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A Mobile Gamma-Ray Scanning System for Detecting Radiation Anomalies Associated with ^{226}Ra-Bearing Materials

T. E. Myrick
M. S. Blair
R. W. Doane
W. A. Goldsmith

HEALTH AND SAFETY RESEARCH DIVISION
OAK RIDGE NATIONAL LABORATORY

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A MOBILE GAMMA-RAY SCANNING SYSTEM FOR DETECTING RADIATION ANOMALIES ASSOCIATED WITH ^{226}Ra-BEARING MATERIALS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

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ABSTRACT

A mobile gamma-ray scanning system has been developed by Oak Ridge National Laboratory for use in the Department of Energy's remedial action survey programs. The unit consists of a NaI(Tl) detection system housed in a specially-equipped van. The system is operator controlled through an on-board mini-computer, with data output provided on the computer video screen, strip chart recorders, and an on-line printer. Data storage is provided by a floppy disk system. Multichannel analysis capabilities are included for qualitative radionuclide identification. A ^{226}Ra-specific algorithm is employed to identify locations containing residual radium-bearing materials.

This report presents the details of the system description, software development, and scanning methods utilized with the ORNL system. Laboratory calibration and field testing have established the system sensitivity, field of view, and other performance characteristics, the results of which are also presented. Documentation of the instrumentation and computer programs are included.

INTRODUCTION

A mobile gamma-ray scanning system has been developed for the Department of Energy (DOE) by members of the Health and Safety Research Division and the Instrumentation and Controls Division at Oak Ridge National Laboratory (ORNL). This system is being used in support of the DOE's radiological survey programs in the vicinity of uranium mill tailings sites and locations formerly utilized under government contract in operations involving radioactive materials. The mobile laboratory was originally developed and built by ORNL in 1979 and was operated until 1981 when it was upgraded to increase the system sensitivity and reliability, and to provide continuous radionuclide-specific analyses. This report gives a detailed discussion of the current version of the scanning van, including a system description, documentation of the software developed, details of the system calibration, and a description of the scanning methods employed.

In 1974, two programs were initiated by the Atomic Energy Commission to (1) identify inactive uranium mill sites and sites formerly utilized for radioactive materials processing, (2) characterize the radiological status of these locations, and (3) determine the need for and extent of remedial actions that would be conducted in order to release the sites for unrestricted or limited use, as required. These programs, now directed by the DOE, were titled the Uranium Mill Tailings Remedial Action Program (UMTRAP) and the Formerly Utilized Sites Remedial Action Program (FUSRAP). All of the UMTRAP sites and most of the FUSRAP sites have undergone comprehensive radiological assessments.[1,2] However, at many of these locations, offsite properties (called vicinity properties) have become contaminated with residual radioactive materials from the primary sites as a result of environmental forces (e.g., wind and water erosion), use of contaminated materials for construction-related activities (e.g., fill material), or inadvertently through use of contaminated materials for other reasons. The broad survey program initiated to identify these contaminated vicinity properties includes the use of historical records searches, direct public inquiries, aerial radiological surveys, and mobile gamma-ray scanning. Upon completion of this property identification process, comprehensive onsite surveys are conducted by the DOE on those properties identified as containing contaminated materials in order to assess the need for the property to be included in the appropriate remedial action program.

The primary mission of the mobile scanning van is to locate and identify those vicinity properties containing residual radioactive materials. Typically, the scanning surveys are conducted as the final phase of the property identification process and are used to (1) verify the results of previous survey work, (2) document locations that were identified by the historical records search or public inquiries, (3) provide the ground-level follow-up surveying support needed to pinpoint the specific properties identified as radiation anomalies by the aerial surveys, and (4) screen large areas of town on a street-by-street basis. In identifying those properties where contaminated materials exist, the scanning system is used to detect changes in the gamma radiation field (relative to background levels) associated with the site, as observed from accessible roadways, alleyways, or other public thoroughfares.

At the majority of the sites included in the FUSRAP program and at all of the UMTRAP sites, the primary radionuclides of concern in the residual materials are members of the ^{238}U decay chain. Typically, the original onsite processing had removed the majority of the ^{238}U, leaving the daughter radionuclides in the waste material (principally ^{226}Ra and its immediate daughter products). Hence, methods to detect this residual contamination must involve the detection of ^{226}Ra. The ORNL scanning van was therefore designed specifically to locate radium-bearing materials by detecting the gamma-rays associated with the ^{226}Ra daughter, ^{214}Bi. Although the system was designed to be radium-specific, by a simple change in the appropriate instrument settings, and the application of a different data analysis algorithm, the van could be utilized to look for numerous other gamma-emitting radionuclides.

The following report sections provide the detailed documentation of the scanning system development. Step-by-step operating procedures are provided in a separate document.[3]

SYSTEM DESCRIPTION

The ORNL mobile gamma-ray scanning system consists of a specially-equipped van housing a sodium-iodide thallium-activated [NaI(Tl)] detection system. The detector consists of three NaI(Tl) crystals, supported in a lead-shielded steel frame to provide a large detector surface area for acceptance of gamma-rays through one side of the survey van. The detector height can be varied with a hydraulic lift mechanism to optimize the detector field-of-view.

The detector output is transferred to a discriminator and computer-controlled interface, designed and fabricated at ORNL. This unit provides for continuous analysis of data inputs for correlation of system location with count rate information. A ^{226}Ra-specific algorithm is employed to identify locations containing residual radium-bearing materials. Multichannel analysis capabilities are included in the system for additional qualitative radionuclide identification. The system is operator-controlled through keyboard instructions to an on-board mini-computer. Data output is provided on the computer video screen, a dual-channel strip chart recorder, and an on-line printer. Data storage is provided by a dual floppy disk system.

VEHICLE AND SUPPORT EQUIPMENT

The scanning vehicle is a modified 1979 Dodge B300 Maxivan (Fig. 1), ordered with the following options.

1. Heavy-duty chasis
2. Heavy-duty cooling system
3. 100-amp alternator
4. Oil cooling system
5. Dual battery system
6. Dual air conditioning system
7. Large capacity gas tank

ORNL-Photo 0998-82

Fig. 1. Modified Dodge Maxivan for use in mobile gamma-ray scanning

The original vehicle roof was modified by the addition of an ambulance-type fiberglass top. This modification increased the inside clearance to 150 cm (60 in.), allowing additional room for equipment installation and operator movement. Windows were added in the rear quarter of the vehicle, on each side, to provide greater visibility for the operator.

A 2.5-cm (1-in.) plywood floor was installed from the driver's compartment to the back of the van and covered with linoleum. Wooden base cabinets were fabricated to fit the left (driver's) side of the van. These cabinets provide lockable drawer space for storage of supplies, maps, spare instrumentation, support equipment, and the necessary technical manuals and logbooks. A large area work top was included for instrument repair and map reading. The operator area at the rear of the van was designed in a console manner to allow convenient access to all equipment. A view of this console area is provided in Fig. 2.

Electrical power on the road is supplied by a 4.5 kW gasoline-powered generator and an uninterruptible power source consisting of a DC to AC power inverter. External AC power can be provided through an alternate circuit during stationary operation. Both systems provide 115-VAC, 60-cycle line power. A battery charging unit is included to maintain sufficient charge on the vehicle battery system. Distribution of electrical power within the van is provided by direct lines and outlet strips. Voltmeters, ammeters, and frequency meters are used to monitor the primary power source. As shown in Fig. 3, the data-handling system (computer, interface unit, and strip chart recorder) is maintained on the uninterruptible power source, while the remaining equipment is directly supplied by the generator or battery supply. Hence, in the event of a generator failure during operation, data storage will be maintained.

Other features incorporated into the vehicle include a radio telephone and an internal intercom sytem. The radio telephone allows communication between ORNL and the field crew during operation for rapid transmittal of survey results or instructions. The internal intercom consists of an aircraft-type voice-activated headphone system that facilitates communications between crew members when noise levels necessitate their use. In order to conduct field tests, electronic diagnostics, and to perform normal system maintenance, support electronic

ORNL-Photo 1003-82

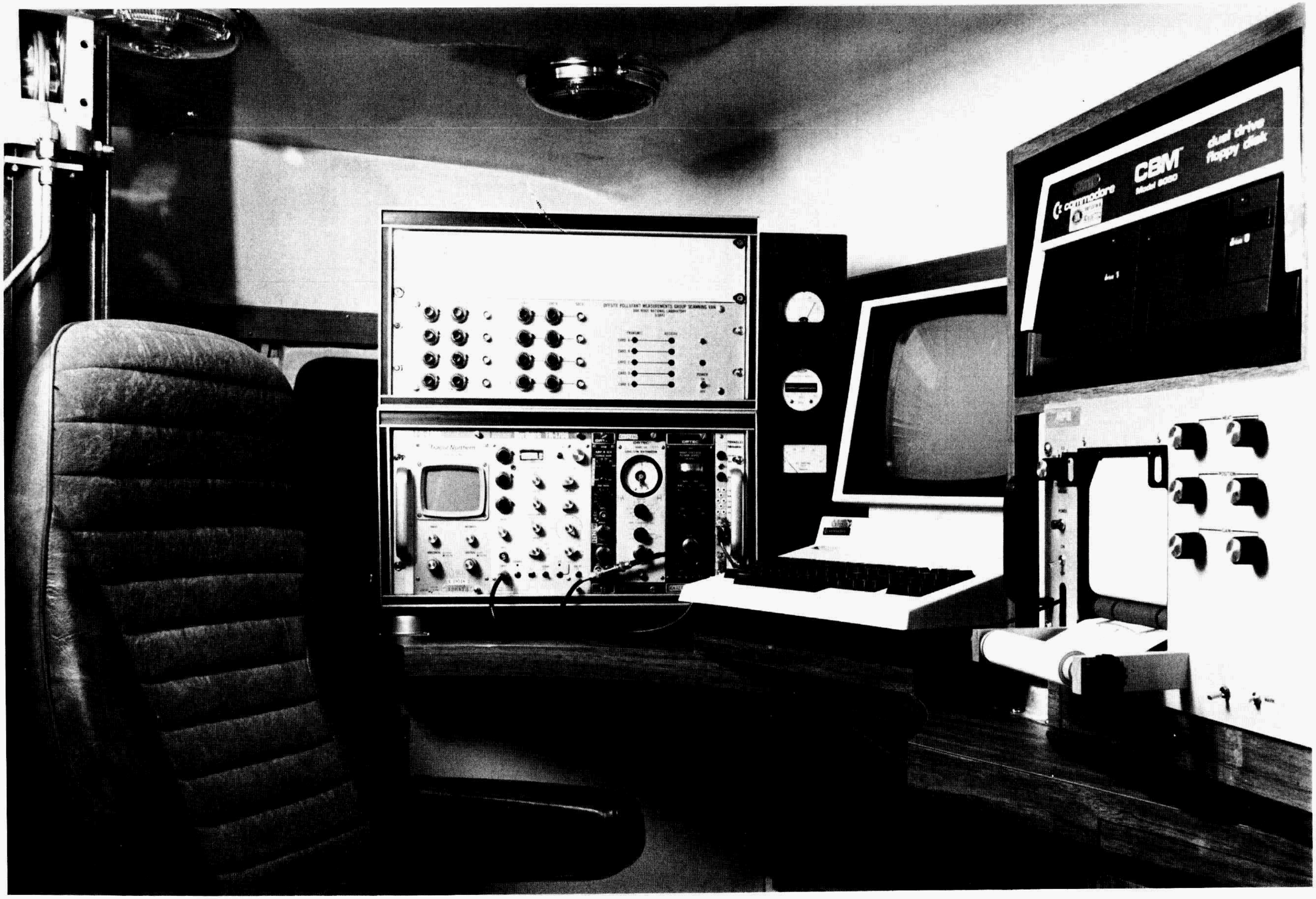

Fig. 2. Scanning van operator's console area

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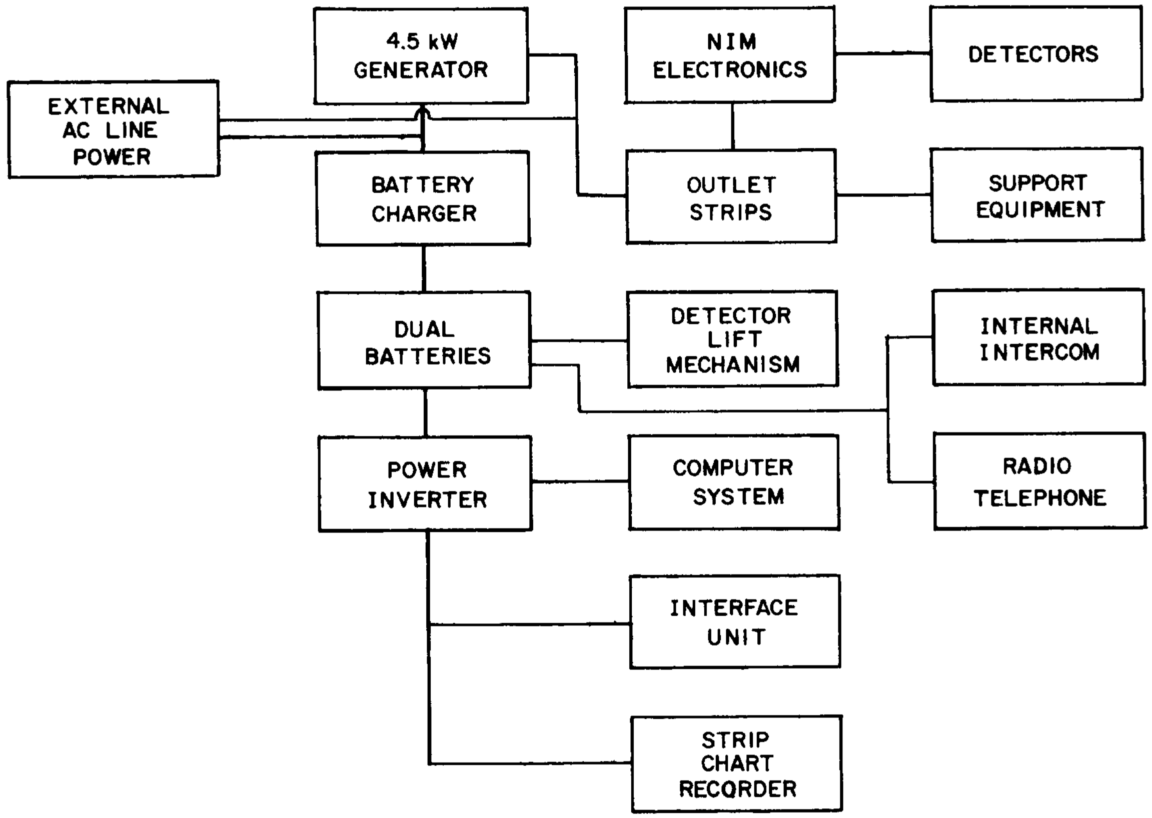

Fig. 3. Schematic of scanning van electrical power distribution system

equipment is maintained onboard. This equipment includes a portable digital multimeter, an oscilloscope, a frequency counter, and a pulse generator. Ancillary electronics supplies and tools, as well as an adequate inventory of mechanical tools, are also stored on the van.

SODIUM-IODIDE DETECTORS

The gamma-ray detection capability on the scanning van is provided by three 10-cm x 10-cm x 40-cm (4-in. x 4-in. x 16-in.) Polyscin® NaI(Tl) log crystals, manufactured by Harshaw Chemical Company. These crystals are housed in thin-walled stainless steel, each with an integral 9-cm (3.5-in.) photomultiplier tube (Fig. 4). The photomultiplier tube bases are wired for high voltage inputs and signal outputs, with focus and tube gain adjustments. The Polyscin® crystal is more resilient than standard NaI(Tl) crystals, a characteristic that is particularly important in the mobile environment that is required of this scanning system. Greater fluctuations in temperature can be tolerated, and the probability of crystal fracture due to mechanical shock is reduced.

Initial testing and evaluation of the crystals was performed by the Instrumentation and Controls Division at ORNL. At the optimum operating voltage of 1000 VDC, the crystal resolutions (full width at half maximum - FWHM) for the 0.662 MeV ^{137}Cs peak were determined to be 6.6%, 6.7%, and 6.7%, respectively, for each of the three units. Since the system design called for the three crystals to act as one detector, the gain and focus adjustments were made to provide a matched output. The observed resolution (FWHM) of the summed signal from all three crystals for ^{137}Cs is 7.0%.

DETECTOR SHIELDING AND SUPPORT

To support the three NaI(Tl) crystals in a side-by-side, vertical position, a steel frame was designed and fabricated at ORNL. In order to restrict the field-of-view of the detectors out one side of the van, shielding was provided for the back, sides, and top of the crystals. This shielding consisted of 2.5-cm (1-in.) lead sheets machined to fit into the crystal housing. Two lead sheets (5 cm total thickness) were used on the back of the detectors, one on each side, and one on the top.

ORNL-Photo 8396-81

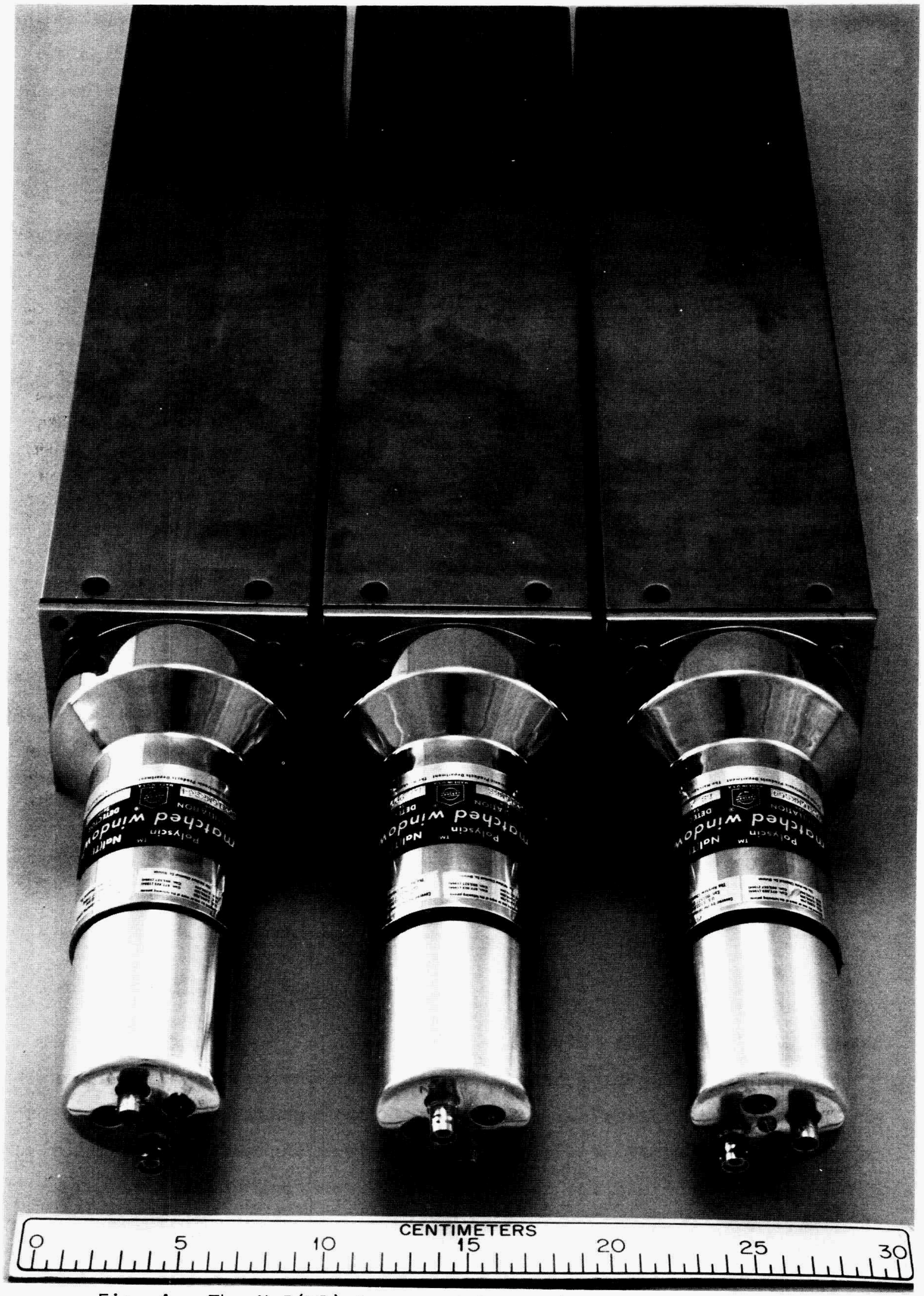

Fig. 4. The NaI(Tl) log crystals used for gamma-ray detection on the scanning van

Styrofoam insulation was inserted between the lead sheets and the crystals to reduce damage to the crystals from vibration or temperature fluctuations. Neoprene cushions were inserted between the crystal casings for added protection. A cross-sectional view of the complete detector assembly is given in Fig. 5, and a photograph of the front side (without the styrofoam cover on the detector front side) is shown in Fig. 6. The completed assembly effectively provides a 30-cm x 40-cm (12-in. x 16-in.) detector surface area for acceptance of gamma-rays.

The detector assembly is mounted on a hydraulic lift mechanism to allow for variation in detector height relative to the ground. By increasing the detector height, a better angle of acceptance is obtained for gamma-rays originating below the soil surface. In addition, shielding problems resulting from street-side obstacles (i.e., parked cars) can be minimized. The lift mechanism consists of two cable-type hydraulic cylinders mounted on a 1-cm steel plate with cable connections to the detector assembly. The total height of the lift mechanism is 142 cm (56 in.), with a 100-cm (40-in.) cable travel. Hydraulic pressure for cable movement is provided by a Monarch Model M303 hydraulic pump/reservoir. The hydraulic unit is remote-controlled and is powered by the vehicle 12 V battery system. A limit switch is mounted at the top of the frame to cut off electrical power to the pump when the maximum travel distance has been reached. Pressure relief is included in the piping network, with overflow routed into an auxiliary hydraulic fluid reservoir. Once the assembly is positioned at the maximum height, steel pins are inserted through the frame and detector assembly, and the hydraulic pressure released. A view of the hydraulic lift mechanism, with the detector assembly in the raised position, is given in Fig. 7. A view of the lowered assembly is provided in Fig. 8.

The detector lift assembly is mounted in the rear of the scanning van on the right (passenger) side. In this position, the detector's field-of-view is out the right side of the van. With the detector assembly in the raised position, the center of the detector is 185 cm (73 in.) above the ground surface. During normal scanning operations, the detector is maintained at the maximum height. Under highway driving conditions, the assembly is lowered to provide better vehicle stability.

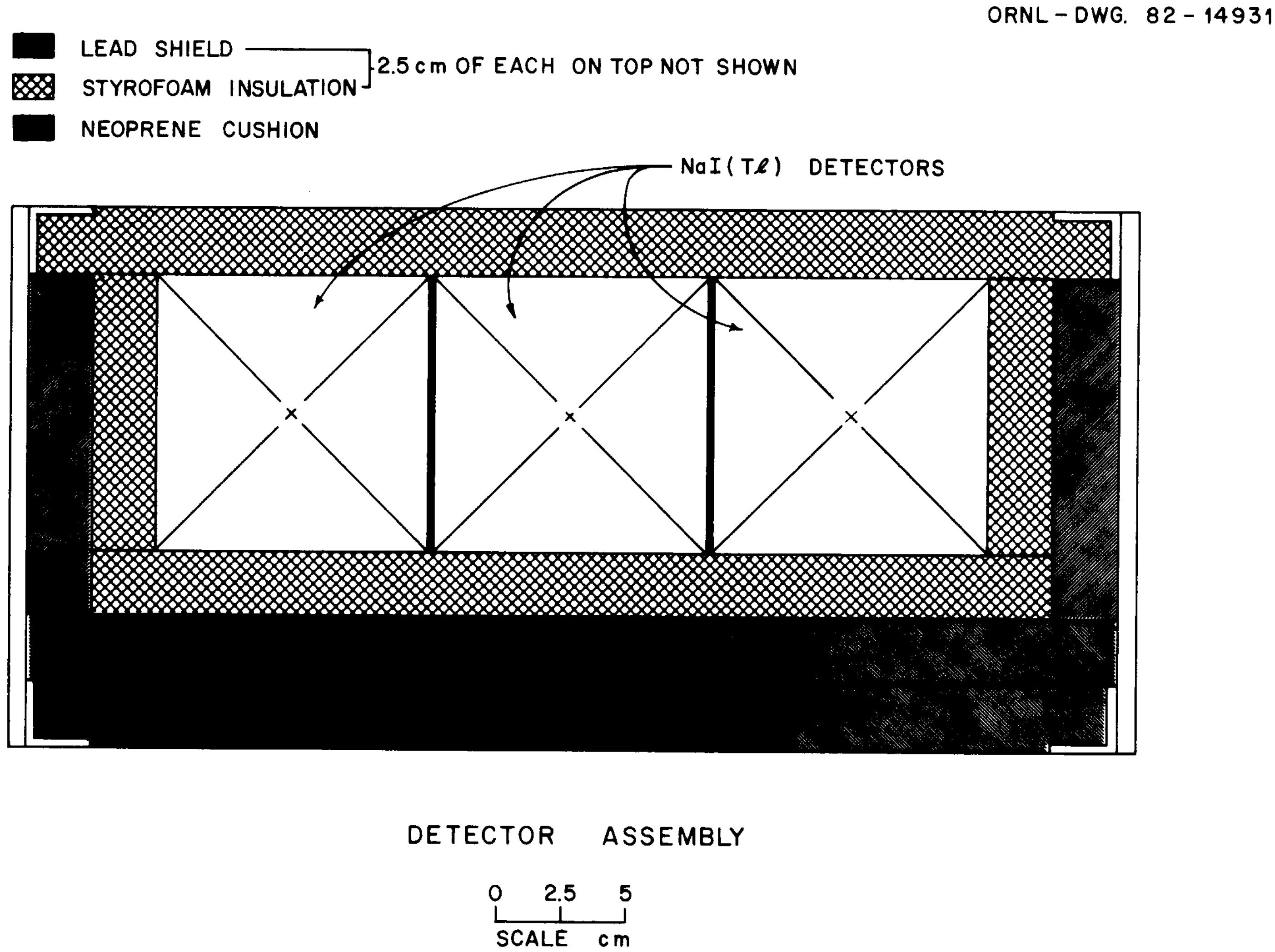

Fig. 5. Schematic of detector assembly

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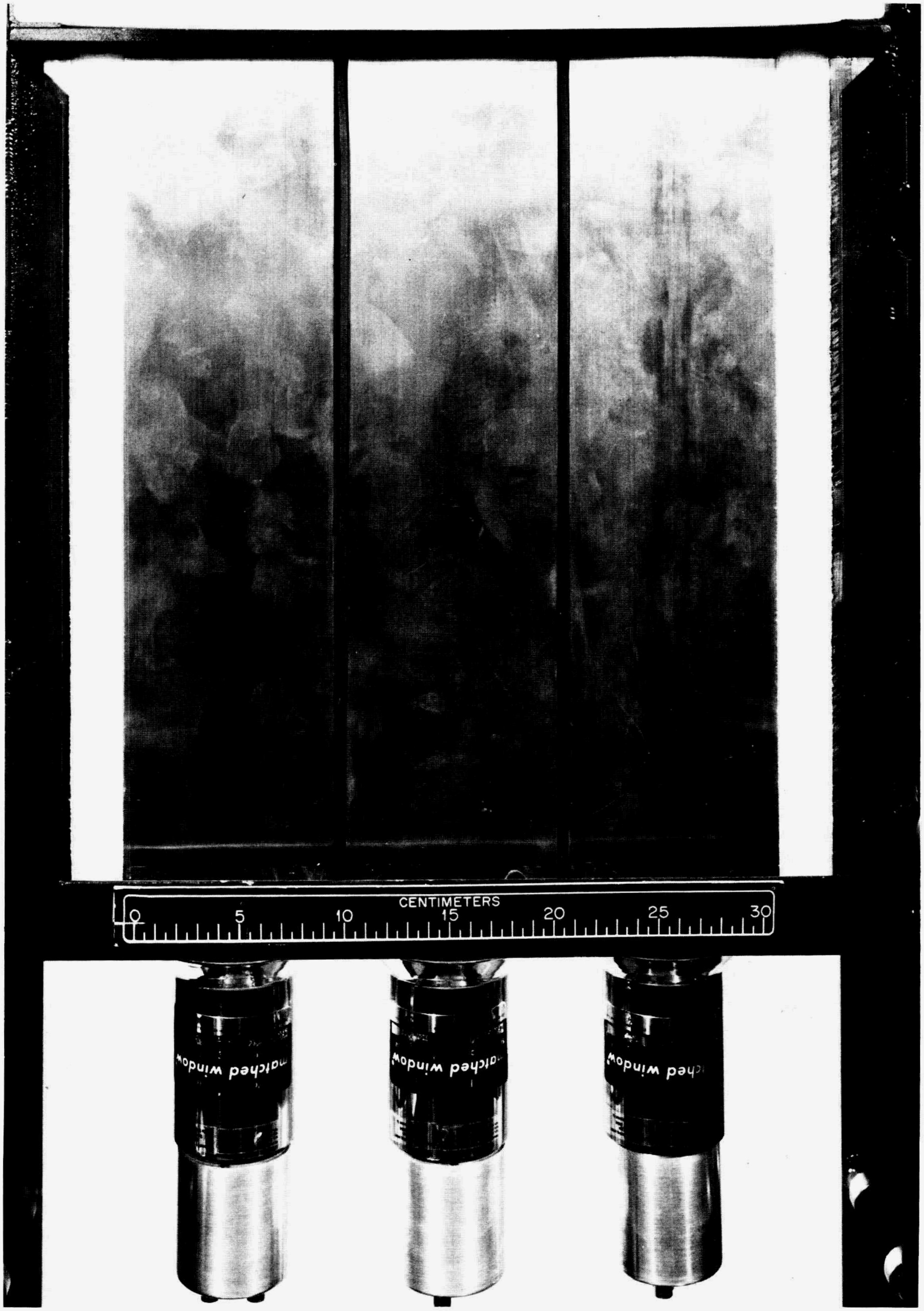

Fig. 6. Front view of detector assembly

ORNL-Photo 8594-81

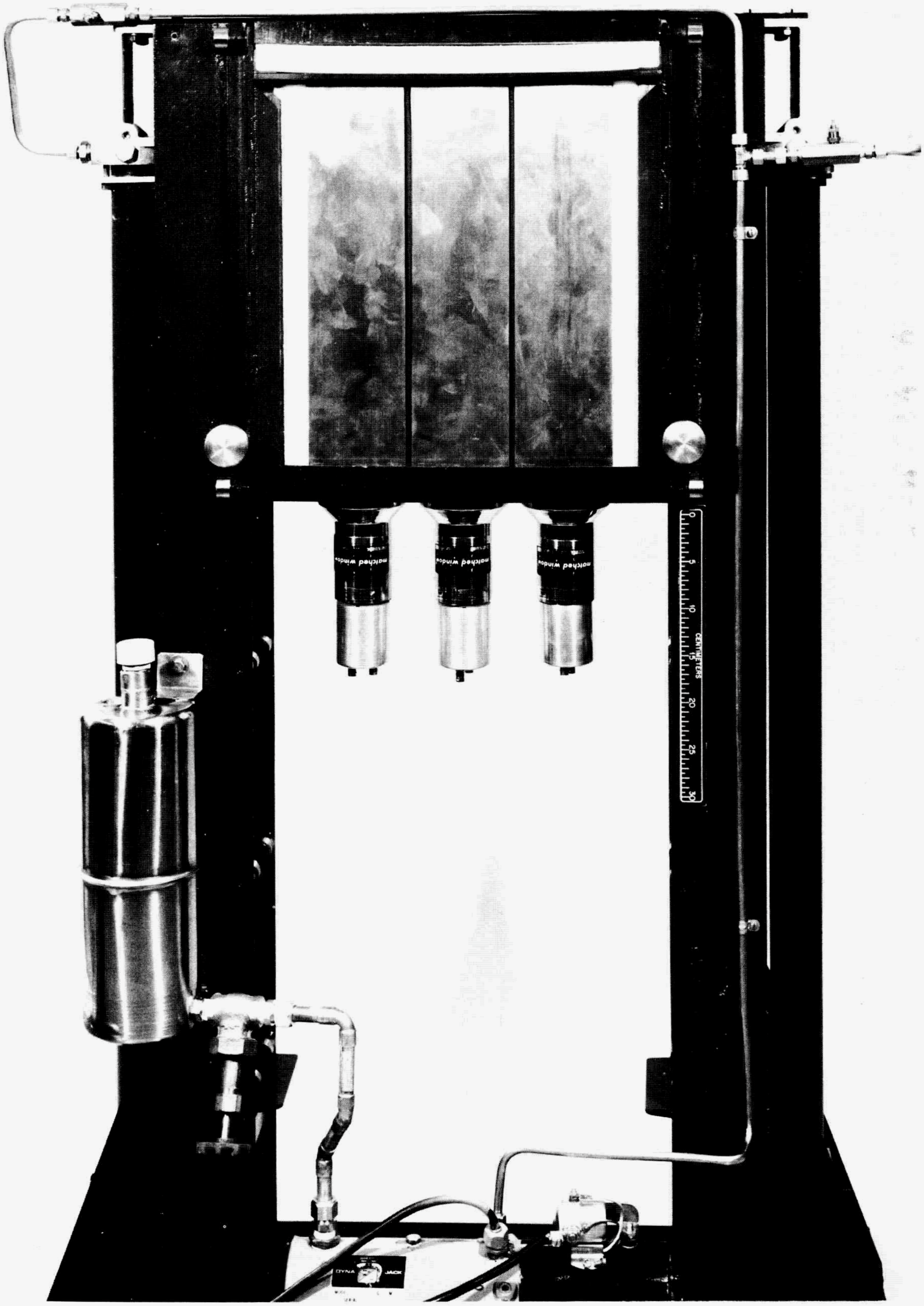

Fig. 7. Hydraulic lift mechanism/detector assembly in raised position

ORNL-Photo 8596-81

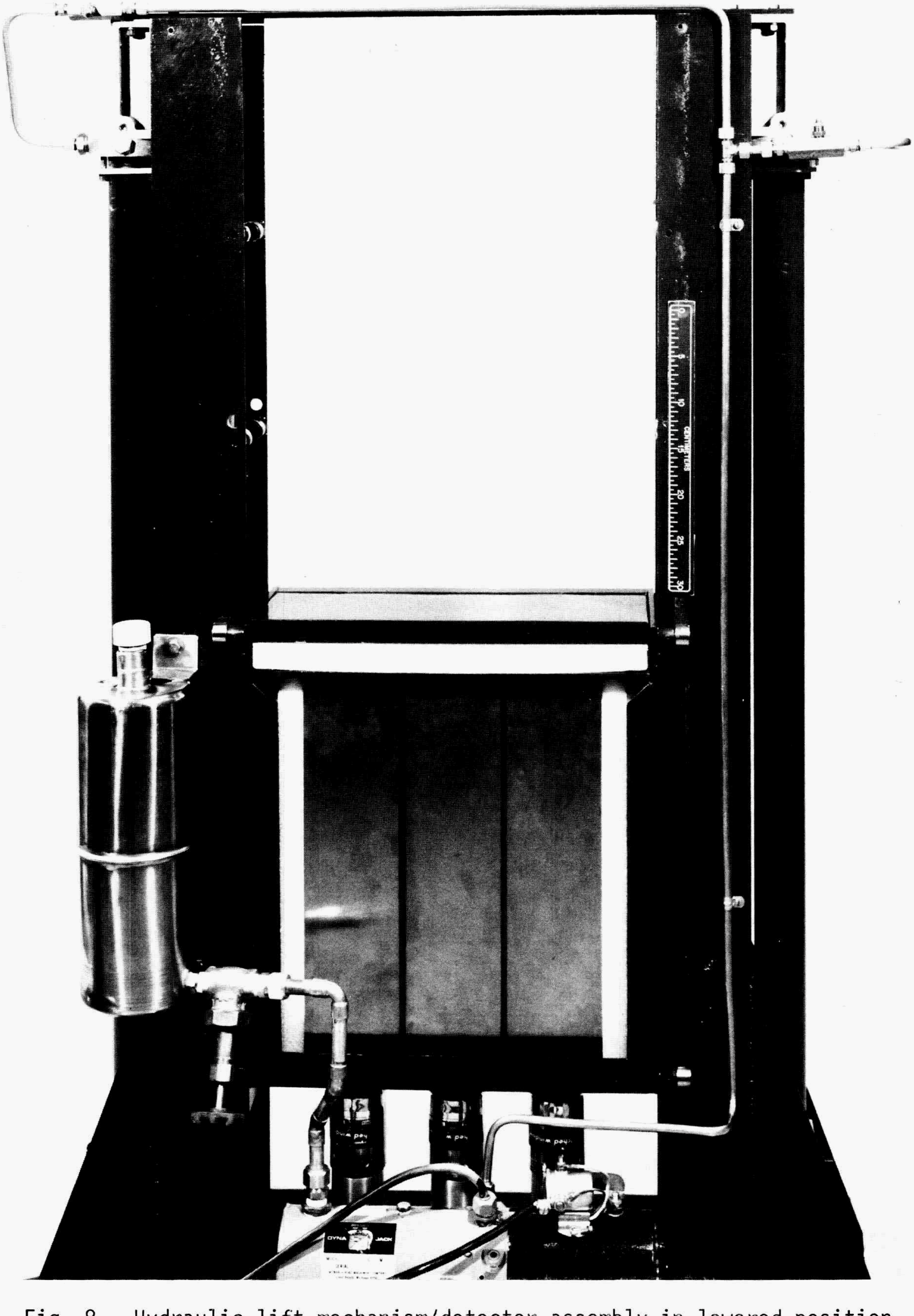

Fig. 8. Hydraulic lift mechanism/detector assembly in lowered position

DATA ACQUISITION SYSTEM

The scanning van data acquisition system is comprised of all the associated electronic equipment that interfaces directly with the NaI(Tl) detector, analyzes the detector output, acquires distance information, provides visual and audible data interpretation, and documents the scan results. Conceptually, this system can be broken down into three major functional units and three ancillary components, as depicted in Fig. 9. The major system units include:

1. <u>NIM Electronics</u> - All instrument modules associated with the Nuclear Instrumentation Module (NIM) equipment rack. These modules interface directly with the detector by providing high voltage, output amplification, and preliminary data analysis capabilities.

2. <u>Interface Unit</u> - Specially-designed electronic unit that provides the communication link between the NIM electronics and the computer system. The unit supplies discrimination and counting capabilities for analysis of input from the detector and the distance transducer.

3. <u>Computer System</u> - Desk-top computer and associated data storage and printing units that control the operation of the entire scanning system.

The ancillary components consist of a distance transducer mounted on the vehicle drive shaft, a strip chart recorder, and a pair of audio alarms. Detailed discussions of each of these data acquisition system units are provided in the following sections.

<u>NIM Electronics</u>

As shown in Fig. 9, the NIM electronics package includes a high-voltage power supply, a preamplifier, an amplifier/single-channel analyzer, a ratemeter, and a multichannel analyzer with display unit. Except for the preamplifier, which is mounted on the detector assembly, all NIM modules are contained in a single instrument rack in the operator console area (Fig. 10). Instrument manufacturers and model numbers for the NIM electronics used on the scanning van are provided on Fig. 9. For detailed descriptions of these units, refer to the appropriate manufacturers' technical manual.

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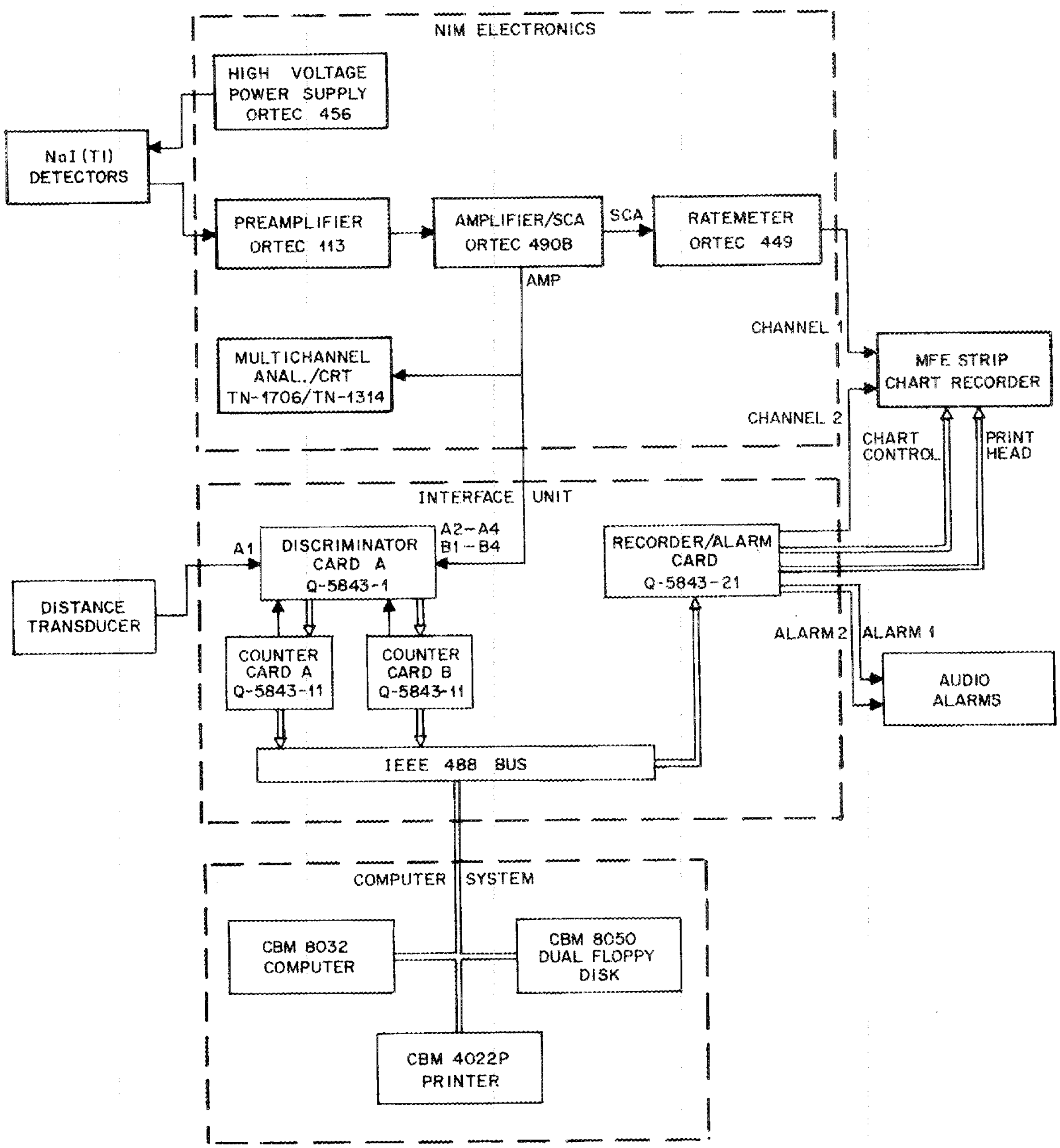

Fig. 9. Data acquisition system flow block diagram

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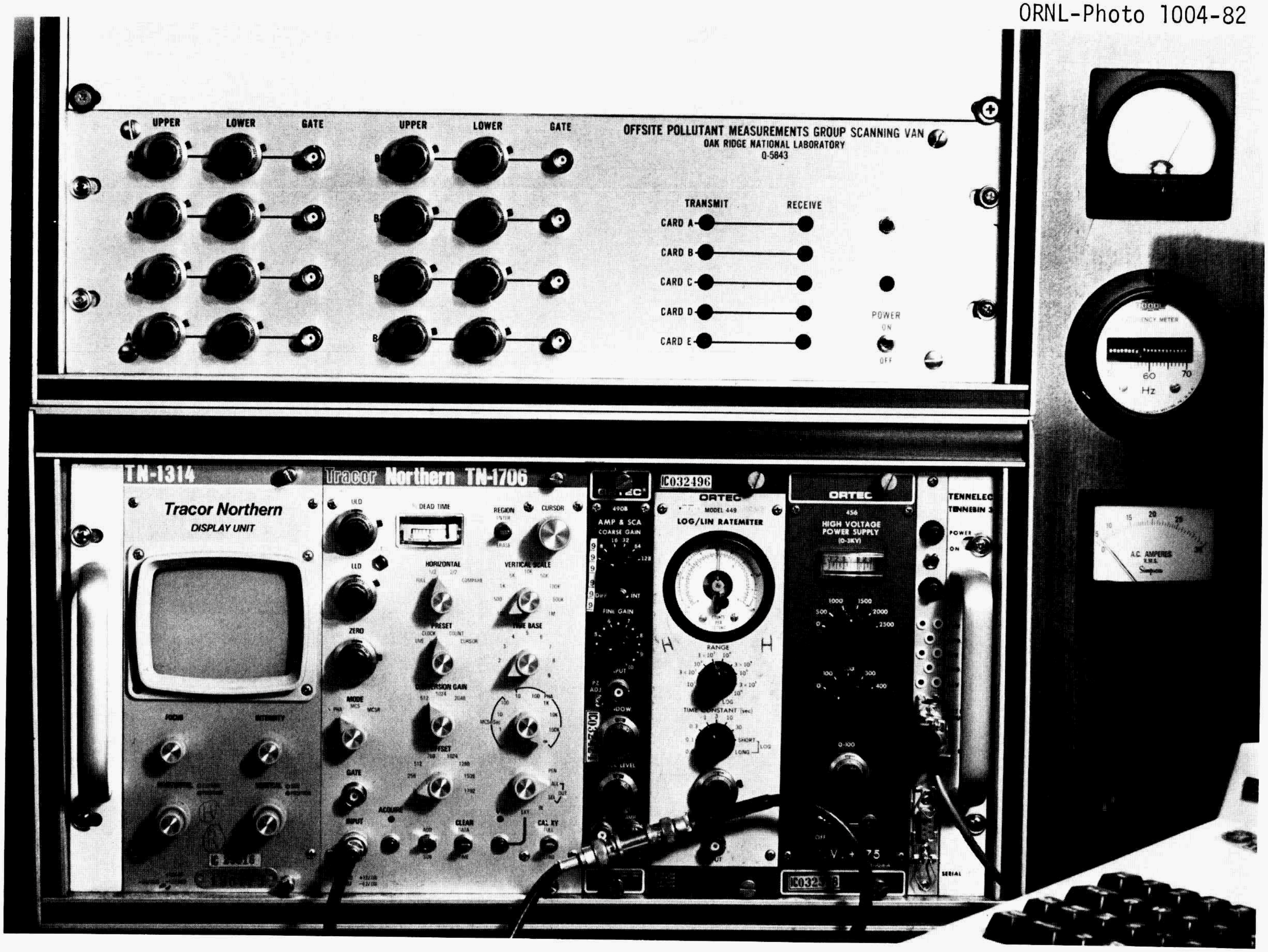

Fig. 10. Front view of the NIM electronics unit (lower bin) and Interface unit (upper bin)

In order for the NaI(Tl) crystals to appear as a single detector to the NIM instrumentation, the high voltage and output signal connections of each photomultiplier tube have been paralleled. The detector is biased at 1000 volts by an ORTEC Model 456 high-voltage power supply and the signal outputs are connected to an ORTEC Model 113 scintillation preamplifier. The output signal on the preamplifier is applied to an ORTEC Model 490B amplifier/single-channel analyzer (SCA). The 490B provides two separate output signals; an amplified signal, and a portion of the amplified signal that has been selected by the single-channel analyzer. The SCA output signal is converted to an analog signal by the ORTEC Model 449 ratemeter. The analog signal is then applied to one of the data channels of the ancillary strip chart recorder. The amplified output of the 490B is connected to the Tracor Northern Model TN 1706 multichannel analyzer and the Interface unit. The multichannel analyzer is used for system calibration and for qualitative analysis of the detector signal. The analyzer is manually controlled with output provided to the Tracor Northern Model TN 1314 display unit.

Interface Unit

The Interface unit, designed and fabricated by the Instrumentation and Controls Division at ORNL, consists primarily of four printed circuit boards. As shown in Fig. 9, the cards provide discrimination and counting capabilities, as well as interfacing the computer system with the distance transducer, strip chart recorder, and the audio alarms. Schematic drawings of the cards are included as Appendix I, with the appropriate drawing numbers referenced on Fig. 9.

Discriminator Card

The discriminator card selects the regions-of-interest (ROI) of the analog input signals that are to be analyzed by the computer. The circuit board contains eight separate window discriminator circuits. The ROI selected by these circuits are established by the 10-turn Helipots mounted on the front panel of the Interface unit (Fig. 10). These pots set the upper and lower threshold (0-8 VDC) for each of the eight data channels. Input signals outside the specified range do not generate an output pulse to the counter cards. The discriminator card is divided into two sections corresponding to the A and B counter cards which receive the output from the discriminator. The input data channels are labeled A1 to A4 and B1 to B4, corresponding to the data flow path through the counter cards. Channel A1 receives its input from the distance transducer, while the remaining channels A2 through B4 accept parallel amplified signal outputs from the ORTEC 490B amplifier.

Counter Cards

Each of the two counter cards (A and B on Fig. 9) contains four separate eight-decade counter/latches, with the associated timing and control logic. Interface circuitry is provided for communication with the computer system via the IEEE 488 bus. Both counter cards are designed to accumulate data from the discriminator board for a one-second period, then transmit the data from all four of its counters as a data burst to the computer.

The counter/latches are Large Scale Integrated (LSI) circuits (LS7030) manufactured by LSI Computer Systems, Inc. This integrated circuit contains an eight-decade BCD counter, latches, and data-multiplexing circuitry. After accumulating data from the appropriate input channel (A1 to A4 or B1 to B4), the discriminator outputs are disabled, the contents of each counter register are transferred to the latches, and the counters are cleared. The timing and control logic establishes the one-second data acquisition period. The time base is divided down from a 10-MHz crystal oscillator. The contents of the latches are then multiplexed onto the computer IEEE 488 bus. This computer interface is provided by a Fairchild digital integrated circuit (96LS488) and a tri-state buffer. The Fairchild circuit contains all the necessary logic to decode the address and for the bus handshake operations. The address for each counter card is selected by programming the Fairchild circuit with the dip switches mounted on the board. When the computer addresses the counter card, the Fairchild circuit enables the tri-state buffer and controls the data transfer to the 488 bus. The format of the data burst to the computer calls for the insertion of a comma between the data from each counter and the use of a carriage return as the delimiter at the end of the transmission.

Recorder/Alarm Card

The recorder/alarm card was designed to provide the interface between the computer, the strip chart recorder, and the audio alarms. This circuit board receives all input data and instructions from the computer via the IEEE 488 bus. The card contains two dedicated channels for transmission of data to the strip chart recorder, and an instruction decade register for control of strip chart options and the two separate audio alarms. The data channels provide an analog signal for strip chart pen movement through a digital-to-analog computer buffer, and digital data for chart print-head operation. A 16-character memory buffer is included in the circuit to minimize data transfer time to the chart print head. Following computer transmission of the data into this storage buffer, the information is transferred to the print head drive electronics independently of the other card functions. The instruction decade register allows computer control of the strip chart drive motor power and event marker (see strip chart description in a following section), as well as sounding the vehicle speed and "hit" criteria (see Software Development section) audio alarms when computer analysis of the scan data indicates that the appropriate criteria have been exceeded.

Computer System

The heart of the data acquisition system on the scanning van is the computer system. This system (1) is the primary means of communication between the system operator and the electronics, (2) provides continuous analysis of the scan data, utilizing a ^{226}Ra-specific algorithm, (3) displays the scan results on a Cathode Ray Tube (CRT) screen for operator observation, (4) maintains a permanent record of the data on floppy disk, and (5) provides printing capabilities for hard copy of the scan results. The computer system consists of three separate units, all manufactured by Commodore Business Machine (CBM), including the CBM 8032 computer, the CBM 4022P tractor printer, and the CBM 8050 dual-drive floppy disk. A photograph of these units is shown in Fig. 11, with a brief description of their operating characteristics given as follows. For more details of the capabilities of these systems, refer to the appropriate technical manual.

ORNL-Photo 3381-82

Fig. 11. Commodore Business Machine computer system

The CBM 8032 computer is a self-contained unit with a keyboard and an 80-column CRT screen. The unit has 32K bytes of user memory and utilizes the CBM Version 4.0 BASIC language. The BASIC library and operating instructions are stored in Read Only Memory (ROM). The operations systems for the associated disk unit and printer are contained within these peripherals, thereby minimizing the use of computer memory for this purpose. Operator interaction with the computer peripherals, as well as the Interface unit, are provided through keyboard entries into the computer. Interpretation of the keyboard commands is accomplished through the use of a CBM Disk Operating System (DOS) program and an ORNL-developed program for all other scan-related functions (see Program Description section for details).

The CBM 8050 disk drive unit is a dual-drive diskette storage device consisting of read/write controls, drive motor electronics, two drive mechanisms, two read/write heads, and track positioning mechanisms. Each drive is designed for use with a single- or double-density, single-sided, 13-cm (5.25-in.) disk. The total storage capacity for each disk is approximately 500 K bytes. The disk unit contains a memory buffer to allow computer data transfer as needed, without delaying subsequent program execution. During normal system operation, Drive 0 is utilized for operating programs interfacing, and Drive 1 is used for scan data storage.

The CBM 4022P printer is a tractor-feed, bi-directional printing device operated through software control from the CBM computer. It prints alphanumeric and graphic characters on an 80-character field. The print head is a dot matrix type, capable of printing 60 characters per second. Printer usage is normally limited to the printout of data summaries at the end of each scan file (see Scanning Methods section), although it is also used to provide hard copies of programs, file directories, and raw data lists.

Ancillary Equipment

Strip Chart Recorder

A dual-channel strip chart recorder, manufactured by MFE Incorporated, is included in the scanning system for additional visual display of scanning data and to provide backup data documentation (Fig. 12). The unit utilizes heat-sensitive chart paper in conjunction with variable temperature marking pens for data recording. Additional data documentation on the chart is provided by an alphanumeric printer and an event marker, both of which print along the margins of the paper. The recorder was modified at ORNL to allow additional computer control of chart drive power and the event marker.

As shown in Fig. 9, input to the strip chart is provided by the ORTEC 449 ratemeter for recording of gross count rate information (channel 1), and from the computer through the Interface unit recorder/alarm card for recording of a modified ratio (channel 2) that identifies data exceeding the preset "hit" criteria. The alphanumeric printer is used to record on the left chart margin each file name as it is created, and to print the vehicle distance traveled every 20 seconds during the scan. The event marker indicates in the right margin of the chart when keyboard entries are made into the computer while scanning. The alphanumeric printer and the event marker inputs are essential in the correlation of the chart data with the data stored on the floppy disk.

Distance Transducer

In order to correlate the location of the scanning vehicle with the gamma radiation measurements being made, a distance transducer was designed and fabricated at ORNL. This device, mounted on the vehicle drive shaft, converts the rotation of the shaft into light pulses that can then be counted. The number of pulses per unit time are correlated by the computer to the distance traveled during that time period using a conversion factor (ft/pulse) determined by system calibration procedures.

The transducer consists of matched infrared light emitter and detector units, secured in an aluminum block holder, and spaced approximately 1.3 cm (0.5 in.) apart. The photo transistor and driver transistors are wired as a Darlington amplifier to improve the detector

ORNL-Photo 1000-82

Fig. 12. Front view of the MFE strip chart recorder (lower bin)

sensitivity. The holder is located underneath the scanning vehicle, adjacent to the drive shaft, attached to the transmission housing. A fabricated metal disk, with four equally-spaced holes, is mounted on the shaft at that point and is positioned between the light emitter and detector (Fig. 13). As the drive shaft and metal disk rotates, the holes alternately align with the light source, allowing light to pass to the detector. A biased voltage of +5 V for emitter operation is provided by the NIM bin power supply. When light strikes the detector, a +5 V pulse is generated and transferred to the Interface unit discriminator card data channel A1. The pulses are summed by the counter card circuitry and the data transmitted to the computer for conversion to distance information. With the present gear ratio of the vehicle transmission, and the current tire size (at proper inflation), each pulse generated by the transducer represents approximately 10 cm (4 in.) of vehicle travel.

Audio Alarms

Audio alarms have been incorporated into the scanning system to alert the operator of measured radiation levels exceeding the preset "hit" criteria, and to warn the driver when the scanning speed is too fast. Two solid state alarm devices are used, one for each purpose. A pulsating alarm is triggered when the appropriate "hit" criteria are exceeded during the one-second counting interval. The other alarm, located next to the driver's compartment, is activated at a vehicle speed of approximately 3 m/s (10 ft/s). Both alarms are controlled by the CBM computer, with commands routed through the Interface unit recorder/alarm card.

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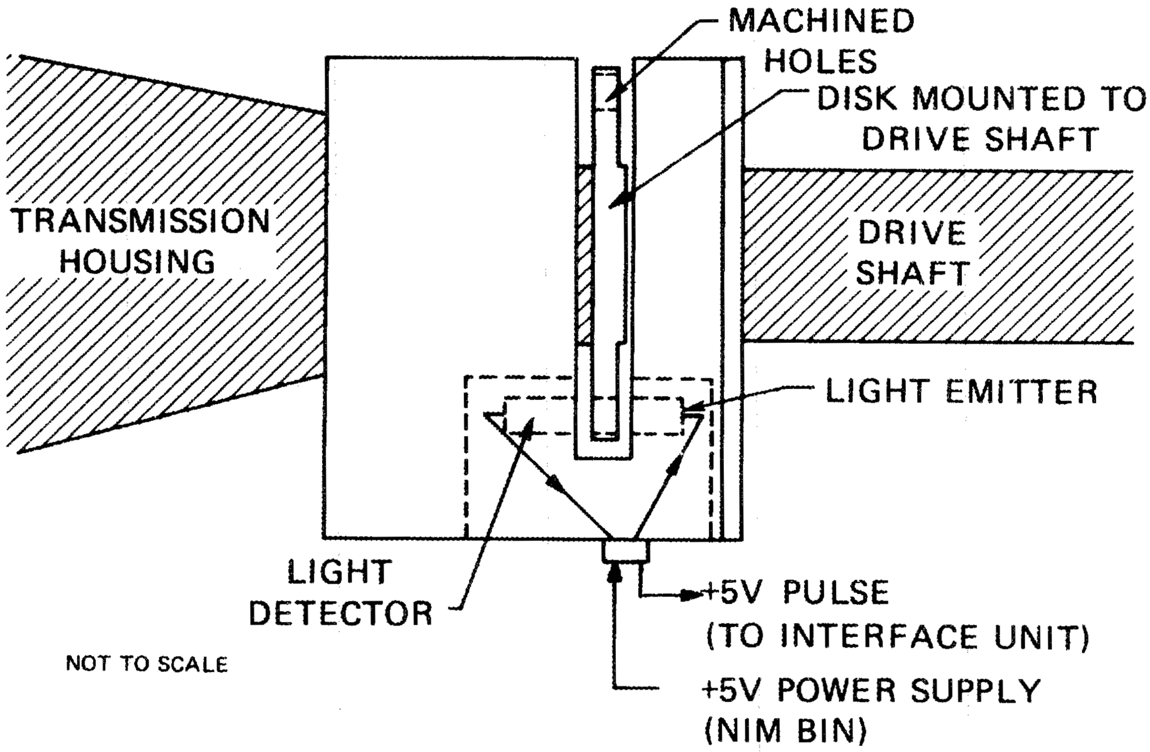

Fig. 13. Schematic of scanning van distance transducer

SOFTWARE DEVELOPMENT

In order to effectively and efficiently utilize the information obtained by the detection and data acquisition systems, computer control and analysis capabilities were necessary. The software developed at ORNL for this purpose was designed to provide (1) ease in operator control of the total system, (2) immediate onsite analysis of the scan data, and (3) adequate documentation of the scan results. The data analysis technique was developed to make the scanning system radium-specific in its detection of radiation anomalies, and to minimize the incidence of "false hits" (e.g., the identification of properties as radiation anomalies when they actually are not). To this end, statistical methods were employed for comparison of input data with normal "background" radiation levels.

This report section presents details of the data analysis techniques employed and provides documentation of the computer program developed. The complete program listing is given in Appendix II.

DATA ANALYSIS TECHNIQUE

The algorithm employed for continuous analysis of the scan data was developed from techniques utilized for aerial scanning of radiologically-contaminated areas.[4] In this analysis, comparison is made between the observed count rates arising from certain naturally-occurring radionuclides and residual radioactive materials. When the observed ratio of these count rates is determined to be statistically different from normal background, the location is identified as a radiation anomaly. Application of this technique for mobile scanning involved modifications in background determinations and in data reduction. The algorithm employed in the scanning system was optimized during field testing at UMTRAP vicinity properties where comprehensive onsite radiological characterization had been completed (see System Calibration section).

In the ORNL system, three regions-of-interest for ^{226}Ra (the 609 keV, 1120 keV, and 1764 keV energy peaks of ^{214}Bi), and one for ^{232}Th (the 2614 keV energy peak of ^{208}Tl) are analyzed each second.

Based on the observed count rates in these energy regions throughout a given area, an average "background" radium-to-thorium ratio ($\bar{R}$) can be determined as follows:

$$\bar{R} = Ra/Th = \frac{\text{Ra count rate}}{\text{Th count rate}} = \frac{C(609) + C(1120) + C(1764)}{C(2614)} \quad (1)$$

where

$C(x)$ = observed count rate for the (x) keV photopeak

Associated with this average ratio is a standard deviation that is dependent upon the variation of the individual Ra and Th components.

$$\sigma_{\bar{R}} = \bar{R}\left[\left(\frac{\sigma_{Th}}{\bar{x}_{Th}}\right)^2 + \left(\frac{\sigma_{Ra}}{\bar{x}_{Ra}}\right)^2\right]^{1/2} \quad (2)$$

where

$\sigma_{\bar{R}}$ = standard deviation of the Ra/Th ratio

$\bar{R}$ = average Ra/Th ratio in background area

σ_{Th} = standard deviation of the count rate in the Th energy region

$\bar{x}_{Th}$ = average Th count rate in background area

$\bar{x}_{Ra}$ = average Ra count rate in background area

σ_{Ra} = standard deviation of the count rate in the Ra energy regions

Thus, for any area to be scanned, there can be computed some Ra/Th ratio, $\bar{R} \pm k\sigma_{\bar{R}}$ (where k is the specified two-sided confidence level), that can be used for comparison with the scan data obtained for each street within that area.

In identifying locations containing residual ^{226}Ra-bearing materials, the scanning system utilizes criteria ("hit" criteria) all based on the observed background Ra and Th count rates and the computed Ra/Th ratio. The first criterion which must be met involves the determination of a minimum count rate in the Ra energy regions that results in a detectable change in the observed Ra/Th ratio. The mathematical expression for this criterion is as follows (derived in Reference 4).

$$C_m = 2k\left[\bar{x}_{Ra}(\bar{R} + 1)\right]^{1/2} + k^2 \qquad (3)$$

where

C_m = minimum Ra count rate above background

k = specified 2-sided confidence level

$\bar{x}_{Ra}$ = average Ra count rate in background area

$\bar{R}$ = average Ra/Th ratio in background area

For a detected count rate to pass this first hit criterion, the total count rate in the three Ra energy windows must exceed $\bar{x}_{Ra} + C_m$.

The second and third hit criteria, either of which must be met before a location is considered an anomaly, are based on comparison of the observed Ra/Th ratio with the computed background ratio. In the second criterion, the observed and background ratios are directly compared, and if the

$$\text{observed Ra/Th} > \bar{R} + k\sigma_{\bar{R}}, \qquad (4)$$

the location is considered to have exceeded the criterion. In the third criterion (called the positive difference technique), a mathematical difference is computed,

$$\text{difference} = \text{observed Ra} - [\text{observed Th}(\bar{R} + k\sigma_{\bar{R}})]. \qquad (5)$$

When this difference is positive, the observed count rate is considered above the criterion.

The second and third criteria, although utilizing the same background ratio for their basis, provide different degrees of sensitivity, depending on the magnitude of the observed count rates in the energy windows. Their combined use provides for a reduction in the incidence of false hits.

In application of the data analysis technique, the 95% confidence level has been specified for statistical analysis of the background data (k = 1.96). For determination of the minimum count rate criterion (Equation 3), the 68% confidence level (k = 1.0) was judged to be the most effective, based on field test results. As an example of the analysis technique, the following data are presented from the field testing. For details of the methods used in obtaining these data, see the Scanning Methods section of this report.

Average background Ra count rate (cps)	262 ± 32
Average background Th count rate (cps)	23 ± 10
Average background Ra/Th ratio	11 ± 4
Computed hit criterion for Ra (cps)	377
Ra/Th ratio used for hit criterion	15

Hence, for a location to be considered a radiation anomaly within the background area for which these data apply, the total Ra counts in any one second interval must exceed 377 and either the corresponding Ra/Th ratio must exceed 15 or the positive difference technique (Equation 5) must indicate a positive value.

PROGRAM DESCRIPTION

As described in the introduction to this section, the software package developed for the scanning system was designed to allow simple operator control, continuously analyze the scan data, and provide adequate documentation of the results. Operator control through keyboard entry was required for accessing the computer peripherals (disk drive and printer), and supplying necessary inputs for data analysis and documentation. The data analysis requirements included (1) providing system calibration aids, (2) determination of hit criteria for data correlation, (3) conversion of distance transducer input into distance traveled information, (4) correlation of distance information with count rate inputs, and (5) comparison of all scan data with the predetermined hit or alarm criteria.

In order to provide ease in operator control of the computer system, a single program was developed to access subroutines that address each of the specific data acquisition or documentation needs. In conjunction with this program (referred to as the Scan Program), the CBM Disk Operating System (DOS) Program is utilized for floppy-disk drive control. The Scan Program (Appendix II) is written in BASIC and includes six primary subroutines (Program Modes):

1. Calibration Mode - Used for system checkout
2. Background Mode - Defines background for area to be scanned
3. Scan Mode - Records all street survey data (scan data)
4. Identification Mode - Used to pinpoint anomaly locations
5. File List Mode - Prints summarized scan data
6. Data Dump Mode - Prints all stored raw data

Computer log-on instructions are provided as a separate part of the program. Operator access to the different program modes is accomplished by single-keystroke entries. Interaction between computer and operator is normally prompted by statements appearing on the computer CRT. Program mode execution is terminated with the EXIT key resulting in an automatic listing of the mode directory. A schematic diagram of the basic program flow is given in Fig. 14, with discussion of each mode of operation as follows.

Log-on Sequence

After the DOS support program has been run to establish computer communications with the disk drive, and the Scan Program executed, the log-on sequence is then conducted. This sequence involves interaction between the computer and operator to record the operator's name and the date of data collection. When this information is provided, the program modes can then be accessed. Under normal operations, the Background Mode is automatically entered to obtain the necessary data for scanning activities. If other modes are desired, they must be specifically addressed at this time.

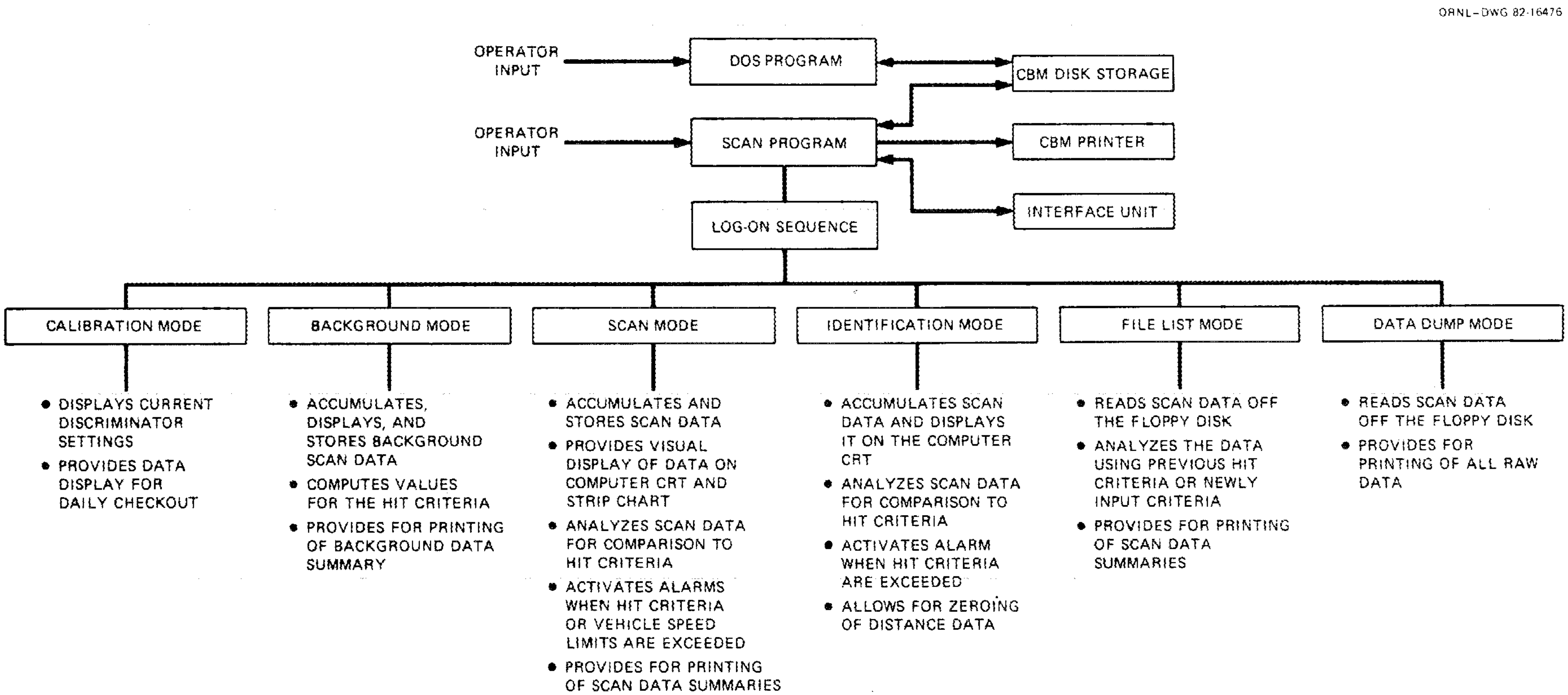

Fig. 14. Software flowchart for the CBM computer system

Calibration Mode

This program mode aids the operator in performance of the daily detector system calibration. When the subroutine is executed, all the necessary calibration information is displayed on the computer CRT for reference. This includes:

1. Identification of the calibration sources used, including the energy of the primary gamma-ray emitted and the channel numbers on the multichannel analyzer display unit where these primary photopeaks should occur, and

2. A table of relevant information on the interface unit input data channels, including the data type (distance pulse or energy ROI), the current settings on the 10-turn Helipots, and the corresponding channel numbers on the analyzer display unit represented by these settings.

This calibration information is updated by program editing when adjustments are made.

The Calibration Mode can be used to display the raw data from each data channel in checking system response (see Field Calibration section). This portion of the program mode is accessed by a single keystroke (any key) and results in a visual display of the one-second data update from the Interface unit. A ten-second sum and thirty-second average of the data representing the total ^{226}Ra energy regions are computed and displayed for use in daily checking of the system sensitivity.

Background Mode

To obtain the necessary data for computation of the appropriate hit criteria, the Background Mode program must be used. This program contains two options, one of which accumulates "new" background data, and the other in which previously-determined (old) background data are input. In both instances, values for the hit criteria are computed and stored for subsequent use.

When the operator selects the "new" background option, the computer displays a condensed set of operating instructions. The operator determines a name for the data file to be generated, and enters that name as the file name on the floppy disk. Data accumulation then begins with raw data storage on the disk. Computer-analyzed data are displayed on the computer CRT, consisting of the one-second update of the total distance traveled (in feet), the total number of counts in the radium energy regions, and the computed Ra/Th ratio. When the program mode is terminated, the disk data file is closed, and computer analysis of the disk-stored data begins. Upon completion of this analysis, a summary of the data are printed, which includes the computed mean and standard deviation of the appropriate energy ROI's, and the values of the hit criteria to be used for the area scanned. An example of such a printout is provided in Fig. 15.

When the operator selects the "old" background option, the computer prompts the operator to provide the necessary input from a previous background file. The data required include the average count rate determined for the radium energy regions, and the mean and standard deviation of the computed Ra/Th ratio. These data can be obtained from a previous background file printout. After the information is entered, computer calculation of the hit criteria is performed, with the results displayed on the computer CRT for a few seconds and the criteria values stored for subsequent use.

Scan Mode

The Scan Mode of operation is used for the accumulation, analysis, storage, and printing of all scan data. When this program mode is selected, input instructions are displayed for operator response. Upon entering the appropriate file name for the area to be scanned, this identification is transferred to the floppy disk system for file creation, the strip chart drive motor is activated, and the file name transmitted to the chart recorder print head for printing. The program then enters a program loop which reads the data from the Interface unit, analyzes the data, and stores it on the floppy disk. The loop is executed at one-second intervals.

In this program loop, the computer first addresses each counter card in the Interface unit, which then transmits its data into computer memory. At this time, the computer relays the data to the floppy disk unit for storage and starts the data analysis process. This analysis begins with the summing of the inputs from each of the three Ra data

```
BACKGROUND FILE NAME---BKG 12

                    MEAN        STD.DEV.
                                1 SIGMA
---------------------------------------------
GROSS COUNTS        2337          48
TOTAL Ra             293          17
Th                    30           5
K                    122          11
Ra/Th                 10           1

HIT CRITERIA
TOTAL Ra COUNTS         406
RATIO                   11
```

Fig. 15. Example printout for the Background Program Mode

channels (total Ra), calculation of the Ra/Th ratio, computation of the positive difference value, and conversion of the number of distance transducer pulses observed into distance traveled for that one-second period, to be added to the previous total. The computer then compares the count rate data obtained with the predetermined hit criteria (see Background Mode section) and the distance data with the preset alarm level (approximately 3 m/s). If either limit is exceeded, the appropriate alarm is sounded. At this point in the program loop, the scan data are displayed on the computer CRT. The displayed data consist of the total distance, total radium counts, Ra/Th ratio, and the sign of the positive difference value (+ or −). When the hit criteria are exceeded, an asterisk is displayed to the right of the normal scan data. The display is updated every second, and a scroll feature employed to allow operator viewing of an entire screen of scan data. An example of the computer display of typical scan data is provided in Fig. 16. As the final step in the program loop, the Ra/Th ratio data are transmitted to the digital-to-analog converter buffer for subsequent recording on the strip chart.

During the gamma scan of a street, names of permanent landmarks (i.e., house numbers and cross streets) can be input into the computer via keyboard entries (maximum of 21 characters) as they are passed by the moving vehicle. As the characters are typed, they are displayed at the bottom of the computer CRT. When the name is completed and a carriage return entered, the landmark information is transmitted to the disk for storage, the name scrolls up the screen with the rest of the scan data, and instructions are sent to the strip chart for event marker operation. In addition, every 20 seconds, the total accumulated distance information is transmitted to the strip chart print head buffer for inclusion on the chart data.

When the Scan Mode is terminated (EXIT key), the disk file is closed and the strip chart motor is turned off. The disk file is then reopened in a read mode for computer analysis and a summarized printout of the stored data. In this analysis, the counting data (total Ra, Ra/Th ratio, and positive difference value) are compared to the preset hit criteria and when these criteria are exceeded, the computer transmits a data summary of that information. The summary printout contains

TOTAL DISTANCE	TOT Ra COUNTS	Ra/Th RATIO	POS DIFF	
0	295	8	-	
0	254	8	-	
6	265	9	-	
15	268	8	-	
25	278	7	-	
35	276	7	-	
46	238	7	-	
52	260	7	-	
66	281	9	-	
74	267	7	-	
81	280	8	-	
87	271	9	-	
97	289	9	-	
e side west bldg				
113	267	9	-	
122	266	8	-	
138	303	9	-	
158	310	8	-	
175	286	8	-	
195	295	9	-	
213	249	7	-	
227	261	10	-	
248	312	8	-	
269	297	8	-	
278	289	10	-	
284	307	11	-	
297	331	10	-	
in pkng lot				
303	355	8	-	
311	348	11	+	*
319	341	6	-	
328	330	10	-	
343	338	10	-	
350	289	7	-	
358	292	9	-	
main bldg				
365	265	7	-	
374	271	8	-	
382	269	7	-	
389	261	9	-	
396	226	6	-	
406	242	12	+	
football field				
412	243	8	-	
420	239	9	-	
428	256	7	-	
435	270	9	-	
442	264	11	-	
447	273	7	-	
455	255	8	-	
462	249	8	-	
468	282	8	-	
474	273	6	-	

Fig. 16. Example of computer display of typical scan data

(1) documentation of the file name, (2) a listing of the hit criteria used in the analysis of the data, (3) all pertinent scan data for the hit location, (4) a remarks column for additional operator input (see Identification Mode section), and (5) identification of the system operator and the date the data were obtained. An example of a data summary printout is given in Fig. 17. The summarized scan data provide location information and a listing of the total Ra counts observed, the Ra/Th ratio, and the magnitude and sign of the computed positive difference value. Approximate hit location information is generated by computing net distances from the landmarks that are input during the scan process. In the data summary, the total distance (from starting point of the scan file) of the most recently input landmark is printed (Total Distance Column), the name or description of that landmark included (Street Number Column), and the net distance from the landmark to the hit location listed (Net Distance Column). All computed distances are given in feet. The dotted lines in the printout are used for data separation to indicate that at least three successive counting intervals contained no readings above the hit criteria. If computer analysis of the scan data determines that no readings on the file exceed the hit criteria, an abbreviated printout is provided (Fig. 18).

Identification Mode

This program mode is used in conjunction with the Scan Mode data summary printout to pinpoint the exact locations of the radiation anomalies identified during the scan. Property addresses and/or detailed descriptions can then be added to the summary sheet in the Remarks/Location Column.

The Identification subroutine is similar to the Scan Mode subroutine in data acquisition and computer CRT display. The major differences are that (1) the strip chart is not activated, (2) no data are transferred to the floppy disk for storage, (3) a distance "zeroing" option is provided, and (4) no data printout occurs. The "zero" option can be accessed anytime during program mode execution (by entering the zero key), to reset the total distance on the computer CRT display to zero. This allows the operator to observe the net distance traveled from a landmark, for comparison with the information provided on the Scan Mode data summary.

SCAN FILE NAME---OLD RVTN HS/A 32

TOTAL Ra COUNT HIT 384
RATIO HIT 11

TOTAL DISTANCE	STREET NUMBER	NET DISTANCE	TOT Ra COUNTS	Ra/Th RATIO	POS DIFF	REMARKS/LOCATION
714	visitor bleachers	425	412	12	49	
		431	521	19	224	
		438	572	21	275	
		442	719	18	268	
		449	827	24	442	
		456	841	27	500	
		512	856	20	383	
		521	909	21	436	
		541	772	15	189	
		558	746	22	372	
		577	691	26	394	
		584	622	19	259	
		606	548	13	97	
		621	492	18	184	
		636	398	12	24	
1365	bldg n end of field	650				
1365	bldg n end of field	81	418	11	11	
		98	470	13	74	
1464	pink fill present	98				
		20	560	15	142	
		28	574	17	211	
		57	589	16	171	
		57	530	14	123	
		65	563	13	79	
		71	541	16	178	

Tim Krohe
T.L.KROHE 6/18/82

Fig. 17. Example of Scan Mode data summary printout

SCAN FILE NAME--WEBBWOOD EAST

TOTAL Ra COUNT HIT 408
RATIO HIT 12

NO ANOMALIES

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T.L.KROHE

6/16/82

Fig. 18. Example of abbreviated Scan Mode data printout

File List Mode

The File List Mode is used to generate a printout of the computer-summarized scan data. This printout has the same format and content as the Scan Mode summaries. When this subroutine is executed, three data analysis options are presented. These include using the previously-stored hit criteria for data comparison, inputing new criteria to obtain a different analysis of the data, or listing all of the data above and below the hit criteria. If the second option is chosen, the computer will ask for the necessary input data (total Ra counts and Ra/Th ratio hit levels) prior to the data analysis loop. Next, the computer reads the floppy disk directory and assigns a number to each data file on the disk. The operator then has the option of either identifying the number of a single file to be listed, or specifying that all files are to be printed.

Once the appropriate options have been selected and all necessary inputs provided, the computer reads the stored scan data for the chosen file(s), analyzes the data, and prints out the results.

Data Dump Mode

This program mode is used to generate a printout of all raw data stored on the floppy disk. The subroutine accesses the data files the same way as the File List Mode, for printouts of single or multiple files. When this subroutine is executed, the raw data are printed out in the format shown in Fig. 19. In addition to the count rate data and distance data, the hit criteria, operator's name, and date of original data acquisition are provided, as shown in the first entries in the Total Distance columns of the printout. No analysis of the scan data occurs when this program mode is executed.

FILE NAME--OLD RVTN HS/A 32

TOTAL DISTANCE (feet)	GROSS (cps)	Ra 0.609MeV (cps)	Ra 1.120MeV (cps)	K 1.460MeV (cps)	Ra 1.764MeV (cps)	Th 2.614MeV (cps)
304						
11						
t.l.krohe						
6/18/82						
0	2156	168	42	123	50	34
0	2136	174	67	111	54	37
0	2188	161	47	139	46	33
6	2188	165	65	123	35	30
15	2166	161	67	112	40	32
25	2268	171	65	134	42	39
35	2271	169	63	115	44	40
46	2137	155	43	114	40	33
52	2137	160	56	115	44	35
66	2163	185	53	126	43	33
74	2259	167	52	115	48	36
81	2324	172	65	129	43	34
87	2246	169	63	138	39	29
97	2320	170	75	139	44	34
e side west bldg						
113	2387	164	51	125	52	29
122	2415	185	45	145	36	34
138	2514	173	76	156	54	32
158	2419	197	66	159	47	39
175	2429	184	51	148	51	34
195	2333	193	58	131	44	33
213	2264	143	60	152	46	34
227	2210	161	63	128	37	27
248	2220	190	65	113	57	37
269	2313	180	73	133	44	35
278	2343	177	66	129	46	30
284	2491	179	76	150	52	29
297	2545	204	67	164	60	34
in pkng lot						
303	2865	238	65	189	52	43
311	2758	205	69	177	74	31
319	2841	236	58	187	47	53
328	2563	206	70	177	54	33
343	2560	213	71	172	54	35
350	2463	172	76	133	41	42
358	2327	192	57	123	43	32
main bldg						
365	2242	165	63	123	37	37
374	2301	168	57	129	46	34
382	2341	173	59	135	37	37
389	2199	165	56	114	40	30
396	2009	158	32	86	36	41
406	2053	141	52	109	49	20

Fig. 19. Example of Data Dump Mode data printout

SCANNING METHODS

Mobile gamma-ray scanning involves the systematic surveying of all streets, alleyways, parking lots, and other public thoroughfares within defined survey boundaries. Any locations found to exhibit gamma radiation levels statistically different from background must be identified to aid in subsequent coordination for future comprehensive onsite surveys. In order to optimize the detection system sensitivity, scanning speeds must be maintained as slow as possible, and source-to-detector distances minimized. Daily calibration of the system is necessary to assure the validity of the scan data. Adequate documentation of locations scanned and actual scan results must be maintained, with reliable long-term storage of all raw data.

Typically, the scanning van is operated by a three-man crew. This crew size provides for a driver, system operator, and data analyst. The system operator is responsible for general system operation, including the daily calibration checks and operating the data acquisition system. The data analyst is responsible for all scan data from the survey, insuring that adequate information is obtained and that the survey log book is maintained. Normally, the data analyst is also responsible for the day-to-day planning of the scanning survey.

The following discussions give details of the methods employed for the normal street-by-street scanning for which the system was designed. Modifications to these survey methods can easily be made when the van is utilized for other purposes (e.g., scanning of large open areas). Step-by-step instructions on the system operation are provided in Reference 3.

FIELD CALIBRATIONS

Prior to the initiation of a scanning survey, and daily during the survey, various system calibrations must be performed. These include calibration of the distance transducer at the beginning of the survey, and daily checks of the detector sensitivity, window discriminator settings, and a four-point energy calibration.

Since continuous correlation is made of distance traveled with detector response during scanning, calibration of the distance-measuring system must be performed. The stability of the system has proven to be adequate such that a field check and recalibration is necessary only at the start of each survey trip (usually at monthly intervals). Calibration of the system requires that at least a 500-foot length of straight, level road be marked off for distance correlation. By accessing the Calibration Program Mode, the cumulative distance (in feet) can be observed on the display screen as the van moves. After traversing the specified distance several times, the average observed distance can be compared to the actual measured distance. A conversion factor can then be determined and changes made in the appropriate locations of the computer program. Variations of $\pm 3\%$ are tolerated with the current system.

Field calibration and checkout of the detector system is conducted on a daily basis, prior to the initiation of scanning activities for that day. After allowing sufficient time for instrument warm-up (minimum of 30 minutes), all instrument settings are checked against a master listing provided by the Calibration Mode of the computer program. The system amplifier gain is then checked by performing an energy calibration with the on-board multichannel analyzer, using check sources of ^{137}Cs, ^{60}Co, and ^{208}Tl. These gamma-ray sources provide peak calibration at four points ranging from 0.66 MeV to 2.61 MeV. Once the gain has been adjusted to place the gamma-peaks in the required channel locations, the entire system is considered calibrated. Spot checks of peak locations are performed throughout the day to assure that no gain shifting has occurred. As a last check before scanning begins, a sensitivity comparison of the detector response is made. Utilizing a ^{137}Cs check source at a specified distance from the detector, an average net count rate is determined. Comparison of this net reading (corrected for source decay) with previous results gives an indication of changes in the detector sensitivity. Differences above the set tolerance level ($\pm 3\%$) require further investigation.

BACKGROUND DETERMINATIONS

Since the data analysis method employed on the scanning van is based on computations involving background count rates in the various energy regions of concern, these background levels must first be established before scanning can begin. To determine these backgrounds, the city to be scanned is divided into small areas (approximately ten city blocks on a side) for which an associated background level would be obtained. Care is taken to assure that the background boundaries encompass areas that are fairly uniform in land use, geology, and topography. This results in more useful and better-defined background information for statistical analysis. In each of these areas, a scan is made using the background mode of operation, at normal driving speed, traversing at least 50% of the streets and alleys included in the section.

At the end of the background scan, the average count rates and associated standard deviations for each of the energy windows are computed, the average Ra/Th ratio and its standard deviation determined, the associated hit criteria calculated, and all the information printed out and stored for later use. If a street-by-street scan of that area is conducted immediately after obtaining the background, the needed information (hit criteria values) will be automatically input to the computer. If several backgrounds are established before any scanning is undertaken, then the necessary input must be entered into the computer by the operator. These data would be obtained either from the computer printout provided when that background was established, or by reanalyzing the data contained on the appropriate data disk.

The background radiation levels established by this method represent an estimate of the average levels observed by the van in a certain section of town. They are used as the statistical baseline for comparison with subsequent scan data for that area. These measurements do not represent "natural" background levels since influences from brick buildings, detector geometry conditions, and other interfering factors have not been excluded.

STREET-BY-STREET SCANNING

After the background levels for the survey areas have been established, the street-by-street scans of these areas can begin. For each street to be scanned, the Scan Program Mode is accessed, and a storage file is opened on the floppy disk system, with the file identified by the name of the street and the direction of travel. Scanning is conducted at a slow speed (~5 mph), with an alarm system utilized to alert the driver when the vehicle is traveling too fast. The distance between the van and the property is maintained at a minimum, driving next to the curb unless obstructions (i.e., parked cars) prevent it. During the scan, the detectors are secured in the raised position to maximize the field of view and minimize the influence of street-side obstructions.

As the scan proceeds, permanent landmarks (e.g., house numbers, cross streets) are systematically input to the computer to be stored along with the rest of the scan data for cross reference. During the scan, when a property is passed which exhibits gamma radiation levels exceeding the preset hit criteria, an alarm is sounded and special notation made on the computer video screen. This alarm continues to sound until the anomaly has been passed. At the end of the scan, the data file is closed and computer analysis of the data begins. This analysis results in the printout of a list of all anomalies identified by the scan, providing exact location information in terms of distance from the input permanent landmarks as well as the count rates observed in the Ra-energy windows and the computed difference technique analysis value. To further define the locations and add additional information, a rescan of each anomaly is then performed in the Identification Program Mode, at an even slower speed, to better define the area of concern and allow for detailed description of property (i.e., house address, or if unavailable, a description of the house). If desired at this time, a detailed spectrum analysis can be undertaken utilizing the on-board multichannel analyzer system over extended time periods (typically 5-10 minutes).

When one side of the street has been analyzed, the other side is scanned in the opposite direction. In addition, all accessible parking areas, alleyways, and other public thoroughfares are scanned within the survey section. When all the scanning has been completed, the complete set of stored raw data for the entire surveyed area can be printed out for future reference. Documentation of the progress of the scanning survey is maintained on a large-scale street map, where streets and alleyways that have been scanned are appropriately marked. At survey completion, this map and the data summary sheets serve as the permanent record of all areas scanned.

SYSTEM CALIBRATION

To define the scanning system performance characteristics, a series of calibration exercises were conducted. These experiments were designed to establish the detection sensitivity, define the directional response of the shielded detectors, and provide some degree of correlation between detector response and soil radium concentration. Field testing of the scanning van was conducted in the vicinity of an eastern UMTRAP site, where offsite properties were known to contain residual radium-bearing materials. Analysis of scan data from several streets was performed to correlate the system response with the radiological conditions that exist at properties on those streets. The results from these tests were used for both computer algorithm development as well as system calibration information.

Calibration activities performed at ORNL utilized sealed-radium standard sources of 1.0 mg and 0.18 mg, and four uranium mill tailings simulated area sources. As shown in Table 1, the exposure rates versus distance for the radium "point" sources were well documented and provided the needed standards for direct detector response. The area sources consisted of numerous individual soil samples that had been analyzed on a Germanium Lithium-drifted (GeLi) detector for ^{226}Ra. Approximately 20 kg of soil was placed in a shallow box of 1-m^2 area, with a nominal soil thickness of 10 cm. The average ^{226}Ra concentration of each source was determined by a weighted averaging of the individual sample GeLi analysis results. The resulting mean ^{226}Ra values for these tailings sources ranged from 35 pCi/g to 1260 pCi/g (Table 1).

DETECTOR SENSITIVITY

In order to test the gross sensitivity of the NaI(Tl) detection system utilized on the scanning van, an experiment was performed to compare the detector response versus distance from a point ^{226}Ra source. The radium source E857 (Table 1) was placed in a source holder at detector height (approximately 2 m from ground surface), and the van positioned in a large, level, open lot with the detector in the raised position. The source-to-detector distance was varied at 5-m intervals and

Table 1. Radiation sources utilized in scanning system calibration

Source	Size	Characteristics
Ra-334B	0.18 mg	12 μR/h at 10 cm 0.6 μR/h at 50 cm 0.15 μR/h at 100 cm 0.01 μR/h at 400 cm
Ra-E857	1.0 mg	100 μR/h at 10 cm 4 μR/h at 50 cm 1 μR/h at 100 cm 0.1 μR/h at 300 cm
Tailings I	2.3×10^4 gm ($1\ m^2$-10 cm thickness)	8.1×10^5 pCi ^{226}Ra total 35 pCi/g weighted average ^{226}Ra concentration Surface exposure rate ~25 μR/h
Tailings II	2.2×10^4 gm ($1\ m^2$-10 cm thickness)	1.0×10^7 pCi ^{226}Ra total 475 pCi/g weighted average ^{226}Ra concentration Surface exposure rate ~50 μR/h
Tailings III	2.1×10^4 gm ($1\ m^2$-10 cm thickness)	1.5×10^7 pCi ^{226}Ra total 715 pCi/g weighted average ^{226}Ra concentration Surface exposure rate ~85 μR/h
Tailings IV	1.9×10^4 gm ($1\ m^2$-10 cm thickness)	2.4×10^7 pCi ^{226}Ra total 1260 pCi/g weighted average ^{226}Ra concentration Surface exposure rate ~250 μR/h

thirty 1-second counts of the gross gamma radiation field obtained. With the source then removed, an average background count rate and associated standard deviation was determined. The results of these measurements are presented in Fig. 20.

The radium source could be statistically detected above the background at distances up to 65 m. At the maximum measured distance, the exposure rate attributable to the radium source was estimated at 0.25 μR/h, based on the documented source strength. This corresponds to the measurement of approximately a 2% increase in the normal background levels. Comparison of these results to similar measurements made on the other currently-available scanning systems[5,6] found that although the range of detection systems were comparable (>60 m), the net sensitivity of the ORNL system (net count rates above background from equivalent sources) was approximately a factor of six better.

DETECTOR DIRECTIONAL RESPONSE

The vertical and horizontal detector response was measured to define the field of view of the shielded detector. The radium source 334B (Table 1) was used at a constant 2 m source-to-detector spacing to provide an equivalent exposure rate at all source positions. The source was positioned first along the vertical centerline of the detectors at the detector raised height. The angular position of the source was then varied at 15° increments (maintaining the constant 2 m source-to-detector spacing) from a location directly in front of the detectors (0°) passing beneath the van (90°), to one directly behind the detectors (180°). Thirty 1-second counts of the source were obtained at each position and the average count rate computed. The resulting data were then normalized to provide an indication of the relative detector response versus source position. A graphic representation of these data are given in Fig. 21. From analysis of this graph, it is evident that the shielding provided by the PM tubes and structural materials on the bottom of the detectors, and the lead shielding on the back side effectively limit the detector field-of-view to surfaces directly below and out the right (passenger) side of the van, as designed. The lead shield behind the detectors reduced the gamma radiation field by approximately a factor of ten.

ORNL-DWG 82-9951

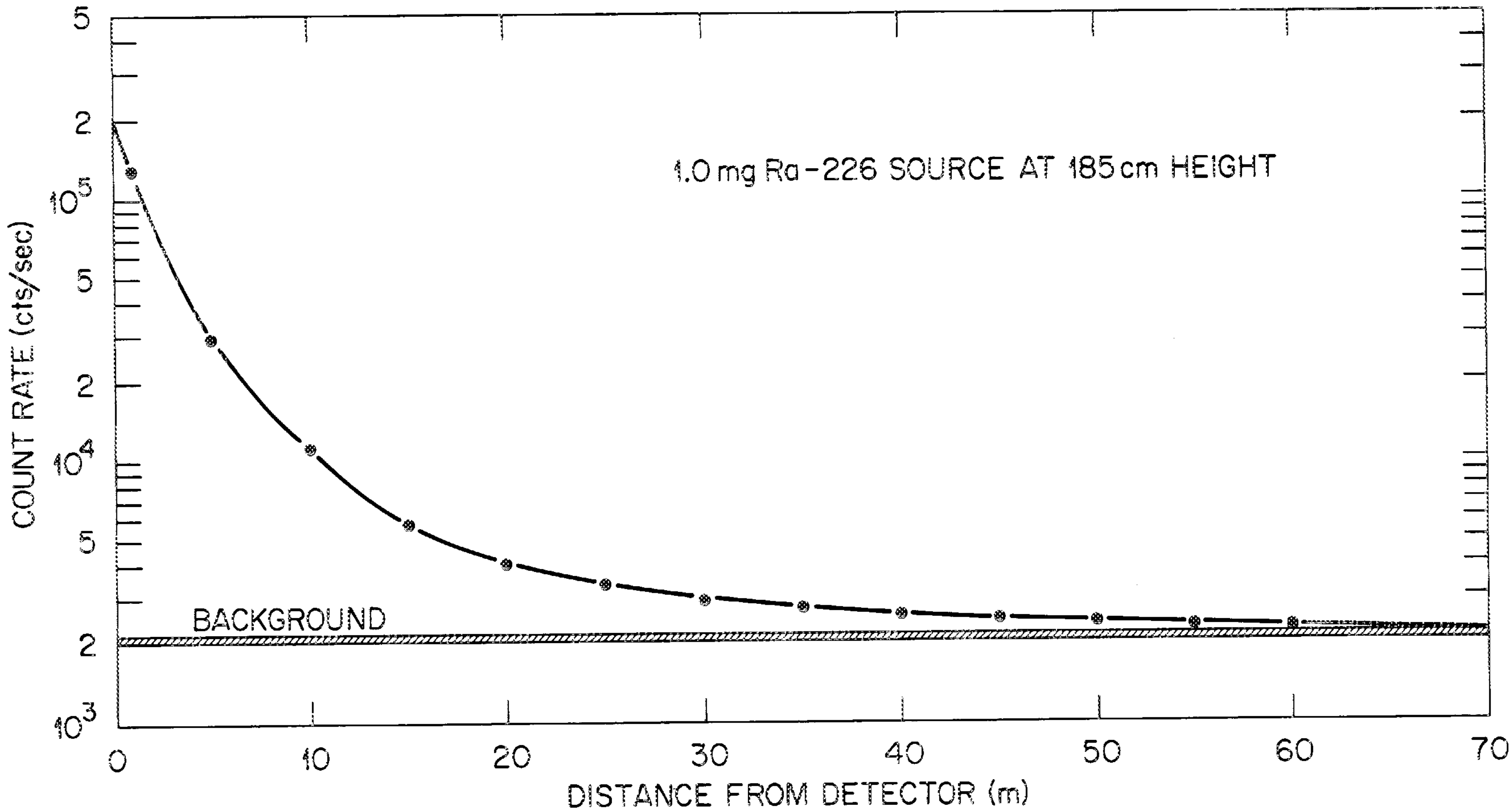


Fig. 20. Gross detector response versus source-to-detector distance

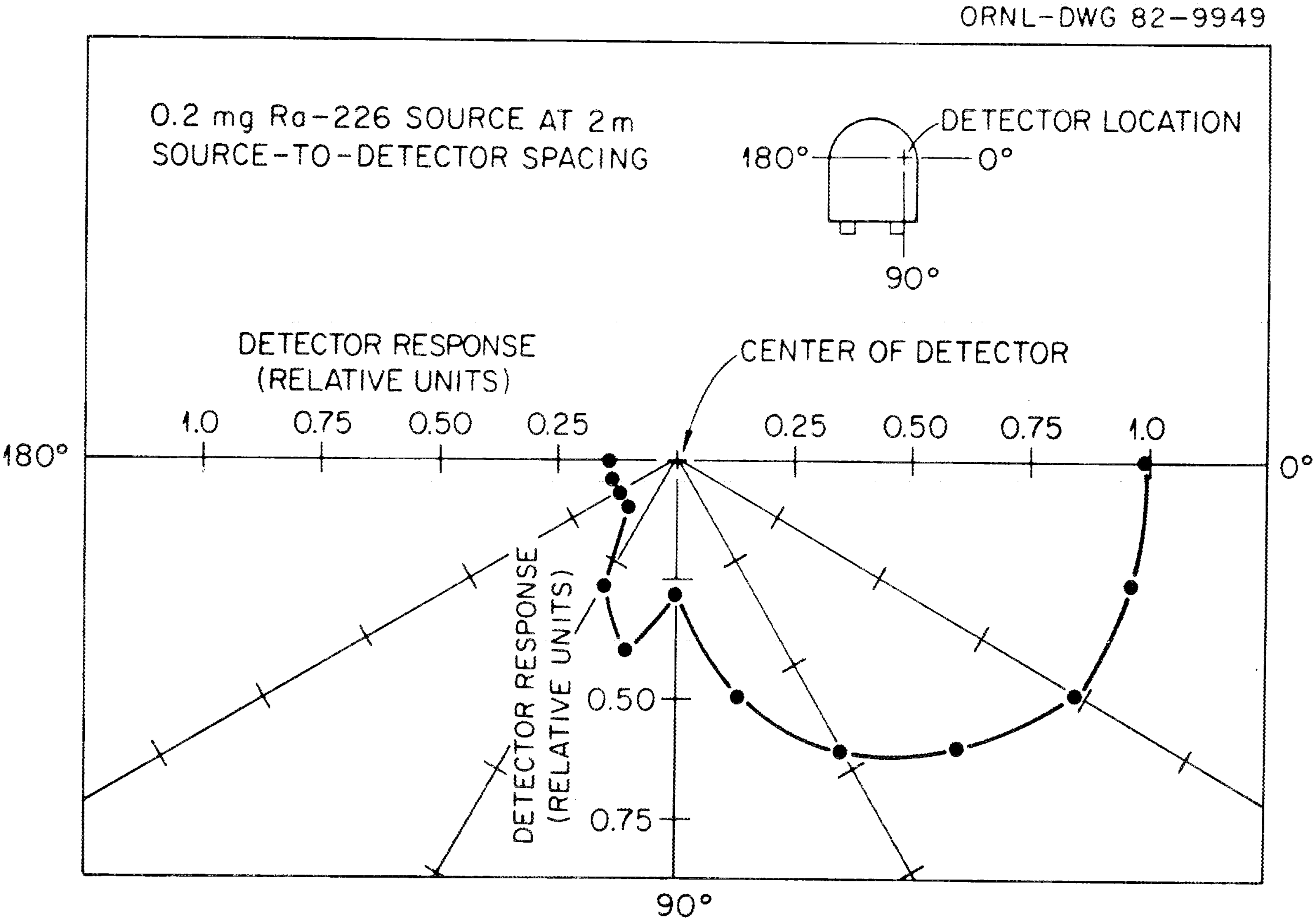


Fig. 21. Detector directional response - vertical plane

The detector response in the horizontal plane was determined by positioning the source at the detector raised height and varying the angular position from one side of the detectors (0°), to directly in front of the detectors (90°), to the other side (180°) in 15° increments. Again, thirty 1-second counts of the source were made at each location and an average count rate computed. The data were normalized and graphed as shown in Fig. 22. These results indicate a symmetrical field-of-view out the right side of the van, with the optimum counting position located directly in front of the crystals, as expected. Since the detection system is mobile, all locations being scanned will pass through this optimum detection area as the vehicle travels by. As shown in Fig. 22, the lead shielding on the detector sides does, however, help to focus the detectors on this optimum point.

SOIL SOURCE CORRELATION

In an attempt to correlate the detection system response to various concentrations of ^{226}Ra in surface soil, analyses of the four area tailings sources (Table 1) were performed. The stationary van was positioned on a large, flat, open lot with the detector in the operating position, and the average background count rate determined. In turn, each of the four small area soil sources were placed on the ground in line with the detector (at the optimum counting location) and the source-to-detector distance varied in 1-m increments from 0 m to 15 m. Thirty 1-second counts of the gross gamma levels were made at each source position and the average value computed. The results of these measurements are shown in Fig. 23.

Analysis of the soil calibration data shows that the detector response varied directly with the source distance and the average ^{226}Ra concentration in the soil. Detection ranges (distance at which the source could be statistically detected above background) varied from 5 m for the 35 pCi/g source, up to 15 m for the 1260 pCi/g source. The optimum counting distance for these small area sources was determined for all four sources to be approximately 1 m from the side of the van.

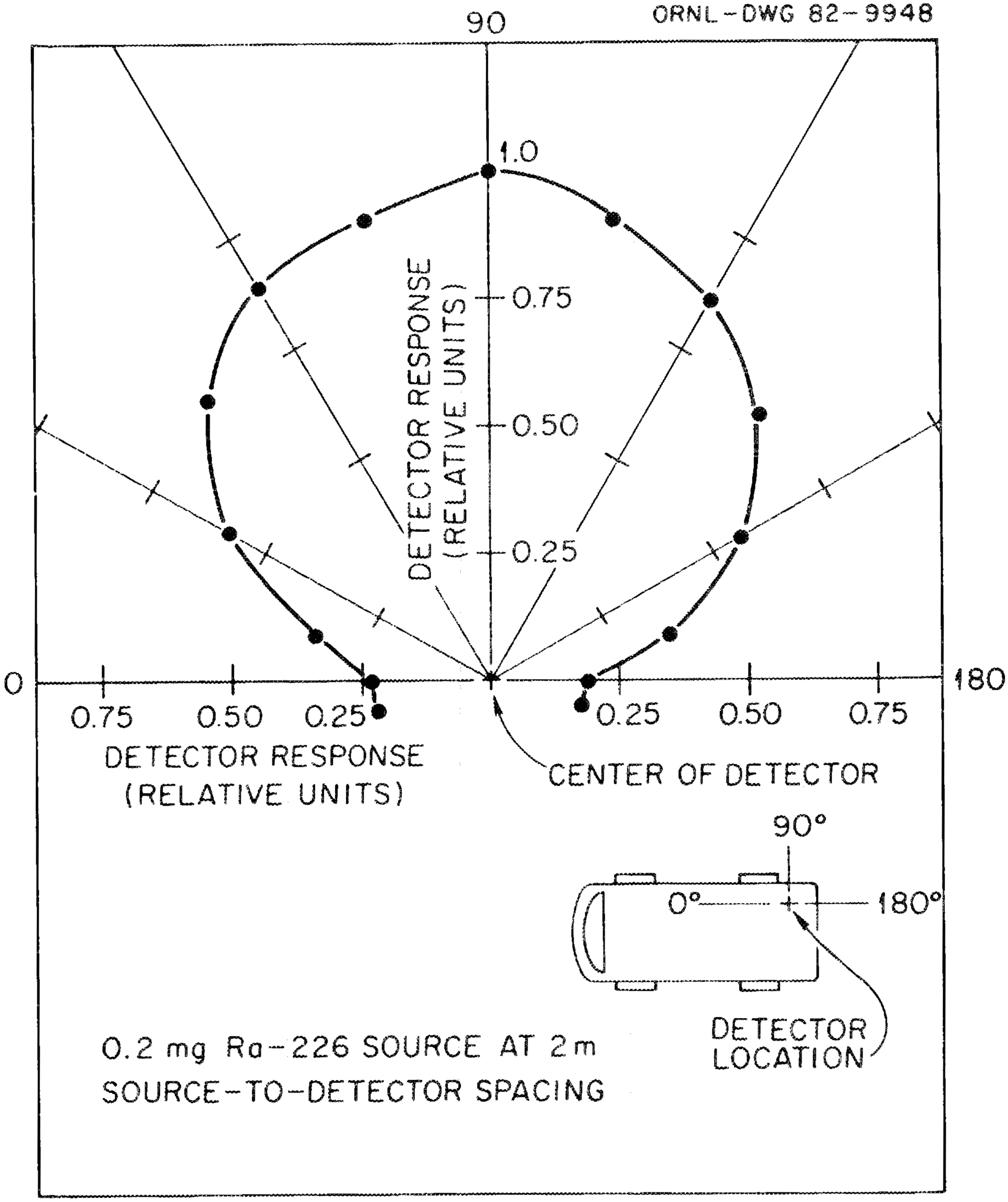


Fig. 22. Detector directional response - horizontal plane

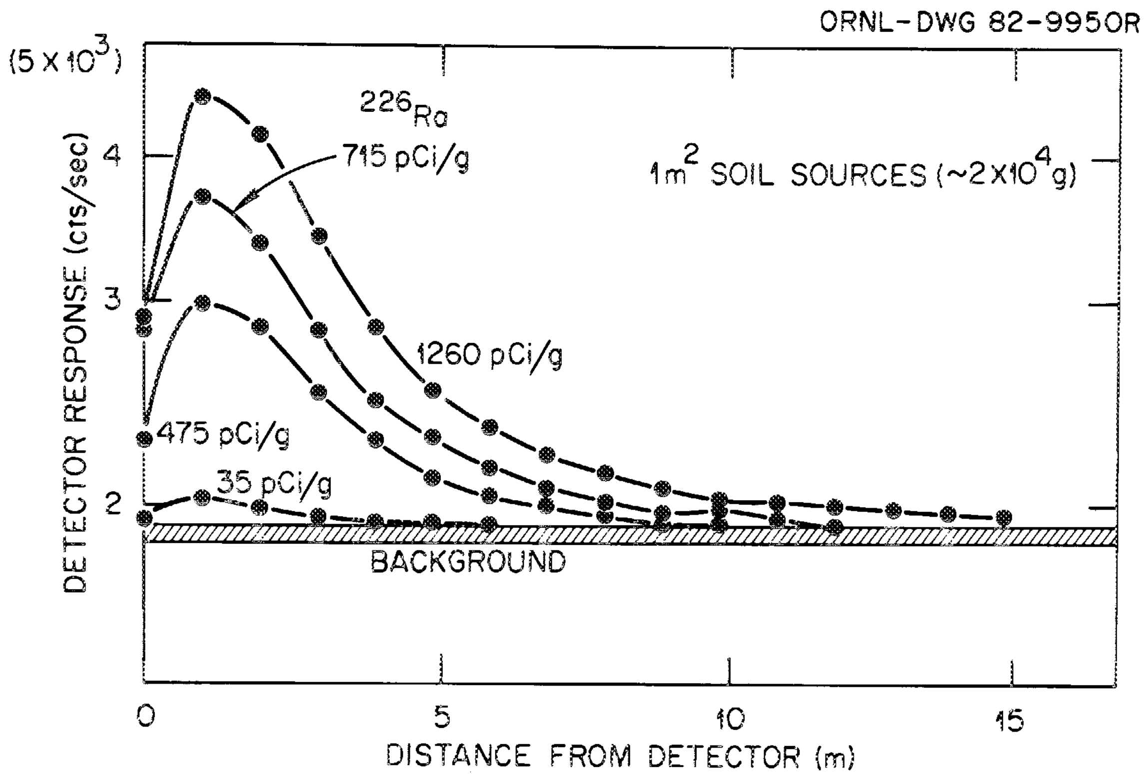


Fig. 23. Correlation of soil ^{226}Ra concentration and gross detector response

Utilizing the Scan Mode of operation, where the van is moving and the hit criteria employed, the same analysis of system response versus source distance was performed. By requiring the total Ra count rate to exceed a minimum level (see Data Analysis Technique section), the effective detector range was reduced, as would be expected. The average reduction in viewing range was 30% for all four sources. The maximum range for the 35 pCi/g source was determined to be 3 m, and for the 1260 pCi/g source, approximately 10 m.

Obviously, as the total volume and area of ^{226}Ra-contaminated soil increases, the ease in detecting it also increases. The source size (1 m^2) used in this correlation exercise was chosen to represent the smallest area for which the scanning system should be expected to detect. The ^{226}Ra concentrations represented by these sources span the range of values normally encountered in the field, although the limit currently established for remedial action is much lower (5 pCi/g in surface soil as specified in 40 CFR 192). It should be noted that no attempt has been made to establish a calibration factor for the scanning system (e.g., pCi/g in soil per detector counts per second) since in practical applications the source-to-detector distance is unknown, the counting geometry variable, and shielding between the contamination and the detector potentially significant.

FIELD TESTING

Prior to the initial use of the scanning van, field testing was performed at locations where radium-bearing residual materials were known to have been used in various applications on private properties. Some 40 properties were included in the testing program. Previous comprehensive radiological surveys of these locations found onsite outdoor areas exhibiting surface gamma exposure rates ranging from 20 μR/h to 700 μR/h over areas of less than 1 m^2 and up to 15 m^2. The contaminated material was in the form of bricks, wood, piping, and soil, and was found to be present at any number of locations on a property. Distances from these materials to adjoining streets or alleys varied from less than 1 m to 20 m. The contamination was often shielded from the roadways by structures and was normally buried a few centimeters underground.

The first phase of the field testing involved comparison of various algorithms proposed for use as the data analysis method for the system. Initially, five different analysis methods were analyzed, (1) a radium-to-thorium ratio technique, (2) a radium-to-potassium ratio technique, (3) a low energy- (<1.46 MeV) to-high energy (>1.46 MeV) ratio technique, (4) gross count rate comparisons to background, and (5) total radium count rate comparisons to background. The sensitivity of each analysis technique was compared on data obtained from several representative contaminated properties. The most sensitive technique proved to be the use of the radium-to-thorium ratios, although the number of false hits occurring with the use of it alone was found to be unacceptable. By modification of the data analysis method to include two other criteria (determination of a minimum total radium count rate and the use of a mathematical difference technique) the incidence of false hits was reduced to an insignificant level. Complete documentation of the resulting data analysis technique employed on the van, based on the field testing, is provided in the Software Development section of this report.

After the choice of the appropriate algorithm for data analysis was made and implemented, the system performance was tested at the properties where sufficient onsite survey data existed. Normal street-by-street scanning methods were employed for the streets and alleys where the properties were located. Of the forty known contaminated locations, only four could not be identified by the ORNL system. At each of these properties, either source-to-detector distance (up to 20 m) exceeded the scanning range of the detectors, or the source size and associated exposure levels were relatively insignificant (less than 1 m^2 and 20 μR/h). No false hits were recorded by the system during the testing. Based on these results, the scanning van performance was deemed acceptable, and the system activated for use in the DOE survey programs.

SUMMARY

A mobile gamma-ray scanning system has been developed by Oak Ridge National Laboratory for use in the Department of Energy's remedial action survey programs. The unit consists of a NaI(Tl) detection system housed in a specially-equipped van. The system is operator controlled through an on-board mini-computer, with data output provided on the computer video screen, strip chart recorders, and an on-line printer. Data storage is provided by a floppy disk system. Multichannel analysis capabilities are included for qualitative radionuclide identification. A ^{226}Ra-specific algorithm is employed to identify locations containing residual radium-bearing materials.

Laboratory calibration and field testing have established the system sensitivity, field of view, and other performance characteristics. Based on these results, the unit was proven to be more sensitive than comparable systems currently available, and provides discriminating capabilities that the other systems do not. The spectrum analysis techniques employed on the ORNL system minimize the detector interferences that arise from geologic formations, geometry factors, and other natural radioactivity influences (e.g., brick buildings).

The mobile scanning system has been proven to be a useful tool in the identification of properties contaminated with residual ^{226}Ra-bearing materials. Validation of historical information, ground-level verification of aerial survey results, and street-by-street screening of large areas are easily and cost-effectively accomplished by the use of this system. The system is limited only by access restrictions (e.g., lack of roads or alleys) and shielding problems (e.g., structures blocking the field of view, or earth shielding of buried materials), which can only be overcome by comprehensive onsite radiological surveys.

REFERENCES

1. U.S. Department of Energy, A Background Report for the Formerly Utilized Manhattan Engineer District/Atomic Energy Commission Sites Program, DOE/EV-0097A, September 1980.

2. U.S. Department of Energy, Background Report for the Uranium Mill Tailings Sites Remedial Action Program, DOE/EP-0011, April 1981.

3. Goldsmith, W. A., T. E. Myrick, B. A. Berven, W. D. Cottrell and F. F. Haywood, Procedures Manual for the ORNL Remedial Action Survey and Certification Activities (RASCA) Program, Oak Ridge National Laboratory, September 1982.

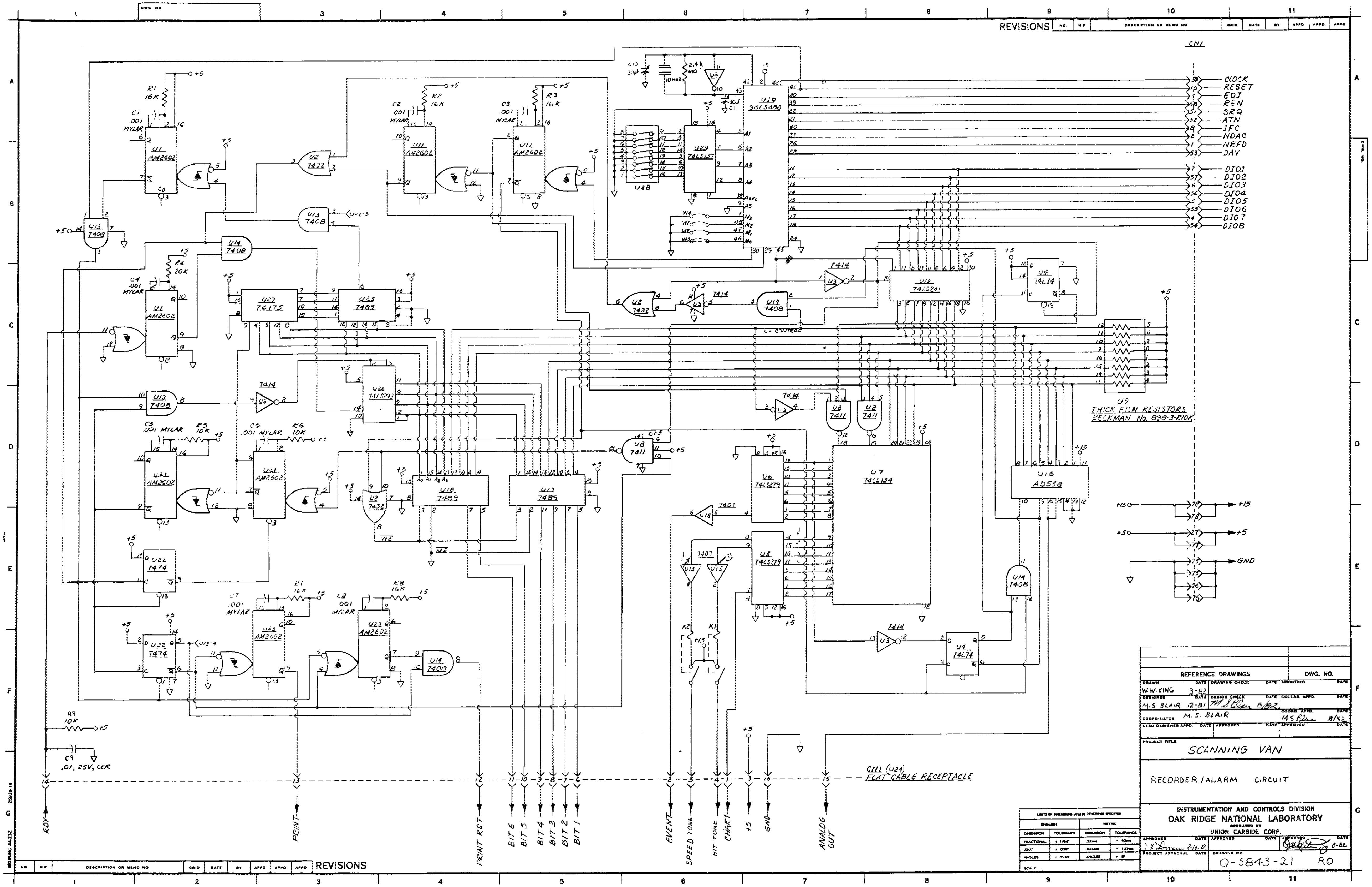
4. Bristow, Q., "The Application of Airborne Gamma-ray Spectrometry in the Search for Radioactive Debris from the Russian Satellite Cosmos 954 (Operation Morning Light)," Current Research, Part B, Geol. Survey of Canada, Paper 78-1B, pp. 151-162, 1978.

5. U.S. Environmental Protection Agency, Above-Ground Gamma-Ray Logging for Locating Structures and Areas Containing Elevated Levels of Uranium Decay Chain Radionuclides, Office of Radiation Programs, Las Vegas, Nevada, ORP/LV-78-2, April 1978.

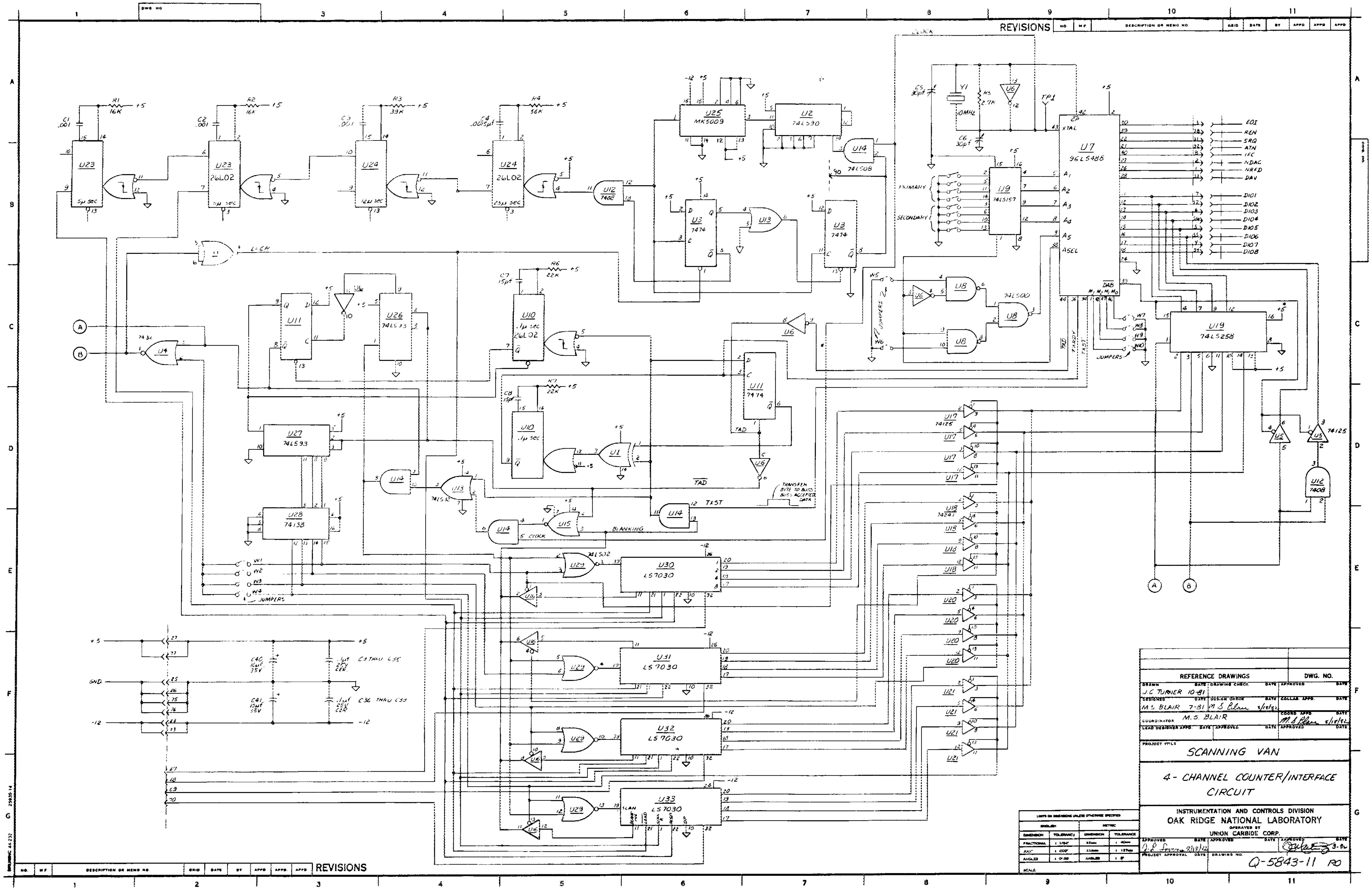
6. Bendix Field Engineering Corporation, EPA-02 Surface Gamma Scanner System, prepared for the Environmental Protection Agency, Office of Radiation Programs, Las Vegas, Nevada, BFEC-1981-7, September 1981.

APPENDIX I

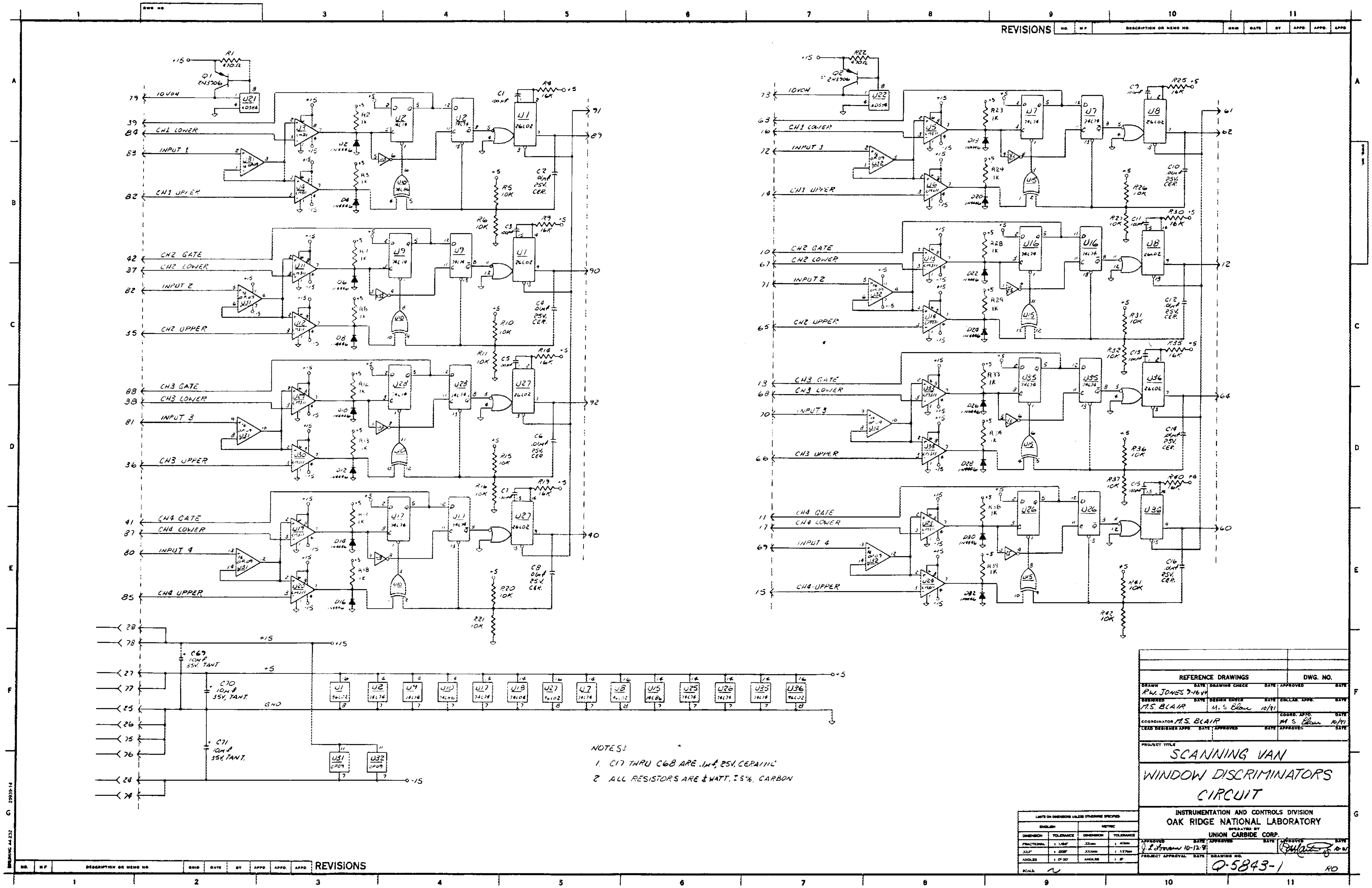
INTERFACE UNIT CIRCUIT BOARD DRAWINGS


REVISIONS
CN1
CLOCK
RESET
EOI
REN
SRQ
ATN
IFC
NDAC
NRFD
DAV
DIO1
DIO2
DIO3
DIO4
DIO5
DIO6
DIO7
DIO8
THICK FILM RESISTORS BECKMAN No. 898-3-R10K
+15
+5
GND
CN11 (U24) FLAT CABLE RECEPTACLE
RDY
PRINT
PRINT RST
BIT 6
BIT 5
BIT 4
BIT 3
BIT 2
BIT 1
EVENT
SPEED TONE
HIT TONE
CHART
+5
GND
ANALOG OUT
REFERENCE DRAWINGS
DWG. NO.
DRAWN W.W. KING 3-82
DESIGNED M.S BLAIR 12-81
DESIGN CHECK 8/82
COORDINATOR M. S. BLAIR
COORD. APPD. 8/82
PROJECT TITLE
SCANNING VAN
RECORDER / ALARM CIRCUIT
INSTRUMENTATION AND CONTROLS DIVISION
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORP.
DRAWING NO.
Q-5843-21 R0

6? 7?


REVISIONS
REFERENCE DRAWINGS
DWG. NO.
J.C. TURNER 10-81
M.S. BLAIR 7-81
M.S. BLAIR
SCANNING VAN
4-CHANNEL COUNTER/INTERFACE CIRCUIT
INSTRUMENTATION AND CONTROLS DIVISION
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORP.
Q-5843-11 R0

6? 7?


REVISIONS
NOTES:
1. C17 THRU C68 ARE .1uf, 25V, CERAMIC
2. ALL RESISTORS ARE ¼ WATT, ±5%, CARBON
REFERENCE DRAWINGS
DWG. NO.
R.W. JONES
M.S. BLAIR
SCANNING VAN
WINDOW DISCRIMINATORS CIRCUIT
INSTRUMENTATION AND CONTROLS DIVISION
OAK RIDGE NATIONAL LABORATORY
UNION CARBIDE CORP.
Q-5843-1
RO

APPENDIX II

SCAN PROGRAM LISTING

```
20 rem scanning van program 6/2/82 msb
40 poke 59468,12
60 open4,4,7:print#4:close4
80 print"▒"spc(10)"input your name ";:input n$
100 printspc(10)"input date (3/4/82)";:input n1$
120 poke 59468,14:dim d$(99)
140 gosub2720
160 open5,6,6:print#5,chr$(131);:close5
161 print"▒▒▒▒▒";spc(16);"▒APPROPRIATE BACKGROUND DATA MUST BE ENTERED"
162 print spc(17);"▒PRIOR TO ACCESSING ANY OTHER PROGRAM MODE"
180 goto4200
200 print"▒▒▒"spc(22)"ORNL RASCA SCANNING VAN":print"▒"
220 print spc(25)"▒PROGRAM DIRECTORY▒";"▒▒"
240 print spc(10);"▒s▒can: records all street survey data (scan data)
260 print spc(10);"▒b▒ackground: define background for area to be scanned"
280 print spc(10);"▒c▒alibration: used for system checkout"
300 print spc(10);"▒d▒ata dump: prints all stored raw data"
320 print spc(10);"▒f▒ile list: prints data above hit criteria"
340 print spc(10)"▒i▒dentification: pinpoint anomaly location▒▒"
360 d=0:d$=""
380 printspc(10)"ENTER ONLY THE FIRST LETTER OF THE DESIRED PROGRAM MODE";
385 print chr$(166)
400 get i$:if i$="" goto560
420 if i$="c" goto6240
440 if i$="b" goto4240
460 if i$="s" goto640
480 if i$="i" goto7160
500 if i$="d" goto8020
520 if i$="f" goto10220
540 i$="":goto200
560 for i=0 to 100:next i
580 printspc(10)"▒ENTER ONLY THE FIRST LETTER OF THE DESIRED PROGRAM MODE      "
600 for i=0 to 100:next i
620 print"▒";:goto380
640 rem scan program
660 print"▒"spc(30)"▒SCAN PROGRAM▒"
680 print"▒▒"spc(5)"The file name should be the primary road to be scanned"
700 print" and the direction of travel should be the last character in the"
720 print" file name.The file name can be no more than 16 characters."
740 print"▒▒"spc(30)"▒example▒"
760 print spc(25)"chartiers av n"
780 print spc(25)"▒road          ▒direction▒"
800 print"Input house numbers systematically and all cross streets."
820 print"▒ Use the exit key to close the scan file and return to the program"
840 print"directory.":print
860 c$=i$:i$="":d=0
880 printspc(25)"INPUT FILE NAME ";
900 let l=16 :gosub2160
920 if s$=chr$(19) goto200
930 gosub 2720
933 for i=0 to 300:next i
935 gosub 2720
940 s$=i$:i$="":l=1
960 print"▒  TOTAL       TOT Ra       Ra/Th       POS"
980 print"DISTANCE     COUNTS      RATIO      DIFF"
1000 print tab(6);chr$(15);"▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒";tab(79);chr$(143);"▒"
1020 open5,6,6:print#5,chr$(130);:for i=0 to 100:next i
```

```
1040 print#5,s$;:close5
1060 open2,8,2,"1:"+s$+",seq,write"
1080 print#2,t1;chr$(13);t2;chr$(13);
1100 print#2,n$;chr$(13);n1$;chr$(13);
1110 d=0
1120 rem loop
1140 for i=0 to 200:next i
1160 gosub2720
1180 gosub2820
1200 open 5,6,6:if l=20 then print#5,d$;:l=0
1220 l=l+1
1240 if r9<t1 goto1340
1260 if r3=>t2 goto1300
1280 if r1<0 goto1340
1300 b1=1:if r1>0 then r1$="+"
1320 r=r-50:goto1380
1340 if r1<0 then r1$="-"
1360 b1=0
1380 if (a1*0.258)>10 then b3=1:goto1420
1400 b3=0
1420 if b3>b4 then print#5,chr$(135);:goto1460
1440 if b3<b4 then print#5,chr$(134);
1460 if b1>b2 then print#5,chr$(133);:r2$="*":goto1500
1480 if b1<b2 then print#5,chr$(132);:r2$=""
1500 for i=0to100:next i:print#5,chr$(136);
1520 if r<0 then r=0
1540 g$=a1$+a2$+a3$+a4$+a5$+a6$+a7$+a8$
1560 print#2,g$;chr$(13);
1570 print"                                                            ":print"■";
1580 print spc(8-len(d$));d$;spc(10-len(r9$));r9$;spc(10-len(r3$));r3$;
1600 print"          "r1$"     "r2$
1620 print b$;"■"
1640 a$="":print#5,chr$(143);chr$(r);
1660 close 5:b2=b1:b4=b3
1680 get a$:if a$="" goto1120
1700 if a$=chr$(13) goto1760
1720 if a$=chr$(19) goto1900
1730 if a$=chr$(20)goto 1840
1740 b$=b$+a$:goto1680
1760 print#2,b$;chr$(13);
1780 open5,6,6:print#5,chr$(137);:close 5
1800 print b$:b$="":goto1120
1820 d=0:b$="":goto1120
1840 if len(b$)=1 then b$=""
1860 if b$=""goto1680
1880 b$=left$(b$,len(b$)-1):goto1680
1900 b$="end":print"■■■"
1920 print#2,b$;chr$(13);
1940 b$="":close 2
1960 open5,6,6:print#5,chr$(131);
1980 print#5,chr$(132);chr$(134);:close5
2000 open 2,8,8,"1:"+s$+",seq,read"
2020 sys 53849
2040 input#2,t1:print t1
2060 input#2,t2:print t2
2080 input#2,n$:print n$
2100 input#2,n1$:print n1$
2120 gosub3040
2140 goto200
2160 rem input road name******
```

```
2180 print chr$(166)"█";
2200 get a$ :if a$<>"" goto2300
2220 for i=0 to 50:next i
2240 print" █";
2260 for i=0 to 50:next i
2280 goto2160
2300 if a$=chr$(13) goto2620
2320 if a$=chr$(19) goto2620
2340 if a$=chr$(34) goto2200
2360 if s$="b" goto2420
2380 if a$=":"ora$="=" goto2200
2400 if a$="," goto2200
2420 if a$<>chr$(20) goto2520
2440 if i$="" goto2200
2460 if len(i$)=1 then i$="" :goto2500
2480 i$=left$(i$,len(i$)-1)
2500 goto2600
2520 if a$<" " goto2200
2540 if a$>"z"anda$<"█" goto2200
2560 if len(i$)=1 goto2200
2580 i$=i$+a$
2600 prints$"_█";:goto2200
2620 print" "; :s$="" :return
2640 rem input from keyboard
2660 get i$ :if i$="" goto2660
2680 if i$=r$ then run
2700 return
2720 rem input 8 channel data******
2740 open6,6,1:open7,6,2
2760 input#6,a1$,a2$,a3$,a4$
2780 input#7,a5$,a6$,a7$,a8$
2800 close6:close7:return
2820 rem cal ratio @ hit******
2840 a1=val(a1$):a2=val(a2$);a3=val(a3$);a4=val(a4$)
2860 a5=val(a5$):a6=val(a6$):a7=val(a7$);a8=val(a8$)
2880 d=d+a1;d$=str$(int(d*.258))
2900 r1=int((a3+a5+a7)-(a8*t2))
2920 r3=int(((a3+a5+a7)/a8)+0.5):r3$=str$(r3)
2940 g$=a1$+a2$+a3$+a4$+a5$+a6$+a7$+a8$
2960 r6=r5:r5=r4:r4=255-r3*4
2980 r9=a3+a5+a7:r9$=str$(r9)
3000 r=int((r4+r5+r6)/3)
3020 return
3040 rem data list*******
3060 open4,4:l=0;d=0
3080 print#4,chr$(1);"SCAN FILE NAME--█";s$;chr$(13);chr$(13)"█"
3100 print#4,spc(25);"TOTAL Ra COUNT HIT "t1
3120 print#4,spc(25);"RATIO HIT           "t2
3140 print#4,chr$(13);
3160 gosub3580
3180 if g$="end"goto200
3200 if x=0 goto3160
3220 l=l+1:if l=1 then gosub4020
3240 r3$=str$(r3):r1$=str$(r1):r9$=str$(r9)
3260 print#4,spc(6-len(a9$));a9$;spc(21-len(b$));b$;
3280 print#4,spc(7-len(d1$));d1$;spc(10-len(r9$));r9$;spc(7-len(r3$));r3$;
3300 print#4,spc(7-len(r1$));r1$;chr$(13);
3320 a9$="":b$=""
3340 for i=1 to 3
3360 gosub3580:rem input data
```

```
3380 if g$="end"goto200
3400 iflen(g$)<30 then print#4,spc(6-len(a9$));a9$;spc(21-len(b$));b$;
3420 iflen(g$)<30 then print#4,spc(7-len(d1$)):d1$;chr$(13);
3440 if x=1 goto3520
3460 next i
3480 print#4,"================================================================================"
3500 goto3160
3520 print#4,spc(34-len(d1$));d1$;spc(10-len(r9$));r9$;spc(7-len(r3$));r3$;
3540 print#4,spc(7-len(r1$));r1$;chr$(13);
3560 goto3340
3580 input#2,g$:if g$=""goto3580
3600 print g$
3620 if len(g$)<30 goto3960
3640 a1$=mid$(g$,3,6):a2$=mid$(g$,11,6):a3$=mid$(g$,20,5):a4$=mid$(g$,28,5)
3660 a5$=mid$(g$,36,5):a6$=mid$(g$,44,5):a7$=mid$(g$,52,5):a8$=mid$(g$,60,5)
3680 a1=val(a1$):a2=val(a2$):a3=val(a3$):a4=val(a4$)
3700 a5=val(a5$):a6=val(a6$):a7=val(a7$):a8=val(a8$)
3720 if a8=0 then a8=1
3740 d=d+a1:d$=str$(int(d*.258))
3760 d1=d-a9:d1$=str$(int(d1*.258))
3780 r1=int((a3+a5+a7)-(a8*t2)):r1$=str$(r1)
3800 r3=int(((a3+a5+a7)/a8)+0.5):r3$=str$(r3)
3820 r9=a3+a5+a7:r9$=str$(r9)
3840 if r9<t1 goto3940
3860 if r3=>t2 goto3920
3880 if r1>0 goto3920
3900 goto3940
3920 x=1:return
3940 x=0:return
3960 if g$="end" goto4140
3980 b$=g$:a9$=d$:a9=int(d)
4000 x=0:return
4020 print#4," TOTAL                  STREET          NET     TOT Ra   Ra/Th    POS"
4040 print#4,"DISTANCE               NUMBER      DISTANCE COUNTS   RATIO    DIFF";
4060 print#4,spc(3)"REMARKS/LOCATION"
4080 print#4,"--------------------------------------------------------------------------------";
4100 print#4,"------------------------"
4120 return
4140 if l=0 then print#4,spc(24);chr$(1)"NO ANOMALIES"
4160 print#4:print#4:print#4,"▒RRRRRRRRRRRRRRRRRRRRRR       ";n1$"▒"
4180 print#4,"     ▒"n$:print#4,chr$(12)
4200 close 2:close 4:b$="":d=0
4220 return
4240 rem background program******
4260 print "▒▒▒"spc(30)"▒BACKGROUND PROGRAM▒"
4280 print"▒▒▒"
4300 printspc(10)"BACKGROUND DATA FOR AREA TO BE SCANNED CAN BE OBTAINED FROM"
4320 print"▒"spc(15)"▒n▒ew file: background scan of area"
4340 print spc(15)"▒o▒ld file: data from previous background file"
4360 print"▒▒▒▒"
4380 printspc(10)"ENTER ONLY THE FIRST LETTER OF THE DESIRED PROGRAM MODE";
4385 print chr$(166)
4400 get i$:if i$="" goto4500
4420 if i$="n" goto4600
4440 if i$="o" goto5860
4460 if i$=chr$(19) goto200
4480 i$="":goto4380
4500 for i=0 to 100:next i
4520 print"▒";
4540 printspc(10)"ENTER ONLY THE FIRST LETTER OF THE DESIRED PROGRAM MODE      "
```

```
4550 gosub 2720
4560 for i=0 to 100:next i
4580 print"▒";:goto4380
4600 t=0:i$=""
4620 print"▒▒▒"spc(25)"BACKGROUND SCAN"
4640 print"▒▒▒"spc(10)"Scan of area should be obtained at normal driving speed"
4660 print"▒▒"spc(10)"Max length of file name is 16 characters"
4680 print"▒▒"spc(10)"Use the exit key to close the background file and"
4700 print spc(8)"return to the program directory.":print"▒▒▒"
4720 print spc(20)"INPUT BACKGROUND FILE NAME  ";
4740 let l=16 :gosub2160
4760 if a$=chr$(19) goto200
4780 s$=i$:i$=""
4800 print"▒  TOTAL      TOT Ra      Ra/Th"
4820 print"DISTANCE     COUNTS      RATIO"
4840 print tab(0);chr$(15);"▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒";tab(79);chr$(143);"▒"
4845 gosub 2720
4847 for i=0 to 800:next i
4850 gosub 2720
4860 open2,8,2,"1:"+s$+",seq,write"
4880 for i=0 to 400:next i
4900 gosub2720
4920 t=t+1:a$=""
4940 gosub2820
4960 m1=a2+m1:m2=m2+(a2-a3):m3=a3+m3:m4=m4+a4+a5+a7
4980 m5=m5+a8:m6=m6+a6
5000 g$=a1$+a2$+a3$+a4$+a5$+a6$+a7$+a8$
5020 print#2,g$;chr$(13);
5040 r9$=str$(r9):r3$=str$(r3)
5060 print spc(8-len(d$));d$;spc(10-len(r9$));r9$;spc(10-len(r3$));r3$
5080 get a$:if a$="" goto4880
5100 if a$=chr$(19) goto5140
5120 goto4880
5140 b$="end":print#2,b$;chr$(13);
5160 gosub5680
5180 b$="":close 2
5200 print"▒▒"
5220 open2,8,2,"1:"+s$+",seq,read"
5240 input#2,g$
5260 print g$
5280 if g$="end" goto5320
5300 g$="":goto5240
5320 close 2:close 5:print"▒▒"
5340 open4,4:print#4,chr$(1);"BACKGROUND FILE NAME---▒";s$;chr$(13)"▒"
5360 m1$=str$(int(m1+0.5)):b1$=str$(int(b1+0.5))
5380 m4$=str$(int(m4+0.5)):m5$=str$(int(m5+0.5)):m6$=str$(int(m6+0.5))
5400 m9$=str$(int(m9+0.5)):b4$=str$(int(b4+0.5)):b5$=str$(int(b5+0.5))
5420 b6$=str$(int(b6+0.5)):r3$=str$(int(r3+0.5))
5440 print#4,spc(16);"MEAN";spc(6);"STD.DEV."
5460 print#4,spc(26);"1 SIGMA"
5480 print#4,"--------------------------------------------------"
5500 print#4,"GROSS COUNTS";spc(8-len(m1$));m1$;spc(10-len(b1$));b1$
5520 print#4,"TOTAL Ra"spc(12-len(m4$));m4$;spc(10-len(b4$));b4$
5540 print#4,"Th"spc(18-len(m5$));m5$;spc(10-len(b5$));b5$
5560 print#4,"K";spc(19-len(m6$));m6$;spc(10-len(b6$));b6$
5580 print#4,"Ra/Th";spc(15-len(m9$));m9$;spc(10-len(r3$));r3$
5620 t2=int(m9+(2*r3))
5640 t1=int((2*(sqr(m4*(m9+1))+1))+m4)
5643 print#4,"▒▒▒▒"
5645 print#4,"HIT CRITERIA"
```

```
5650 print#4,"TOTAL Ra COUNTS    "t1
5655 print#4,"RATIO              "t2
5656 print#4,chr$(12):close4
5660 goto200
5680 rem cal mean @ std. dev.*******
5700 m1=m1/t:m2=m2/t:m3=m3/t:m4=m4/t
5720 m5=m5/t:m6=m6/t
5740 b1=sqr(m1):b2=sqr(m2):b3=sqr(m3):b4=sqr(m4)
5760 b5=sqr(m5):b6=sqr(m6)
5780 r3=sqr((b4/m4)*(b4/m4)+(b5/m5)*(b5/m5))
5800 m7=m2/m3:m8=m4/m6:m9=m4/m5
5820 r3=int(m9*sqr((b5/m5)*(b5/m5)+(b4/m4)*(b4/m4)))
5840 return
5860 rem input background data from old file******
5880 print"■":l=10:i$=""
5900 print spc(20)"■INPUT BACKGROUND DATA FROM OLD FILE■"
5920 print spc(10)"INPUT TOTAL Ra COUNTS (MEAN)";
5940 gosub2160
5960 m4=val(i$):i$=""
5980 print:print spc(10)"INPUT Ra/Th RATIO (MEAN)";
6000 gosub2160
6020 m9=val(i$):i$=""
6040 print:print spc(10)"INPUT Ra/Th RATIO (STD. DEV.)";
6060 gosub2160
6080 r3=val(i$):i$=""
6100 t2=int(m9+(2*r3))
6120 t1=int((2*(sqr(m4*(m9+1))+1))+m4)
6140 print:print spc(10)"■■■NEW HIT CRITERIA"
6160 print spc(10)"TOTAL Ra"t1
6180 print spc(10)"RATIO"t2
6200 for i=0 to 2000:next i
6220 goto200
6240 rem calibration program******
6260 print"■";spc(25)"■CALIBRATION/INSTRUMENT SETTINGS■"
6280 print spc(25)"■PHOTOPEAK CHANNEL SETTINGS"
6300 print spc(25)"Cs-137(0.661MeV) channel 111"
6320 print spc(25)"Co-60(1.170MeV) channel 192"
6340 print spc(25)"Co-60(1.330MeV) channel 217"
6360 print spc(25)"Tl-208(2.614MeV) channel 424"
6380 print spc(30)"■■WINDOW DISCRIMINATORS"
6400 print"ROI"spc(20)"UPPER   CHANNEL#"spc(10)"LOWER   CHANNEL#":print
6420 print"A1 distance"spc(14)"10.0"spc(21)"1.50"
6440 print"A2 gross counts"spc(10)"7.00"spc(21)"0.06"
6460 print"A3 0.609MeV"spc(14)"1.88      120"spc(13)"1.35       90"
6480 print"A4 0.609MeV"spc(14)"1.86      120"spc(13)"1.31       90"
6500 print"B1 1.120MeV"spc(14)"3.06      200"spc(13)"2.66      170"
6520 print"B2 1.460MeV"spc(14)"4.12      260"spc(13)"3.33      215"
6540 print"B3 1.764MeV"spc(14)"4.81      305"spc(13)"3.75      260"
6560 print"B4 2.614MeV"spc(14)"8.00      500"spc(13)"5.76      382■■"
6580 print spc(20)"DEPRESS ANY KEY TO START THE PROGRAM"chr$(166)
6600 get i$:if i$="" goto6660
6620 if i$=chr$(19) goto200
6640 goto6740
6660 for i=0 to 50:next i
6680 print"■"spc(20)"DEPRESS ANY KEY TO START THE PROGRAM     ";"■"
6700 for i=0 to 50:next i
6710 gosub 2720
6713 for i=0 to 800:next i
6715 gosub 2720
6720 fori=0 to 400:next i
```

```
6725 goto6580
6740 a9=0:x$="   ":t=1
6760 gosub2720
6770 gosub 2820
6780 print"▒dist";"           ";"gross";"           ";"Ra"
6800 print"pulse";"        ";"counts";"    ";"0.609MeV"
6820 printspc(8-len(d$));d$;x$;a2$;x$;a3$:print
6840 print"   Ra          K          Ra          Th"
6860 print"1.120MeV   1.460MeV   1.764MeV   2.614MeV"
6880 printa5$;x$;a6$;x$;a7$;x$;a8$
6900 print:print:print
6920 print:print"10 second count 0.609MeV"
6940 print spc(14-len(a9$));a9$
6950 print:print"average count rate="m4
6960 a3=val(a3$)
7000 a9=a3+a9
7020 if t=10 goto7110
7040 t=t+1
7060 get i$:if i$="" goto6760
7080 if i$=chr$(19) goto200
7090 if i$=chr$(48) then d=0
7100 i$="":goto6760
7110 m3=m2:m2=m1:m1=a9
7115 m4=int((m3+m2+m1)/3)
7120 t=0:a9$=str$(a9):a9=0
7140 goto7040
7160 rem identify program*******
7180 print"▒"spc(27)"▒IDENTIFICATION PROGRAM▒▒▒"
7200 print"THIS PROGRAM IS TO PINPOINT THE EXACT LOCATION OF THE ANOMALIES."
7220 print"The data is not stored in this program.If a permanent record is"
7240 print"needed then return to the SCAN program▒▒"
7260 print spc(10)"TO RESET DISTANCE,DEPRESS 0"
7280 print spc(10)"TO EXIT PROGRAM,DEPRESS EXIT KEY▒▒▒"
7300 print spc(10)"DEPRESS ANY KEY TO START THE PROGRAM"chr$(166)
7320 get i$:if i$="" goto7380
7340 if i$=chr$(19) goto200
7360 goto7460
7380 for i=0 to 50:next i
7400 print"▒"spc(10)"DEPRESS ANY KEY TO START THE PROGRAM      ";"▒"
7420 for i=0 to 50:next i
7440 goto7300
7460 print"▒  TOTAL       TOT Ra      Ra/Th      POS"
7480 print"DISTANCE     COUNTS      RATIO      DIFF"
7500 print tab(0);chr$(15);"▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒";tab(79);chr$(143);"▒"
7510 gosub 2720
7513 for i=0 to 800:next i
7515 gosub 2720
7520 open 5,6,6
7540 for i=0 to 400:next i
7560 gosub2720
7580 gosub2820
7600 if r9<t1 goto7700
7620 if r3<t2 goto7700
7640 if r1<0 goto7700
7660 print#5,chr$(133);:r2$="*"
7680 r1$="+":goto7760
7700 if r1<0 then r1$="-"
7720 if r1>0 then r1$="+"
7740 print#5,chr$(132);:r2$=""
7760 if r<0 then r=0
```

```
7780 close 5
7800 r9$=str$(r9)
7840 print spc(8-len(d$));d$;spc(10-len(r9$));r9$;spc(10-len(r3$));r3$;
7860 print"        "r1$"    "r2$
7880 i$=""
7900 get i$:if i$="" goto7520
7920 if i$=chr$(19) goto7980
7940 if i$="0" then d=0
7960 i$="":goto7520
7980 print"▒▒"
8000 open 5,6,6:print#5,chr$(132):close5:goto200
8020 rem data dump program******
8040 print"▒";spc(27)"▒DATA DUMP PROGRAM▒▒"
8060 gosub9160
8080 gosub9780
8100 if a$=chr$(19) goto200
8120 if a1$="" goto9060
8140 gosub8200
8160 gosub9800
8180 goto8100
8200 a=val(a1$):d=0
8220 print"▒"
8240 open4,4:print#4,chr$(1);"FILE NAME--▒";d$(a);chr$(13);chr$(13)"▒"
8260 print#4,chr$(13);chr$(13)
8280 print"    TOTAL                Ra         Ra    ";
8300 print#4,"    TOTAL                Ra         Ra    ";
8320 print"     K         Ra         Th    "
8340 print#4,"     K         Ra         Th    "
8360 print"  DISTANCE     GROSS  0.609MeV   1.120MeV";
8380 print#4,"  DISTANCE     GROSS  0.609MeV   1.120MeV";
8400 print"  1.460MeV  1.764MeV  2.614MeV"
8420 print#4,"  1.460MeV  1.764MeV  2.614MeV"
8440 print"   (feet)      (cps)     (cps)      (cps) ";
8460 print#4,"   (feet)      (cps)     (cps)      (cps) ";
8480 print"   (cps)      (cps)     (cps)  "
8500 print#4,"   (cps)      (cps)     (cps)  "
8520 print tab(0);chr$(15);"▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒";tab(79);chr$(143)
8540 print"▒"
8560 open 2,8,8,"1:"+d$(a)+",seq,read"
8580 input#2,g$
8600 if g$=""goto8580
8620 if len(g$)<20 goto8980
8640 a1$=mid$(g$,3,6):a2$=mid$(g$,11,6):a3$=mid$(g$,20,5):a4$=mid$(g$,28,5)
8660 a5$=mid$(g$,36,5):a6$=mid$(g$,44,5):a7$=mid$(g$,52,5):a8$=mid$(g$,60,5)
8680 a1=val(a1$):a2=val(a2$):a3=val(a3$):a4=val(a4$)
8700 a5=val(a5$):a6=val(a6$):a7=val(a7$):a8=val(a8$)
8720 if a8=0 then a8=1
8740 if g$=g1$goto9020
8760 g1$=g$
8780 d=d+a1:d$=str$(int(d*.258))
8800 a2$=str$(a2):a3$=str$(a3):a5$=str$(a5)
8820 a6$=str$(a6):a7$=str$(a7):a8$=str$(a8)
8840 print spc(10-len(d$))d$;spc(10-len(a2$))a2$;spc(8-len(a3$))a3$;
8860 print#4,spc(10-len(d$))d$;spc(10-len(a2$))a2$;spc(8-len(a3$))a3$;
8880 print spc(10-len(a5$))a5$;spc(10-len(a6$))a6$;spc(10-len(a7$))a7$;
8900 print#4,spc(10-len(a5$))a5$;spc(10-len(a6$))a6$;spc(10-len(a7$))a7$;
8920 print spc(10-len(a8$))a8$
8940 print#4,spc(10-len(a8$))a8$
8960 goto8580
8980 if g$="end" goto9020
```

```
9000 print g$:print#4,g$:goto8580
9020 print"▓▓":close 2
9040 print#4,chr$(19):close 4:return
9060 for a=1 to l
9080 d=0
9100 gosub8220
9120 next a
9140 goto200
9160 rem read directory******
9180 print"▓▓▓"spc(20)"READING DIRECTORY PLEASE WAIT"
9200 open 2,8,4,"#5"
9220 print#2,"i1"
9240 open 15,8,15:x2=1:a=1
9260 print#15,"u1"4,1,39,x2
9280 get#2,a$:if a$="" then9280
9300 x1=asc(a$)
9320 if x1>77 goto9380
9340 get#2,a$:if a$="" then9340
9360 x2=asc(a$)
9380 fori=1 to 8
9400 get#2,a$:if a$="" then9400
9420 if a$<>chr$(129) goto9400
9440 l=0
9460 get #2,a$:if a$="" goto9460
9480 get #2,a$:if a$="" goto9480
9500 if a$=chr$(160) goto9620
9520 if l=18 goto9620
9540 if a$>chr$(90) then a$=""
9560 if a$<chr$(32) thena$=""
9580 b$(i)=b$(i)+a$:l=l+1
9600 goto9480
9620 if i=1 then c$=b$(1)
9640 if i=1  goto9680
9660 if b$(i)=c$ goto9760
9680 d$(a)=b$(i):a=a+1:next i
9700 for i=1 to 8:b$(i)="":next i
9720 if x1>77 goto9760
9740 goto9260
9760 close 2:close 15:return
9780 rem list directory******
9800 print"▓":l=a-1
9820 for i=1 to l
9840 print i"  "d$(i);:i=i+1:if d$(i)="" goto9900
9860 printtab(25)i"  "d$(i);:i=i+1:if d$(i)="" goto9900
9880 printtab(50)i"  "d$(i):if d$(i)="" goto9900
9900 next i
9920 print"▓▓"
9940 print"To print a file enter the number of that file."
9960 print"To print all files depress only the return key."
9980 print"To return to the program directory depress the exit key."
10000 print"▓▓":a1$=""
10020 printspc(26)"INPUT FILE NUMBER "a1$;chr$(166)
10040 get a$:if a$="" goto10120
10060 if a$=chr$(19) goto10200
10080 if a$=chr$(13) goto10200
10100 a1$=a1$+a$
10120 fori=0 to 50:nexti
10140 print spc(26)"▓INPUT FILE NUMBER "a1$"      ▓"
10160 fori=0 to 50:nexti
10180 goto10020
```

```
10200 return
10220 rem file list program******
10240 print"█"spc(30)"█FILE LIST PROGRAM████"
10260 print spc(10)" THIS PROGRAM WILL LIST ALL DATA ABOVE HIT CRITERIA.███"
10280 print spc(20)"█u█se stored hit criteria"
10300 print spc(20)"█i█nput new hit criteria"
10320 print spc(20)"█l█ist all data████"
10340 printspc(10)"ENTER ONLY THE FIRST LETTER OF THE DESIRED PROGRAM "chr$(166
)
10360 get i$:if i$="" goto10480
10380 if i$="u" goto10580
10400 if i$="i" goto10900
10420 if i$="l" goto11220
10440 if i$=chr$(19) goto200
10460 i$="":goto10340
10480 for i=0 to 100:next i
10500 print"█";
10520 printspc(10)"ENTER ONLY THE FIRST LETTER OF THE DESIRED PROGRAM
10540 for i=0 to 100:next i
10560 print"█"::goto10340
10580 rem use stored hit criteria
10600 print"█"spc(20)"█LIST DATA USING STORED HIT CRITERIA█"
10620 gosub9160
10640 gosub9780
10660 if a$=chr$(19)goto200
10680 if a$="" goto10880
10700 a=val(a1$):d=0
10720 s$=d$(a)
10740 open 2,8,8,"1:"+s$+",seq,read"
10760 input#2,g$:if g$="" goto10760
10780 t1=val(g$)
10800 input#2,g$:if g$="" goto10800
10820 t2=val(g$)
10821 input#2,n$:print n$
10822 input#2,n1$:print n1$
10840 gosub 3040
10860 goto200
10880 rem
10900 rem input new hit criteria
10920 print"█"spc(20)"█INPUT NEW HIT CRITERIA"
10940 gosub9160
10960 gosub9780
10980 if a$=chr$(19)goto200
11000 if a$="" goto11200
11020 a=val(a1$):d=0
11040 s$=d$(a)
11060 open 2,8,8,"1:"+d$(a)+",seq,read"
11080 print"input total Ra counts";:input t1
11100 print"input ratio hit";:input t2
11120 gosub3040
11140 gosub9800
11160 goto10980
11180 end
11200 rem
11220 rem list all data
11240 print"█"spc(20)"█LIST ALL DATA"
11260 gosub9160
11280 gosub9780
11300 if a$=chr$(19)goto200
11320 if a$="" goto11520
```

```
 11340 a=val(a1$):d=0
 11360 s$=d$(a)
 11380 open 2,8,8,"1:"+s$+",seq,read"
 11400 input#2,g$:if g$="" goto11400
 11420 t1=0
 11440 input#2,g$:if g$="" goto11440
 11460 t2=0
 11480 gosub9800
 11500 goto11300
 11520 end
ready.
```

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