS load elements. Adaptation of coverage to other regions of interest within the photon energy range 0.5-15 keV can be accommodated. Satisfactory overall spectral resolving power is achieved in the detector package design, and the HW-1024 spectrometer will be sufficiently sensitive to measure PRS spectra at practical source-to-instrument distances.

The Phase I program's major goal, the integration of high resolution x-ray spectometry measurements into the DNA Instrument Upgrade strategy, is achieved by the design of the spectrometer's digital interface package. Set-up of the HW-1024 spectrometer for a PRS shot and subsequent acquisition of data will be effected by the two-way communication link provided by the interface package between the facility CPU and the instrument, illustrated in the spectrometer system block diagram shown in Figure 2. The spectrometer-mounted DIM will provide clock and trigger signals to the sensor cassette throughout the shot sequence, and will automatically digitize and store raw data at the instant of the shot. At the initiative of the facility CPU, a transfer of data from the DIM buffer memory to the CPU core will take palce along the package's fiber optic links. TTL and RS232 translator modules located in the screen room will interface the links to the facility CPU and trigger generators. Except for the arming of the system by the experimentalist prior to a shot, the acquisition and transfer of data will occur without user intervention.

As will be described in Section 4.1, the digital interface package offers measurement dynamic range that is superior to that provided by photographic film spectrum recording (2000:1 versus 500:1). This benefit has been achieved by layout of analog and digital components in close proximity, by isolation of the DIM power supply from EMP-induced AC line surges, and by free-running operation of the SSPA sensors and the digitizing/buffering components of the DIM. Precautions have been taken to shield system electronics from extraneous radiation and EMP interference.

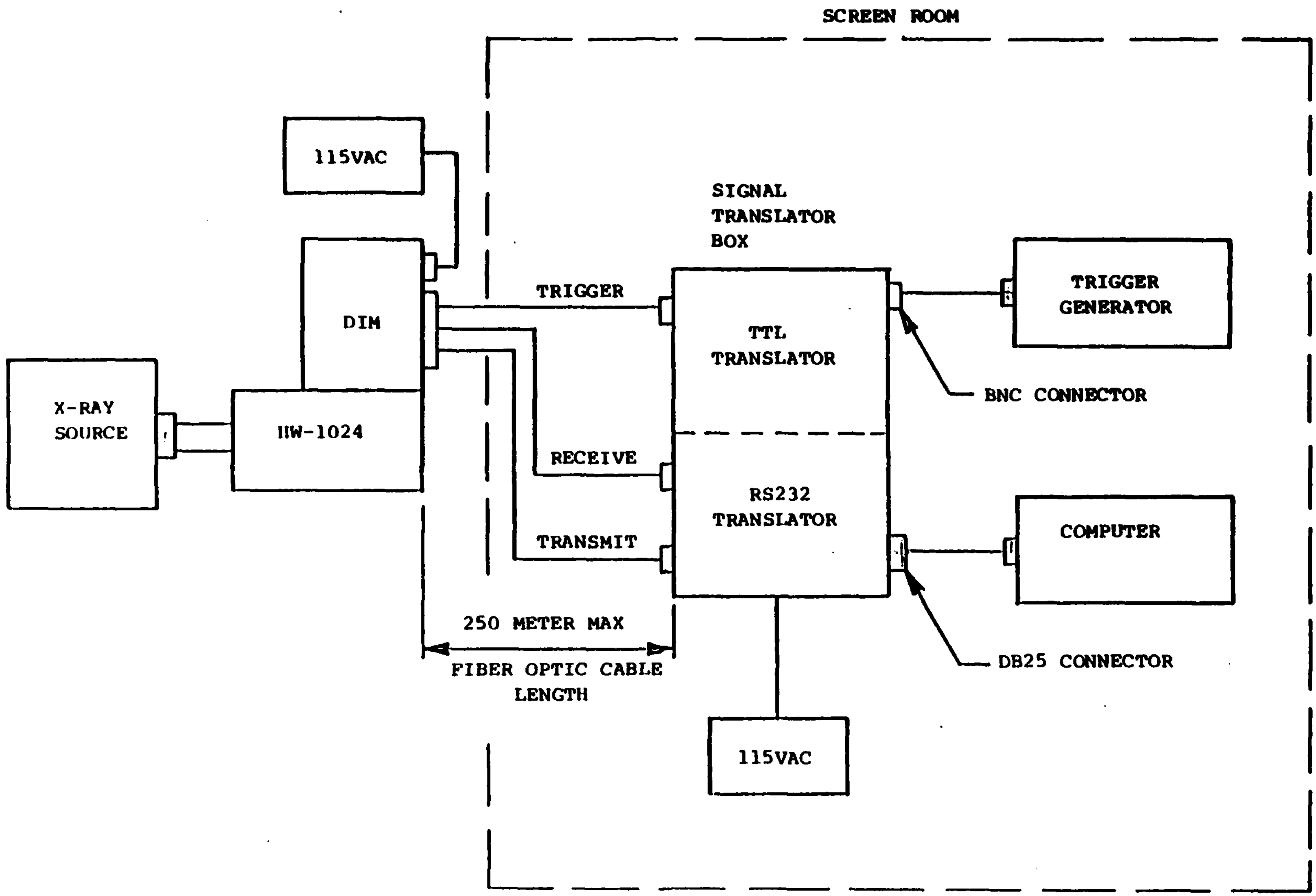

Figure 2. Spectrometer system block diagram.

The active spectrometer will be compatible with existing computer resources and software. Software will be written in Fortran 77 and will run under an RSX-11M+ operating system. Only one computer terminal, one dedicated RS232 port and a relatively small amount of RAM will be required for instrument control and data acquisition. The system software is designed to function both as a stand-alone package and as an integrated package operating in parallel with the comprehensive instrument configuration and data acquisition programs (FTDAS) residing at PRS REMOTE CPUs.

System software has been organized into two categories:

1. spectrometer testing and arming prior to a PRS shot and subsequent automatic transfer of raw data; and
2. post-shot reduction and archiving of spectrum results.

As will be described in Section 5, two software modules (TEST and ARM) will allow an experimentalist in the screen room to confirm the readiness of the instrument and to initiate the autonomous data recovery cycle. Following the shot, the module REDUCE will operate on the raw data to remove all configuration-dependent factors, yielding as a final product a spectrum in physical units (fluence in keV/keV-sphere versus photon energy in keV) for which instrumental factors are transparent. To obtain this result, the software will refer to instrument response files previously loaded by the user using the PARAM module. The reduced spectrum, in physical units, will then serve as input data for subsequent user-defined spectroscopic analysis operations. The software module ARCH will effect the archival storage of the reduced spectra at the discretion of the user.

SECTION 3
DETECTOR PACKAGE DESIGN

A necessary first step in the digital acquisition of high resolution x-ray spectroscopic data is the use of electro-optic detectors, rather than photographic film, to sense crystal-dispersed beam patterns. The detector package described here accomplishes this function. Section 3.1 is a demonstration of the feasibility of the electro-optic detector approach. Section 3.2 describes the functions and features of the detector package components.

3.1 SPECTROMETER X-RAY MEASUREMENT PERFORMANCE.

This section provides a brief review of crystal-dispersion spectroscopy techniques and then a thorough demonstration of feasible detector package performance from the standpoints of PRS measurement coverage, resolving power, and sensitivity.

3.1.1 Single Crystal X-Ray Dispersion Elements.

An x-ray diffraction crystal functions as an angle-tuned, narrow-band interference mirror for soft x rays. The tuning condition (the Bragg Law) in its most simple form is

$$E = \frac{hc}{2d} \cdot \frac{1}{\sin \theta_B}$$

θ_B is the angle of incidence of x rays on a particular crystallographic plane of the crystal;

d is the interplanar spacing for the plane of interest;

E is the centroid of a narrow band of photon energies for which the plane has particularly high specular reflectivity; and

hc is the product of Planck's Constant and the speed of light (hc = 12.39644 keV-A).

As stated above, the condition ignores refractive effects which are significant only for especially small values of θ_B and E.

While any natural single-crystal will contain a semi-infinite number of distinct crystallographic planes, x-ray spectroscopists have come to rely on a limited set of single-crystal materials and planes. The following are representative examples of materials and planes used as crystal dispersion elements.

Material	Plane	2d(A)
KAP (potassium acid phthalate)	(001)	26.62
PET (pentaerythritol)	(002)	8.726
LiF (lithium fluoride)	(200)	4.028

Samples of each of these representative materials can be readily prepared by cleaving so that the plane of interest is rigorously parallel to a large face of the sample. The noted materials can, in addition, be reliably bent elastically to conform to cylinders of several inches radius of curvature.

The spectral width ΔE of the passband centered on E is characteristically quite small owing to the high degree of crystalline perfection found in natural single-crystals. Resolving powers $E/\Delta E$ in the range from 1,000 to 3,000 are typical for the common single-crystal dispersion elements.

The common measure of the reflection efficiency of a single-crystal is the integrated reflection coefficient, R_θ, a function of E. This quantity is usually measured experimentally by observing the probability of reflection of monochromatic x-rays (at a single value of E) as a crystal sample is slewed through the appropriate Bragg angle. These data are called a "single-crystal rocking curve." The integral of the rocking curve, representing a reflection probability-bandwidth product or "throughput," is R_θ. It is converted into a probability-bandwidth product over energy space, R_E, by the transformation

$$R_E = R_\theta \frac{dE}{d\theta_B} = R_\theta \ E \ \tan\theta_B$$

3.1.2 Pulsed-Source Spectrometry.

The spectral analysis of the x rays emitted by a steady-state laboratory source is conventionally obtained by slowly rotating a single-crystal dispersion element in the source beam over a wide range of Bragg angles, the crystal rotation being tracked by an x-ray counter that intercepts the dispersed beam. The correlation between Bragg angle and dispersed energy is provided by the Bragg Law. For an x-ray source of very short duration, such as a PRS simulator, neither crystal rotation nor x-ray counting are possible. For this unconventional application, unique dispersion element geometry and dispersed-beam detection techniques are required.

The fundamental rules for the design of a pulsed-source spectrometer are the following:

(1) The single-crystal dispersion element must be cylindrically curved so that it presents a range of Bragg angles simultaneously to the beam to be analyzed; and

(2) The dispersed beam reflected by the crystal must then fall on an extended, spatially-resolving detector in such a way that a one-to-one correlation between Bragg angle and location on the detector is preserved.

The correlation between detector location and Bragg angle is called the spectrometer's dispersion solution. The attendant correlation between Bragg angle and dispersed energy again employs the Bragg Law.

Two representative crystal-detector geometries, each using a circular-cylindrical crystal, are shown in Figure 3. For the convexly-curved geometry shown in Figure 3a, an unambiguous dispersion solution is obtained for all positions of a comparatively-long detector. The concave crystal geometry shown in Figure 3b compresses the spectrum onto a shorter detector, although at the risk of losing dispersion-solution uniqueness if the detector is placed too close to the quasi-focus. In practice, the convex geometry complements the use

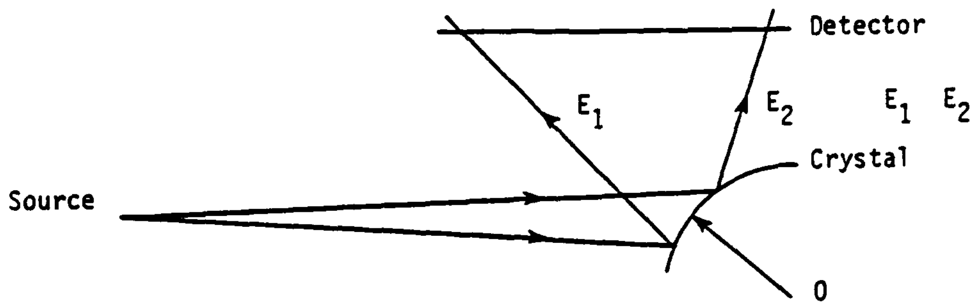

Figure 3a. Concave crystal dispersion.

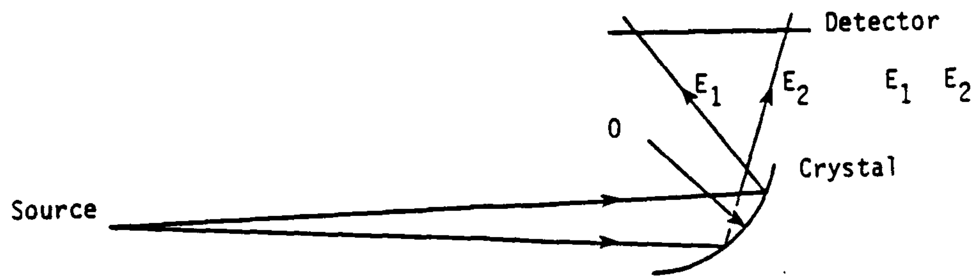

Figure 3b. Concave crystal dispersion.

Figure 3. Concave and convex crystal dispersion.

of detectors having low cost per unit length, such as photographic film. The concave geometry best exploits high-value electro-optic detectors such as the SSPA. The concave geometry also offers more subtle advantages such as near-linearity of the dispersion solution and better sensitivity uniformity.

3.1.3 PRS Measurement Requirements.

In the sections that follow, the feasibility of the active-recording crystal spectrometer, in terms of photon energy range coverage, resolving power and sensitivity, will be proven for each of the important PRS load radiations listed below. These PRS measurement requirements were developed in concert with the DNA PRS community and have been reviewed by Maxwell Laboratories, Naval Research Laboratory, and Physics International. These missions are intended to be representative of the tasks to which the new spectrometer will be applied. They are not exclusive, and application of the spectrometer to alternative missions in the 0.5 to 15 keV photon energy region appears feasible.

PRS Load Radiation	Required Photon Energy Range	Required Bragg Angle Range with Noted Crystal	
neon K-series	0.90 - 1.41 keV	KAP	19.3° - 31.2°
nickel L-series	0.88 - 1.38	KAP	19.7° - 32.0°
krypton L-series	1.60 - 2.75	KAP	9.7° - 16.9°
argon K-series	3.10 - 4.36	PET	19.0° - 27.3°

The table above demonstrates that three missions (neon, nickel and argon loads) can be satisfied by a single curved crystal design that admits radiation over the Bragg angle range $19° \leq \theta_B \leq 34°$. This design, here designated as type M (indicating its order in the HW-1000 inventory) performs the low energy, neon/nickel measurements when fitted with KAP crystal material, and the argon measurement when fitted with a PET crystal. A second crystal design, designated type N and providing Bragg angle coverage $9.75 \leq \theta_B \leq 17°$ will satisfy the krypton measurements when fitted with KAP crystal material.

The dispersion solution, resolving power, and sensitivity of the types M and N crystal designs are calculated in the following sections.

3.1.4 Dispersion Solutions.

Figure 4 illustrates a general source/crystal/detector geometry that will be used to calculate the dispersion solution of a spectrometer in which a concave crystal, illuminated by a point-like source, diffracts radiation to a linear detector. The crystal's center of curvature, the point 0, is a datum about which important distances (either given or calculated) are measured. The given parameters are defined as

- r the crystal radius of curvature;
- h the horizontal displacement of the source;
- s the vertical displacement of the source;
- f the distance below 0 that the detector plane crosses a vertical line extended through 0; and
- α the angle of inclination of the detector plane from horizontal.

The angle θ which locates positions on the crystal arc is the independent variable of the problem. The following parameters will be calculated as functions of θ;

- θ_B the Bragg angle at the crystal location identified by θ;
- E the dispersed photon energy, calculated by the Bragg Law with θ_B;
- δ the elevation angle of the source as seen from the θ-point; and
- g the location at which the dispersed x ray strikes the detector plane.

The correlation, $g(\theta)$ versus $E(\theta)$, is the required dispersion solution.

From Figure 4 it is found that

$$\tan \delta = \frac{r \cos\theta - s}{r \sin\theta + h}$$

and, therefore

$$\delta = \arctan \frac{r \cos\theta - s}{r \sin\theta + h} .$$

Parameters:

r: radius

h: source distance

s: source height

f: film pl. height

α: film pl. tilt

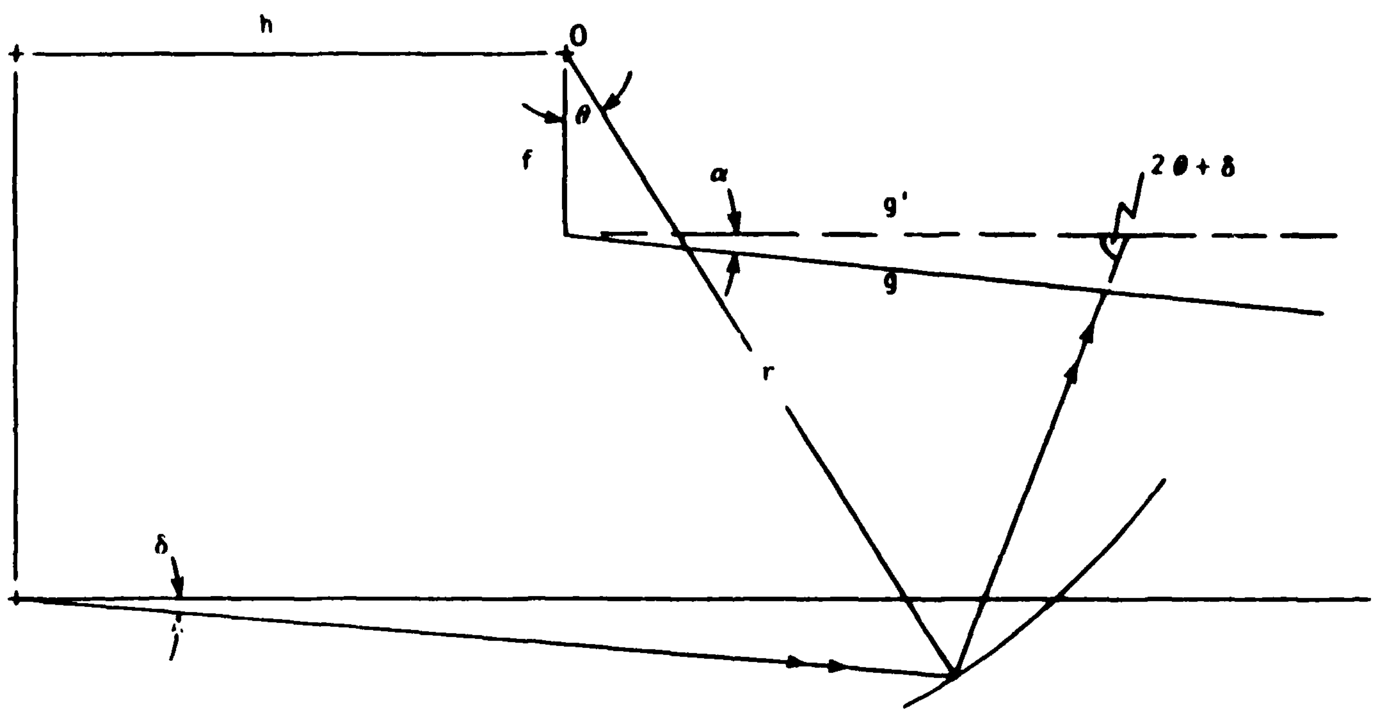

Figure 4. Concave crystal-linear detector dispersion geometry.

From the sense of measure of θ, the Bragg angle of a ray propagating horizontally is exactly θ. For a source point located a finite distance forward of 0, the Bragg angle is increased by the elevation angle of the source, and

$$\theta_B = \theta + \delta(\theta) .$$

Then

$$E(\theta) = \frac{hc}{2d} \cdot \frac{1}{\sin(\theta+\delta)} .$$

The detector plane location $g(\theta)$ must be calculated in two steps. A pseudo-detector plane, along which distances are measured by the coordinate $g'(\theta)$, is extended horizontally a distance f below 0. From Figure 4, we find

$$\tan(2\theta+\delta) = \frac{r\cos\theta - f}{g' - r\sin\theta}$$

and that

$$g'(\theta) = r\sin\theta + (r\cos\theta - f)/\tan(2\theta+\delta)$$

Next, applying the Law of Sines to the triangle that contains α, g', and g, we find that

$$\frac{g}{\sin(2\theta+\delta)} = \frac{g'}{\sin(2\theta+\delta+\alpha)}$$

and, therefore

$$g = g' \frac{\sin(2\theta+\delta)}{\sin(2\theta+\delta+\alpha)}$$

$$g(\theta) = r\sin\theta + (r\cos\theta - f)/\tan(2\theta+\delta) \frac{\sin(2\theta+\delta)}{\sin(2\theta+\delta+\alpha)}$$

The formulas above will be used to calculate feasible dispersion of the type M and N crystal designs, for source distances h in the range from 1 m to ∞.

A crystal design is specified by a list of given parameters and θ range that allow calculation of a dispersion solution. The following specifications, while not the only ones possible, have been found to yield feasible solutions:

Parameter	Type M	Type N
r	5.16"	15.86"
s	4.503"	15.004"
f	-0.87"	-5.00"
α	37°	64°
θ-range	18.45°-34.33°	9.07°-17°

For the type M crystal fitted with KAP and with h = ∞

g = 5.761", E = 1.430 keV at θ = 19.00°

g = 4.766", E = 0.830 keV at θ = 34.00°

and with h = 1 m

g = 5.780", E = 1.430 keV at θ = 18.45°

g = 4.769", E = 0.830 keV at θ = 34.33°

Hence, locating a Reticon detector of length 1.024" over a range in g from 4.766" to 5.780" (Δg = 1.024") satisfies, with a type M/KAP crystal, the neon and nickel measurement missions for sources located in the range 1 m $\le h \le \infty$.

When the type M crystal is fitted with PET material, the same span in g receives x rays in the photon energy range 2.541 $\le$ E $\le$ 4.364 keV, which satisfies the argon measurement requirements.

Considering now the type N design fitted with KAP and with h = ∞

g = 20.466", E = 2.750 keV at θ = 9.75°

g = 19.492", E = 1.593 keV at θ = 17.00°

and with h = 1 m

g = 20.515", E = 2.750 keV at θ = 9.07°

g = 19.492:, E = 1.593 keV at θ = 17.00°

Hence, locating a 1.024" long Reticon detector over the span

$$\Delta g = 20.515" - 19.492" = 1.023"$$

satisfies, with the type N/KAP crystal, the krypton measurement.

From the standpoint of dispersion, the two crystal designs specified above satisfy the four important PRS load measurements described in Section 3.1.3 for any source-to-spectrometer distance in the range from 1 m to ∞ .

3.1.5 Detector-Limited Resolving Power.

When dealing with a spectrometer detector of finite spatial resolution such as the Reticon detector, it must be determined if the spectrometer's overall resolving power is unacceptably degraded by the finite sensor element width (0.001" for the Reticon RL1024S detector). This is done by calculating the increment in photon energy dE that maps into a sensor width dg. The required formulas are given below:

$$\frac{dE}{dg} = \frac{dE}{d\theta} \Big/ \frac{dg}{d\theta}$$

where

$$\frac{dE}{d\theta} = -E \cot(\theta + \delta) \cdot \left(1 + \frac{d\delta}{d\theta}\right)$$

$$\frac{dg}{d\theta} = \frac{dg'}{d\theta} \quad \frac{\sin(2\theta + \delta)}{\sin(2\theta + \delta + \alpha)} + g' \frac{d}{d\theta} [\text{sine term}]$$

with

$$\frac{dg'}{d\theta} = r \cos\theta - \frac{r \sin\theta}{\tan(2\theta + \delta)} - \frac{r \cos\theta - f}{\sin^2(2\theta + \delta)} \left(2 + \frac{d\delta}{d\theta}\right) ,$$

$$\frac{d\delta}{d\theta} \left[\text{sine term}\right] = \frac{2 + \frac{d\delta}{d\theta}}{\sin(2\theta + \delta + \alpha)} \quad \cos(2\theta + \delta) - \frac{\sin(2\theta + \delta)}{\tan(2\theta + \delta + \alpha)} ,$$

TABLE 1 Type III crystal, parallel beam dispersion

E	θ	ψ	$\frac{d\psi}{d\theta}$	$\frac{dE}{d\psi}$	T_{Be}	$T_{Kimfoil}$	R	R_θ	S	V/F
(keV)	(°)	(°)	$\left(\frac{°}{radian}\right)$	$\left(\frac{eV}{mil}\right)$	(0.5 mil)	(2 μm)	(V/keV)	(Radians)	(keV·cm²)	$\left(\frac{volts}{keV/keV\text{-}cm^2}\right)$
0.833	34.00	4.766	-2.103	0.587	0.109	0.375	3.29×10^{-6}	4.35×10^{-5}	4.75×10^{-8}	6.39×10^{-15}
0.85	33.22	4.796	-2.254	0.576	0.123	0.394	3.54×10^{-6}	4.44×10^{-5}	4.66×10^{-8}	7.99×10^{-15}
0.90	31.16	4.884	-2.664	0.559	0.167	0.448	4.28×10^{-6}	4.72×10^{-5}	4.54×10^{-8}	1.45×10^{-14}
0.95	29.35	4.974	-3.043	0.555	0.215	0.499	4.99×10^{-6}	4.99×10^{-5}	4.52×10^{-8}	2.42×10^{-14}
1.00	27.75	5.064	-3.398	0.559	0.265	0.545	5.66×10^{-6}	5.25×10^{-5}	4.55×10^{-8}	3.72×10^{-14}
1.05	26.33	5.153	-3.733	0.568	0.314	0.587	6.29×10^{-6}	5.50×10^{-5}	4.61×10^{-8}	5.34×10^{-14}
1.10	25.05	5.240	-4.055	0.580	0.363	0.625	6.86×10^{-6}	5.74×10^{-5}	4.69×10^{-8}	7.30×10^{-14}
1.15	23.89	5.325	-4.365	0.595	0.410	0.659	7.39×10^{-6}	5.97×10^{-5}	4.79×10^{-8}	9.56×10^{-14}
1.20	22.83	5.408	-4.667	0.611	0.455	0.690	7.85×10^{-6}	6.19×10^{-5}	4.88×10^{-8}	1.20×10^{-13}
1.25	21.87	5.488	-4.956	0.628	0.497	0.718	8.27×10^{-6}	6.40×10^{-5}	4.99×10^{-8}	1.47×10^{-13}
1.30	20.00	5.567	-5.237	0.647	0.536	0.742	8.63×10^{-6}	6.60×10^{-5}	5.09×10^{-8}	1.75×10^{-13}
1.35	20.18	5.643	-5.510	0.667	0.573	0.765	8.95×10^{-6}	6.79×10^{-5}	5.20×10^{-8}	2.04×10^{-13}
1.40	19.43	5.717	-5.776	0.687	0.606	0.785	9.22×10^{-6}	6.97×10^{-5}	5.30×10^{-8}	2.32×10^{-13}
1.430	19.00	5.761	-5.935	0.700	0.625	0.796	9.36×10^{-6}	7.07×10^{-5}	5.36×10^{-3}	2.50×10^{-13}

TABLE 2 Type NI crystal, parallel beam dispersion

E	θ	ψ	$\frac{dy}{d\theta}$	$\frac{dE}{dy}$	T_{Al}*	T_{Be}	$T_{Kimfoil}$	R	R_θ	S	V/F
(keV)	(°)	(°)	$\left(\frac{"}{radian}\right)$	$\left(\frac{eV}{mil}\right)$	(2 μm)	(0.5 mil)	(2 μm)	(V/keV)	(Radians)	(keV-cm²)	$\left(\frac{volts}{keV/keV\text{-}cm^2}\right)$
1.593	17.00	19.492	-4.848	1.075	0.113	0.712	0.845	9.92×10^{-6}	7.57×10^{-5}	2.43×10^{-7}	1.64×10^{-13}
1.6	16.92	19.499	-4.908	1.072	0.116	0.715	0.847	9.93×10^{-6}	7.59×10^{-5}	2.42×10^{-7}	1.69×10^{-13}
1.7	15.90	19.593	-5.681	1.051	0.155	0.756	0.869	10.11×10^{-6}	7.83×10^{-5}	2.30×10^{-7}	2.37×10^{-13}
1.8	14.99	19.689	-6.379	1.054	0.198	0.791	0.888	10.19×10^{-6}	8.04×10^{-5}	2.24×10^{-7}	3.17×10^{-13}
1.9	14.19	19.783	-7.002	1.073	0.243	0.820	0.903	8.34×10^{-6}	8.71×10^{-5}	2.21×10^{-7}	3.30×10^{-13}
2.0	13.46	19.875	-7.580	1.102	0.288	0.844	0.916	8.87×10^{-6}	8.34×10^{-5}	2.19×10^{-7}	4.32×10^{-13}
2.1	12.81	19.964	-8.103	1.140	0.332	0.864	0.927	9.35×10^{-6}	8.41×10^{-5}	2.18×10^{-7}	5.41×10^{-13}
2.2	12.22	20.050	-8.587	1.183	0.376	0.881	0.936	9.78×10^{-6}	8.48×10^{-5}	2.17×10^{-7}	6.58×10^{-13}
2.3	11.68	20.133	-9.038	1.231	0.418	0.896	0.944	10.15×10^{-6}	8.49×10^{-5}	2.16×10^{-7}	7.73×10^{-13}
2.4	11.19	20.212	-9.455	1.283	0.457	0.908	0.950	10.48×10^{-6}	8.45×10^{-5}	2.15×10^{-7}	8.87×10^{-13}
2.5	10.74	20.288	-9.844	1.339	0.495	0.919	0.956	10.76×10^{-6}	8.38×10^{-5}	2.14×10^{-7}	1.00×10^{-12}
2.6	10.32	20.362	-10.213	1.398	0.530	0.928	0.960	11.01×10^{-6}	8.27×10^{-5}	2.12×10^{-7}	1.10×10^{-12}
2.7	9.93	20.432	-10.562	1.460	0.562	0.936	0.965	11.23×10^{-6}	8.12×10^{-5}	2.09×10^{-7}	1.19×10^{-12}
2.75	9.75	20.466	-10.725	1.492	0.578	0.939	0.966	11.32×10^{-6}	8.03×10^{-5}	2.07×10^{-7}	1.23×10^{-12}

* An additional 2 μm-thick aluminum filter has been added to the Type NI design.

TABLE 3. Type H2 crystal, parallel beam dispersion

E	θ	g	$\frac{dg}{d\theta}$	$\frac{dE}{dg}$	T_{Be} *	R	R_θ	S	V/F
(keV)	(°)	(")	$\left(\frac{"}{radian}\right)$	$\left(\frac{eV}{mil}\right)$	(0.5 mil)	(V/keV)	(Radians)	(keV-cm^2)	$\left(\frac{volts}{keV/keV\text{-}cm^2}\right)$
2.541	34.00	4.766	-2.103	1.791	0.923	10.87×10^{-6}	12.8×10^{-5}	4.27×10^{-7}	4.28×10^{-12}
2.6	33.12	4.800	-2.274	1.753	0.928	11.01×10^{-6}	12.9×10^{-5}	4.11×10^{-7}	4.20×10^{-12}
2.7	31.75	4.857	-2.545	1.714	0.936	11.23×10^{-6}	13.1×10^{-5}	3.93×10^{-7}	4.13×10^{-12}
2.8	30.49	4.916	-2.802	1.697	0.943	11.41×10^{-6}	13.3×10^{-5}	3.81×10^{-7}	4.10×10^{-12}
2.9	29.33	4.975	-3.047	1.694	0.949	11.57×10^{-6}	13.6×10^{-5}	3.76×10^{-7}	4.13×10^{-12}
3.0	28.26	5.034	-3.282	1.700	0.954	11.69×10^{-6}	13.9×10^{-5}	3.72×10^{-7}	4.15×10^{-12}
3.1	27.28	5.092	-3.507	1.714	0.958	11.80×10^{-6}	14.3×10^{-5}	3.74×10^{-7}	4.23×10^{-12}
3.2	26.36	5.151	-3.726	1.733	0.962	11.88×10^{-6}	14.6×10^{-5}	3.74×10^{-7}	4.27×10^{-12}
3.3	25.50	5.208	-3.940	1.756	0.966	11.95×10^{-6}	15.0×10^{-5}	3.77×10^{-7}	4.35×10^{-12}
3.4	24.70	5.264	-4.147	1.783	0.969	11.99×10^{-6}	15.5×10^{-5}	3.84×10^{-7}	4.46×10^{-12}
3.5	23.95	5.320	-4.349	1.812	0.972	12.02×10^{-6}	15.9×10^{-5}	3.89×10^{-7}	4.54×10^{-12}
3.6	23.24	5.375	-4.548	1.843	0.974	12.04×10^{-6}	16.4×10^{-5}	3.97×10^{-7}	4.66×10^{-12}
3.7	22.58	5.429	-4.740	1.877	0.976	12.04×10^{-6}	16.9×10^{-5}	4.05×10^{-7}	4.76×10^{-12}
3.8	21.95	5.482	-4.931	1.912	0.978	12.03×10^{-6}	17.5×10^{-5}	4.16×10^{-7}	4.89×10^{-12}
3.9	21.37	5.534	-5.117	1.949	0.980	12.00×10^{-6}	18.1×10^{-5}	4.28×10^{-7}	5.03×10^{-12}
4.0	20.80	5.584	-5.300	1.987	0.982	11.97×10^{-6}	18.7×10^{-5}	4.42×10^{-7}	5.20×10^{-12}
4.1	20.27	5.634	-5.479	2.026	0.983	11.92×10^{-6}	19.3×10^{-5}	4.51×10^{-7}	5.28×10^{-12}
4.2	19.77	5.683	-5.654	2.067	0.984	11.87×10^{-6}	20.0×10^{-5}	4.65×10^{-7}	5.43×10^{-12}
4.3	19.29	5.731	-5.828	2.108	0.985	11.80×10^{-6}	20.7×10^{-5}	4.80×10^{-7}	5.58×10^{-12}
4.364	19.00	5.761	-5.935	2.135	0.986	11.76×10^{-6}	21.1×10^{-5}	4.88×10^{-7}	5.66×10^{-12}

* Kimfoil transmissions all exceed 96% and have been ignored.

and

$$\frac{d\delta}{d\theta} = - \frac{r \sin \theta + r \cos \theta \tan \delta}{(1 + \tan^2 \delta)(r \sin \theta + h)} .$$

These formulas have been used to calculate the values of $\frac{dE}{dg}$ listed in Tables 1 through 3 pertaining to the type M/KAP, type M/PET, and type N/KAP designs for the lowest-dispersion limiting case of $h = \infty$. The worst-case spectral resolution for each design is listed below:

Crystal	Worst-Case Resolving Power	Worst-Case Spectral Resolution
Type M/KAP	0.59 eV/pixel at 0.833 keV	$E/\Delta E = 1412$
Type M/PET	1.79 eV/pixel at 2.541 keV	$E/\Delta E = 1420$
Type N/KAP	1.08 eV/pixel at 1.593 keV	$E/\Delta E = 1475$

These resolutions are comparable to those due to crystal diffraction profile widths and are satisfactory for PRS measurement purposes. Hence, the crystal designs are feasible from the standpoint of detector-limited resolving power.

3.1.6 Spectrometer Sensitivity.

It is assumed that a 2 μm-thick Kimfoil film will be used as a debris shield within the spectrometer and that a light-tight 0.5 mil beryllium foil will be placed over the x-ray-sensitive Reticon detector. We define the spectrometer sensitivity $S \left\{ \text{keV-cm}^2 \right\}$ to be the quantity that, when multiplied by a source fluence $F \left\{ \frac{\text{keV}}{\text{keV-cm}^2} \right\}$, debris and light-tight foil transmissions T_{KIM} and T_{Be} and Reticon x-ray sensitivity $R \left\{ \frac{\text{volts}}{\text{keV}} \right\}$ yields a signal voltage $V \left\{ \text{volts} \right\}$. That is

$$V \left\{ \text{volts} \right\} = F \left\{ \frac{\text{keV}}{\text{keV - cm}^2} \right\} \cdot S \left\{ \text{keV - cm}^2 \right\} \cdot T_{KIM} \cdot T_{Be} \cdot R \left\{ \frac{\text{volts}}{\text{keV}} \right\} .$$

From this definition, the spectrometer sensitivity S is the product of the crystal's energy-space probability-bandwidth product R_E (defined in Section 3.1.1) and the cross sectional area of beam that exposes one Reticon sensor element.

The quantity

$$R_E = R_\theta \cdot \frac{dE}{d\,\theta_B} = R_\theta \cdot E/\tan\theta_B$$

where R_θ is the commonly tabulated integrated reflection coefficient.

A measure of aperture height is $a = r\cos\theta$, and $\frac{da}{d\theta} = -r\sin\theta$. Thus, the area of beam at the spectrometer aperture that exposes a unit area of detector is

$$\frac{da}{dg} = \frac{da}{d\theta}\Big/\frac{dg}{d\theta} = -r\sin\theta\Big/\frac{dg}{d\theta}$$

For a Reticon sensor area A_d = 0.001" x 0.1" = $6.45 \times 10^{-4}\text{cm}^2$, we then have

$$S = R_E \cdot \frac{da}{dg} \cdot A_d$$

$$= -6.45 \times 10^{-4}\,(R_\theta \cdot r\cos\theta)\Big/\frac{dg}{d\theta}\ \left\{\text{keV-cm}^2\right\}.$$

The formulas given in Section 3.1.5 are used to calculate the different $\frac{dg}{d\theta}$.
The R_θ data of Gilfrich, et al., (Applied Spectroscopy 29, No. 4, 1975, pp 322-6) have been used to obtain the following least-square binomial fits:

for KAP, $R_\theta \times 10^5 = -1.838 + 9.093 \cdot E - 2.002 \cdot E^2$

for PET, $R_\theta \times 10^5 = 17.906 - 5.882 \cdot E + 1.518 \cdot E^2$.

Compilations of $\frac{dg}{d\theta}$, R_θ and S are given in Tables 1 through 3 for the three crystal configurations.

3.1.7 Overall Spectrometer Response.

The only additional factors needed to calculate the spectrometer response V/F are the filter transmissions and the Reticon x-ray sensitivity. The x-ray absorption coefficients tabulated by McMasters, et al., (LLNL document UCRL-50174) have been used to calculate the values of T_{KIM} and T_{Be} listed in Tables 1 through 3.

The Reticon x-ray sensitivity calibration published by Koppel (Advanced X-Ray Analysis 19, 1976, pp 587-96) is formulated as

$$R = C_E \cdot V_{FS} \cdot T^{SiO_2} \; A_{dl}^{Si} + T_{dl}^{Si} \cdot \frac{\mu^{Si} \cdot L_o}{\mu^{Si} \cdot L_o + 1} \; f_x$$

where

C_E is the signal charge created by a unit of absorbed x-ray energy, $C_E = 1.602 \times 10^{-19}$ coul/0.00355 keV;

V_{FS} is the ratio of Reticon full-scale voltage to full-scale signal charge, $V_{FS} = 5$ volts/14×10^{-12} coul;

T^{SiO_2} is the transmission of a 1.07 μm-thick SiO_2 passivation layer;

A_{dl}^{Si} is the absorption of a 3.8 μm-thick silicon depletion layer;

$\frac{\mu^{Si} L_o}{\mu^{Si} L_o + 1}$ is the diffusion region charge collection probability for a diffusion length $L_o = 57.9$ μm and silicon x-ray absorption coefficient μ^{Si};

T_{dl}^{Si} is the transmission of the silicon depletion layer; and

f_x is the observed deficiency of the model, $f_x = 1 - 0.119 = 0.881$.

Again the x-ray coefficients published by McMasters were used to calculate the values of R and of overall response V/F listed in Tables 1 through 3.

3.1.8 Measurement Feasibility.

The tabulated values of V/F have been used to examine the feasibility of the proposed active-recording spectrometer from the standpoint of sensitivity. The PRS loads described in Section 3.1.3 each have been observed to radiate fluences F in the ranges listed below. For each load it is possible (using the V/F data presented in Tables 1 through 3) to calculate a spectrometer-to-source distance h which will cause upper-limit fluences to generate a full-scale Reticon signal and lower-limit fluences to generate one-thousandth full-scale signals. These distances, listed below, are quite practical for instrument deployment at PRS facilities, demonstrating the feasibility of the active-recording spectrometer on the basis of sensitivity.

PRS Load Radiation	Observed Fluence Range, F	Corresponding Spectrometer-to-Source Distance, h
neon K-series	$3x10^{16}$ - $3x10^{19}$	1.4 meter
nickel L-series	$8x10^{16}$ - $8x10^{19}$	2.2
krypton L-series	$8x10^{16}$ - $8x10^{19}$	3.9
argon K-series	$2x10^{16}$ - $2x10^{19}$	3.7

Figure 5 provides an example of the coverage provided over a nominal argon PRS spectrum when the spectrometer is deployed 3.7 meters from the plasma and fitted with a type M/PET crystal. All significant source radiation is contained within the measurement envelope of the active-recording spectrometer in this configuration.

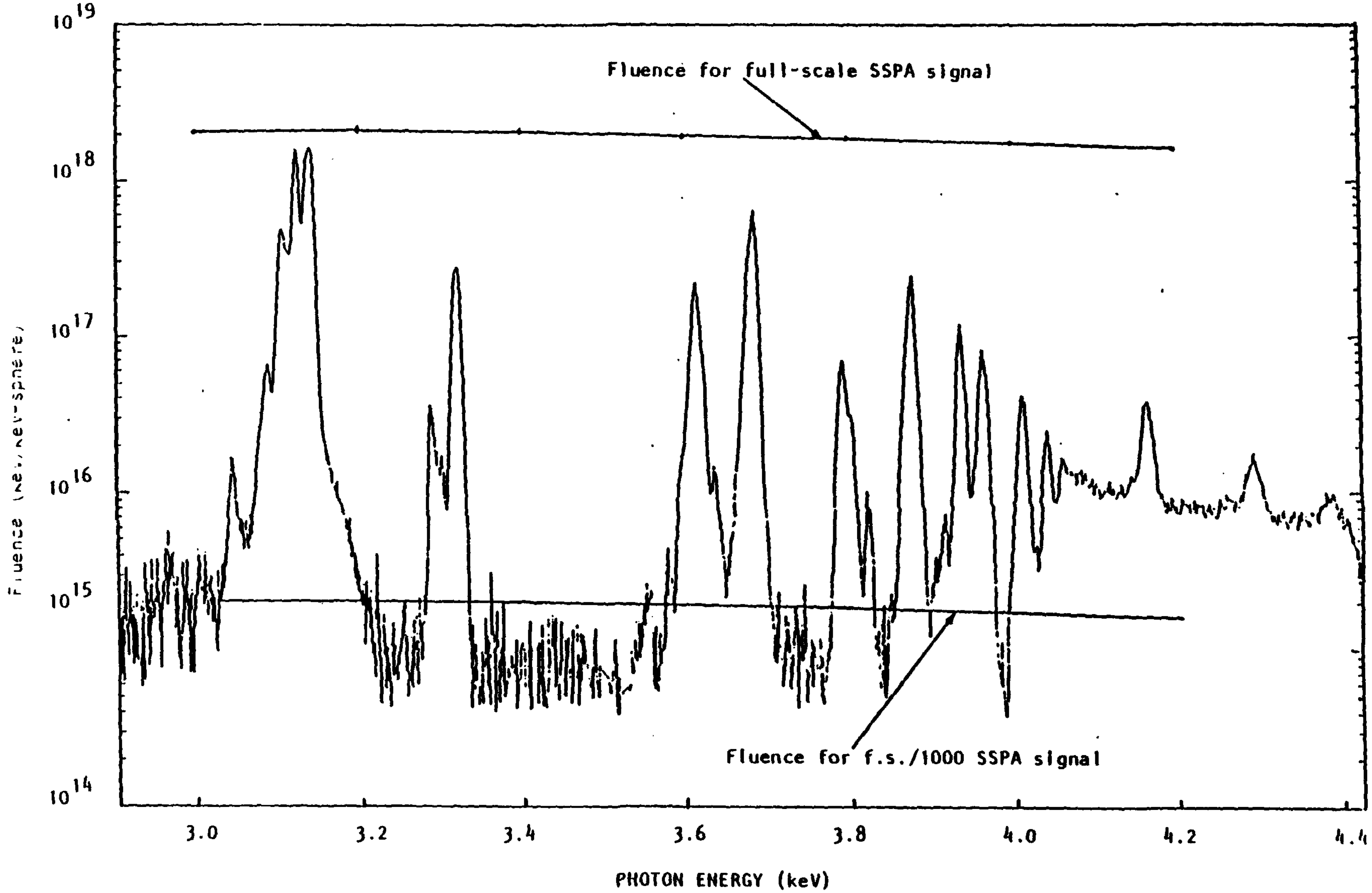

Figure 5. PRS argon load spectrum and type M/PET sensitivity for h=3.7 m.

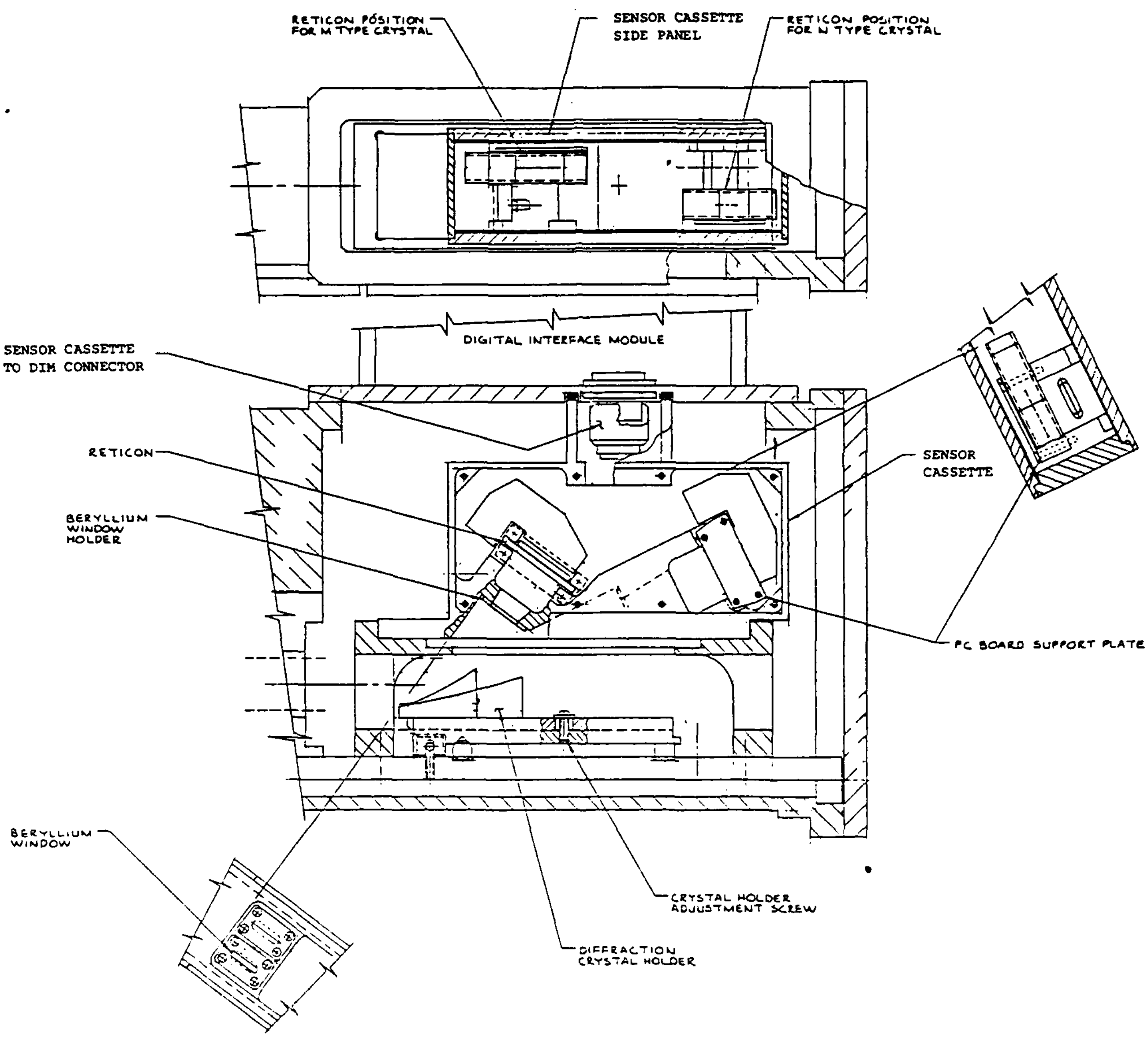

Figure 6. Layout design of the detector package.

3.2 DETECTOR PACKAGE HARDWARE DESIGN.

The components of the detector package, shown schematically in Figure 6, are the following:

1. a pair of specially-designed diffraction crystal holders mounted to a common baseplate; and
2. a sensor cassette containing two SSPA detectors and associated analog signal electronics.

The design features of each of these components are described in the following sections.

3.2.1 Diffraction Crystal Holders.

Each diffraction crystal holder will consist of a base-piece and a matching clamp. These pieces will be carefully machined to retain a thin section of single-crystal material in one of the two concave-circular-cylindrical geometries specified in Section 3.1.4 as the type M or type N designs. For example, the type M clamp will have a radius of 5.16" and will be slotted to admit rays to the crystal over the angular range 18.5° to 34.3°. Correspondingly, the type N clamp will have a radius of 15.85" and will admit rays over the range 9.1° to 17.0°. For both holders, the width of exposed crystal (i.e., the width of the clamp slot) will be 0.25", and the overall clamp width will be 0.50".

Either one or two crystal holders will be deployed in the spectrometer by mounting onto a removable baseplate. Two holders of identical type or of mixed type will be accommodated on the baseplate, affording the experimentalist considerable versatility in measurement-directed configuration of the instrument.

The crystal holder baseplate will be fitted with a pair of miniature translation stages to which the crystal holders will be attached. The stages, actuated by accessible eccentric-motion adjustment screws, will allow precise crystal/SSPA detector co-alignment to be obtained.

3.2.2 Sensor Cassette.

The sensor cassette housing, tightly sealed to prevent the transmission of stray electromagnetic radiation to the contained active electronics, will be machined to mount to the cassette base of the existing HW-1000 spectrographs. Apertures in the housing that admit crystal-diffracted x rays to the SSPA detectors will be sealed with 0.5 mil-thick beryllium windows or with blank flanges to preserve EMI shielding. Radiation shielding of the active MOS electronics on the SSPA substrate will be provided by a 0.02"-thick tantalum shield. This tantalum shield will contain a 0.1" x 1.0" central slit that allows only diffracted x-ray exposure of the SSPA diode sensing area.

The cassette housing will provide four internal mounting stations for two printed circuit boards that each support an SSPA detector and its associated charge amplifiers. Two side-by-side forward mounting stations will complement diffraction crystals of the type M design. Two side-by-side rear stations will complement the type N design. The assignment of the two SSPA/electronics boards to the four available mounting stations will be done at the discretion of the PRS experimentalist.

Each detector printed circuit board, shown schematically in Figure 6, will accommodate a Reticon RL1024S SSPA detector and two current-integrating charge amplifiers. The x-ray-sensitive portion of this SSPA is a linear array of 1024 sensor elements, each 1 mil wide and 0.1" long, and spaced on 1 mil centers. A pair of analog shift registers built into the SSPA sequentially connect the sensor elements to one of two video output lines in an interleaved fashion. The sensor current pulses appearing on the video lines will be integrated and amplified by a pair of adjacent amplifiers constructed in the manner suggested by R. W. Simpson ("Noise in Large-Aperture Self-Scanned Diode Arrays," Rev. Sci. Instrum 50, June 1979). Clock and timing signals will be distributed commonly to the two SSPA detectors and their associated amplifiers.

SECTION 4

DIGITAL INTERFACE PACKAGE

4.1 DIGITAL INTERFACE PACKAGE DESIGN REQUIREMENTS

This section decribes the operating sequence of the instrument control and data recovery electronics, and then considers estimation of spectrometer dynamic range and mitigation of interference effects.

4.1.1 Operating Sequence.

The purpose of the digital interface package is to provide the crucial hardware link that allows system software to control and recover data from a pair of Reticon x-ray sensitive self scanning photodiode arrays (SSPA) contained in the sensor cassette. The recovered data is transmitted to the host computer via a fiber optic link. Communication with the host computer is in ASCII 7-bit code.

The data from each 1024 element array consists of a background scan followed by a scan of the flash x-ray spectra. The taking of data is initiated by a trigger signal coincident with the x-ray event. The purpose of the background data is to allow for correction of the shot data for array leakage current and for fixed pattern noise. The data is held in a circular digital buffer. At the request of the host computer, the transmission of data to the host computer may begin any time after the shot. A uniformity correction table, accessible by the host computer, is provided to correct for the non-uniform pixel-to-pixel response of the SSPA. Uniformity correction has little effect on the noise of the measurement.

4.1.2 Dynamic Range Estimation.

Consistent with cost and size constraints, the design of the digital interface package preserves the intrinsic signal-to-noise ratio and dynamic range of the SSPA detector. Noise-generating factors such as SSPA leakage current, charge amplifier noise, analog-to-digital converter quantization and random noise, SSPA clock and supply noise, and electromagnetic interference are all estimable.

For strong spectral lines the instrument will be primarily limited by the noise in the number of x-ray photons collected (shot noise limited - approximately 7000 to 1 peak signal to r.m.s. noise). For most work the effects of temperature on the SSPA and other electronics will be more significant to the repeatability of strong spectral lines than shot noise.

For very weak spectral lines the noise of the SSPA, charge amplifier, and analog-to-digital converter will play a limiting role. At a temperature of 25°C, levels from various sources are estimated as follows:

SSPA	1200 electrons
charge amp	1100 electrons
analog-to-digital converter	1600 electrons
	---------------
r.m.s. total	2300 electrons

For most measurements a background correction will be made. The uncertainty of the background is the same as above; thus, the final measurement has a noise of

measurement	2300 electrons
background correction	2300 electrons
	---------------
r.m.s. total	3200 electrons

This gives a saturated spectral line to r.m.s. noise of about 20,000 to 1. For single shot spectra looked at without advanced statistical techniques, this should yield a usable dynamic range of about 2,000 to 1. X-ray sensitivity and resolution are discussed elsewhere in this report. The much greater dynamic range of the SSPA compared to film should provide more detailed spectra and should reduce the number of "missed" shots due to under or over exposure.

Since the leakage current of the SSPA is a strong function of temperature, a temperature sensor is included in the sensor cassette to measure the temperature of the SSPAs. Baseline shifts which change over time at constant temperature or do not correlate with temperature indicate a malfunction in the instrument. Other gains and offsets are a much lesser function of temperature.

4.1.3 Interference Mitigation.

The digital electronics package is designed to operate satisfactorily in a harsh electromagnetic interference (EMI) environment generated by a pulsed-power machine. The signals generated by the SSPAs are large in number (1024 per SSPA), yet very small in magnitude (resolution of about 1,000 electrons required). The peak power of the pulse power machine is very high (about 2 terawatts) with a fast rise time (on the order of 10 nanoseconds). Thus, strong induction fields can be expected near the machine where the spectrograph is operated (about 2 meters from the plasma source). Further, large currents can be expected in the structure of the machine causing conducted interference to occur. Interference can enter the instrument via the power line, via the diagnostic port, via the signal connections and by radiation and induction to the outer case of the instrument. Because the nature of the pulsed-power EMI environment is poorly understood, a conservative approach to shielding, filtering, and isolation has been adopted.

Radiation and EMI shielding is provided by the thick aluminum walls of the electronics enclosures. All signals to and from the instrument are via three fiber optic cables. The fiber optic cables are terminated in the screen room at the electrical interface translator box. The use of fiber optics completely eliminates the possibility of ground loops and represents only a very small breach of the instrument's EMI shield.

Power to the instrument is 115 VAC 50/60 Hz. The power supply is highly isolated with extensive voltage spike protection.

4.1.4 System Specifications.

DETECTOR

Number of detectors: 2 each

Detector positioning: 2 discrete user-selectable positions

Operating temperature: room temperature

Type of detector: self-scanned photodiode array (Reticon RL1024S) without window

Number of elements: 1024

Element spacing and size: 25 micrometer spacing with 2.5 mm aperture

Uniformity of response (uncorrected): specified by Reticon as ±10%

Uniformity of response (corrected): estimated at ±1%

Effective dark signal: estimated as 0.4% typical of saturated signal at 25°C; doubles every 8°C increase in temperature

ANALOG-TO-DIGITAL CONVERSION

Number of ADC bits: no missing codes at 14 bits; 16 bits total

Number of ADCs: 2 per detector; 4 total

Sampling rate per ADC: 47.6 kHz

Effective sampling rate: 95.2 kHz per detector

Total sampling time: 10.9 ms total for both detectors

Sampling linearity: 0.1% of full scale plus detector nonlinearity

Sampling, amplifier, and detector noises: low enough to achieve a dynamic range of 10,000 to 1 at 25°C (saturated signal to r.m.s. noise) after uniformity and background correction

Calibration stability: zero ±0.02% of F. S. per 1°C exclusive of the detector

Detector temperature: A temperature transducer is attached to the detector PC board; the temperature is digitally readout via a 4 and 1/2 digit analog-to-digital converter with a resolution of 0.1°C.

DIGITAL INTERFACE MODULE (DIM)

Control microprocessor: 8085

Program ROM: 16K bytes of EPROM (4K for uniformity correction tables; 4K for background correction tables; 8K for program)

Program RAM: 16K bytes static RAM

Data memory: dual port; 8K byte static RAM

Buffer size and arrangement: Two (2) each of 1024 samples per detector arranged as preshot background and shot data

Serial interface: Two (2) fiber optic cables (Hewlett Packard HFBR-3000 series glass fiber cable with SMA type A style connectors) not exceeding 250 meters forming a full duplex asynchronous serial data path operating at 9600 baud (factor settable from 110 baud to 38.4K baud); X-ON/X-OFF protocol used to control data flow; separate fiber optic to RS232C level converter will be provided for computer end of data link; hardware handshaking such as CTS (clear to send) will not be supported.

Arming requirements: via the serial link

Triggering requirements: triggering to occur coincidental with (±1 microsecond) the x-ray event via fiber optic cable (same HP series as above). A positive or negative pulse (switch selectable) of 800 mV or more into 50 ohms will drive an electrical to fiber optic translator; the pulse is to have a rise time of less than 10 nanaoseconds and a minimum duration of 100 nanoseconds.

SOFTWARE INTERFACE

Serial ASCII: ASCII codes hex 20 through hex 77 plus hex 11 (X-ON) and hex 13 (X-OFF)

Commands to module: arm trigger; disarm trigger; software trigger; send status; send uniformity table n; send background table n; send detector data n; send temperature; interrupt.

Status information: power on; armed; data available; data remaining.

Data format: numbers represented as ASCII integer decimal strings with leading zeros. Data block sent with checksum (to be defined).

POWER

Operating: 115 ±12 VAC, 50-60 Hz, 0.5 A.

Standby: same as operating.

Spike protection: The unit will absorb a normal mode spike of 40 joules 10,000 times without degradation. Common mode spikes are rejected by the power supply transformer and, hence, limited by the dielectric withstand of the transformer and line input filter. No impedance has been added to shunt common mode spikes to case ground.

ENVIRONMENTAL

Temperature: 15° to 40°C

Humidity: 20% - 90% (no condensation)

Altitude: 0 - 4,000 meters

Shock and vibration: 4 g's for 4 ms with less than 0.1% of F.S. of data aberration.

NOTE: The detectors and electronics are enclosed in a heavy all-metal enclosure. The metal is continuous or has highly clamped joints except for thin beryllium windows for each detector and an EMI gasketed joint between the sensor cassette and the electronics package. The windows are electrically bonded to the sensor cassette.

The power supply is designed for high common mode rejection by use of a double boxed power transformer with through-the-wall construction. Normal mode noise is attenuated both by filtering and by the use of metal oxide varisitors (MOVs). The power supply is separated from the electronics package by a heavy shield which completely surrounds the supply.

Signals to and from the package are via fiber optic cables.

It is believed that the above measures will make the package highly resistant to electrical interference.

PHYSICAL

Form factor: To mount to HW-1000 spectrometer in place of the film cassette and the removable top cover. Will increase the height of the spectrometer by 9.8 inches.

Size: approximately 9.8" x 7.5" x 2.8"

4.2 Electronic Design

The system hardware component most crucially required for integration of the active-recoding spectrometer into the DNA Instrumentation Upgrade strategy, and the one requiring the highest degree of innovative development is the digital interface module (DIM). Anticipating the requirements of non-DNA users, the DIM design presented here is sufficiently versatile to support spectrometer use in stand-alone applications as well as in PRS DAS-integrated roles. This duality of application extends to the spectrometer software package, described in Section 5, that complements the DIM hardware.

The functions of the DIM are to digitize and temporarily store signal level data received from the SSPA detector/amplifier circuits located in the sensor cassette. To accommodate both DNA DAS-integrated and stand-alone roles, the DIM functions are controlled by an on-board microprocessor that allows autonomous DIM operation.

Figure 7 is a DIM layout drawing and Figure 8 is a block diagram of the DIM and relevant portions of the sensor cassette. Figure 9 is a scanning circuit diagram.

The output of each charge amplifier is fed to a fast 16-bit analog-to-digital converter (ADC). Each ADC is started at the same time. At the end of the conversion time each ADC output is latched into a pair of registers. The registers are serially read into a local static random access memory (SRAM) during the next conversion cycle. See the timing diagram for details. Although the ADCs are 16 bit, due to comparator noise and other errors the true resolution of the ADCs is only 14 bits. The extra bits may be useful for very small signals and for repeated measurements where averaging can be used.

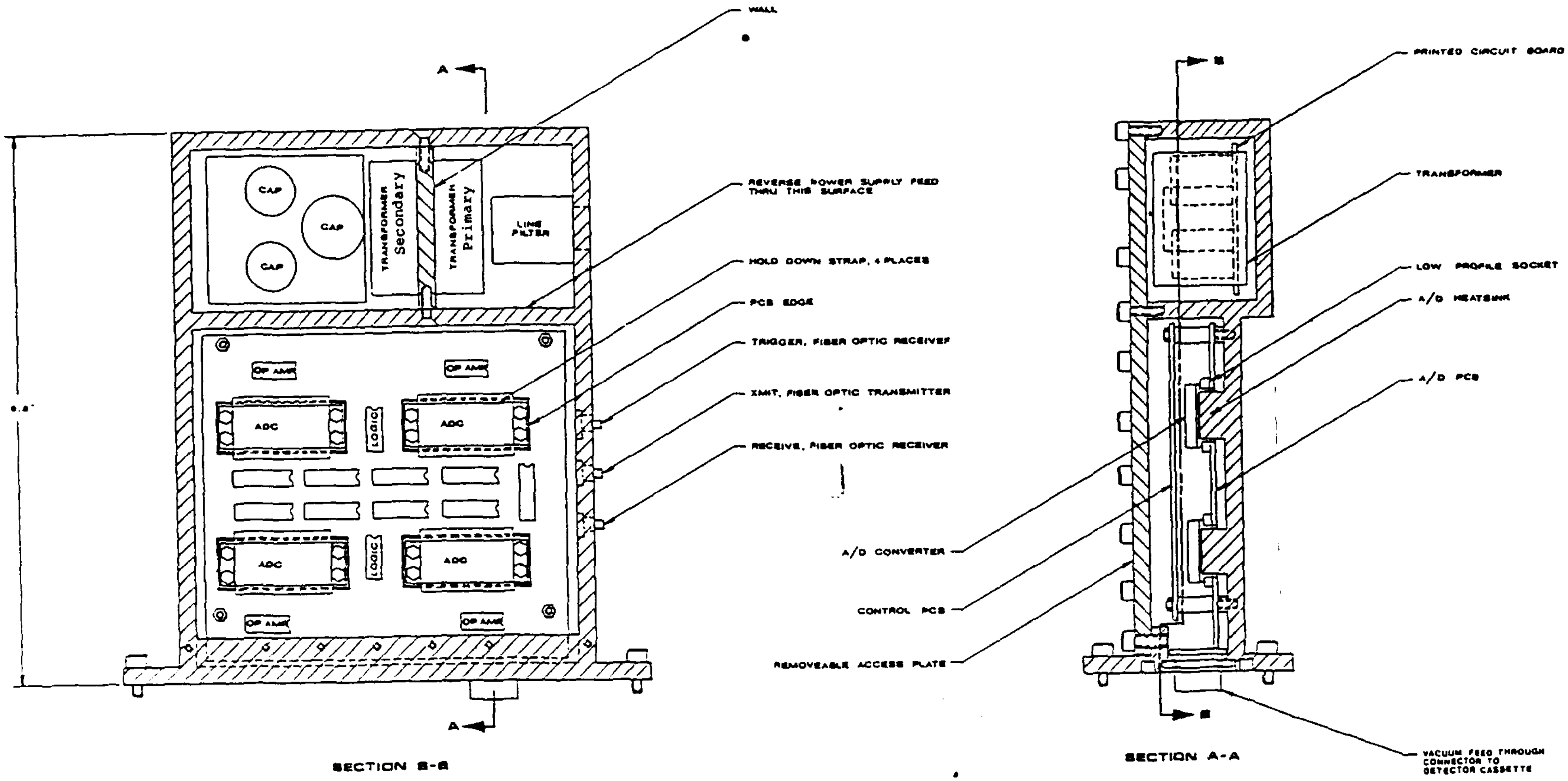

Figure 7. Layout design of the digital interface module.

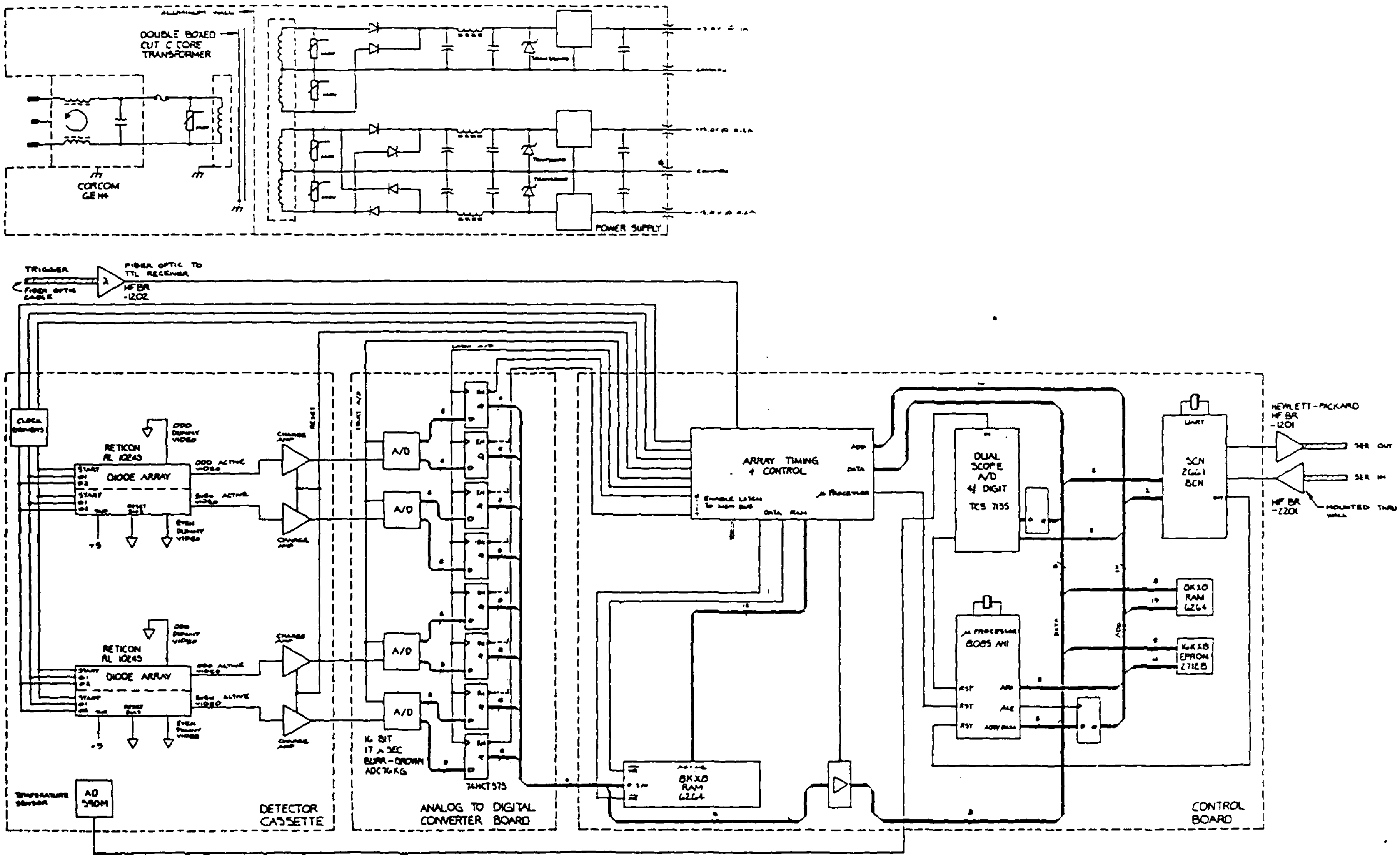

Figure 8. DIM block diagram.

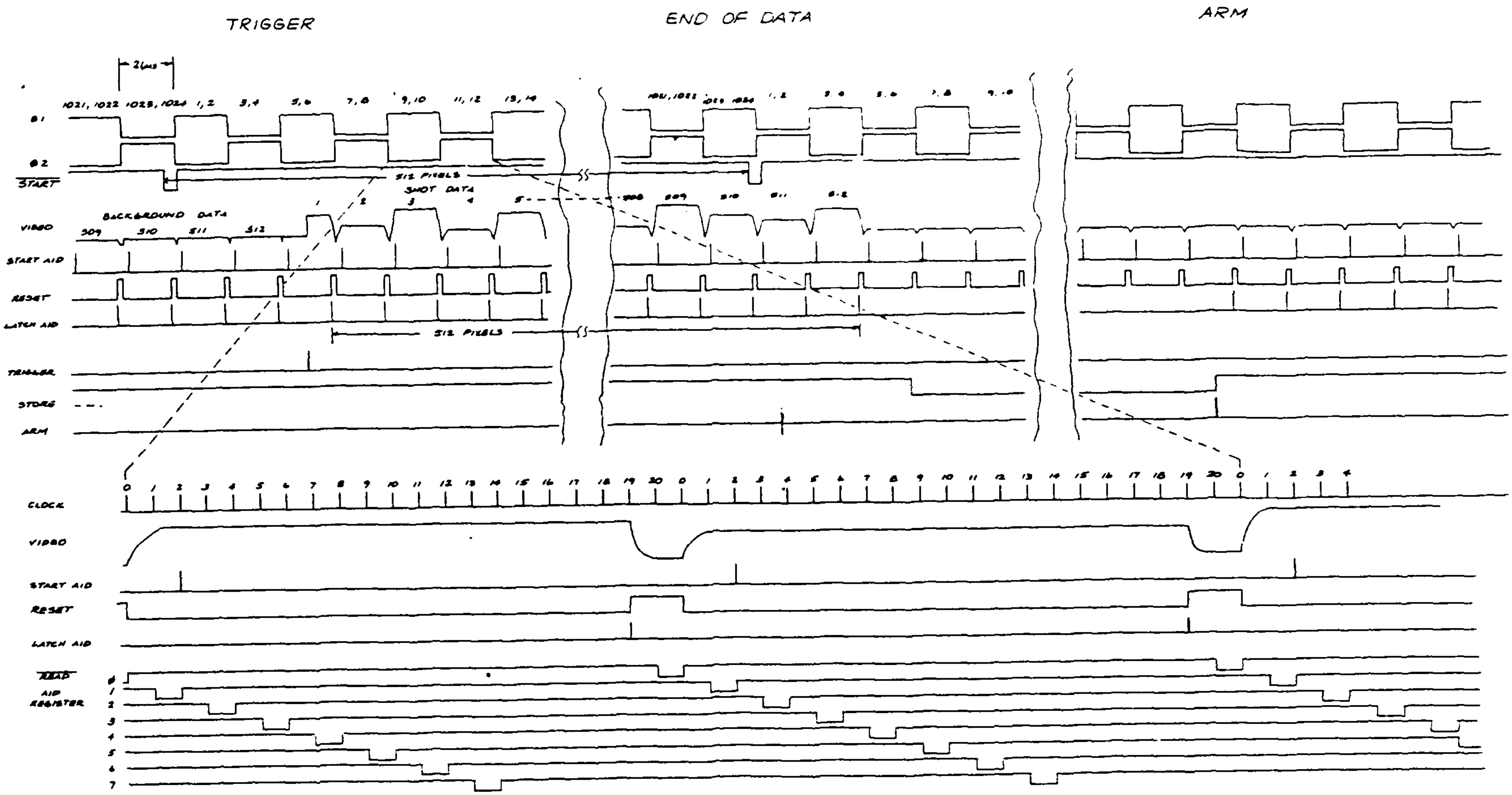

Figure 9. Scanning Circuit Timing Diagram.

The use of four fast ADCs (17 μsec.) instead of multiplexing a single converter was dictated by the need to quickly scan the arrays to reduce the errors introduced by the dark (leakage) current of the SSPAs. At 14 to 16 bits, the size and power dissipation of a single very fast ADC with multiplexer would be prohibitive. With the present configuration, the SSPAs dark current noise contribution is not significant below 24°C, but it becomes significant above an array temperature of 40°C.

The clocks required to operate the SSPAs, the ADCs, and the transfer of data to the local SRAM are generated by the array timing and control section of the DIM. The major signals from this section are shown in the timing diagram (Figure 9). When the instrument is ARMED, data is continuously written to the SRAM in a circular fashion. When a TRIGGER is received, the address of the SRAM at that instant is latched into a register and a second register acting as a counter allows the data-taking to continue for 511 more data conversion cycles to completely read out the SSPAs once. The instrument is then DISARMED. Note that the SRAM is configured to be 1024 conversion cycles long which stores two complete readouts of the SSPAs. Thus, the SRAM contains both the x-ray data and the background scan just before the trigger event.

An 8085 microprocessor is used to communicate with the host computer and to control the overall operation of the instrument. The microprocessor upon receiving a command via the universal asynchronous receiver transmitter (UART) takes control of the array timing and control section to pass the data to the host. The microprocessor reads the register which recorded the address at which the trigger occurred and allows the microprocessor to sort the interleaved data in the SRAM. The unsigned binary data is sorted, converted to binary-coded decimals, and finally converted to ASCII digits for transmission to the host computer. To ARM the instrument, the microprocessor receives a command from the host computer and then enables the writing of data to the SRAM. All previous stored data is lost.

The firmware for the microprocessor is stored in a 16K byte EPROM. Working memory is an 8K byte SRAM. A dual slope analog-to-digital converter and linear temperature sensor are used to measure the SSPAs temperature.

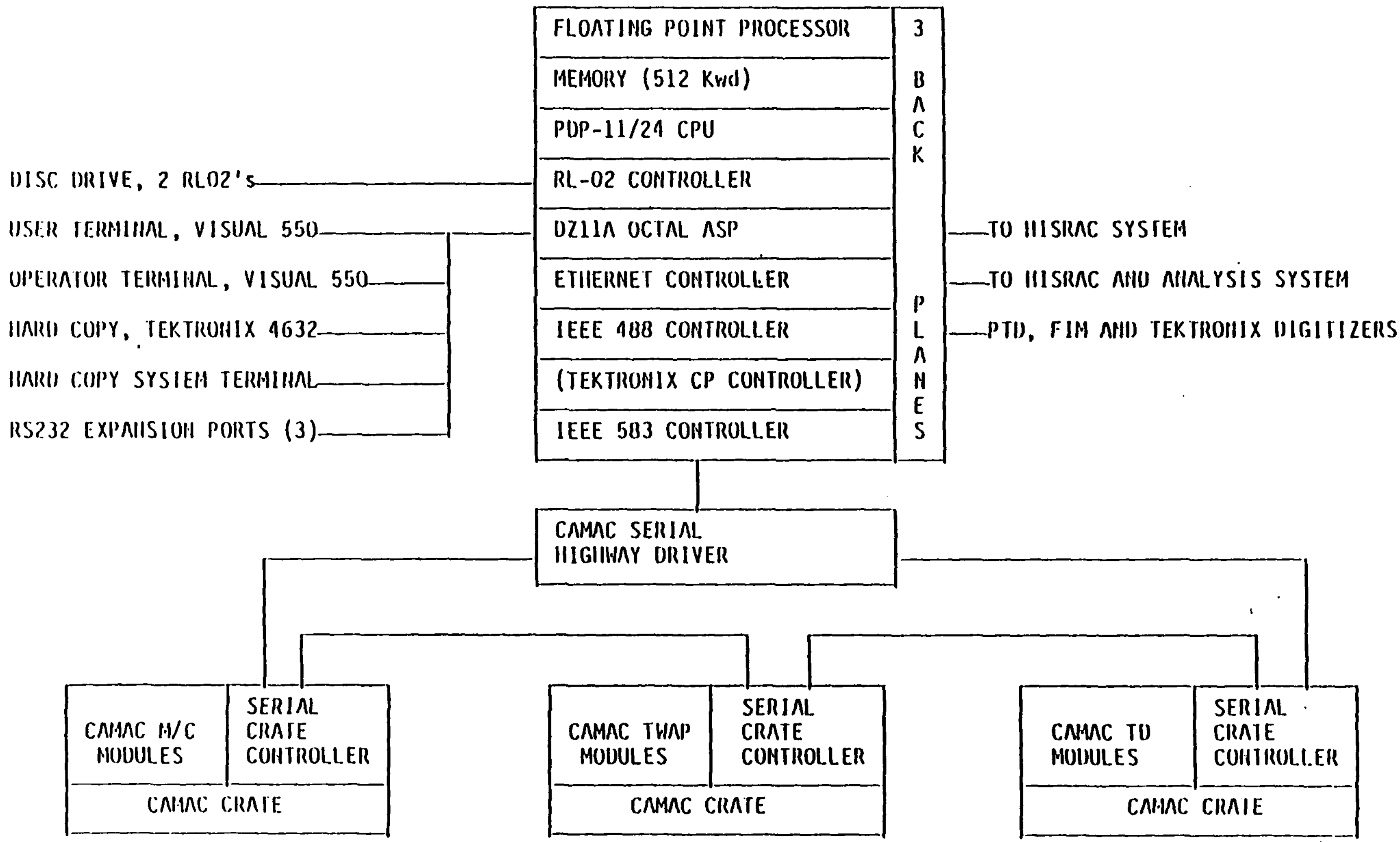

Figure 10. Remote simulator system hardware diagram.

SECTION 5

SYSTEM SOFTWARE PACKAGE

The integration of the active-recording spectrometer into the DNA Instrumentation Upgrade strategy requires the development of PRS DAS-compatible software. The software must both operate the instrument during a PRS shot sequence and also assist the experimentalist in the reduction and archiving of data. The final product of the data reduction phase is an x-ray spectrum expressed in physical units (with instrument response factors removed) that serves as the starting point for more elaborate, experiment-directed spectroscopic analysis. The discussion of software organization contained in this section begins with consideration of requirements, with emphasis on PRS-DAS compatibility. A description of software components ("modules") and software package organization follow in Section 5.2. A software operating sequence is illustrated in Section 5.3.

5.1 SOFTWARE REQUIREMENTS.

The active spectrometer software package has been designed to satisfy three important operating constraints. First, the software will operate in the environment of existing hardware standards defined for the REMOTE system as part of the DNA NWE Instrumentation Standard. Secondly, the software will be compatible with the existing operating system and applications software. Finally, the software will successfully exercise the active readout HW-1024 spectrometer from parameter data file creation to the archival of HW-1024 acquired data. Each of these areas is detailed in the sections that follow.

5.1.1 Software to Hardware Interface Requirements.

The hardware compatibility requirements placed on the spectrometer data acquisition software are twofold. First, in an overall sense, the package will be compatible with the DNA NWE Instrumentation Standard to which the existing instrumentation systems were designed. Thus, the software will require no new or additional hardware to be added to existing systems. Secondly, in an application sense, the software will satisfy all software interface requirements as defined by the HW-1024 spectrometer. This will include the utilization of the RS232 serial communications interface protocol acting as the CPU-to-spectrometer data link.

5.1.2 Software to Instrumentation System Interface Requirements.

The HW-1024 data acquisition system (DAS) software will operate using the hardware configuration described in the ARACOR Technical Report TR82-112C-1-08 (Rev A) entitled "Product Specification for NWE Simulator Instrumentation Systems." The baseline hardware architecture described in this document consists of a Digital Equipment Corporation (DEC) PDP 11/24 CPU with a 1 Mbyte RAM, two RL02 10.4 Mbyte disk drives, a DEC DZ11-A octal asynchronous serial port (ASP), two Visual 550 terminals, a DEC LA-120 line printer and Tektronix 4632 hardcopy unit. This architecture will support three IEEE standards in addition to the RS232 protocol. These are the IEEE 488 (GPIB), IEEE 583 (CAMAC) and IEEE 802.3 (Ethernet) standards. The IEEE 488 and IEEE 583 standards provide monitorcontrol and data acquisition capability while the IEEE 802.3 standard provides a local area network (LAN) among distributed CPUs. A block diagram detailing the architecture is shown in Figure 10. In particular, the software will use one of the available three (3) RS232 expansion ports. The RS232 data communication link is the DEC DZ11-A octal asynchronous serial port board. This represents the CPU-to-spectrometer interface. It will support data communications up to 9600 baud.

5.1.3 Software to Spectrometer Interface Requirements.

The spectrometer will be interfaced to the CPU via the RS232 serial data link. All spectrometer functions will be controlled by a 8085 microprocessor located in the digital interface module (DIM). The microprocessor will have available 16 Kbytes of program read only memory (EPROM) and 8 Kbytes of random access memory (RAM). Additionally, the spectrometer-acquired data will be stored in an 8 Kbyte RAM that is separate from the microprocessor memory.

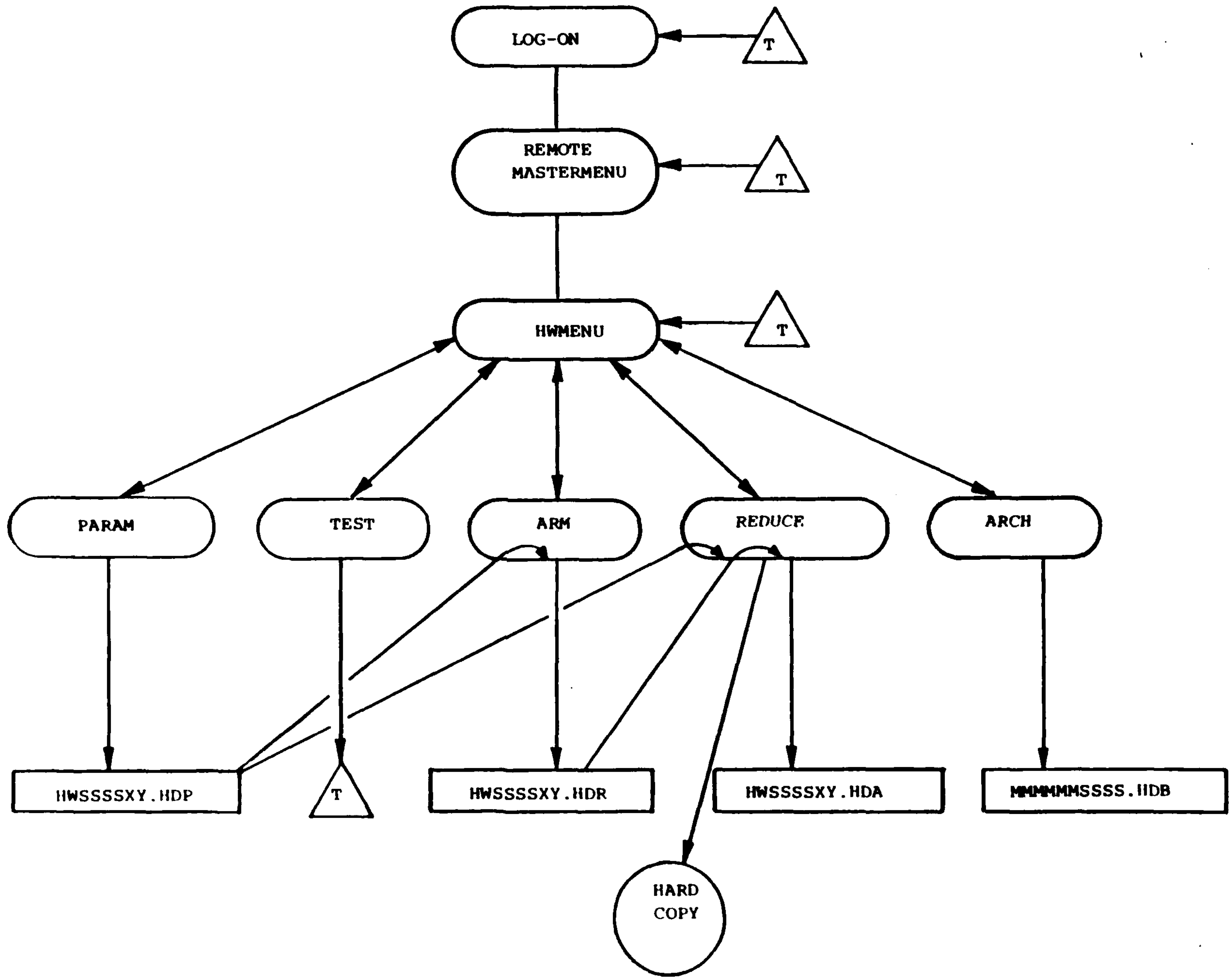

Figure 11. Primary menu (HWMENU) data flow diagram.

The RS232 serial interface link will support full duplex asynchronous data communication at a baud rate of 9600. The X-ON/X-Off protocol will control the data flow. Hardware handshaking, such as clear-to-send (CTS), will not be supported. Maximum separation distance will be 250 meters for fiber optic transmission.

The software will support the ASCII code standard. Specifically, this will include the characters SP (hex 20 through DEL (hex 77), X-ON (hex 11) and X-OFF (hex 13). All software controllable spectrometer operating parameters will have a unique command that consists of these characters. These commands are the following:

1. ARM TRIGGER
2. DISARM TRIGGER
3. ENABLE SOFTWARE TRIGGER
4. SEND DIM STATUS
6. SEND SSPA DATA
7. SEND SSPA CORRECTION DATA
8. SEND TEMPERATURE
9. INTERRUPT

The ARM/DISARM Trigger commands are used when an external event trigger (trigger specifications: positive TTL pulse into 50 ohms with the rise time less than or equal to 10 ns and whose minimum pulse duration is 100 ns) is anticipated while the ENABLE SOFTWARE TRIGGER is used for test purposes only. The SEND DIM STATUS will include the most current DIM status regarding the power (i.e., on/off), arming, data available to transmit, data remaining in RAM. The INTERRUPT command will interrupt any DIM process and return control to the operator terminal. All data transmission (i.e., STATUS, BACKGROUND, SSPA, SSPA CORRECTION and TEMPERATURE DATA) will begin immediately upon receipt by the DIM of the appropriate command by the end-of-command terminator. The data will be transmitted to the REMOTE CPU RAM and, where appropriate, written to the system storage device. A checksum operation will be performed at both the transmitting and receiving end to ensure the integrity of the data transmission.

5.1.4 Software-to-Software Requirements.

The DAS software will be compatible with the specification described in the ARACOR Technical Report TR82-112-C-1-06 (Rev. C) entitled "Development Specification for REMOTE System Software." The software will be written using the Fortran 77 programming language operating on the DEC RSX-11/M-Plus operating system. In particular, the software will be executable either as part of the FTDAS applications package or as a stand-alone piece of code. Additionally, the software requires the RSX 11/M-PLUS DZ11 device driver as the operating system to ASP software interface.

The FTDAS interface is structured in such a way that little modification will be required to operate the spectrometer software. As part of the SBIR Phase II effort, three FTDAS-related modifications wil be proposed. First, the FTDAS.CMD startup indirect command file will be modified to include a top-level menu that consists of the HW spectrometer (HWMENU) and FTDAS options. Second, FTDAS will be changed so that the software control will be returned to the top level menu upon any FTDAS exit command. Finally, the quick look portion of FTDAS will be modified to include a link to the HWMENU primary menu immediately following a PRS shot so that parallel processing can take place. The latter change means that the HWMENU menu will be displayed on a second user terminal immediately following an event. In the event that only a single terminal exists, the HWMENU will be displayed upon completion of the FTDAS quick look option.

5.2 SOFTWARE FUNCTIONAL MODULES.

The software developed for the spectrometer will contain five modules that are readily accessible through the HWMENU primary menu. These modules will support the creation of parameter files that are subsequently referred to during data reduction, testing of the spectrometer digital interface module (DIM), arming of the spectrometer in preparation for a PRS shot, reduction of spectrometer acquired data and the final archival of all shot data. The five software modules are described below.

1. PARAM (PARAMeters). This module provides the user with the software to create new and to modify existing spectrometer parameter files that contain filter transmission, crystal, geometry and SSPA detector information. Files appropriate to the instrument configurations described in Section 3 will be provided to the user by ARACOR.

2. TEST (TEST hardware). The means to test the arm/disarm, scan trigger, temperature check, data display and status display functions of the DIM are provided by this module.

3. ARM (ARM Spectrometer). This module arms the DIM for a shot trigger, monitors for a DIM "ready to transmit data" status, and creates a temporary shot data file on the REMOTE CPU.

4. REDUCE (REDUCE data). The reduction of spectrometer data is performed by this module.

5. ARCH (ARCHive). The spectrometer reduced data set is created and combined with other output data sets that may exist to form the final shot data base for data archival.

The main menu, HWMENU, is shown in Figure 11. This represents the top-level man-machine interface for the spectrometer software. The five modules that make up the applications software package provide the user-to-spectrometer interface via the RSX-11/M-PLUS operating system. Where appropriate, full advantage of existing system level software will be taken to avoid the development of redundant software.

A detailed description of the five applications software modules follows below. The spectrometer data file structure and file nomenclature is shown in Figures 12 to 14, respectively. The detailed data and control flow diagrams for each module are included in the Appendix.

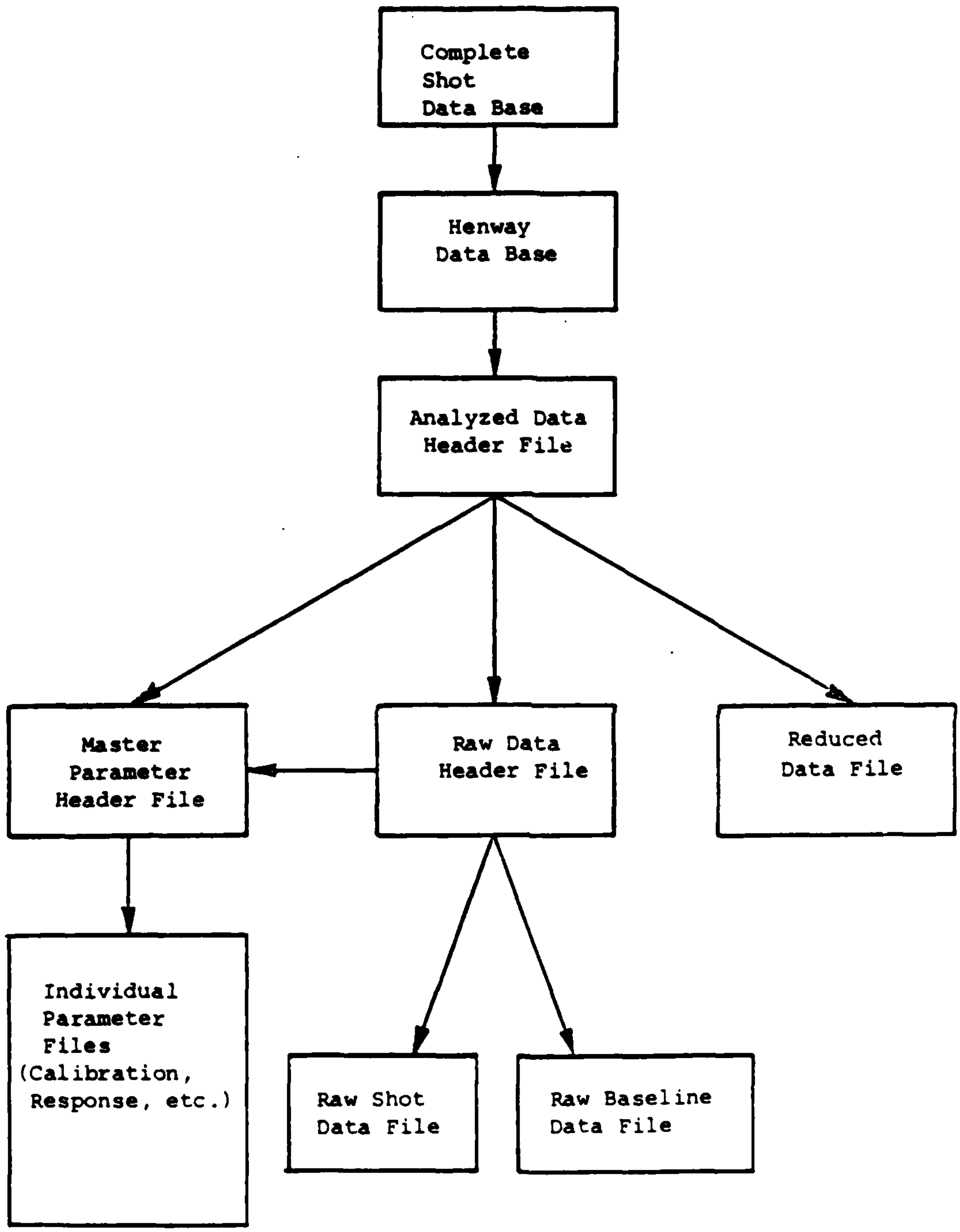

Figure 12. System file structure.

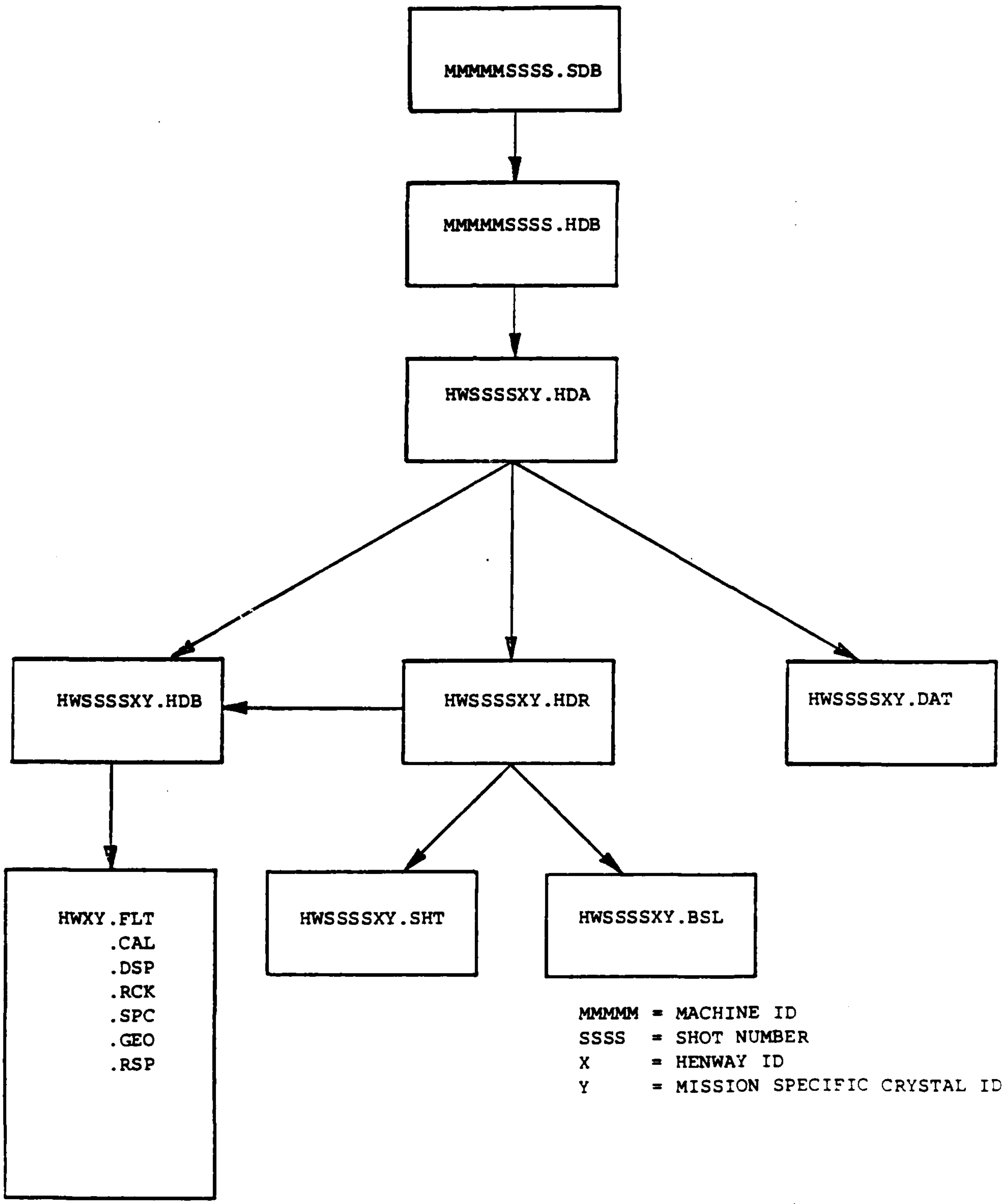

Figure 13. System file nomenclature.

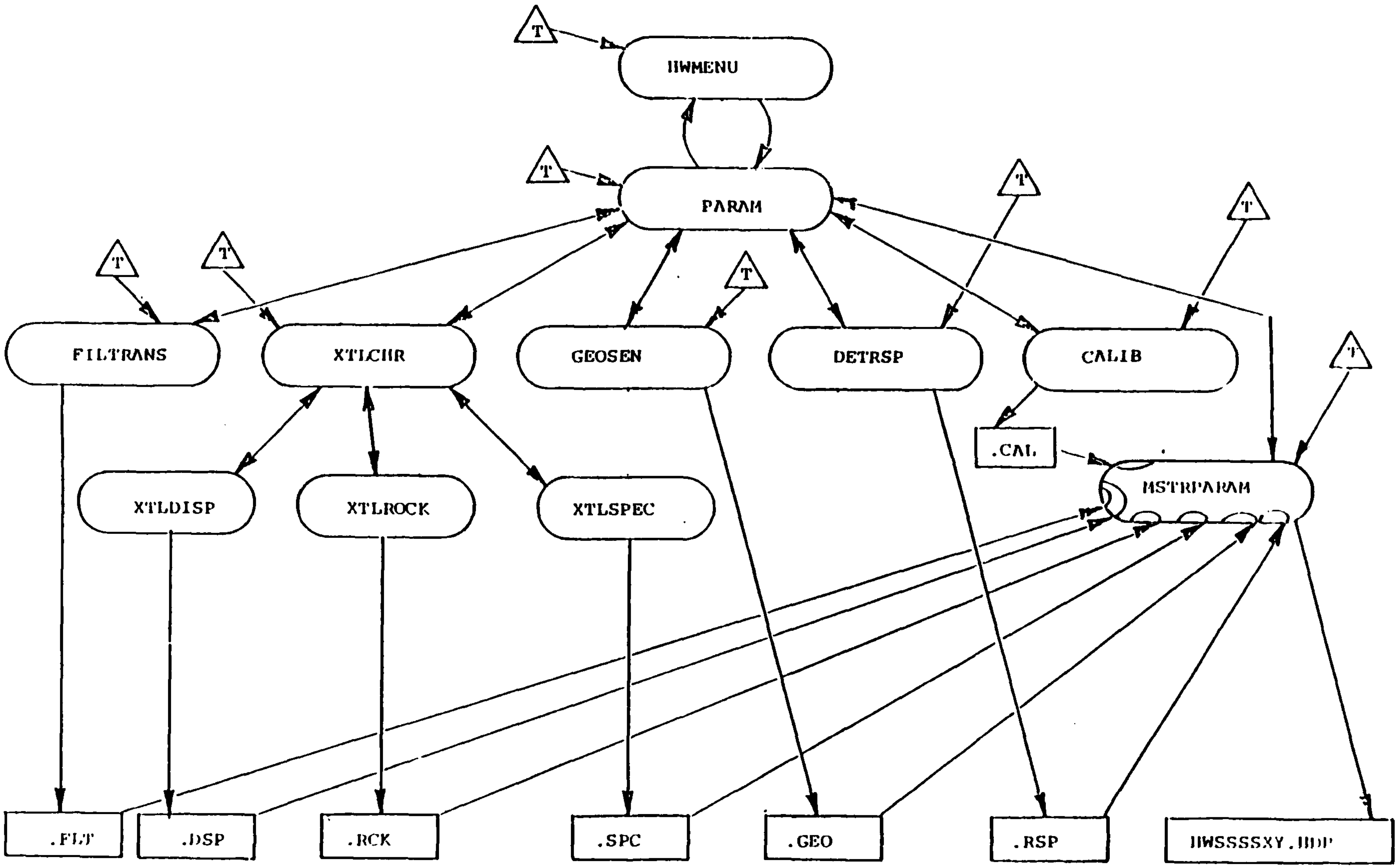

Figure 14. Spectrometer setup menu (PARAM) data flow diagram.

5.2.1 Module PARAM.

The PARAM software module will assist the user in the creation of all parameter files required to fully reduce the spectrometer acquired spectral data to a spectrum expressed in physical (configuration-transparent) units. These will include the analytical tools required to calculate sensitivities as a function of photon energy for all filter, crystal, geometry and SSPA parameters. The major functions of the software are to

1. calculate filter transmission factors as a function of photon energy and Bragg angle;
2. calculate crystal dispersion Bragg angles as a function of the SSPA's individual photodiodes location;
3. calculate crystal rocking curves (defined in Section 3.1.1) as a function of Bragg angle for a fixed photon energy;
4. calculate crystal spectral bandpass curves as a function of photon energy for a fixed Bragg angle;
5. calculate the geometrical sensitivities as a function of Bragg angle;
6. calculate the response of the SSPA as a function of photon energy; and
7. create the master PARAM file that includes header and data information for the individual responses listed above and CPU-to-DIM RS232 port assignment.

PARAM will allow the user to choose between two options, both of which are operated in an interactive mode. The first option will allow the user to perform any calculations and file creations required for a particular experiment. This includes the option to exercise any or all of the previously listed functions. The second option will allow the user to simply input names of existing PARAM files that reside on disk. Thus, these options allow the user to either "cold" or "warm" start an experiment.

5.2.2 Module TEST.

The TEST software module will allow the user to exercise certain test features associated with the DIM that demonstrate it is functioning properly. The major functions of the software are to

1. test the arm/disarm function;
2. test the software scan trigger function;
3. read the current temperature of the SSPA;
4. transmit and display RAM data;
5. transmit and display ROM conversion data; and,
6. transmit and display current DIM status.

The arm/disarm function (function 1) allows for DIM testing using external triggers. The scan trigger function (function 2) provides a software trigger simulation. Since variations in ambient temperature affect the operating performance of the SSPAs, the temperature option is included (function 3). This option will read, transmit, and display the SSPA temperature and is an information transfer rather than control function. Any subsequent action that may be required as a result of this information will be the responsibility of the user. The data transmitted from DIM RAM and ROM will be displayed in a tabular format, using functions 4 and 5, with the information linked to a particular SSPA channel number. Finally, the DIM status function will indicate the condition of DIM power, arming, data availability and accountability, temperature and trigger information. The latter information will include the SSPA channel number at which the trigger occurred.

5.2.3 Module ARM.

The ARM module provides the shot control portion of the spectrometer DAS software. It will allow the user to remotely arm the spectrometer in preparation of a shot. This operation will include the monitoring of the DIM for a receipt of trigger indicator. Before the software issues the arm command to the DIM, it prompts the user for experimental information. Functionally, the software provides the following:

1. identification of the event with a unique machine, shot and spectrometer number via a link to the master parameter file;
2. arming the DIM for the trigger shot; and
3. spawning a child process to monitor the DIM for spectral shot data and to write the data to a disk file.

The event identifiers and parameter file name are obtained from the user via program prompts. Error checking is provided for these inputs. Once the ARM module has found the specified master parameter file and read the particular RS232 port assignment to monitor, a monitoring child process is spawned and the user's terminal is returned to remote TOPMENU for other tasks. When a trigger is sensed by the DIM, the SSPA is scanned first for baseline data and next for spectral data. The shot data are read and transmitted to the control CPU where a raw data file is created and written to disk. The process that begins with the arming of the DIM and ends with the disk resident raw data file is automatic and transparent to the user. Therefore, no primary ARM menu exists and all user input will be done with program prompts.

5.2.4 Module REDUCE.

The REDUCE software module will provide the user with the analytical tools necessary to reduce the spectral data recorded by the spectrometer. This software will include both quick look (data expressed in original engineering units) and spectral reduction options. Functionally software will provide the following:

1. extraction of data from previously archived databases;
2. reduction and display of background data;
3. reduction and display of background-corrected foreground data;
4. reduction and display of spectral data; and
5. creation of reduced data files.

REDUCE allows the user to reduce data from either an archived quick-look database or from the current shot database. The quick-look data will be displayed in an SSPA charge vs diode number form. The reduced spectral data will be displayed as fluence (in units of keV/keV-sphere) versus photon energy (in units of keV) format. The disk resident file that results from REDUCE will include header and data information for both the quick-look and reduced data.

5.2.5 Module ARCH.

The ARCH software module will provide the user a means to archive all shot data related to a unique shot number. The user will be required to provide shot information via program prompts. A master shot file containing parameter, raw, and reduced spectrum data will result from this module. The major functions of the software are

1. identification of the unique event parameters;
2. creation of spectrometer database;
3. linking of spectrometer data file with other DAS instrumentation data files; and
4. creation and storage of a master shot database.

There is no primary menu associated with ARCH. Upon selection of this option from the main menu, all user input will be done through program prompts.

After receipt of the unique event identifiers, ARCH will combine the output files of the PARAM, ARM and REDUCE modules. This includes header and data information. In the event the user desires to combine the spectrometer database with another shot database associated with a different set of instrumentation hardware (i.e., high speed transient recording), the ARCH software will create a master shot database. This will contain all header and data files associated with the instrument-specific shot databases.

5.3 INSTRUMENT OPERATION.

A typical operational sequence illustrating how the user and software interact to acquire spectrometer data is presented here. This description includes the software steps from user log-on to the final archival of an integrated shot database. This sequence assumes that the DNA Instrumentation Software FTDAS package is running in concert with the spectrometer DAS software and that the DNA Instrumentation Standard hardware is available at the REMOTE CPU.

The sequence begins with the booting of the RSX-11/M-PLUS operating system (assuming the system is powered up). This is done by either the CPU front panel boot switch or the RSX-11/M-PLUS boot command. Upon completion of the boot, the user must log-on the RSX-11/M-PLUS operating system by using the appropriate account and password. Once the user is logged-on, the system responds by placing the user in the Monitor Console Routine (MCR). This acts as the interface between the user and the RSX-11/M-PLUS system. Immediately following this, the startup command file FTDAS.CMD is activated. Initiated by FTDAS.CMD, the OPS and DAS portions of the FTDAS package and all equipment driver software are loaded into the RAM of the REMOTE CPU, and the top-level menu, TOPMENU, is displayed at the user's CRT.

The TOPMENU menu consists of four options. They are the following:

1. exercise HW-1024 spectrometer (HWMENU);
2. define and configure DAS hardware (OPS);
3. exercise DAS event functions (DAS); and
4. exercise IDL-based Analysis Package (ANAL).

The user must first define all hardware and software experimental parameters. This includes both pre-event instrument configuration and event related information. The user can use either the HWMENU or DAS option to supply the REMOTE CPU with this information. In this illustrative operational sequence, the HWMENU option is chosen first.

Table 4. Summary of instrument parameter calculations.

Characterization	Functional Relation
1. Filter transmission, T, as a function of photon energy, E, and Bragg angle, θ_B	$T(\theta_B, E)$ vs E
2. Crystal characterization	
a) Crystal Dispersion, θ_B, as a function of SSPA channel number	θ_B vs channel number
b) Rocking curve response, R_θ, as a function of θ_B at E=constant	R_θ vs $\theta_{B/E=constant}$
c) Spectral bandpass curve response, R_E, as a function of E at θ_B=constant	R_E vs E/ θ_B=constant
3. Geometrical sensitivity, S_G, as a function of θ_B	S_G vs θ_B
4. SSPA response, R, as a function of E	R vs E

where E = keV, θ_B = degrees, channel number = SSPA diode number, R = C/keV/cm^2, and T, R_θ, R_E and S_G are unitless fractions of 1.

Upon entering the HWMENU, the options discussed in the previous section are displayed to the user. These options are: (1) PARAM, (2) TEST, (3) ARM, (4) REDUCE, and (5) ARCH. In order to define and create the requisite spectrometer parameter files, the PARAM option must be selected. As a result of this choice, all parameter files associated with filter transmission, crystal, geometrical, and SSPA response properties are created. All of the analytical software associated with these characterizations are included. A summary of the particular characterization and the functional relationship associated with each are shown in Table 4. The result of this step is the calculation of factors that transform SSPA acquired charge data as a function of diode number (i.e., pC vs. channel number) to source fluence data (i.e., keV/keV-steradians vs keV).

The PARAM characterization files are stored in a master file that follows the naming convention of

HWSSSSXY.HDP

where
HW = Henway
SSSS = Shot ID
X = Henway ID
Y = Crystal Mission ID.

Each individual file is named

HWXY.EEE

where HWXY is as defined previously, and
EEE is an extension ID that can assume the following values:

FLT = Filter Transmission,
DSP = Dispersion Curve;
RCK = Rocking Curve;
GEO = Geometrical Sensitivity; and
RSP = SSPA Response.

All files are stored in the master shot database file MMMMSSSS.SDB.

Additionally, CPU-dependent information, such as the RS232 port assignment, are inputted to the system during creation of the master parameter file. This information is stored as header text in the HWSSSSXY.HDP file. Upon completion of PARAM, the user returns to the HWMENU main menu.

The sequence may continue with the selection of the TEST option. This option allows the user to functionally test the DIM operation. Before exercising this option, the spectrometer DIM package must be properly hardwareinterfaced to the REMOTE CPU by connection of the DIM to an available RS232 port. The software port assignment was specified by the user during the earlier exercised PARAM option.

This option is specifically tailored to achieve DIM functional verification before a cost-intensive PRS shot. Additionally, this option can be used for periodic SSPA off-line testing. The functions of TEST are those described in the previous section. In summary, TEST allows the user to check the ARM/DISARM function of both external and software-supplied event triggers, check and display SSPA temperature and review the current DIM status. Corrective action suggested by status errors will be the responsibility of the user. The user is returned to the HWMENU upon the completion of TEST.

At this point in the operational sequence, the user may, if necessary, exit HWMENU and return to TOPMENU to begin the configuration of the IEEE 488 and 583 transient recording hardware. This begins with the selection of the OPS option. Before any OPS function can be performed, the user must ensure that specific databases have been established. These databases are defined in detail in the BDM authored manual entitled "FTDAS Software Operations Manual 9C-215-OM-83-001 Volume I" dated 22 December 1983. The reader should consult this manual for more detailed operating information regarding the FTDAS software package.

For an actual shot event the user will select the ARM option from HWMENU. The user will be prompted for the shot master parameter file. Once the ARM module has read the appropriate RS-232 port to monitor, the DIM will be armed for the shot trigger signal. After the child process is spawned to monitor the DIM and write the DIM transmitted shot data to a disk file, the user terminal is returned to the REMOTE TOPMENU for other tasks.

It is important to point out that during the execution of an event, two software tasks will run in a multi-tasking mode. These are the ARM task and transient digitizer DAS tasks associated with FTDAS. This is done to decouple the two pieces of software so that the spectrometer stand-alone capability is preserved for non-DNA users while yet allowing the DNA user to take full advantage of the system hardware and software so that parallel processing is accommodated. The DNA user takes advantage of the facts that the RSX-11/M-PLUS software allows for more than one task to run on the system at the same time and that the DZ11-A octal ASP will handle up to eight RS232 communication devices.

The spectrometer data are processed using the REDUCE menu. Both the quick-look data (SSPA charge vs diode number) and reduced data (fluence vs photon energy) can be displayed on the user terminal or hard-copied on a Tektronix 4632 unit.

Normally, the user will first process the quick-look data files (.BSL and .SHT) to produce a reduced data file (.DAT) using the UNFOLD subroutine. After the user inputs both the shot number (SSSS) and the instrument identification code (XY), the appropriate master parameter file (HWSSSSXY.HDR) will supply the proper individual parameter files for the reduction calculations. UNFOLD will plot both the quick-look data and reduced data on the user terminal allowing before and after inspection before writing the reduced data files (.DAT and .HDA).

For data archival, the ARCH module will format the individual data and parameter files into a master spectrometer database. ARCH will access the proper .HDP (parameters), .HRD (quick-look data) and .HDA (reduced data) header files, append them to one another and build the master archival database file labeled MMMMMSSSS.HDB.

The DNA PRS facility user will normally acquire two separate databases from each shot: (1) the HW-1024 x-ray spectrometer data and (2) the transient digitizer (TD) data acquired using FTDAS. The ARCH module will combine the two data bases into a single integrated database for disk or tape storage. ARCH will fetch the TD database, append the HW-1024 spectrometer archival files (.HDB) to it and rename the complete integrated database MMMMSSSS.SDB. This completes a typical operational sequence for the system software.

The system software provides complete instrument control, data acquisition, analysis and archival with few differences presented to the user whether operated in the stand-alone mode or in concert with TD data acquisition under FTDAS.

A P P E N D I X

Control/DAS Software Modules

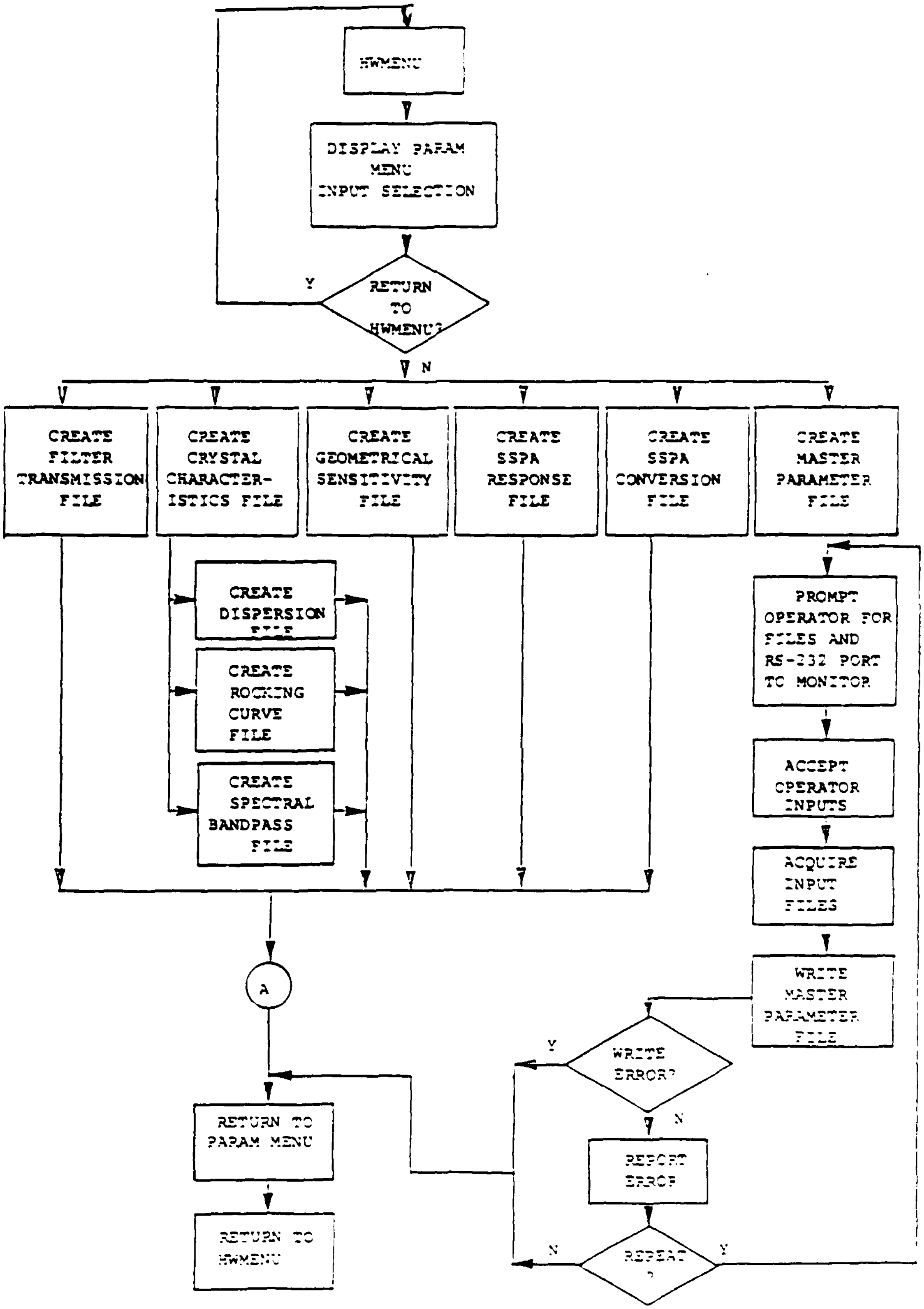

Figure 15. PARAM control flow.

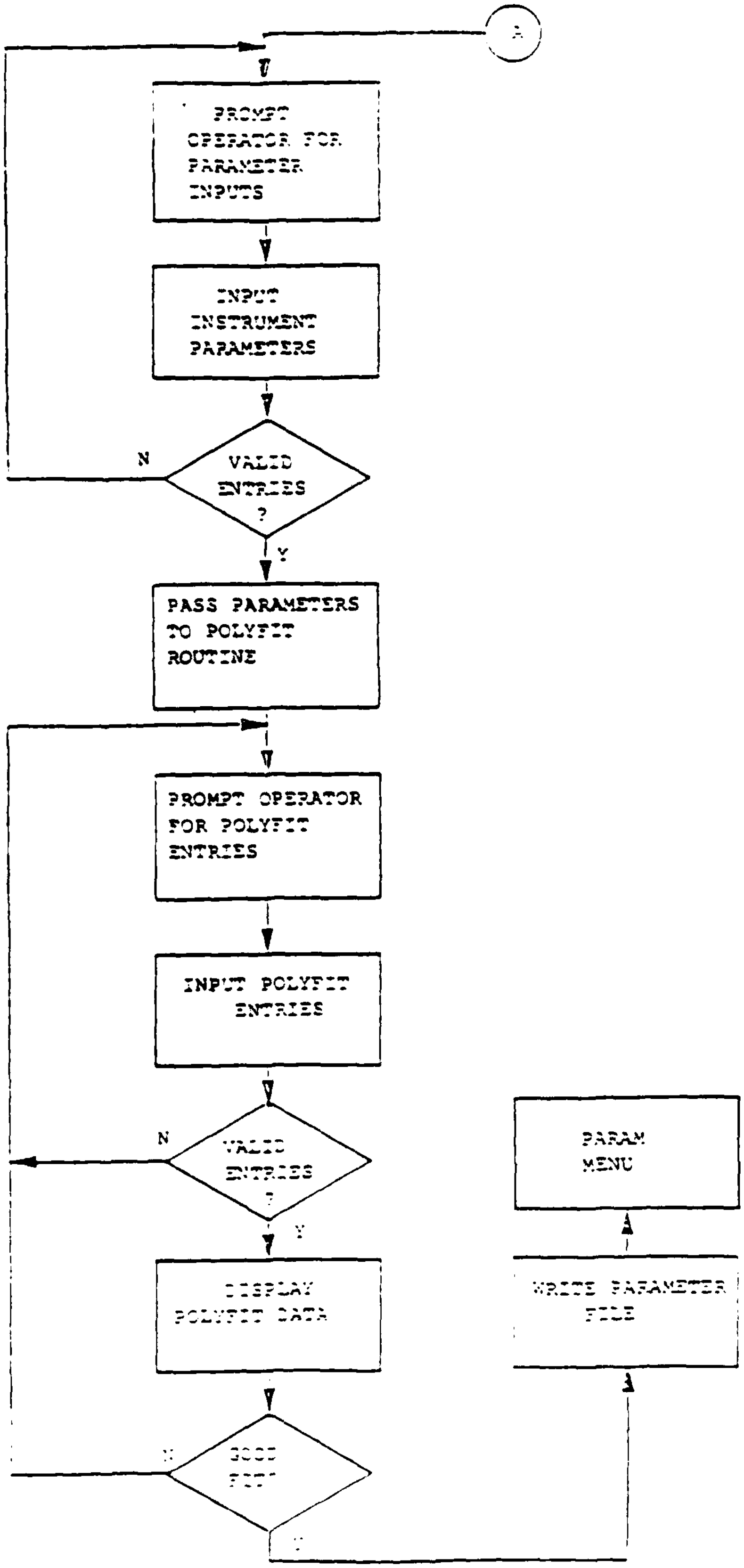

Figure 15. PARAM control flow. - concluded

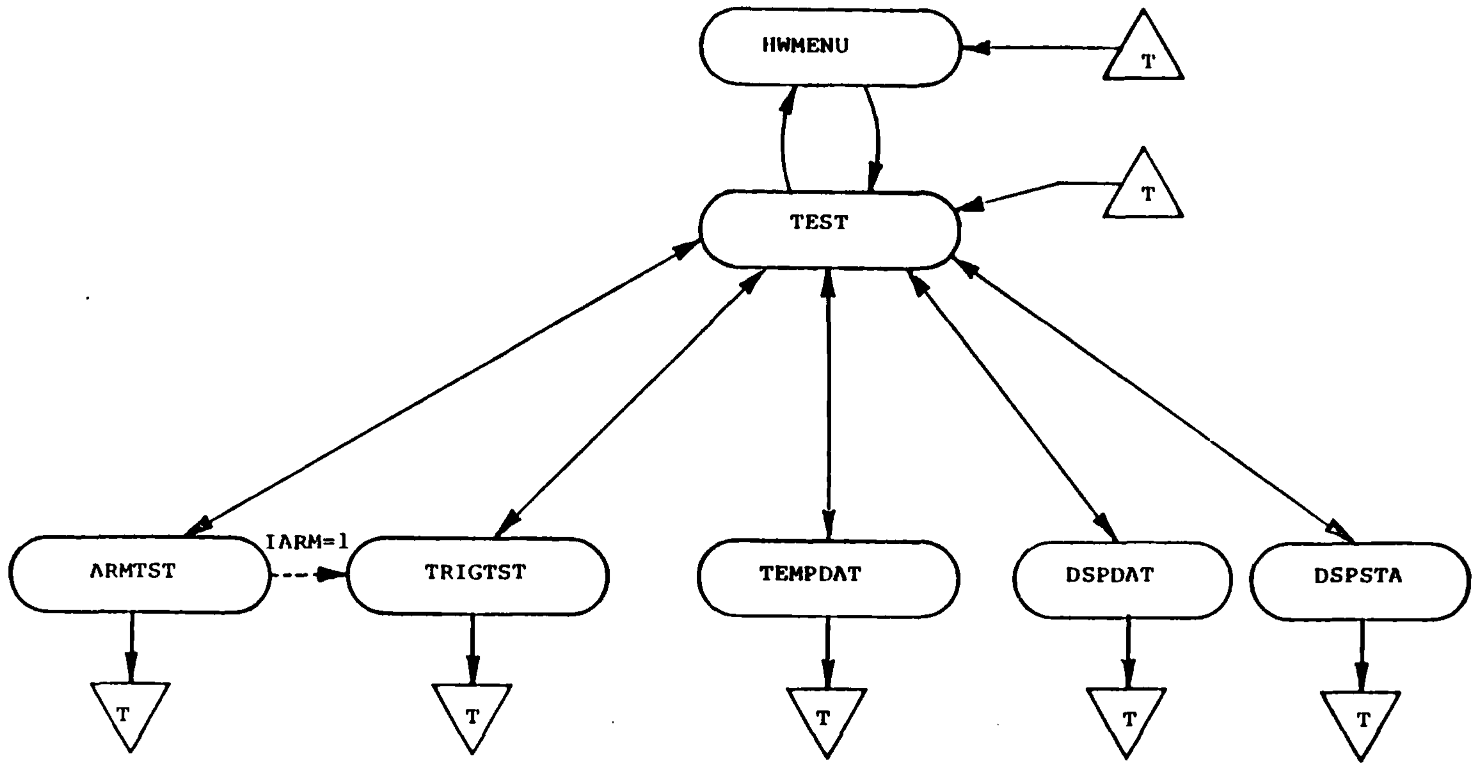

Figure 16. Spectrometer test menu (TEST) data flow diagram.

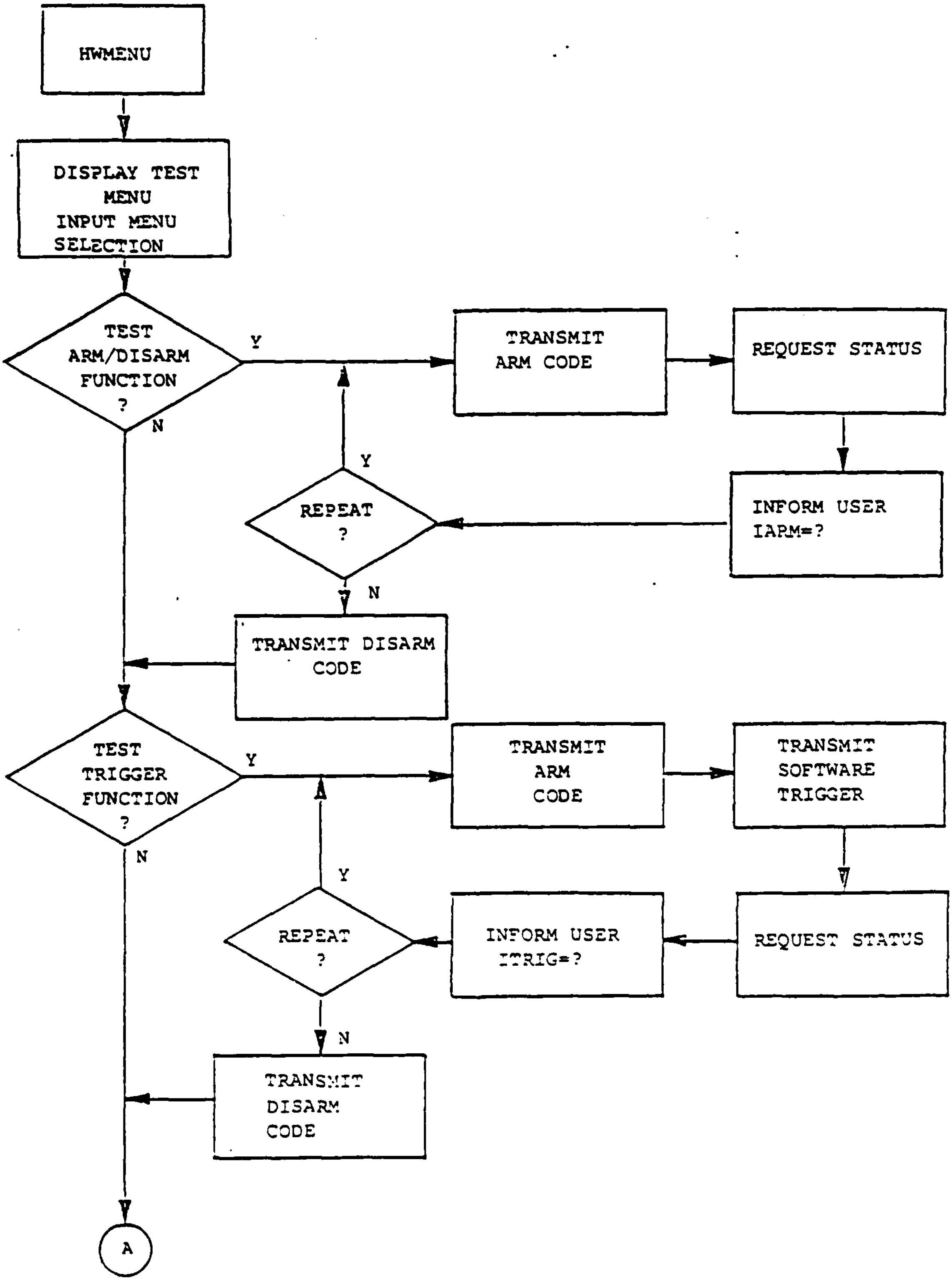

Figure 17. TEST control flow.

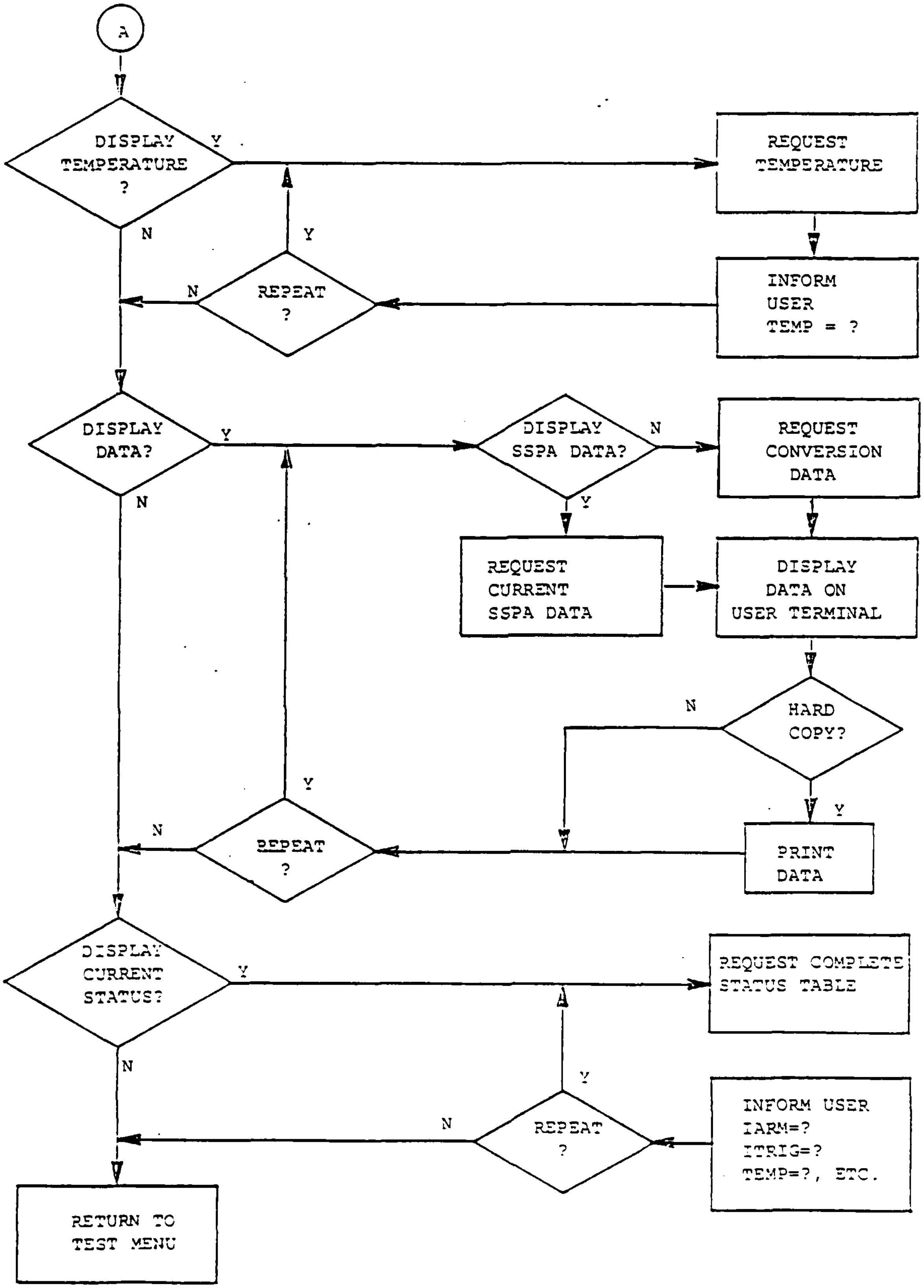

Figure 17. TEST contrcl flow. - concluded.

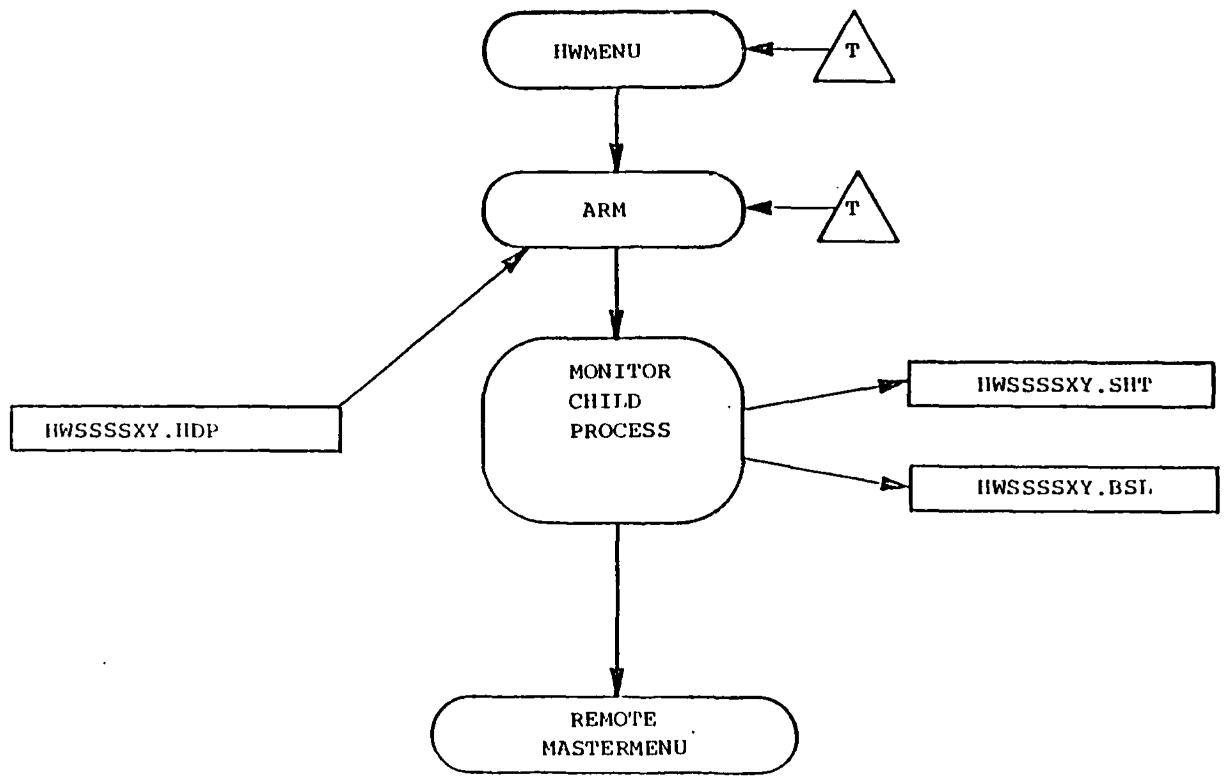

Figure 18. Shot execution (ARM) data flow diagram.

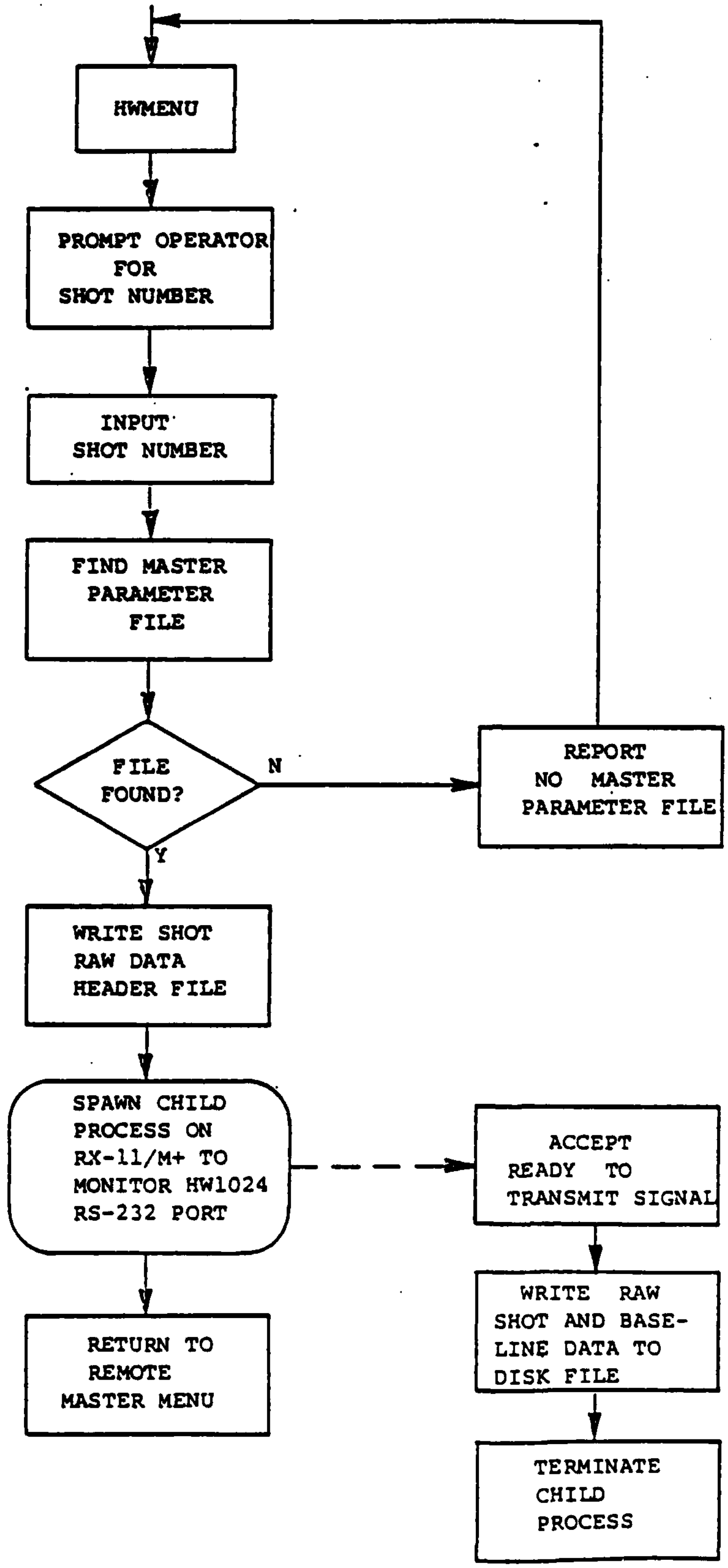

Figure 19. ARM control flow.

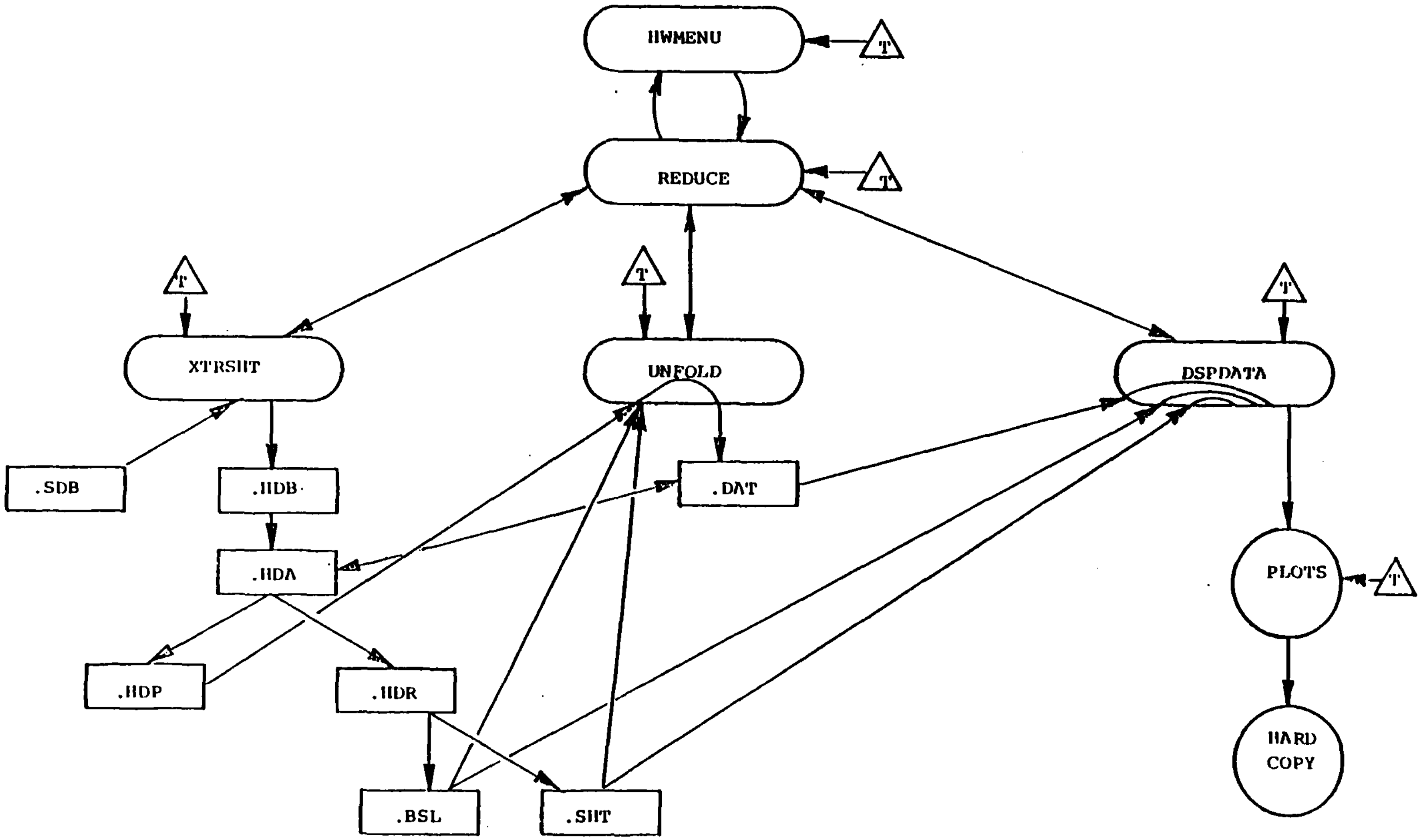

Figure 20. Data reduction menu (REDUCE) data flow diagram.

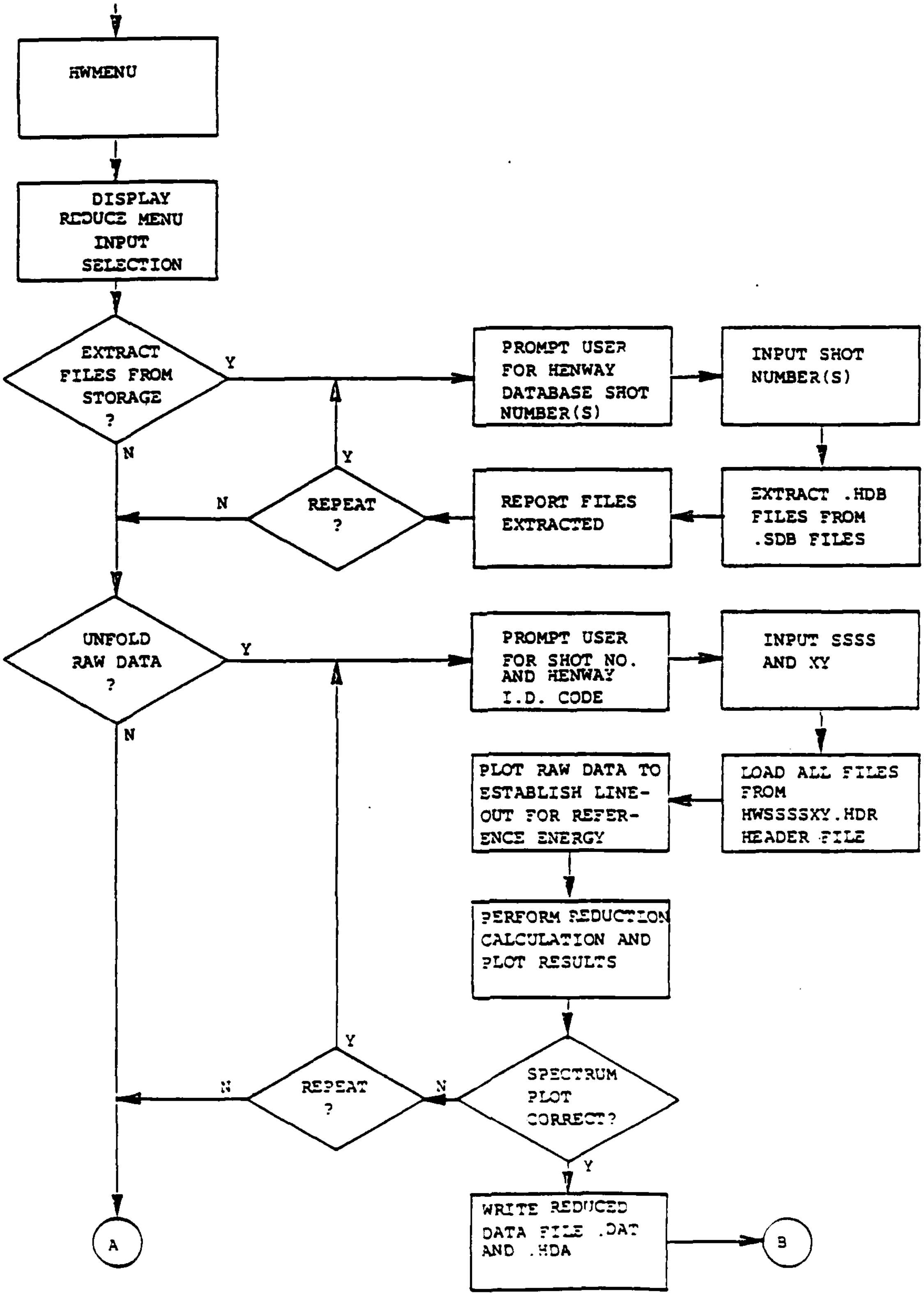

Figure 21. REDUCE control flow.

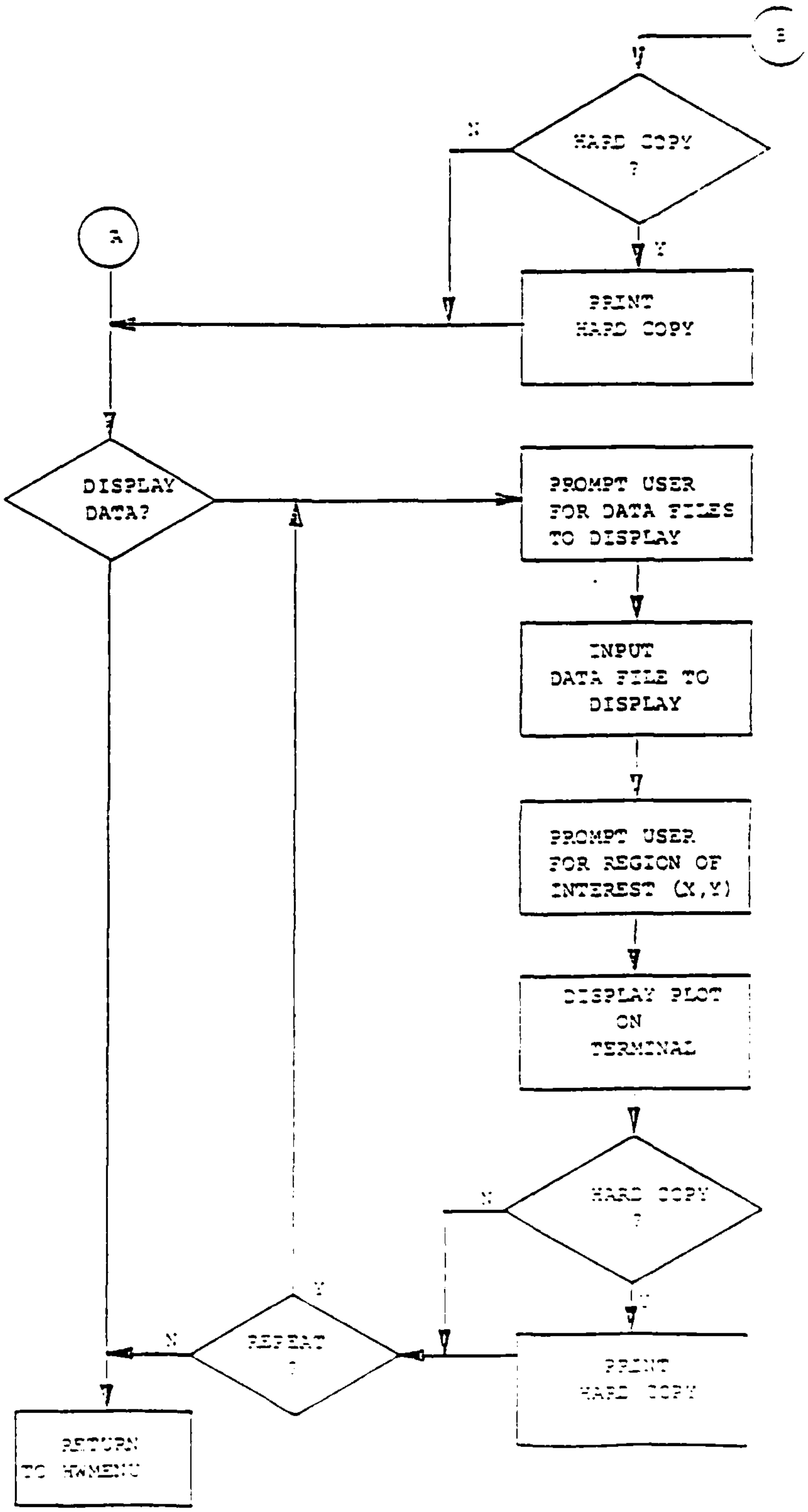

Figure 21. REDUCE control flow. - concluded.

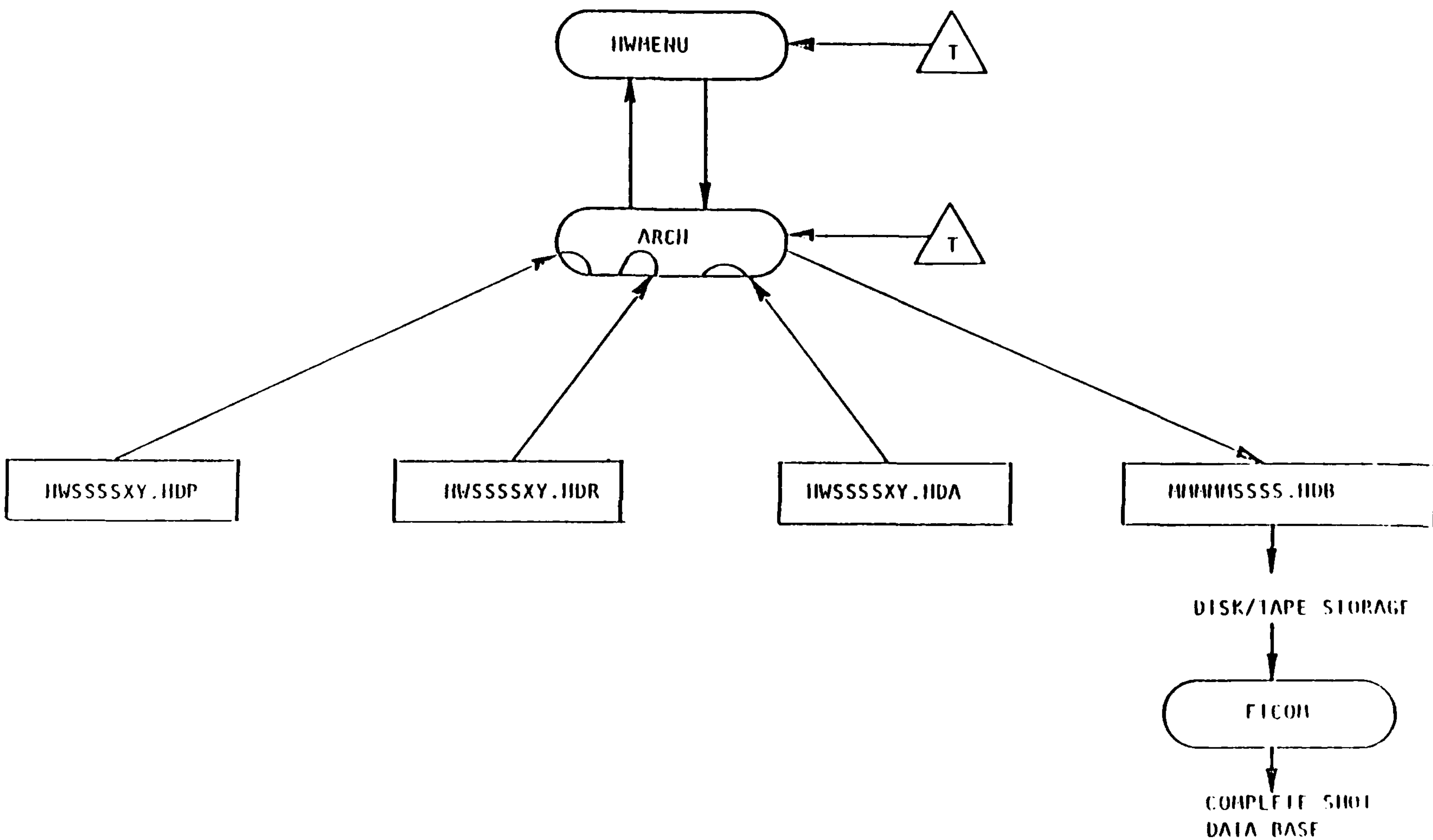

Figure 23. Data archival (ARCH) data flow diagram.

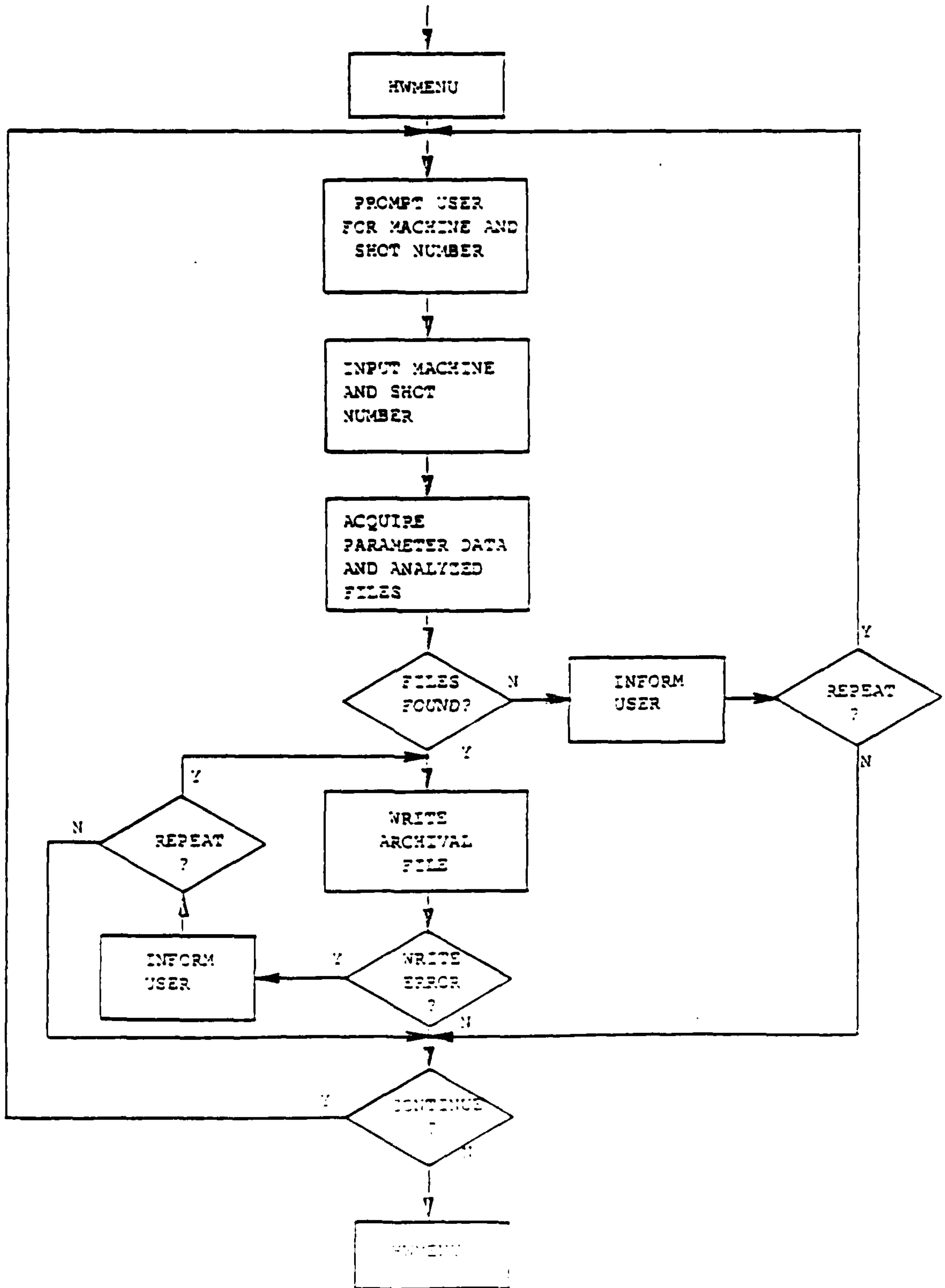

Figure 24. ARCH control flow.

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