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HERMES II EXPERIMENTERS' MANUAL (REVISED)

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ABSTRACT

The HERMES II is a high-intensity laboratory photon source for the conduct of gamma-ray radiation effects experiments as well as a high-energy pulsed electron beam generator for a variety of potential applications. The purpose of this manual is to serve as a basic source of information for prospective users of HERMES. Included is a brief discussion of the design and operation of the accelerator system as well as a summary of environmental data for X-ray operation and output characteristics for electron beam modes. The manual also contains a description of the HERMES experimental facilities, including geometry of the test cell, instrumentation and data collection capabilities, and services and support available to experimenters.

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SECTION 1

INTRODUCTION

The HERMES II [1, 2], shown in Figure 1-1, is a high-energy, pulsed electron beam or bremsstrahlung X-ray generator. It was designed and constructed by Sandia Laboratories personnel and is in operation at the Technical Area V facilities, Kirtland Air Force Base (East), Albuquerque, New Mexico.

The purpose of the machine is to provide a high-intensity laboratory photon source for the conduct of gamma-ray radiation effects experiments. While primarily intended for use as a bremsstrahlung generator, HERMES II is also capable of generating electron beams with a variety of potential applications. HERMES development is an ongoing program, devising new configurations and modes of operation to satisfy changing test requirements of the users.

The purpose of this manual is to serve as a basic source of information for prospective users of HERMES. Section 2 contains a brief discussion of the design and operation of the accelerator system. A summary of environmental data for X-ray operation is presented in Section 3 and output characteristics for electron beam modes are given in Section 4. Section 5 describes the HERMES experimental facilities, including geometry of the test cell, instrumentation and data collection capabilities. Services and support available to experimenters are outlined in Section 6.

The final section of this manual, Section 7, pertains to Energy Research and Development Administration and Department of Defense organizations and contractors, other than Sandia Laboratories.

A bibliography of Sandia Laboratories reports and open literature publications concerning HERMES developments and applications is contained in the Appendix.

The information contained herein supplements the presentation in the TREE Simulation Facilities Handbook [3] and constitutes a complete revision of the original HERMES II Experimenters' Manual [4]. In most cases, the depth of material is sufficient to allow the user to determine the applicability of HERMES II to his proposed experiment and to permit irradiation calculations and planning. For the purposes of jointly ascertaining technical feasibility of experiments and providing additional information, as required, the facility staff will serve as active participants in test plan development. Additional data or detail may be obtained from the HERMES staff (telephone (505) 264-3197) or the Operations Supervisor, Beam Source Applications Division (5232).

OUTPUT SPECIFICATIONS

10-13 MV, 100 kA

50 ns FWHM, 3000 rads/m

Figure 1-1. Artist's Drawing of HERMES II

SECTION 2

DESIGN AND OPERATION OF THE FACILITY

2.1 General

The principal components of HERMES, as shown in the simplified schematic diagram of Figure 2-1, consist of a Marx generator, a Blumlein transmission line and an output tube. Stored low-voltage energy is converted to high voltage by the Marx generator and transferred to the Blumlein transmission line, which serves as a fast-discharge, low-inductance energy source for the tube. Transformer oil is used as the insulating dielectric.

Figure 2-1. Simplified HERMES II Schematic Diagram

The Marx generator consists of a bank of capacitors, charged in parallel and discharged in series by means of spark gap switches. The Marx generator pulse charges the intermediate cylinder to negative potential, while the outer cylinder (the tank wall) and the central cylinder remain at ground potential. Figure 2-2 shows an equivalent circuit during the charging cycle for the intermediate cylinder. For this circuit:

L_m = total Marx generator inductance

C_m = total Marx generator capacity

R_s = total Marx generator series resistance

- R_p = equivalent Marx generator parallel resistance
 C_1 = capacity between intermediate and central cylinders
 C_2 = capacity between intermediate and outer cylinders
 L_1 = Marx switch inductance
 L_2 = central cylinder isolating inductance.

Figure 2-2. Equivalent Marx-Blumlein Charging Circuit

When the voltage on the intermediate cylinder reaches a predetermined value, the Blumlein switch closes by self-breakdown. The voltage transient created propagates between the central and intermediate cylinders. When the voltage transient reaches the output-tube end of the transmission line, a voltage is created across the tube for twice the electrical transit time of the transmission line. For a lossless system and a matched tube-to-Blumlein impedance, the tube voltage is equal to the charging voltage applied to the intermediate cylinder.

The output tube is an evacuated, insulating chamber, with a space-charge-limited cathode and a "thick target" anode for bremsstrahlung production, or an anode thin enough to allow electrons to pass through it with minimal loss if electron beam experiments are to be performed. In the latter case, the electrons emerge from the tube into a drift chamber where beam control is accomplished.

2.2 Marx Generator

The Marx generator is designed as an 18-megavolt, 1-megajoule energy storage system and is described in detail in a paper by Prestwich and Johnson [5]. It consists of 186 capacitor stages arranged in 31 rows, with each stage as two 0.5-microfarad, 100-kV BICC capacitors in parallel. Each pair of stages is separated by a pressurized, individually housed gas spark gap switch. The assembly, shown schematically in Figure 2-3, is immersed in transformer oil in a steel tank 6.1 m (20 ft) in diameter and 12.2 m (40 ft) in length.

Figure 2-3. Schematic Diagram - Marx Generator

The Marx generator output capacity is 5.38 nF. The calculated inductance and series resistance are $80 \mu\text{H}$ and 20Ω , respectively. The resistors interconnecting the capacitors are made of tygon tubing filled with a copper sulfate solution. The ground resistors are each $50 \text{ k}\Omega$ and the charging resistors are each $1.7 \text{ k}\Omega$. The Marx generator is dc-charged with a variable $\pm 125\text{-kV}$, 250-mA power supply that can be operated manually or automatically.

During the charge cycle, the capacitors are functionally in parallel through the copper sulfate charging resistors, and the spark gaps act as open circuits. When the desired charging voltage (100 kilovolts maximum) has been achieved, the power supply is electrically disconnected from the capacitor bank, and a high-voltage signal is initiated on the trigger line. Three triggered spark gaps are fired, establishing six stages in series. Spark gaps adjoining the series section are then successively overvolted, causing the Marx generator to erect toward full output voltage on a ramp function.

2.3 Blumlein Transmission Line

The negative voltage output of the Marx generator is placed on the intermediate cylinder of a coaxial Blumlein transmission line. This consists of three concentric cylinders, each approximately 8.5 m in length, which are insulated from each other by transformer oil and dielectric supports. The outer cylinder is the tank wall, 4.9 m in diameter. The intermediate cylinder has a 3.5-m diameter, and the corresponding diameter for the central cylinder is 2 m. Since the dielectric constant of the oil is 2.14, the characteristic impedances of the outer and inner coaxial lines are, respectively, 11 and 22 Ω . The electrical length of each line or the one-direction transit time, τ , is 44 nanoseconds. The corresponding outer and inner capacitances are 3.4 nF and 1.8 nF, respectively. The return line, corresponding to inductance L_2 in Figure 2-2, is 6.5 μ H. The Blumlein pulse-forming line is required because the current risetime of the Marx generator is in excess of the desired pulse width.

During Blumlein charging, the outer and central cylinders, across which the tube is electrically located, are held near ground potential. When the Marx generator has erected to approximately 90 percent of its full output voltage, the Blumlein switch between the central and intermediate cylinders experiences self-breakdown, launching a traveling wave in the inner coaxial line. The voltage as a function of position and time during the first three transit times can be seen in the voltage-time diagrams of Figure 2-4. In fact, the switch has finite risetime and affects the wave-shape of the voltage pulse across the output tube. Using formulas developed by Martin [6], the switch risetime can be determined by:

$$\tau_R = \frac{5}{Z^{1/3} E^{4/3}}$$

$$\tau_L = \frac{L}{Z}$$

where

τ_R = risetime due to the resistive phase of the breakdown (ns)

τ_L = risetime due to the inductive phase of the breakdown (ns)

E = electric field strength in the switch (0.43 MV/cm)

Z = impedance of the inner transmission line (22 Ω)

L = inductance of the spark channel (nH).

These time constants, together with the time constant associated with the output tube, produce the 60-nanosecond risetime of the output voltage pulse.

Figure 2-4. Blumlein Voltage-Time Diagrams

High-density polyethylene truncated cones are used to support the Blumleins. This material is selected because of its high pulsed-breakdown voltage and mechanical strength and because its dielectric permittivity is similar to that of the insulating oil.

2.4 Output Tube

The voltage pulse formed by the Blumlein structure is impressed across the diode, which consists of an insulating and vacuum holding structure, a field emission cathode, and an anode. The specific configuration varies with the mode of operation and several alternate designs will be illustrated in Sections 3 and 4 of this manual.

The tube envelope consists of eighteen to twenty-one cross-linked polystyrene insulators 1.8 m (72 in.) in diameter, alternated with aluminum grading rings. Each polystyrene insulator is 10.2 cm (4 in.) thick and the aluminum grading rings are 1.6 cm (5/8 in.) thick. The grading rings provide a more uniform voltage gradient across the insulator surfaces and capacitively grade the pulsed voltage. At pressures within the tube of typically 10^{-7} torr, the insulator rings can withstand an electric field of 72 kV/cm before surface breakdown occurs. For a 10-MV pulse on the 21-ring tube, the stress on the insulators is about 48 kV/cm. This reduced operating level extends the life of the tube and increases the interval between scheduled maintenance.

Details of the cathode shank and emitting cathode tip construction vary for the different tube designs. In the high-impedance diode, the shank and hemispherical cathode tip are 15.2 cm (6 in.) in diameter and made of 303 stainless steel. The cathode-anode separation is typically 28.5 cm (11.25 in.), which produces a tube impedance of approximately 120Ω and an inductance of $2.2 \mu\text{H}$. The gap size is used as an operating variable of the prepulse diode.

The X-ray mode conventional anode is a thick, high-Z target (0.152-cm thick tantalum) selected for maximum efficiency in converting beam energy to bremsstrahlung radiation. A 0.95-cm thick aluminum plate filters the remaining electrons and low-energy X-rays from the beam. Composite converters of specialized design are employed in some of the HERMES II bremsstrahlung modes.

The anode used for electron beam operation is a thin, low-Z target (0.0127-cm thick titanium) which allows passage of the electrons with minimum energy loss. The beam is extracted into a drift region chamber in which its propagation and focusing can be controlled by current density and background gas pressure as well as by applied magnetic fields.

2.5 Nominal Environments

At its present stage of development, the HERMES II has a number of operational modes, each with its distinctive environmental parameters. Output data for these modes will be presented in Section 3 (X-ray modes) and Section 4 (electron beam modes) of this manual.

SECTION 3

X-RAY MODE ENVIRONMENTS

3.1 Introduction

The HERMES II accelerator was originally designed for primary application as a pulsed bremsstrahlung source. While a significant amount of E-beam experimentation is now being performed, the great majority of machine experience has been accumulated in the X-ray mode of operation. In this section, X-ray environmental capabilities are summarized to allow a potential experimenter to determine the usefulness of HERMES in his application and to permit irradiation calculations and planning. The facility staff will serve in a consulting role during test planning for determining the technical feasibility of proposed experiments.

There are currently three operational X-ray modes--the high-impedance photon generation diode using a conventional converter, the enhanced bremsstrahlung design, and the prepulse diode.

The high-impedance diode is the original design configuration of the HERMES II system. Operations using this output tube with a standard bremsstrahlung converter constitute a large percentage of all pulses to date.

In the enhanced bremsstrahlung or pinched beam X-ray mode experiments [7], the beam is extracted from the diode through a titanium anode. Beam self-focus in a neutral gas is used to compress the beam onto a second target which serves as the bremsstrahlung converter. The consequent small spot size of the compressed beam has resulted in increased dose rate capabilities of the machine, at the sacrifice of large exposure area, however.

The prepulse diode [8] currently under development may also be used in the X-ray mode. Preliminary results of tests are presented later in this section.

The bremsstrahlung environments of HERMES are both spatially and temporally variable and, ideally, should be specified by photon intensity and spectrum as a function of position and time throughout the exposure volume. Because of the expense and complexity of calculations or measurements, this information is not totally available in either experimental or theoretical form. In most applications, however, such detail is unnecessary and data have not been generated simply for complete documentation. Diagnostic data which are critical to some new experiment, but not presently available, can be generated.

In addition, the X-ray outputs of HERMES are dependent upon numerous machine parameters, such as charge voltage, anode-cathode geometry, and switch settings. The environmental definitions which follow are for the standard configuration at the highest, reliable operating level. The operator can adjust some of the parameters, producing minor output changes. However, similar variations can usually be achieved through appropriate selection of the experiment location, and the time to adjust the machine and characterize new environmental parameters is generally not justified.

3.2 High-Impedance Diode X-Ray Mode

The standard output-tube configuration of the high-impedance diode X-ray mode is identified in Table 3-I and illustrated in Figure 3-1. The exposure is performed at a location in the test cell chosen by the experimenter on the basis of the environmental definition. The most common selection criteria involve a compromise between high dose rate, large sample area and desired photon beam uniformity.

TABLE 3 I

High-Impedance Diode X-Ray Mode Standard Configuration

Anode Chamber	1.64-m (64.75-in.) diameter
Tube Length	21-ring
Anode	0.152-cm (0.06-in.) tantalum
Cathode Shank	15.2-cm (6-in.) diameter
Cathode Tip	15.2-cm (6-in.) diameter hemi-spherical stainless steel
Anode-Cathode Gap	28.5 cm (11.25 in.)
Blumlein Oil Gap Switch	22.9 cm (9 in.)

The nominal operating parameters of the accelerator and output characteristics are summarized in Table 3-II. The dose and dose rate given as nominal values apply to an exposure location at 7 cm from the anode plane, where a nearly uniform dose is available over an area of approximately 400 cm². The highest X-ray dose per pulse produced by HERMES in this mode is of the order of 6×10^4 rads (Si), corresponding to a peak dose rate of 1.2×10^{12} rads (Si)/s. This occurs in a thin annular ring on the tube faceplate and is usable for a limited class of experiments only.

Figure 3-1. HERMES II High-Impedance Diode

TABLE 3-II

High-Impedance Diode X-Ray Mode Nominal Operating Parameters

MARX GENERATOR

Charging Voltage	70 kV
Repetition Rate	3 pulses/hour

DIODE

Peak Diode Voltage	10 MV
Peak Diode Current	100 kA
Total Beam Energy	75 kJ (18 kcal)

X-RAY ENVIRONMENT

Peak Dose/Pulse	at 7 cm $\left\{ \begin{array}{l} 4 \times 10^4 \text{ rads (Si)} \\ 8 \times 10^{11} \text{ rads (Si)/s} \end{array} \right.$
Peak Dose Rate	
Pulse Width	
	50 ns

3.2.1 Total Dose and Isodose Contours

The total dose per pulse and isodose contours in the exposure volume may be modified by altering numerous machine parameters, such as charge voltage, anode-cathode gap spacing and Blumlein oil gap (BOG) switch setting, but the desired outputs can usually be achieved by appropriate selection of the exposure location without altering the standard machine configuration.

The data presented in this section are taken at standard values for electrical and mechanical parameters of HERMES II, as previously identified in Table 3-I. This is the highest, reliable level of machine operation at the present stage of development.

Figure 3-2 presents the total X-ray dose per pulse along the tube axis as a function of distance from the anode faceplate. Approximate $1/R^2$ dependence can be observed at distances in excess of 50 cm.

The exposure pattern of HERMES II has been shown to have good azimuthal symmetry. Transverse profiles of the total dose per pulse at several axial locations are illustrated in Figure 3-3. The experiment position at 7 cm from the anode, with a high and nearly uniform total dose over an area of 400 cm^2 , is a frequently used location.

Figure 3-4 combines the on-axis and transverse dose mappings into a set of isodose contours for the HERMES II exposure volume. Relative doses in this figure are normalized to unity at the beam centerline on the anode faceplate.

Figure 3-2. High-Impedance Diode X-Ray Dose per Pulse as a Function of Distance from Anode

Figure 3-3. Transverse High-Impedance Diode Bremsstrahlung Dose Profiles

Figure 3-4. HERMES II High-Impedance Diode Isodose Curves

The isodose-per-pulse contours for HERMES II have been established by dose measurements using silver phosphate and cobalt glass dosimeters and calcium fluoride thermoluminescent detectors. The thermoluminescent dosimeters are calibrated in rads (Si), whereas the glasses have been calibrated in rads to the particular glass, using the Sandia Gamma Irradiation Facility, a cobalt-60 source. Results were interpreted by the Sandia Laboratories Dosimetry Laboratory. The accuracy and repeatability of the particular dosimetric systems in use are estimated at ± 15 percent or better, depending upon the detector redundancy employed.

3.2.2 Output Waveform and Dose Rate

Dose rate as a function of time has been measured using photodiodes, Compton diodes, and PIN semiconductor detectors at various positions in the experimental volume. While some conflicting results have been encountered, the majority of data leads to the conclusion that pulse shape is independent of position and dose rate.

Figure 3-5 is a reproduction of a Compton diode output signal obtained during a HERMES II operation. Because the shape is independent of position and voltage level, an arbitrary scale has been used on the ordinate. Note that the full width at half-maximum dose rate is 50 nanoseconds. Estimated accuracy of this value is ± 5 nanoseconds.

Figure 3-5. High-Impedance Diode X-Ray Pulse Shape

Using the curve of Figure 3-5, the following dose rates can be determined by relating the integral under the normalized curve to total dose:

$$\text{Mean dose rate during 155 ns pulse} = 6.5 \times 10^6 \text{ D}$$

$$\text{Mean dose rate during 50 ns between half-maximum points} = 1.4 \times 10^7 \text{ D}$$

$$\text{Peak dose rate} = 1.8 \times 10^7 \text{ D},$$

where D is the dose per pulse.

3.2.3 Photon Spectrum

A magnetic Compton spectrometer, designed to measure the gamma ray spectrum from intense pulsed sources in the presence of gamma rays, electrons and/or neutrons, has been used to characterize the HERMES II bremsstrahlung environment [9]. The measured results at two values of charging voltage are shown as smooth curves in Figure 3-6. Shown also in the figure for comparison are the semiempirical spectra, normalized to the gamma-spectrometer results, obtained from the ETRAN-15 Monte Carlo code using an electron spectrum derived from tube current-voltage (I-V) data and a one-dimensional approximation for the tantalum anode.

Figure 3-6. HERMES II High-Impedance Diode Photon Spectrum

To our knowledge, HERMES II is the only facility in its range of voltage and current whose photon spectrum has been measured. The close agreement between experiment and theory in this spectrum, however, lends credence to photon spectra based upon tube output waveforms and calculated with Monte Carlo electron/photon transport codes.

3.2.4 Pulse Monitors

The HERMES operating staff routinely monitors Marx generator voltage, diode voltage and diode current on each pulse. The time-dependent waveforms are photographically recorded from an oscilloscope trace, and typical results are shown in Figures 3-7 and 3-8. While these data are not direct measurements of environmental exposures at the experiment location, in the absence of extraordinary occurrences, they may be used to verify similarity of a series of nominally identical pulses.

Figure 3-7. Marx Generator Output Voltage

Figure 3-8. High-Impedance Diode Output Voltage and Current

Voltage waveforms are obtained from resistive/capacitive dividers with an accuracy estimated at ± 15 percent.

The current waveform is taken across a series resistor in the anode chamber structure with an accuracy estimated at ± 15 percent.

At the request of the experimenter, tube voltage and current waveforms will be monitored and processed in the instrument van. Tube voltage will be corrected for diode inductive effects. Corrected voltage and current are used to calculate beam power versus time and its integral, electron energy spectrum and time-dependent tube impedance. The data are available in hard-copy plots or as a digital printout.

In addition, a Compton diode is routinely used to monitor the dose rate waveform in a non-interfering location. The peak Compton detector output voltage is essentially proportional to total dose, as seen in Figure 3-9, and will provide an immediate indication of the exposure level. The proportionality factor is, of course, dependent upon the particular device used and its location with respect to HERMES II and the experiment sample, and this factor must be redetermined for each new configuration.

Figure 3-9. Compton Diode Output as an Indicator of Total Dose

The total dose exhibits somewhat greater variance than tube voltage and current; therefore, users are also encouraged to distribute radiation dosimeters at representative locations on their experiment to obtain direct measurements of the dose during each exposure. A discussion of available dosimetry is contained in Section 6.4 of this manual.

3.2.5 Pulse Repetition Rate and Reproducibility

The Marx generator pulse repetition rate is nominally three pulses per hour.

Operating experience has indicated the following standard deviations within a continuous series of nominally identical HERMES high-impedance diode X-ray pulses:

Tube Voltage	± 5%
Tube Current	± 5%
Total Dose/Pulse	± 20% .

There may be additional variance between two nominally identical series which are separated by changes of machine configuration or an extended time interval.

3.2.6 Neutron Yield

A preliminary measurement of HERMES II neutron yield during a high-impedance diode X-ray pulse was reported in Reference 10. The yield is estimated as 2×10^{10} neutrons per pulse, which is considered a lower bound. The estimated accuracy is a factor of 5.

3.3 Pinched Beam X-Ray Mode

The pinched beam or enhanced bremsstrahlung X-ray mode of HERMES II operation was developed in a series of experiments which are reported in Reference 7. The objective was to generate bremsstrahlung X-rays from a self-focused HERMES electron beam rather than from the diffuse distribution at the high-impedance diode anode. In this way, higher dose and dose rate capabilities could be achieved at the expense of total beam energy.

After testing several configurations, the "standard" design identified in Table 3-III and illustrated by Figure 3-10 was specified. The overall tube structure is the high-impedance diode, as previously described in Section 3.2. At the location of the original anode, however, a 0.0127-cm (0.005-in.) thick titanium foil is installed. A second titanium foil is spaced approximately 3.8 cm (1.5 in.) from the first and serves as a debris catcher. This is necessary to prevent loss of diode vacuum due to blowback of material from the bremsstrahlung converter.

The focusing cone shown in Figure 3-10, operated at atmospheric pressure, permits self-forces of the extracted electron beam to compress beam electrons to a small spot size. Near the point of maximum pinch, the composite bremsstrahlung converter shown in Figure 3-11 is installed.

TABLE 3-III

Pinched Beam X-Ray Mode Standard Configuration

Anode Chamber	1.64-m (64.75-in.) diameter + focusing cone (see Fig. 3-10)
Tube Length	21-ring
Anode	Composite (see Fig. 3-11)
Cathode Shank	15.2-cm (6-in.) diameter
Cathode Tip	15.2-cm (6-in.) diameter hemi- spherical stainless steel
Anode-Cathode Gap	28.5 cm (11.25 in.)
Blumlein Oil Gap Switch	22.9 cm (9 in.)

Figure 3-10. Standard HERMES II Pinched Beam X-Ray Tube

Figure 3-11. HERMES II Pinched Beam Bremsstrahlung Converter

The nominal operating parameters of this condition are summarized in Table 3-IV. In brief, the pinched beam provides a maximum dose of 3×10^5 rads (Si) and a dose rate of 6×10^{12} rads (Si)/s; this represents an increase by a factor of 5 over the peak capabilities of the high-impedance diode X-ray mode.

3.3.1 Total Dose

Total dose per pulse along the beam axis versus distance from the composite anode is presented in Figure 3-12. Approximate $1/R^2$ dependence can be observed at distances in excess of 20 cm.

TABLE 3-IV

Pinched Beam X-Ray Mode Nominal Operating Parameters

MARX GENERATOR

Charging Voltage	70 kV
Repetition Rate	3 pulses/hour

DIODE

Peak Diode Voltage	10 MV
Peak Diode Current	100 kA
Total Beam Energy	75 kJ (18 kcal)

X-RAY ENVIRONMENT

Peak Dose/Pulse	3×10^5 rads (Si)
Peak Dose Rate	6×10^{12} rads (Si)/s
Pulse Width	50 ns

Transverse profiles, generated by averaging two pulses with off-axis measurements in four directions, are illustrated in Figure 3-13.

Figure 3-12. Pinched Beam Mode X-Ray Dose per Pulse as a Function of Distance from Composite Anode

Figure 3-13. Transverse Pinched Beam Bremsstrahlung Dose Profiles

Figure 3-14 combines the on-axis and transverse dose mappings into a set of isodose contours for the enhanced bremsstrahlung X-ray environment. Relative doses in this figure are normalized to unity at the beam centerline on the anode plane. At distances exceeding 20 cm from the anode plane and within an angle of approximately 80° , symmetric about the centerline, the exposure pattern closely resembles that of a point source.

Figure 3-14. Enhanced Bremsstrahlung Mode Isodose Contours

Data for these figures were obtained with calcium fluoride thermoluminescent detectors, calibrated in rads (Si) on a cobalt-60 irradiation source. Estimated accuracy and reproducibility of these measurements is ± 15 percent.

3.3.2 Output Waveform and Dose Rate

Dose rate as a function of time was measured during a HERMES II pinched beam X-ray mode operation using a Compton diode detector, and Figure 3-15 reproduces the output signal waveform, normalized to a peak value of unity. Note that the pulse width at half-maximum intensity is 50 nanoseconds. Estimated accuracy of this result is ± 5 nanoseconds.

Figure 3-15. Pinched Beam X-Ray Pulse Shape

Using the curve of Figure 3-15, the following dose rates can be determined:

Mean dose rate during 155 ns pulse = 6.5×10^6 D

Mean dose rate during 50 ns between half-maximum points = 1.16×10^7 D

Peak dose rate = 1.68×10^7 D ,

where D is the dose per pulse.

3.3.3 Photon Spectrum

No measurement or calculation of the pinched beam mode photon spectrum has been performed. It is not expected to differ greatly from the spectrum obtained for high-impedance diode X-ray operation.

3.3.4 Pulse Monitors

The HERMES operating staff routinely monitors Marx generator voltage, diode voltage and diode current on each pulse. The time-dependent waveforms are photographically recorded from an oscilloscope trace, and typical results are shown in Figures 3-16 and 3-17. While these data are not direct measurements of environmental exposures at the experiment location, in the absence of extraordinary occurrences, they may be used to verify similarity of a series of nominally identical pulses.

Voltage waveforms are obtained from resistive/capacitive dividers with an accuracy estimated at ± 15 percent.

The current waveform is taken across a series resistor in the anode chamber structure with an accuracy estimated at ± 15 percent.

Figure 3-16. Marx Generator Voltage

Figure 3-17. Pinched Beam Diode Voltage and Current

At the request of the experimenter, tube voltage and current waveforms will be monitored and processed in the instrument van. Tube voltage will be corrected for diode inductive effects. Corrected voltage and current are used to calculate beam power versus time and its integral, electron energy spectrum and time-dependent tube impedance. The data are available in hard-copy plots or as a digital printout.

In addition, a Compton diode is routinely used to monitor the dose rate waveform in a non-interfering location. The peak Compton detector output voltage is expected to be proportional to total dose, as described in Section 3.2.4, and to provide an immediate indication of the exposure level. The proportionality factor is, of course, dependent upon the particular device used and its location with respect to HERMES II and the experiment sample, and this factor must be redetermined for each new configuration.

The total dose exhibits somewhat greater variance than tube voltage and current; therefore, users are also encouraged to distribute radiation dosimeters at representative locations on their experiment to obtain direct measurements of dose during each exposure. A discussion of available dosimetry is contained in Section 6.4 of this manual.

3.3.5 Pulse Repetition Rate and Reproducibility

The Marx generator pulse repetition rate is nominally three pulses per hour. The target (composite anode) is destroyed and must be replaced in the interval between pulses. However, if the experimental setup does not restrict access, this operation can be completed in 20 minutes and does not limit the repetition rate.

Operating experience has indicated the following standard deviations within a continuous series of nominally identical HERMES pinched beam mode X-ray pulses:

Tube Voltage	$\pm 5\%$
Tube Current	$\pm 5\%$

There are insufficient data to specify a standard deviation on the total dose per pulse. In most cases, ± 20 -percent reproducibility is expected; in occasional instances of abnormal beam wander, however, larger variations may be observed. There may be additional variance between two nominally identical series which are separated by changes of machine configuration or an extended time interval.

3.4 Prepulse Diode [8]

The prepulse diode with a large anode-cathode gap setting has capabilities similar to those of the high-impedance diode in addition to low impedance characteristics at small spacings. Among the objectives of the prepulse diode development are:

- a) To produce spatially localized, very high dose-rate capabilities which exceed those presently available from the pinched beam (enhanced bremsstrahlung) mode. This operation will require application of an external B_z field in the gap and drift region.
- b) To generate X-ray pulses of considerably smaller pulse width at half-maximum intensity, while operating the tube at close spacing between anode and cathode.
- c) By use of very high current densities at relatively low voltage, to generate an ion beam current for fusion system material studies.

The prepulse diode generally consists of an 18-ring assembly and contains prepulse switches in both the tube connector and cathode shank. The tube design, with the anode-cathode gap configuration shown in Figure 3-18, requires application of an external axial magnetic field (B_z) in the gap and drift region for effective utilization of the beam. An alternate design of the anode-cathode region, illustrated in Figure 3-19, has been used for the data which are presented here. This latter configuration can function without an applied B_z field. The diode performance in preliminary tests with this alternate design, as a function of the anode-cathode geometric and material variables, is briefly presented in Section 4.3 (Prepulse Diode Electron Beam Mode). In this section, X-ray environmental data for a single history are presented.

HERMES pulse number 12418 employed a carbon anode with a 1.9-cm (0.75-in.) diameter tungsten carbide insert on the beam centerline. The cathode was a 7.6-cm (3-in.) diameter blunt carbon tip, with field enhancement provided by a metallic insert. The gap spacing was 6.35 cm and Marx charging voltage was 70 kV. Diode voltage and current waveforms are the sample traces presented as Figures 3-20 and 3-21. The centerline dose at the converter face was measured by calcium fluoride thermoluminescent detectors to be 8.2×10^4 rads (Si). The Compton diode output waveform is shown in Figure 3-22. The unusual feature of this environment is the relatively narrow pulse width of 41.4 nanoseconds, only 83 percent of the normal value for HERMES II in other X-ray modes.

Figure 3-18. HERMES II Prepulse Diode

Figure 3-19. Prepulse Diode Alternate Anode-Cathode Geometry

Figure 3-20. Prepulse Diode Voltage (Pulse 12418)

Figure 3-21. Prepulse Diode Current (Pulse 12418)

Figure 3-22. Prepulse Diode X-Ray Pulse Shape -HERMES II Pulse 12418

SECTION 4

ELECTRON BEAM MODE ENVIRONMENTS

4.1 Introduction

As the result of continuing development, HERMES II has become an extremely versatile electron beam generator. Electron beam outputs are available from both the high-impedance diode and the prepulse diode. In this section, we will identify the principal features of each E-beam environment, including beam energy and geometry, output waveform, electron energy spectrum and monitoring capabilities, to the extent permitted by the present state of diagnostic data.

The high-impedance diode, by virtue of its longer history, has the more extensively diagnosed electron beam environment. Available data, using a cylindrical drift chamber and the atmospheric focusing cone or pressure cone [11], are reported later in this section.

A prepulse diode [8] with low impedance capabilities and increased diode currents at lower electron energies is also available. To obtain satisfactory beam propagation and energy concentration, a strong magnetic guide field and single-ended magnetic bottle have been designed for this work. The sample to be exposed must be immersed in the applied magnetic field and confined within an evacuated drift region.

The E-beam environment is difficult to characterize in detail. Fortunately, in most cases, only time-integrated characterization is necessary. Even this constitutes a formidable problem, since the energy and angular distribution of the electrons in the beam are not accurately known. Furthermore, either an experiment or beam diagnostic device may interact with or significantly perturb the beam. It is, however, possible to obtain relatively precise energy deposition information for selected materials. As the result of these uncertainties, very careful attention must be devoted in E-beam experimental plants to the measurement of environmental parameters of interest.

4.2 High-Impedance Diode Electron Beam Mode

Electron beam operations with the high-impedance diode have been conducted using either of two drift chambers. Table 4-1 identifies the standard output-tube configuration with the cylindrical drift tube, for which the environmental characterizations discussed in Sections 4.2.1 through 4.2.6 have been performed. This chamber, shown in Figure 4-1, is a hollow cylindrical conductor

85.1 cm (33.5 in.) in diameter and 101.6 cm (40 in.) in length, with lucite viewing windows 20.3 cm (8 in.) by 91.4 cm (36 in.) in each side. The experimenter should consult the facility staff concerning a mounting structure for the sample within the drifter chamber.

TABLE 4-I

High-Impedance Diode E-Beam Mode Standard Configuration

Anode Chamber	1.64-m (64.75-in.) diameter
Tube Length	21-ring
Anode	0.0127-cm (0.005-in.) titanium
Cathode Shank	15.2-cm (6-in.) diameter
Cathode Tip	15.2-cm (6-in.) diameter hemispherical stainless steel
Anode-Cathode Gap	28.5 cm (11.25 in.)
Drift Chamber	85.1-cm diameter cylinder
Blumlein Oil Gap Switch	22.9 cm (9 in.)

Figure 4-1. HERMES II High-Impedance Diode and Drift Tube

Results of electron beam diagnostic experiments in the optional atmospheric focusing cone are discussed in Section 4.2.7.

The nominal operating characteristics for the standard configuration are summarized in Table 4-II. Operating parameters can be adjusted within certain limits, if necessary, but additional diagnostic time must be scheduled when nonstandard conditions are desired.

TABLE 4-II

High-Impedance Diode E-Beam Mode Nominal Operating Parameters

MARX GENERATOR

Charging Voltage	70 kV
Repetition Rate	3 pulses/hour

DIODE

Peak Diode Voltage	10 MV
Peak Diode Current	100 kA
Total Beam Energy	75 kJ (18 kcal)

TARGET E-BEAM ENVIRONMENT

Transported Beam Energy	40-60 kJ (10-15 kcal)
Peak Fluence	500 cal/cm ²
Pulse Width	105 ns

4.2.1 Total Beam Energy

The total beam energy produced by the high-impedance diode at normal operating parameters is approximately 75 kJ (18 kcal), but a significant fraction may be lost in focusing, depending on the experiment location. Transport efficiency and spatial distribution of the beam at the target are primarily dependent upon the drift chamber pressure and axial location of the experiment.

The total beam energy transported over a distance of 88.9 cm (35 in.) from the anode is plotted as a function of drift tube pressure in Figure 4-2. The scatter of data points about the fitted curve is relatively large.

The variation of the beam transport efficiency as a function of axial position in the drift tube is illustrated in Figure 4-3. This series of measurements was made at 400 torr in the drift chamber and is not necessarily representative of similar measurements at other background gas pressures.

Estimated accuracy of these data, obtained using a segmented, graphite total stopping calorimeter, is ± 20 percent. While the information presented is considered to be typical, significant variations are observed in nominally identical pulses which are separated by an extended period of machine operation and/or changes in the accelerator configuration. Note that an identical point on Figures 4-2 and 4-3, transported energy at 88.9 cm from the anode and background gas pressure of 400 torr, indicates results differing by approximately 40 percent for these two series. Over a single continuous series with identical conditions, however, the outputs are less scattered. Nevertheless, we stress the recommendation for routine measurements by each experimenter.

Figure 4-2. High-Impedance Diode E-Beam Energy Transport to 88.9-cm Drift Chamber Position

Figure 4-3. High-Impedance Diode E-Beam Energy Transport at 400-Torr Drift Tube Pressure

4.2.2 Beam Geometry

The spatial distribution of energy within the HERMES electron beam is a sensitive function of diode and drift chamber conditions, and significant variations in the profiles may be observed from time to time. However, over a continuous series of identical pulses, the distribution is relatively stable. For these reasons, the information presented is only illustrative of expected profiles and their dependence upon system variables. If spatial distribution of the incident fluence is an important parameter of the experiment, it should be measured regularly during each series of nominally identical HERMES II shots.

Figure 4-4 is a typical set of beam profile measurements at various experiment locations in the drift chamber. It is important to note that profiles generally exhibit a drastic dependence upon pressure and should be determined for each test configuration. Drift region pressure during these measurements was 400 torr.

Figure 4-4. High-Impedance Diode E-Beam Profiles at 400-Torr Drift Tube Pressure

The variation of peak energy fluence as a function of drift tube pressure is shown in Figure 4-5. The calorimeter was located at 88.9 cm (35 in.) from the anode plane. Peak fluence occurred on or near the beam centerline and any off-set, observed most frequently at low drift tube pressures, indicates the presence of a slight beam wander.

The data for Figures 4-4 and 4-5 were obtained with the segmented, graphite total stopping calorimeter and have an estimated accuracy of ± 20 percent. Total beam energy is, of course, the surface integral of the incident fluence profile.

4.2.3 Output Waveform

There exists a number of output waveforms which may have meaning to various experimenters. Diode voltage and current waveforms for the anode-cathode gap are obtained by routine pulse monitors. These two may be time-synchronized and used to determine beam power in the anode-cathode gap as a function of time.

Figure 4-5. High-Impedance Diode E-Beam Fluence Variation

Tube voltage and current waveforms were presented in Section 3.2, 4 and indicate a pulse width at half-maximum current of approximately 105 nanoseconds. At least to first order, the primary current waveform in the drift chamber can be approximated by the tube current, except at the leading edge. Figure 4-6 presents the beam power versus time waveform, calculated from tube voltage and current measurements and normalized to unity peak. The pulse width at half-power points is 62 nanoseconds and is estimated to have an accuracy of ± 20 percent. This curve is considered to be representative of the power waveform at the experiment location.

Figure 4-6. High-Impedance Diode Power (Program DIODE)

4.2.4 Electron Energy Spectrum

No experimental measurement of the HERMES II electron energy spectrum is available at this time. Throughout the pulsed accelerator community, however, this information is generally obtained from time-synchronized voltage and current traces. At Sandia, digitized values of the tube current and voltage are processed, taking proper account of tube inductance, in a three-parameter fitting program, DIODE [12], developed by Sandia Laboratories. Spectral results obtained by this method are used to calculate energy deposition profiles and photon spectra, which exhibit good agreement with measured data. The technique is estimated to be accurate to ± 20 per cent.

Figure 4-7 illustrates the HERMES differential electron energy spectrum, normalized to one electron. The information was generated according to the technique briefly described above.

Figure 4-7. High-Impedance Diode Electron Energy Spectrum Normalized to Unity Integral

Energy deposition profiles for this HERMES electron beam have been measured using linear array calorimeters. In addition, the spectrum calculated from I - V data can be used in an electron-photon transport code to compute the deposition profile. Figure 4-8 performs a comparison of measured data in beryllium using a linear array calorimeter with EZTRAN calculations at 45° and 60° angles of incidence [13]. The measured curve was obtained at an incident fluence of 532 cal/cm^2 ; similar, but not identical, results are obtained at other fluences ranging between 66 cal/cm^2 and 488 cal/cm^2 . Reference 13 concludes that best agreement with experimental data is obtained at an angle of incidence between the two values presented.

Figure 4-8. Dose Depth Profiles in Beryllium

4.2.5 Pulse Monitors

The HERMES operating staff routinely monitors Marx generator voltage, diode voltage and diode current on each pulse. The time-dependent waveforms are photographically recorded from an oscilloscope trace, and typical results are as shown previously in Figures 3-7 and 3-8. While these data are not direct measurements of environmental exposures at the experiment location, in the absence of extraordinary occurrences in the drift region, they may be used to verify similarity of a series of nominally identical pulses.

Voltage waveforms are obtained from resistive/capacitive dividers with an accuracy estimated at ± 15 percent.

The current waveform is taken across a series resistor in the anode chamber structure with an accuracy estimated at ± 15 percent. It should be noted, however, that correct measurement requires beam current to return via the drift chamber and anode plate.

At the request of the experimenter, tube voltage and current waveforms will be monitored and processed in the instrument van. Tube voltage will be corrected for diode inductive effects. Corrected voltage and current are used to calculate beam power versus time and its integral, electron energy spectrum and time-dependent tube impedance. The data are available in hard-copy plots or as a digital printout. This instrumentation and the processing computer routine DIODE are discussed in Sections 5.3 and 6.2, respectively.

Graphite total stopping calorimeters, described in Reference 14, are available to measure total beam energy and beam profiles at the experiment location, but cannot, in general, be used

simultaneously with sample exposures. It is recommended that calorimetric measurements be made at regular intervals during each series of nominally identical pulses.

4.2.6 Pulse Repetition Rate and Reproducibility

The Marx generator pulse repetition rate is nominally three pulses per hour.

Operating experience has indicated the following standard deviations within a continuous series of nominally identical HERMES high-impedance diode E-beam pulses:

Tube Voltage	$\pm 5\%$
Tube Current	$\pm 5\%$

Additional variance may be observed between two nominally identical series which are separated by changes of machine configuration or an extended time interval. There are insufficient data to quote nominal variance of total beam energy and peak fluence.

4.2.7 Options

An alternate drift chamber, the atmospheric focusing cone illustrated in Figure 4-9, is available for use in the high-impedance diode electron beam mode. Both the cone and the 18.1-cm (7.125-in.) diameter cylinder are operated at atmospheric pressure. Therefore, the experiment is not subjected to a vacuum environment. However, control over the exposure level and spatial distribution of the beam is limited to physical positioning of the sample.

Figure 4-9. HERMES II Atmospheric Focusing Cone

Measurements of centerline fluence as a function of calorimeter distance from the end of the focusing cone are presented in Figure 4-10. The data points are a composite of results obtained during several series of pulses using different calorimeters. Figure 4-11 illustrates radial fluence profiles at various distances into the cylinder. These plots were generated during a single continuous series [15].

Figure 4-10. Fluence Versus Axial Distance from the Focusing Cone

During the latter series, energy deposition profiles for the HERMES II electron beam were determined using interferometer techniques. Figure 4-12 compares interferometer-measured and ELTRAN-calculated dose-depth relationships at an effective angle of incidence of 30° in quartz and tungsten carbide [15]. The apparent discrepancy in effective angle of incidence between Figures 4-8 and 4-12 can be explained by noting that particle trajectories produced by neutral-gas focusing are complex curved paths with strong dependence on position relative to the pinch and geometry of the drift chamber.

Figure 4-11. Fluence Versus Radial Position

Figure 4-12. HERMES II High-Impedance Diode E-Beam Dose-Depth Curves Measured in the Atmospheric Focusing Cone and Calculated. Incident fluence is approximately $80 \text{ cal}/\text{cm}^2$.

4.3 Prepulse Diode Electron Beam Mode [8]

The prepulse diode, with anticipated capabilities varying from high impedance operation at large anode-cathode spacings to low impedance performance at small gap sizes, is currently under development at HERMES II. The objectives of this development are primarily related to improvements in X-ray mode capabilities that have been discussed in Section 3.4. When completed, however, the tube will also be available for electron beam mode applications at voltages between 4 and 10 MeV. It is possible that, if the prepulse diode at large anode-cathode spacing operates without compromise of high-impedance capabilities, this tube and the high-impedance diode will be used interchangeably.

The tube configuration and an alternate anode-cathode region were previously illustrated in Section 3.4 and are not repeated here.

Operations to date have been devoted to beam generation using the alternate anode-cathode design with a bremsstrahlung converter. Tube data provide preliminary indications of E-beam performance characteristics. Figures 3-20 and 3-21 have presented the tube voltage and tube current, and Figures 4-13 and 4-14 present the output power waveform and the time-integrated electron energy spectrum obtained during one pulse in the development experiments. The example shown employed a field-enhanced 7.6 cm (3-in.) diameter carbon cathode tip, spaced at 6.35 cm from a composite carbon/tungsten carbide anode (Figure 3-19).

Figure 4-13. Prepulse Diode Power (Program DIODE)

Figure 4-14. Prepulse Diode Electron Energy Spectrum Normalized to Unity Integral

Figures 4-15 through 4-17 summarize the variation of prepulse tube parameters with the anode-cathode gap spacing. Note the similarity to high-impedance diode characteristics at a 28.6-cm spacing.

Figure 4-15. Prepulse Diode Tube Voltage Variation

Figure 4-16. Prepulse Diode Tube Current Variation

Figure 4-17. Prepulse Diode Beam Energy Variation

5. Experimental Facilities

SECTION 5

EXPERIMENTAL FACILITIES

5.1 Location

HERMES II occupies the east end of building 6596 in Sandia Laboratories Technical Area V. A map of the area, which is located approximately 8 km (5 miles) south of the main technical area, is given in Figure 5-1.

Figure 5-2 shows the physical layout and dimensions of that section of the building containing the HERMES facility. Also shown is an area south of the building where a user can place his own instrumentation vans.

Entry into the facility is provided by the 3.88-m-wide by 6.1-m-high (12.75-ft by 20-ft) door into the test cell or by the 3.6-m-wide by 6.1-m-high (12-ft by 20-ft) roll-up door on the south side of the building.

The screen room next to the shield wall is for the experimenter's use.

When HERMES is pulsed, no one is permitted beyond the sliding gate, and users will normally remain in the experimenter's area as outlined by a dashed line in Figure 5-2.

5.2 Test Cell

5.2.1 Floor Plan

A detailed plan view of the HERMES test cell is shown in Figure 5-3. The drawing is to scale and indicates the area available for use by the experimenter.

Figure 5-1. Map of Sandia Laboratories Technical Area V

Figure 5-2. HERMES II Facility Area in Building 6596

Figure 5-3. Detailed Plan View of HERMES II Test Cell and Inset Showing an Elevation View.

Particular items of which the experimenter should be aware include the following:

- A metal grating platform 3 m by 7.9 m and 1.8 m above the floor (10 ft by 26 ft by 6 ft) occupies the entire floor area of the test cell. When the platform is in place, the beam centerline is 1.66 m (5.45 ft) above the plating. With the platform removed, the centerline is 3.47 m (11.41 ft) above the floor. The inset in Figure 5-3 is an elevation drawing showing this configuration.
- The actual test volume measures approximately 6 m (20 ft) in width and 3 m (10 ft) in depth. The 3-m (10-ft) depth of the test volume may be extended by operating with the roll-up door and/or the shield door open. However, this condition is undesirable and should be requested only if no other alternative is available.
- An instrumentation cable boom, 3 m (10 ft) in length, is mounted on the south wall of the test cell at a height of 2.44 m (8 ft) above the platform. Attached to the boom are two extension arms, each being 1.52 m (5 ft) in length. Both the boom and the arms can be swiveled to various positions. Extending from the instrumentation boom to the cross plates on the arms are solid RF shieldings (conduits) which terminate in flexheads. These conduits shield coaxial cables which connect directly to the instrumentation vans outside the building.
- Approximately 15 m (50 ft) of multiconductor shielded cable enters the test cell through a junction box located on the west shielding wall. This cable connects the cell with the Data Acquisition and Display System, which is used to record calorimeter data.
- A closed-circuit television system monitors the test cell from the control console.
- An intercom system connects the test cell with the control console and the instrumentation van.
- There are three electrical power junction boxes in the test cell as indicated in Figure 5-3. Each box has four outlets providing 110-V single-phase AC power.

- Power can also be supplied to the experiment through the RG 214/U cable from the instrumentation van. The power level supplied is limited to the voltages and currents which can be safely transmitted over the coaxial cable.
- A compressed air extension hose is located on the wall near the vacuum station.
- There are three cable pass-thru ports in the south wall of the building near the sliding gate. They measure 30 cm by 36 cm (12 in. by 14 in.) and are 8 cm (3 in.) above the ground. These allow cabling to be routed to user instrumentation vans south of the building.

5.2.2 Test Sample Handling

Access to the facility is through the two doors previously mentioned. An overhead crane with 1800-kg (2-ton) capacity is available to lift large or heavy experimental equipment within the test cell. The facility normally provides any other equipment necessary for handling heavy items.

A mobile hydraulic table, with dimensions of 1 m by 2 m, is provided for positioning experiments in the HERMES test cell. The table top can be adjusted in height and can lift a maximum of 1800 kg (4000 lbs). Equipment tiedown points are provided by numerous recesses in the concrete shield wall of the test cell which expose steel reinforcing bars.

5.3 Instrumentation and Data Collection

5.3.1 Instrumentation Van

The HERMES facility is supported by an instrumentation van (B62), from Sandia Laboratories Field Instrumentation Department (1120), which is manned by two technicians. Personnel from this department are available to advise the experimenter on the use of the instrumentation and to offer suggestions for best utilization of this capability. Use of this instrument van and consultation with the instrumentation group is recommended.

The van is connected to the HERMES test cell by forty RG/214 50- Ω coaxial cables, fifteen RG/22B cables and five cables, each consisting of nineteen twisted-pair shielded wires. All of these cables are approximately 300 ft in length, which does not include the coaxial delays installed in the vans. The cables are protected by solid RF shielding (conduit) over all but the last 1.5 m (5 ft) in front of the accelerator, where triaxial cable is used instead. As an option, 5:1 cable equalizers (Hi-pass filters) can be placed in series with the coaxial cables to compensate for high-frequency signal loss.

Two types of connectors are used on the instrumentation boom in the HERMES test cell. One is the Trompeter BJ78 Triax jack bulkhead connector and the other is the Amphenol 22950 Twinax with the parallel key. The connector terminal boards on the flexheads of the shielding conduit have four Triax and three Twinax on them. The user is urged to adapt his experiment to conform with these connectors and to use the outer shield not as a signal-carrying wire but as a shielding wire. Modifications to this connector configuration are possible, but, because of the time required, advance arrangements should be made.

An intercom connects the HERMES test cell with the instrumentation van. In operation, van personnel will bring annotated data (photos, hardcopy graphs, etc.) to the experimenter in the test cell after each shot.

The following is a list of the instrumentation and systems available in the B62 van for HERMES experiment support.

OSCILLOSCOPES

<u>Qty.</u>	<u>Make</u>	<u>Model</u>	<u>Sensitivity</u>	<u>Bandwidth</u>
15	HP	183D	Horizontal: 1 ns/div to 50 ns/div Vertical: 0.01 V/div to 1 V/div	250 MHz
17	Fairchild	757F	Horizontal: 50 ns/div to 2 s/div Vertical: 0.02 V/div to 40 V/div	100 MHz

The above oscilloscopes are equipped with Beatty-Coleman rollback Polaroid cameras which can use 10,000 ASA Polaroid film.

SIGNAL GENERATORS

<u>Qty.</u>	<u>Make</u>	<u>Model</u>	<u>Purpose</u>
1	Tektronix	RM 181	To provide time marks on oscilloscope traces
1	EH	127	Pulse output for general use
1	Rutherford	A12	Multiple delay (3 pulses) generator
1	EH	132A	General pulse and single delay use
1	LLL	LE9891-1M2	Pulse for triggering oscilloscopes
1	Wavetek	144	General signal generator use
1	EEO	811	Time code generator
1	Tektronix	109	Fast risetime pulse for system checks
1	EG&G	SG-29-A	Fiducial generator for correlating data
5	TRW/STL	46	Delay generators

REGULATED POWER SUPPLIES

An assortment of DC power supplies is available to cover almost any voltage or current requirement the installed cables are rated to carry.

METERS AND TESTERS

Qty.	Make	Model	Purpose
1	NANOFAST	536	Time-interval measurement
1	EG&G	LE1 3807-1	Direct reading cable length in ns
1	Ballantine	AC-DC	Precision voltage calibrator
1	HP	738BR	Precision voltage source
1	HP	3476A	Digital multimeter
2	HP	3400A	RMS voltmeter
1	HP	5233L	Electronic counter

MULTIPLEX DATA RECORDING SYSTEM

This system consists of all the voltage-controlled oscillators, filters, amplifiers, discriminators and tape recording equipment necessary to record and playback up to 48 channels of 20-kHz data. If a higher frequency option is desired, the system can be used to record up to 13 channels of 400-kHz data.

Experimenters planning to use the multiplex system should coordinate their plans with the instrumentation personnel at least 60 days in advance of the planned experiment date. This will allow signal conditioning cards to be built and simulation equipment adapted for dry-run system checkout prior to experiment arrival.

TRANSIENT DIGITIZER SYSTEM

This system consists of the following major items:

- 11 ea. Tektronix R7912 Transient Digitizers capable of recording single-shot transients in the 500-MHz frequency range (and below);
- 1 ea. Digital Equipment Corporation PDP 11/10 computer (operating under Tektronix WDI-RT 11-02 software) with 32K core memory;
- 1 ea. International Memory System (dual disk memory with up to 2.5 megaword storage capability).

The data from this system are in the form of hardcopy plots and/or digital data recorded on cassettes.

This system is presently being used with several E-beam/flash X-ray facilities in Area V. Time constraints prevent sophisticated new software from being incorporated on short notice (unless supplied by the experimenter). Experimenters who want to process their data with special software should make the arrangements at least 30 days or more ahead of the scheduled test date.

Preliminary arrangements for Instrumentation Van services can be made through the Operations Supervisor in the Beam Source Applications Division. One may also contact the instrumentation personnel in the Simulator Instrumentation Division (1126) at 264-4447.

5.3.2 On-Line Computer Data Collection and Processing

The Data Acquisition and Display System (DADS), when used with HERMES, has been programmed to reduce data of electron beam energy fluence measurements. The system includes the EMR 6130 digital computer in Building 6588 and a remote terminal in the screen room in the office area of Building 6596.

The DADS accepts the outputs of planar and linear array calorimeters. These data are then reduced using a library program already in the computer. The reduced data, which are returned in the form of oscilloscope displays and teletype tabulations, include beam profile and characteristic deposition curves. An example of teletype tabulations is shown in Figure 5-4.

The output of the calorimeter goes directly to the remote terminal of the DADS system through a multiconductor shielded cable previously mentioned. This cable extends into the test cell and is fitted with a 100-pin connector.

Experimenters can use their own calorimeters but must check with facility personnel to ensure compatibility with the system. The software on DADS assumes a Chromel-Alumel Type K standard thermocouple is being used.

Voltage and current waveforms are sampled by monitor resistors and are also digitized through the use of DADS. The user can also supply his own FORTRAN program and operate on the data in real time. Output is available as CRT displays or in printed form from the remote terminal in the screen room.

The DADS is available to all experimenters, including use of the remote terminal at the accelerator facility.

```

HERMES II
SHOT NO. 13057
TIME 1106 DATE 11/23/76
IDCODE, OCTAL= 025011 DECIMAL= 10761
PRESSURE= 1.00E 00 TORR

ANODE TO CALORIMETER DISTANCE 7.9 INCHES = 20 cm
EBEAM, (BEAM ENERGY)= 1.0949E 04 CAL.
RING 1, AVE. CAL/SQ. CM.= 3.7464E 02 S, PCT. = .00000E 00
RING 2, AVE. CAL/SQ. CM.= 1.7728E 02 S, PCT. = 3.0932E 01
RING 3, AVE. CAL/SQ. CM.= 5.9155E 01 S, PCT. = 2.7016E 01
R1= 1.3413E-01 R2= 6.5742E-01
MAX. BEAM ENERGY DENSITY = 3.7464E 02 CAL./SQ.CM.

```

BEAM ENERGY DENSITIES	
ELEMENT NO.	CAL./SQ.CM.
1	3.7464E 02
2	2.5027E 02
3	1.4103E 02
4	2.0450E 02
5	1.0203E 02
6	1.9406E 02
7	1.2110E 02
8	2.5869E 02
9	1.4655E 02
10	6.8312E 01
11	6.0481E 01
12	6.2208E 01
13	5.1498E 01
14	1.2225E 01
15	5.8458E 01
16	7.0214E 01
17	5.3456E 01
18	6.1402E 01
19	8.0858E 01
20	6.5548E 01
21	6.5203E 01

Figure 5-4. Sample Calorimetric Output Data

5.3.3 Screen Room

A 1.8-m by 3-m (6-ft by 10-ft) screen room in the experimenter's area next to the shield wall is for use by the experimenter. It has four 110-V single-phase AC power outlets in each of four junction boxes in the room. Electronic signals are passed between the screen room and the test cell by means of a wall panel containing fifteen HN feedthrough bulkhead connectors. Also, the panel has four waveguides of 4-cm (1.5-in.), 5-cm (2-in.) and 10-cm (4-in.) diameter for passing cabling through the wall. Shielded cabling, which must be provided by the experimenter, should be at least 18.3 m (60 ft) long to reach from the screen room to the HERMES test cell.

Instrumentation is not necessarily furnished for use with the screen room and the experimenter must check in advance to determine if any will be available.

5.3.4 Screen Boxes

Several small screen boxes are available for use by experimenters. These boxes range in volume from 0.027 m^3 (1 ft^3) to 0.43 m^3 (16 ft^3). The largest box is 0.6 m by 0.6 m by 1.2 m (2 ft by 2 ft by 4 ft). Cable access to the inside of the box is by means of a waveguide.

Experimenters normally provide their own screen boxes. It is recommended that users check with the Operations Supervisor on the availability of facility screen boxes.

5.3.5 User-Provided Instrument Van

An area on the south side of Building 6596 is available if the experimenter wishes to provide his own shielded instrumentation trailer. Two Appleton AEO-10453 100-A, 220-V three-phase female power connectors are installed at the trailer location. Power cables should not be less than 9.1 m (30 ft) in length and should terminate with a compatible Appleton connector.

Monitor cables from this trailer location to the HERMES test cell should be a minimum of 24.4 m (80 ft) in length.

5.4 RF Interference and Shielding

Sandia Laboratories has conducted a program of measurements to determine the radiated electromagnetic fields at various locations in Technical Area V [16]. Sources in these measurements included the HERMES II, REBA and REHYD accelerators within Building 6596 and pulsed power devices in Buildings 6595 and 6591.

One of the measurement points was located in the HERMES II experimenter's area, near the screen room. Peak electric fields of 3.1 kV/m were detected during a HERMES II firing. In addition, 2.3-kV/m fields were found during REBA operations and 3.1-kV/m fields were caused by a REHYD pulse. This interference environment is harsh when the experimenter is attempting to make sensitive measurements. In spite of this noise generation, proper use of screen rooms and the instrument van as well as shielding of the experiment and signal cables can reduce the RF interference to acceptable levels for most applications. The shielding system enables gathering zero-time data that are of the order of 100 mV in magnitude.

To assist in noise reduction, an instrument van and screen rooms are installed at the accelerator facility, as described in Section 5.3. The instrument van is shielded by its own structure and the walls of Building 6596 and can be used to provide somewhat protected power to the

experiment. The screen room provides filtered 110-V single-phase electrical power and is rated for a minimum attenuation of 120 dB over a frequency range to 10^4 MHz. The screen cages, properly used, provide approximately 30-dB attenuation in the RF range.

Figure 5-5 illustrates a well-designed shielding and grounding plan for an accelerator experiment. Note that one continuous shielded volume envelopes the experiment, signal and power cables and the monitoring instrumentation. Great care is also exercised to avoid ground loops.

Figure 5-5. Shielding and Grounding

In addition to radiated EM noise, photons can directly excite transient currents in shield cables [17]. Signal cables which are in areas of significant x-radiation should be shielded from the source with lead blocks available at the facility.

After the experiment and monitoring system is assembled, it is recommended that a noise-only measurement be made during a HERMES pulse to verify proper installation and obtain quantitative results.

5.5 Ground Motion Environment [18]

When the HERMES II accelerator is pulsed, a pronounced mechanical shock is generated which causes a noticeable ground motion around the machine. While structurally insignificant in magnitude, it may present a problem in certain types of experiments.

Measurements of the vertical and radial acceleration of the ground caused by operation of the HERMES facility were made at various points outside of the building. Figures 5-6 and 5-7 are representative samples of the accelerations which were recorded. In general, the measurements showed vertical maxima of approximately 0.1 g or less and radial maxima down by a factor of three from the vertical. The frequencies of excitation associated with these accelerations were in the range of 20 to 50 Hz.

Figure 5-6. Vertical Ground Motion Outside of Building 6596
Due to Pulsing of HERMES II

Figure 5-7. Radial Ground Motion Outside of Building 6596
Due to Pulsing of HERMES II

5.6 Timing and Sequencing

The timing and sequencing circuits of HERMES II are relatively simple and can be modified to meet the requirements of most experimenters if sufficient advance notice is given. The principal timing difficulty is high jitter under even optimum conditions.

A pulse operation is normally initiated manually, but can be started by the experimenter's sequencing circuits, if necessary. This requires a fast-rising pulse in excess of 20 volts magnitude with a duration of 5 to 7 microseconds to be delivered into a $50\text{-}\Omega$ load. If this firing pulse, which triggers the Marx generator, is to be provided by a user's sequencing unit, it must be initiated within 10 seconds after a verbal command from the operator.

Pulse delay, measured from the initiation of the Marx generator trigger to radiation output, and pulse jitter, defined as the maximum observed deviation from the mean pulse delay, are highly sensitive to machine parameters which have not been completely identified. While the

quantities are relatively stable over a continuous series of pulses, the effects of modification in configuration and maintenance efforts cannot be predicted. The results of past measurements give the following extremes for a series of several pulses.

	<u>Pulse Delay</u> <u>(μs)</u>	<u>Pulse Jitter</u> <u>(μs)</u>
Shortest Mean Delay	11.5	2.5
Longest Mean Delay	42.0	5.0

Timing signals can be provided to the experimenter from a variety of sources. The Marx generator trigger signal, reference for the pulse-delay measurements given above, is the discharge of a $0.05\text{-}\mu\text{F}$ capacitor charged to approximately 20 V. The RC time constant of the discharge is determined by the load resistance in the user's circuit. Switch closures can be provided at times from 5 to 10 seconds before the pulse, but pulse jitter measured from this closure is in the millisecond range.

A pickoff from the Marx generator monitor, with a pulse delay of approximately $1.2\text{ }\mu\text{s}$ to radiation output, can also be supplied to the experimenter; jitter from this signal has not been determined. Finally, a pickoff from the Compton diode X-ray monitor can be provided.

SECTION 6

SERVICES AND SUPPORT

6.1 Support Staff

The operating staff of HERMES II, exclusive of instrumentation personnel, normally consists of two operators and a supervisor. These personnel will assist the experimenter in determining and establishing the correct experimental setup. This assistance includes positioning the equipment and setting up other necessary equipment such as vacuum systems. Under normal circumstances, however, they do not provide monitoring or instrumentation services.

If experiments involve radioactive or toxic substances, a Sandia Laboratories health physicist is assigned the responsibility of regulating personnel exposures and ensuring that proper handling procedures are employed.

The Sandia technical staff is available for consulting services on a limited basis only.

6.2 Computational Facilities and User Programs

6.2.1 Facilities

There are two computer facilities in Building 6588 available to the experimenter for running his FORTRAN programs.

In addition to supporting the Data Acquisition and Display System (DADS), the EMR 6130 computer performs standard processing and execution of programs. This enables the experimenter to operate on experimental data as they are processed and digitized by the DADS system.

There is also a remote terminal in Building 6588 which gives the user access to three CDC 6600 computers in Area I. The terminal includes a CRT display unit for accessing the computers, a card reader, a 136-character line printer and an IBM 028 keypunch machine. Instructions for operating this equipment are provided at the terminal.

For those who wish to submit their programs at the main computing center, a courier makes regular deliveries to Area I.

6.2.2 User-Oriented Computer Programs

In general, the HERMES staff does not perform computer calculations for users or provide programming support for experiments. There are, however, several codes used in machine design and analysis that may prove useful to experimenters and with which a limited amount of assistance can be provided. These codes are briefly described and referenced below.

6.2.2.1 DADS Calorimetry Data Reduction -- This code processes E-beam calorimetric measurements and provides hardcopy output data such as those illustrated in Figure 5-4. The system, with on-line read capability as described in Section 5.3.3, is implemented on the DADS system and available for use.

6.2.2.2 DIODE [12] -- The DIODE program provides a means of extracting maximum useful information from HERMES voltage and current waveforms. The code permits the introduction of a time delay applied to a specified parameter, either current or voltage, and of an inductance value used in correcting the raw voltage. Outputs include plots of current and raw voltage versus time, corrected voltage versus time, impedance versus time, power versus time, energy versus time, and the energy spectrum. The EMR 6130 computer provides two modes of data entry -- from digitized data cards read under the background batch system, and by transfer of data under the real-time system from available high-speed, on-line digitizers at HERMES. Program option selections are made at an EMR remote terminal, and processing results appear on a display oscilloscope at the remote terminal.

This program is also being used by the transient digitizer system described in Section 5.3.1.

Several DIODE calculation results have been presented in this manual (e.g., Figures 4-6, 4-7, 4-13, and 4-14).

6.2.2.3 COMPTD -- This program accepts digitized waveforms and calculates the first derivative and integral. Outputs are available as printed data and plotted curves. The code is intended for processing Compton diode output signals.

6.2.2.4 SANDYL [19] -- SANDYL is a FORTRAN code for computing photon-electron transport and deposition in complex systems by the Monte Carlo method. In this computation, a large number of possible particle trajectories are generated one at a time and, as the particle proceeds through the material of the system, contributions to the quantities making up the desired information are tallied. After a number of trajectories, the averages of these quantities are statistical approximations to the solution. All histories of source and secondary particles with energies in the 1 keV to 1000 MeV range are followed through the system.

The problem geometry is divided into zones of homogeneous atomic composition bounded by sections of planes and quadrics. Thus, the material of each zone is a specified element or combination of elements.

For a photon history, the trajectory is generated by following the photon from scattering to scattering using the various probability distributions to find distances between collisions, types of collisions, types of secondaries, and their energies and scattering angles. The photon interactions are photoelectric absorption (atomic ionization), coherent scattering, incoherent scattering, and pair production. The secondary photons which are followed include bremsstrahlung, fluorescence photons, and $e^+ - e^-$ annihilation radiation.

The condensed-history Monte Carlo method is used for the electron transport. In a history, the spatial steps taken by an electron are precomputed and may include the effects of a number of collisions. The corresponding scattering angle and energy loss in the step are found from the multiple scattering distributions for these quantities. Atomic ionization and secondary particles are generated within the step according to the probabilities for their occurrence.

Electron energy loss is through inelastic electron-electron collisions, bremsstrahlung generation, and polarization of the medium (density effect). Included in the loss is the fluctuation due to the variation in the number of energy-loss collisions in a given Monte Carlo step (straggling). Scattering angular distributions are determined from elastic nuclear-collision cross sections corrected for electron-electron interactions. The secondary electrons which are followed include knock-on, pair, Auger (through atomic ionizations), Compton, and photoelectric electrons.

It should be kept in mind that sacrifices have been made in efficiency to obtain generality. A user may be able to achieve significant economies in computer run time either by programming modifications or by the judicious use of the zoning and variance reduction techniques available in the code and discussed in Reference 19.

6.2.2.5 TIGER [20] -- TIGER is a one-dimensional multilayer electron-photon Monte Carlo transport code which is useful for design and analysis of pulsed E-beam and flash X-ray experiments. It lacks the generality of the three-dimensional multimaterial SANDYL code, but contains similar physics and is simpler and less expensive to use. Examples of problems in which TIGER may be used to assist experimenters include:

- definition of photon and/or electron energy angular distributions after material penetrations;
- generation of charge and dose-depth profiles in layered materials.

EXTRAN, a predecessor of TIGER, treated only a single material layer [21].

6.2.2.6 CYLTRAN [22] -- CYLTRAN contains essentially the same physics and numerical algorithms as the one-dimensional code TIGER and the three-dimensional SANDYL program but is written for cylindrically symmetric material geometries.

6.3 Experiment Preparation and Office Spaces

The experimenter's area, as shown by dashed lines in Figure 5-2, serves as a preparation area and office space. The HERMES test cell can be used for experiment preparation when it is not otherwise in use and when the machine is not undergoing maintenance. As a rule, space is limited and the experimenter should, as much as possible, have his equipment ready when he arrives at the facility.

6.4 Dosimetry

The Sandia Laboratories Dosimetry Laboratory (Building 6594) is available for use by all flash X-ray experimenters. The laboratory uses the TLD-400 thermoluminescent detector as the standard dosimeter. It is a 0.317-cm by 0.317-cm by 0.089-cm (0.125-in. by 0.125-in. by 0.035-in.) chip of calcium fluoride (manganese-activated) which will measure doses from 1 rad (Si) up to 6×10^5 rads (Si).

Sandia Laboratories will provide and read a limited number of dosimeters for the experimenter. If one should need a significant number of dosimeters, he should make his requirements known to the facility staff early in order to prepare for the experiment. It normally requires about twenty minutes to prepare and read a dosimeter series using a TLD reader. Because of this time constraint and also because the laboratory supports several facilities, the experimenter should arrange a dosimeter reading schedule with the dosimetry laboratory personnel at (505) 264-7567.

Dosimeters should be taken to the laboratory as soon as they have been exposed. Experimenters will then be notified when the results are ready.

6.5 Photographic Services

The experimenter should arrange to make use of the services of the Photographic and Reproduction Services Department (3170). Experimenters may also provide their own photographic equipment and material.

Cameras and film are included with all Sandia oscilloscopes.

6.6 Shop Facilities

Light machine-shop facilities such as a grinder-buffer and a drill press are available at the HERMES site. The facility staff will assist the experimenter with minor machining tasks. Additional questions should be addressed to the Operations Supervisor at (505) 264-3197.

6.7 Scheduling

A HERMES experiment should be scheduled at least six months in advance and a test plan submitted at least thirty days prior to the scheduled date. This may be done by contacting the Operations Supervisor in the Beam Source Applications Division (5232) at (505) 264-3197. At the time of scheduling, the availability of required monitoring equipment should be determined, the environmental conditions required by the test should be discussed, and any arrangements regarding the services mentioned in this manual should be concluded.

The experimenter is urged to plan his experiment to conform with the HERMES machine and, if possible, avoid modifications to the accelerator.

It is strongly suggested that prospective users of HERMES make a preliminary visit to the facility to acquaint themselves with it and to gain first-hand information on the compatibility of experiment and machine.

SECTION 7

INFORMATION FOR NON-SANDIA USERS

7.1 Contract Procedure

The services of HERMES II may be made available to agencies of the Energy Research and Development Administration and the Department of Defense and to private corporations having ERDA or DOD contracts. Such use must be justified on the basis that HERMES II provides a unique environment not available elsewhere and that such use will not interfere with Sandia programs.

ERDA or DOD agencies or contractors desiring to use the HERMES II facility are required to establish a contract with the Special Programs Division of the Albuquerque Operations Office of the Energy Research and Development Administration. The complete mailing address is:

Director, Special Programs Division
ERDA
Albuquerque Operations Office
Albuquerque, New Mexico 87115.

This contract should be requested only after making full technical arrangements with Sandia Laboratories.

Preliminary arrangements, including technical information, schedule availability, and procedural requirements, are made directly with the Beam Source Applications Division (5232) of Sandia Laboratories.

The complete mailing address is:

Operations Supervisor
HERMES II Facility
Beam Source Applications Division (5232)
Sandia Laboratories
Post Office Box 5800
Albuquerque, New Mexico 87115.

Telephone contact may be made by calling (505) 264-2676 or (505) 264-3197. Following this contact, negotiations with the ERDA, Albuquerque Operations Office, should begin.

7.2 Cost Information

Preliminary cost information can be obtained from the Operations Supervisor of the HERMES II facility. Firm cost information is obtained from the Albuquerque Operations Office of ERDA.

The following schedule of charges will prevail for all users of HERMES II:

MACHINE TIME (EXCLUSIVE USE)

- 1) Monday through Friday: regular charges per hour.
- 2) Due to the heavy demand for use of HERMES II, users should be prepared to conduct tests and experiments on an extended shift basis (up to ten hours per day).
- 3) Overtime (outside normal working days): to be determined (available only if previously scheduled or required by unforeseen conditions).

MACHINE TIME (SHARED USE)

- 1) Charges prorated among users.

NON-MACHINE TIME (SETUP AND PREPARATION)

- 1) No charge if work does not interfere with machine operations.

Since the beam is of limited dimension, exclusive use of the machine is ordinarily scheduled. All users are required to acknowledge time charges at the HERMES II facility before their departure.

7.3 Security and Visitor Control

An ERDA "Q" or DOD "Secret" clearance is required to gain entry to the HERMES II facility. Security arrangements should be completed at the earliest convenient time but not less than two weeks before any preliminary visit or use of the HERMES II machine.

Security arrangements are to be made through Sandia Laboratories at the following address:

Visitor Access and Administration Section
Division 3433-1
Sandia Laboratories
Post Office Box 5800
Albuquerque, New Mexico 87115
Telephone: (505) 264-4494.

7.4 Shipping Information

To avoid any delays in shipment, users are urged to ship materials at least two weeks in advance of the date they will be needed. Address shipments to:

Operations Supervisor
HERMES II Facility Building 6596
Beam Source Applications Division (5232)
Sandia Laboratories
Post Office Box 5800
Albuquerque, New Mexico 87115.

APPENDIX

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DISTRIBUTION:

Martin Marietta Aerospace
P. O. Box 5837
Orlando, FL 32805
Attn: J. G. Simmons

Aerojet Electro Systems Co.
1100 W. Hollyvale St.
Azusa, CA 91702
Attn: G. E. Moffett

General Electric Co.
3198 Chestnut, Rm. 6018
Philadelphia, PA 19101
Attn: J. S. Walunas

General Electric Co. (2)
6500 Chestnut
Philadelphia, PA 19101
Attn: N. Turner
R. Casey

Hughes Aircraft Co.
Bldg. 700, Stop B1223
500 Superior Ave.
Newport Beach, CA 92663
Attn: M. Eaton

Lockheed Palo Alto Research Laboratory
Bldg. 204, Org. 52-11
3521 Hanover St.
Palo Alto, CA 94304
Attn: J. F. Riley

Lockheed Missiles and Space Co.
Dept. 8585, Bldg. 182
P. O. Box 504
Sunnyvale, CA 94088
Attn: P. Perry

Los Alamos Scientific Laboratory
Group WX-1
P. O. Box 1663
Los Alamos, NM 87544
Attn: P. Barbo

Mission Research Corp.
5601 Domingo Rd.
P. O. Box 8693
Albuquerque, NM 87108
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Ktech Corp.
911 Pennsylvania NE
Albuquerque, NM 87110
Attn: D. V. Keller

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Kearzott Div.
150 Totowa Rd.
Wayne, NJ 07470
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1000	G. A. Fowler
1100	C. D. Broyles
1111	C. R. Mchl
1111	S. R. Dolce
1112	J. D. Plimpton
1112	M. M. Conrad
1115	J. L. Benson
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