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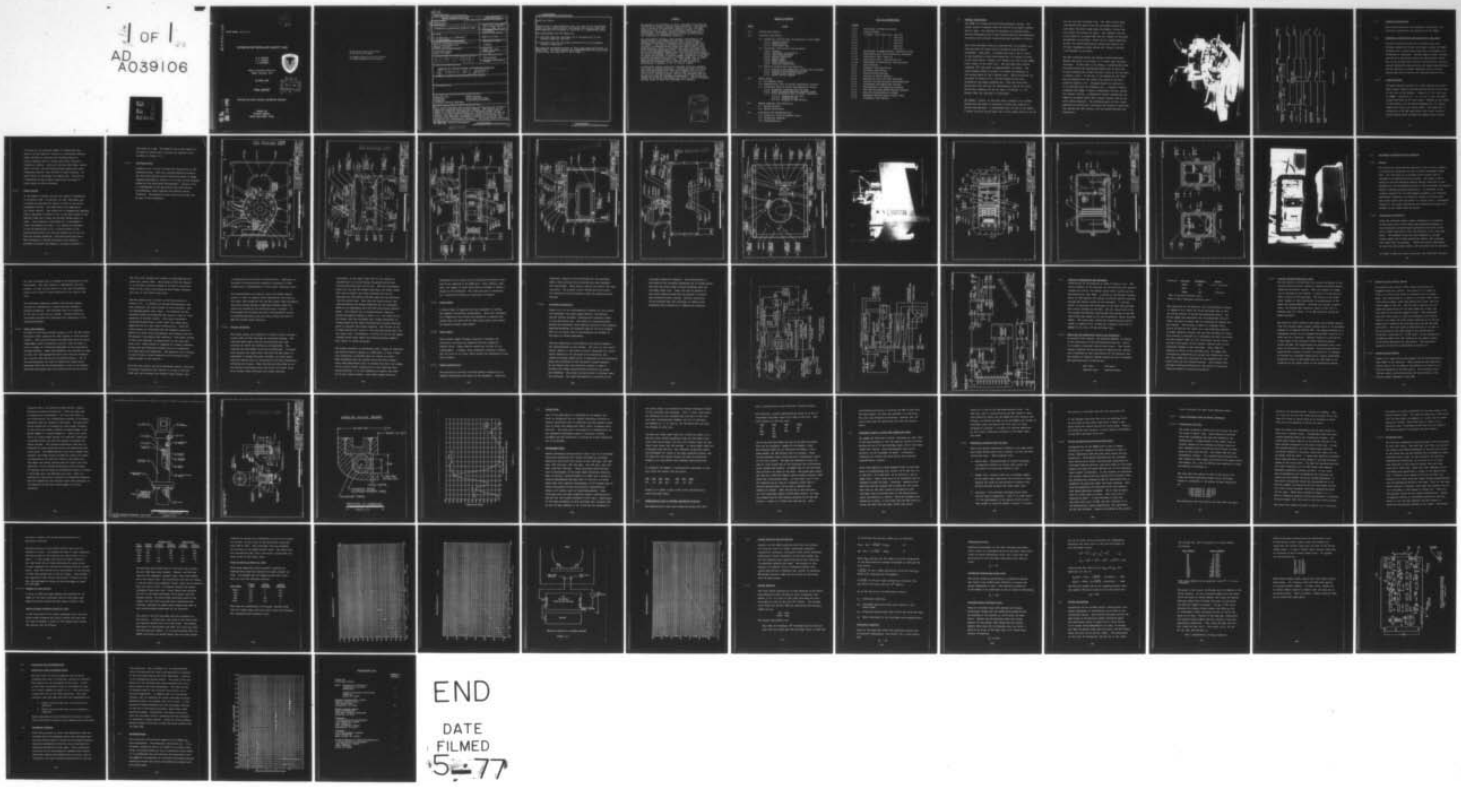

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AUTOMATED M9 PROPELLANT QUANTITY GAGE

D. W. BLINCOW
S. C. DOMINEY
J. H. McCORMICK

GENERAL NUCLEONICS DIVISION/TYCO
POMONA, CALIFORNIA 91767

30 APRIL 1976

FINAL REPORT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the construction and operation of the Automated M9 Propellant Quantity Gage (AMPQG). The purpose of the AMPQG is to measure the quantity of propellant powder sealed within the 40 mm cartridge cases at a production rate of one per second. The gage uses a radioactive source of Americium 241, a scintillation detector and digital electronics to measure the propellant by a backscatter technique. The accept/reject decision

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level is set at 80% propellant fill, but due to the statistical nature of the signal source, cartridges with more or less than 80% propellant are accepted or rejected on a probability basis.

The requirements for the AMPQG are:

(1) Not more than one cartridge can be accepted out of one million tested at 55% fill.

(2) Not more than one cartridge rejected out of five hundred tested at 100% fill.

The gage was acceptance-tested at Milan Army Ammunition Plant in March 1976. The test results and recommendations for future gage construction are presented in this report.

SUMMARY

The quantity of propellant in 40 mm cartridge cases must be controlled to ensure reliable weapon operation. The optimum time to measure the propellant quantity on the cartridge production line is after the propellant chamber is sealed. Conventional techniques, such as weighing or absorbtion radiography, are inadequate because metal tolerances mask the variations in propellant quantity.

The measurement technique used employs scattering of low energy gammas using Americium 241 and a scintillation detector (previously investigated under Contract DAAA-21-71-C-0484). The sensor consists of a tungsten probe, containing a collimated annular Americium source and a collimated detector, which is inserted into each cartridge case for a ½-second measurement time. The Americium source fits around the propellant chamber while the scintillation detector views the chamber from above. The collimation is designed to allow the detector to receive gammas scattered by the propellant and prevent detection of direct gamma rays or gamma rays scattered by the metal case. The pulses from the detector are processed by all digital data processing electronics to produce a "go" or "no-go" signal.

A mechanical system routes the cartridge from the assembly line into a rotating carrousel, inserts the probe and sorts the cartridge either back onto the assembly line or into a reject tray, depending on the signal from the electronics, at a rate of one per second. Most of the problems with the system were with the mechanical mechanisms. The system was tested at the Milan Army Ammunition Plant in Milan, Tennessee, and was shown to sort the cartridges as required.

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1.0 GENERAL DESCRIPTION

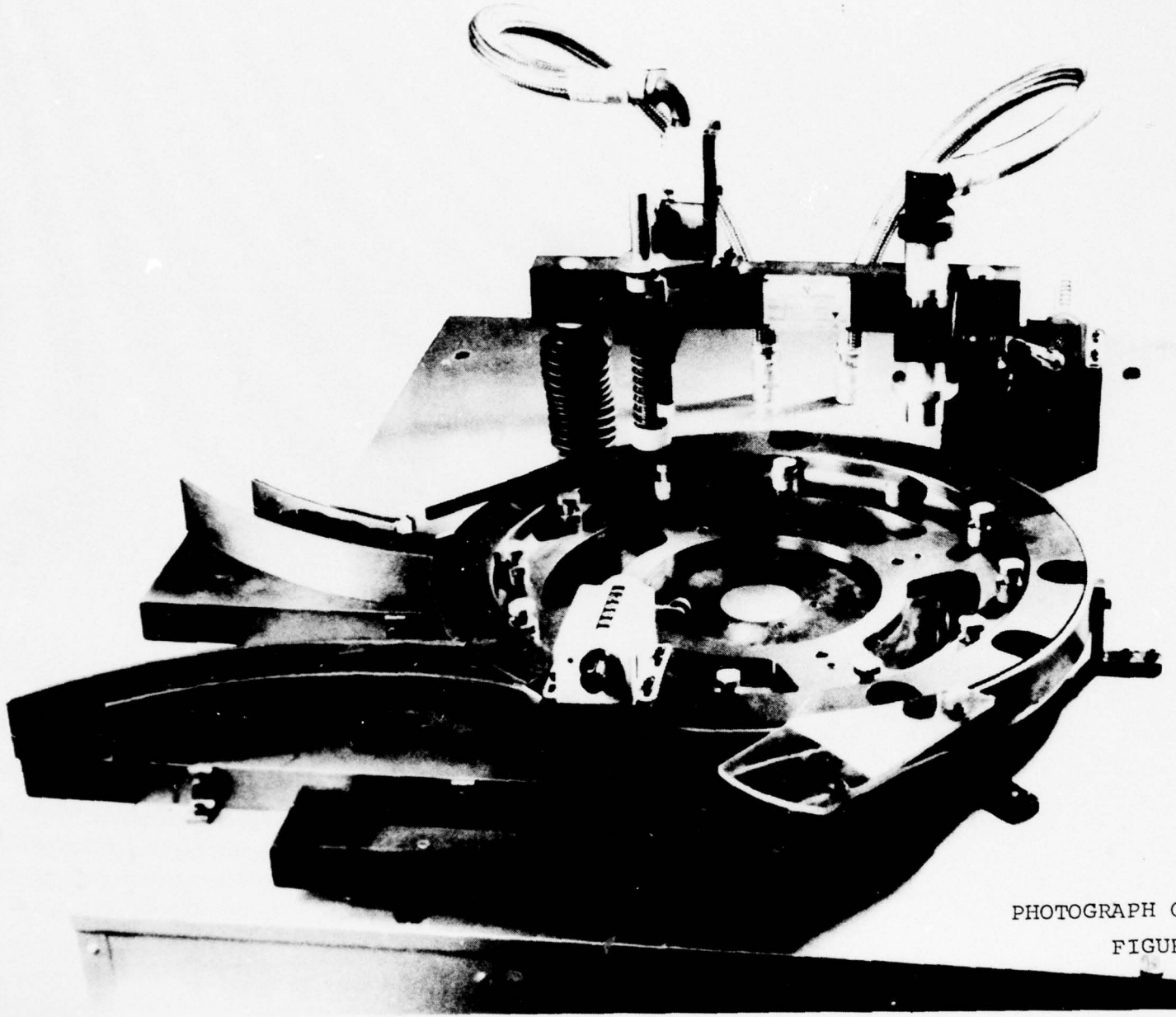
The AMPQG is a mechanical/electronic/nucleonic system. The entire system is powered from 120 volt AC 60 Hz power, drawing about 8 amps. The sequence of operation is outlined below, and the following parts of this section describe the mechanical, electronic and nucleonic construction and operation in detail.

The 40 mm cartridge cases are received from the assembly line and move down the entry shute by pressure from following cartridges. Each shell is pushed into one of the 12 slots in the carrousel as that slot pauses for 0.75 second in front of the entry shute. Figure 1.0-1 shows a top view of the AMPQG with a shell in the first slot. The carrousel then rotates (indexes) 30^{o} (one slot) in approximately .25 second. The timing diagram shown in Figure 1.0-2 shows the sequence of the various parts of the 1 second cycle. Above and behind the carrousel in Figure 1.0-1, the two sensors can be seen attached to the sensor mounting bar. This bar moves down during the first part of the stationary portion of the cycle. This motion requires 1/6 of the total .75 second, or .125 second, that the carrousel is stationary.

The Number 1 sensor, on the left side in Figure 1.0-1, merely checks that the shell is correctly in place and contains no obstructing material. A microswitch near the top of the Number 1 sensor rod will switch power off if this sensor fails to go all

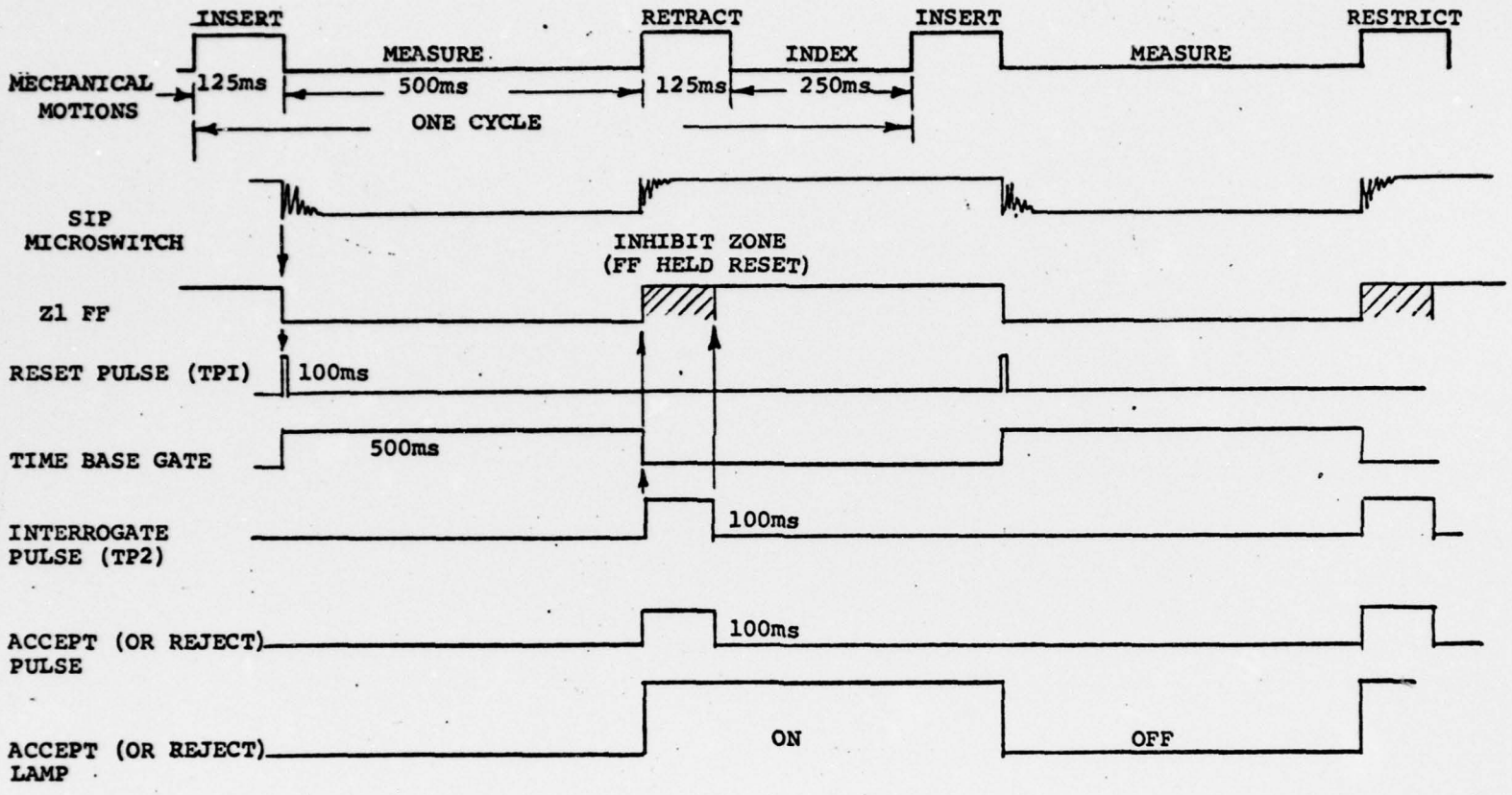
the way into the cartridge case. Two index cycles later (the fourth full cycle since the cartridge entered the carrousel) the shell stops under the Number 2 sensor and this sensor now enters the shell. The "measure" portion of the cycle is initiated when the SIP (Sensor In Position) microswitch is activated. After the 0.5 second measuring period, the sensor mounting bar raises both sensors out of their respective shells during the "retract" portion (.125 second) of the cycle.

The data collected during the measure period determines whether the shell is an accept or a reject (see following sections). If the shell is an accept, a solenoid below the carrousel drives the appropriate memory pin up (note the 12 pins located just inside the shell slots on the carrousel in Figure 1.0-1). If the pin is not pushed up, the shell will be ejected into the reject tray shown in the foreground of Figure 1.0-1. Accepted shells are carried on to be fed back onto the assembly line. A plunger located alongside the Number 1 sensor re-depresses the pins during the "insert" motion. A mechanical counter accumulates the number of accepted shells and a second counter sums up the total shells measured. The following parts of this report describe the mechanical, electronic and nucleonic operations, the testing and test results, and the system analysis and calibration.



PHOTOGRAPH OF AMPQG FROM ABOVE

FIGURE 1.0-1



TIMING DIAGRAM

FIGURE 1.0-2

2.0 TECHNICAL DESCRIPTION

This section presents the mechanical, electrical, and nucleonic construction and operation of the AMPQG.

2.1 MECHANICAL CONSTRUCTION AND OPERATION OF THE AMPQG

The basic system consists of a circular shell case conveyor system that starts and stops to allow the AMPQG detector unit to enter each shell case to determine its acceptance or rejection. Several types of shell conveyor systems were considered during the early design stages, and it was decided after laision with Picatinny Arsenal, several mechanical manufacturing and design organizations, and the facility at Milan, Tennessee that a circular motion type device such as was selected would be best.

2.1.1 Indexing Motion

The basic machine consists of a main chassis with sheet metal panels totally enclosed and sealed with access door to the rear of the chassis. Figure 2.1-1 is a top view of AMPQG. Figures 2.1-2, -3, -4, and -5 show the AMPQG viewed from each of the four sides. Mounted in the center of the chassis is a 12-station Swanson-Erie "J" series index drive with a 14" turret table. The index unit is driven by a ½ HP TEFC gear motor with v-belt friction clutch pulley which provides the proper ratio to drive

the index at the required number of indexes per hour. Mounted on the index 14" turret is a 12-station aluminum wheel recessed to position the cartridge case at a precise spacing under a tooling plate when indexed to inspection station. Parts are fed into this wheel during dwell of index, carried around during index cycle under inspection station, then carried to eject stations. At each station on the wheel is a memory pin. This pin is a two-position (up or down) sensing pin to accept or reject parts at eject stations.

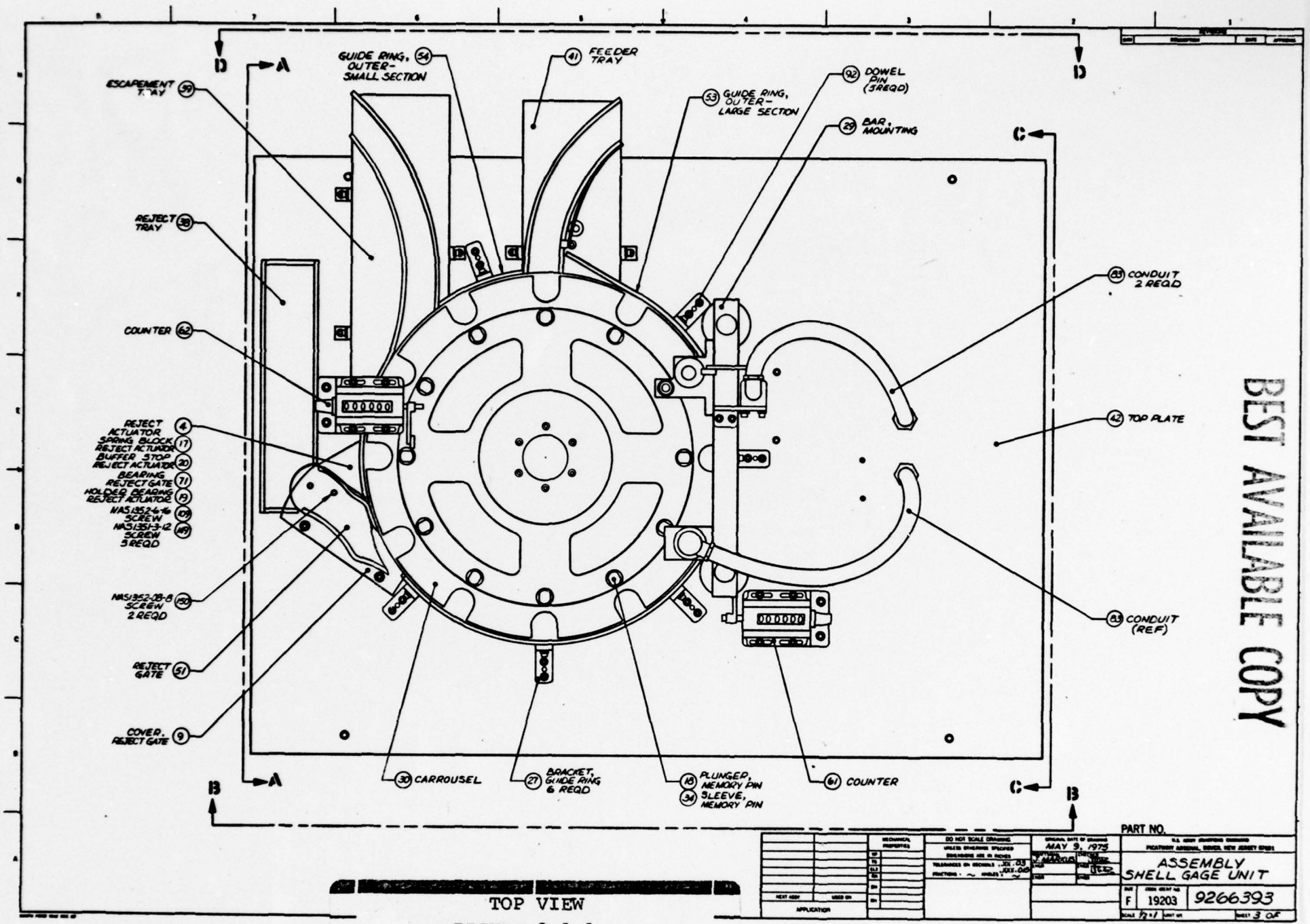
2.1.2 Sensor Motion

At the Number 2 sensor station, the casing is determined to be good or bad. If the part is good, the memory pin is pushed up allowing the casing to eject at the parts-acceptable station. All other parts are rejected at the reject station. The sensor bar is mechanically operated from a cam, shown in Figure 2.1-6, on the drive shaft of the Swanson Index unit to move up and down during dwell of index. Also mounted on the sensor bar is the Number 1 sensor and memory pin reset. If a casing is misloaded or has an obstruction in it, a safety switch on the sensor mounting bar will stop the machine so it will not harm the sensing mechanism. The mechanical parts have been designed for minimum maintenance and safeties provided to prevent any damage to casing or machine in

the event of a jam. The complete top of the chassis is covered for safety and to prevent any operator error, as shown in Figure 2.1-7.

2.1.3 Electronics Bay

Figures 2.1-8, -9, and -10 show the construction of the electronics bay. This unit provides mounting fixtures for the three printed circuit boards and three DC power supplies described in Section 2.2, as well as the terminal strips for the hard-wired interconnects. Figure 2.1-11 is a photograph of the electronics bay with printed circuitboards, power supplies and terminal strips installed. The explosion proof cover for this bay can be seen in the foreground.



TOP VIEW

FIGURE 2.1-1

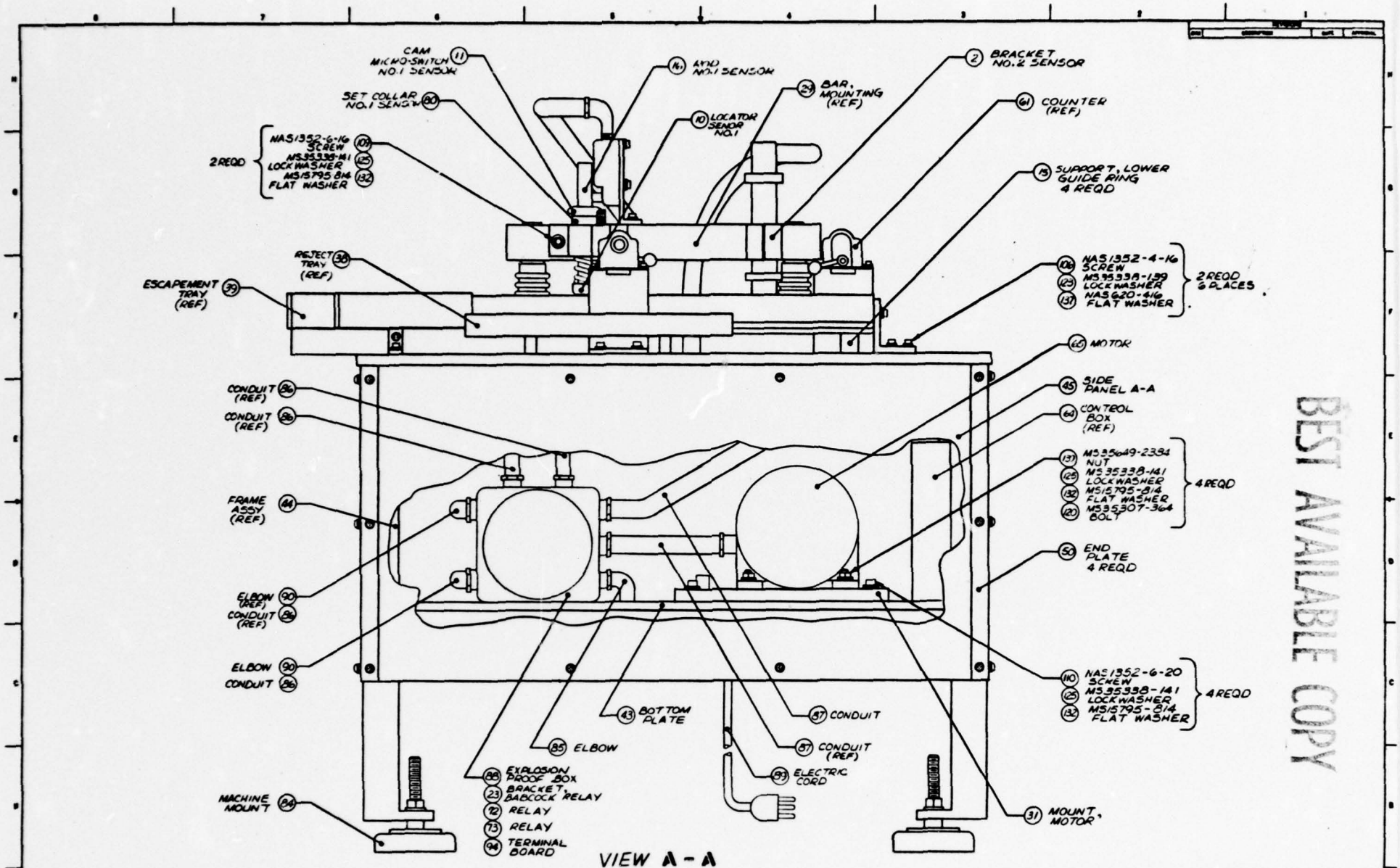


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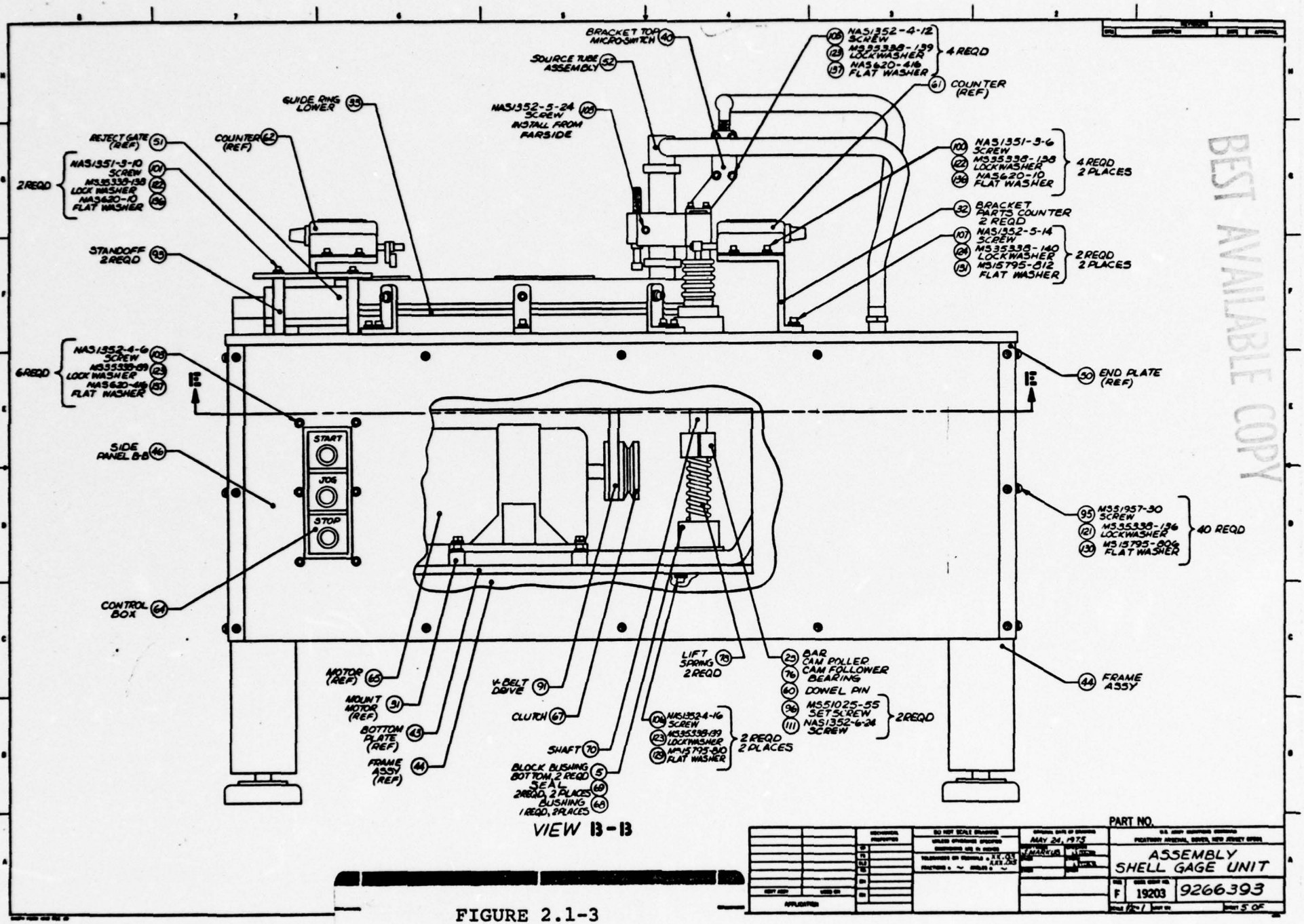
FIGURE 2.1-2



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ASSEMBLY SHELL GAGE UNIT

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FIGURE 2.1-3

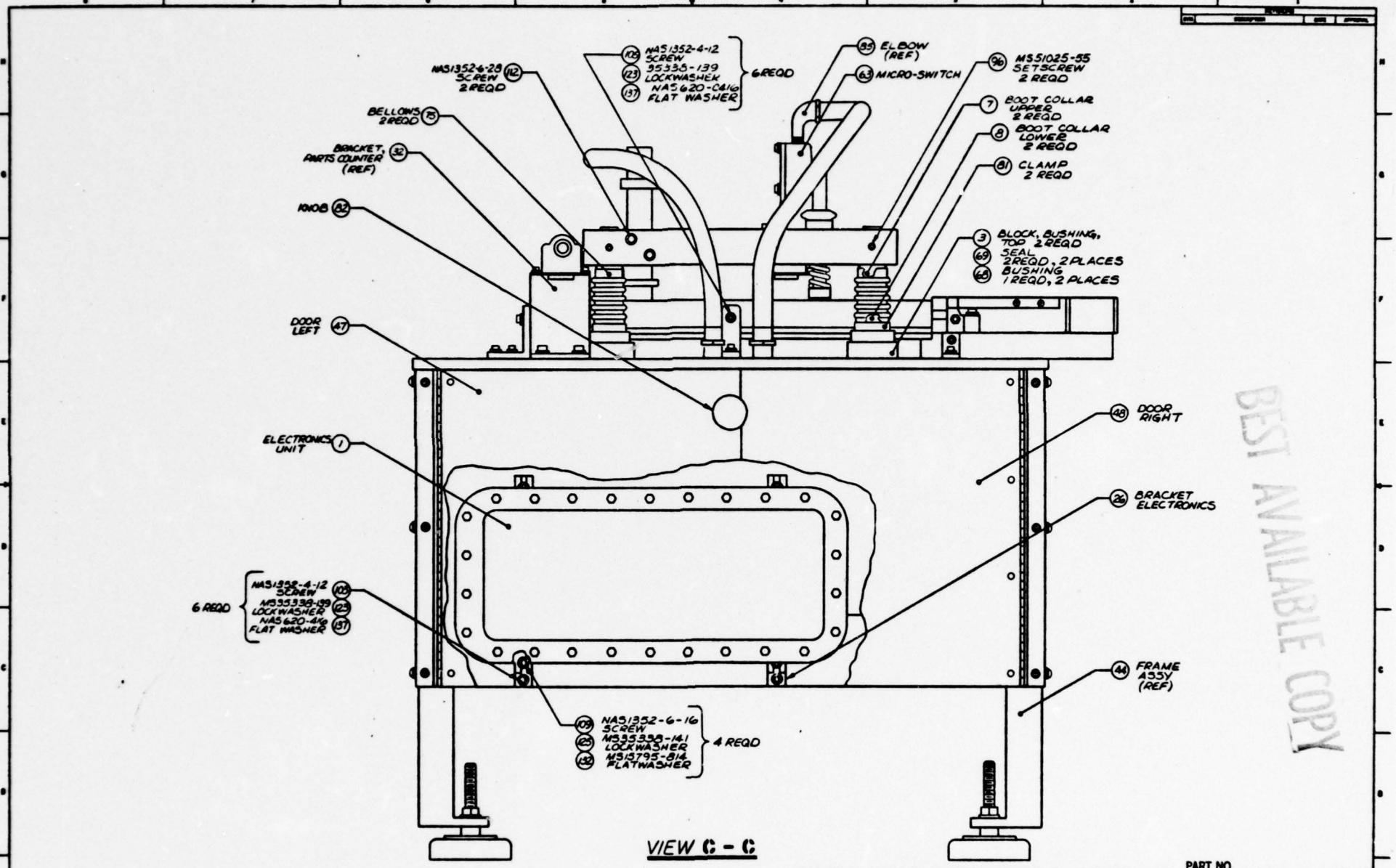

FIGURE 2.1-4

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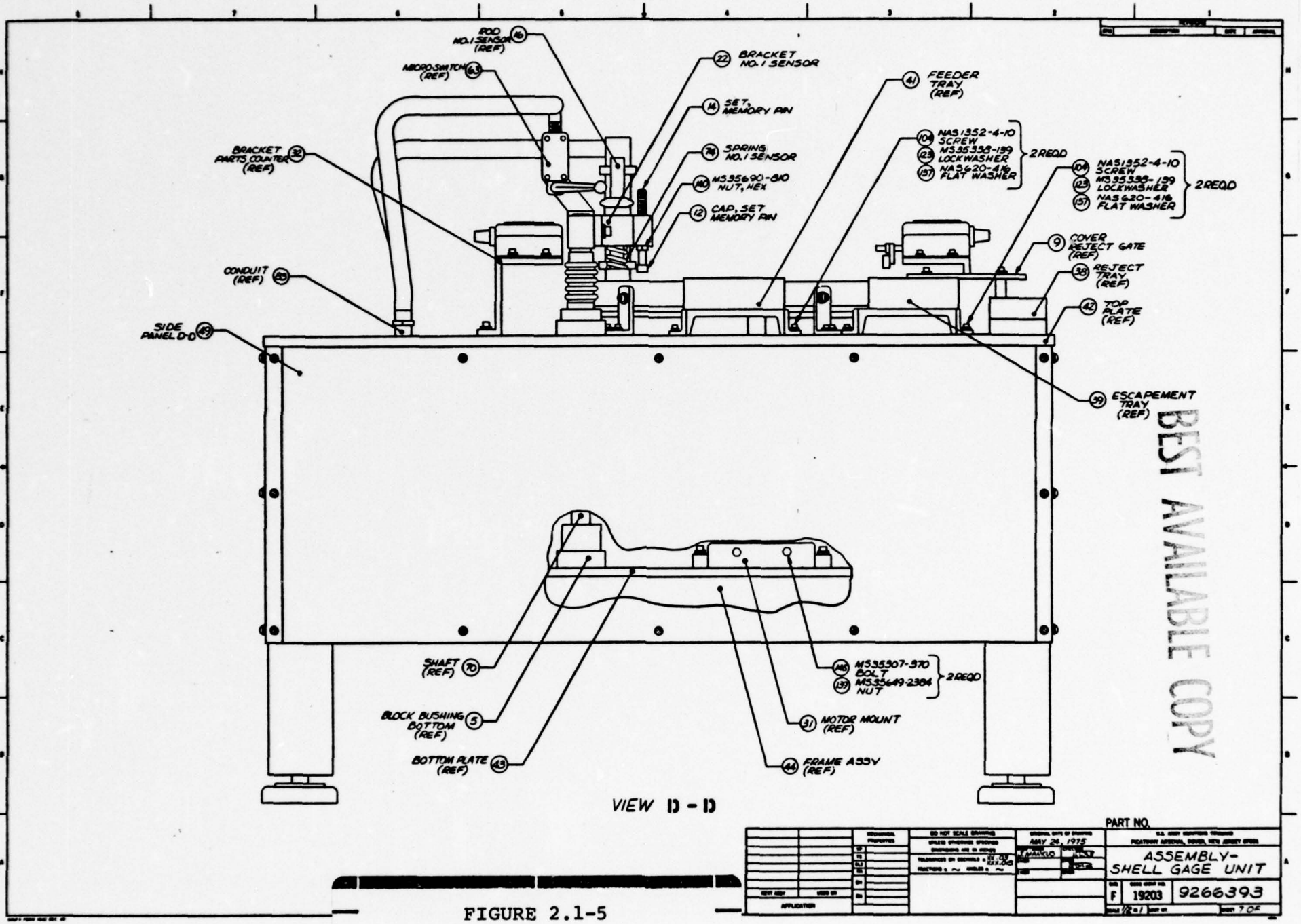

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FIGURE 2.1-5

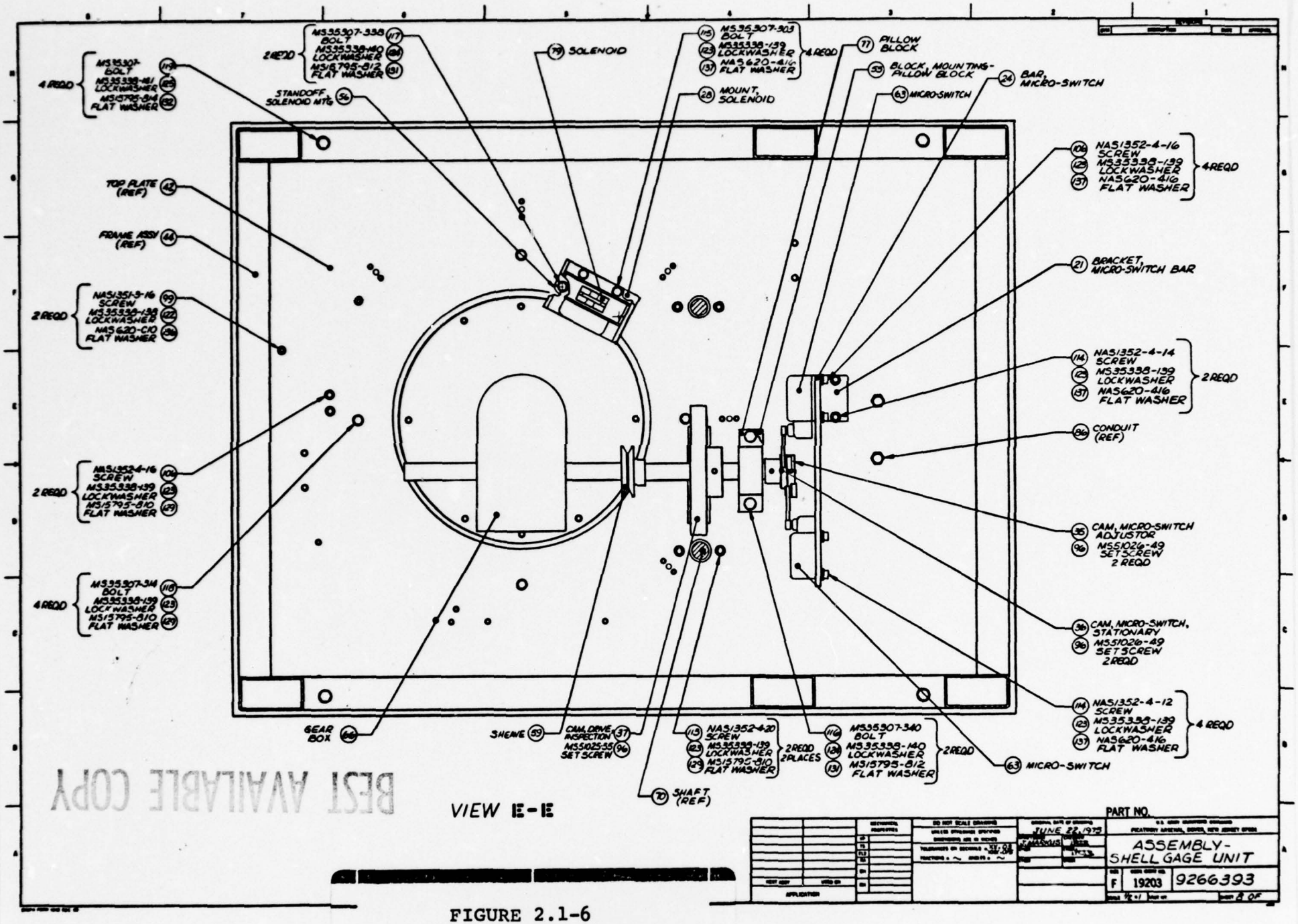

FIGURE 2.1-6

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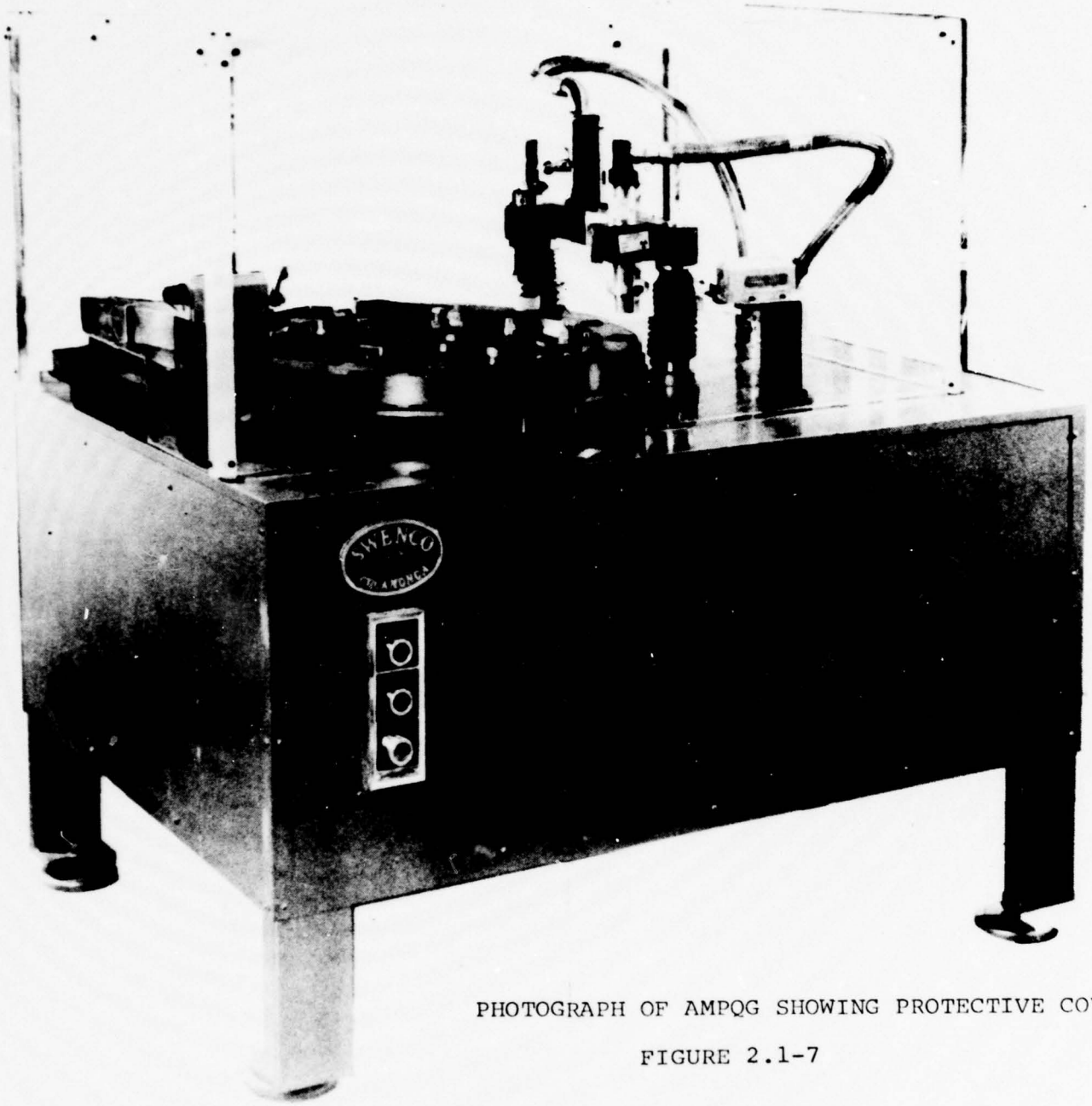
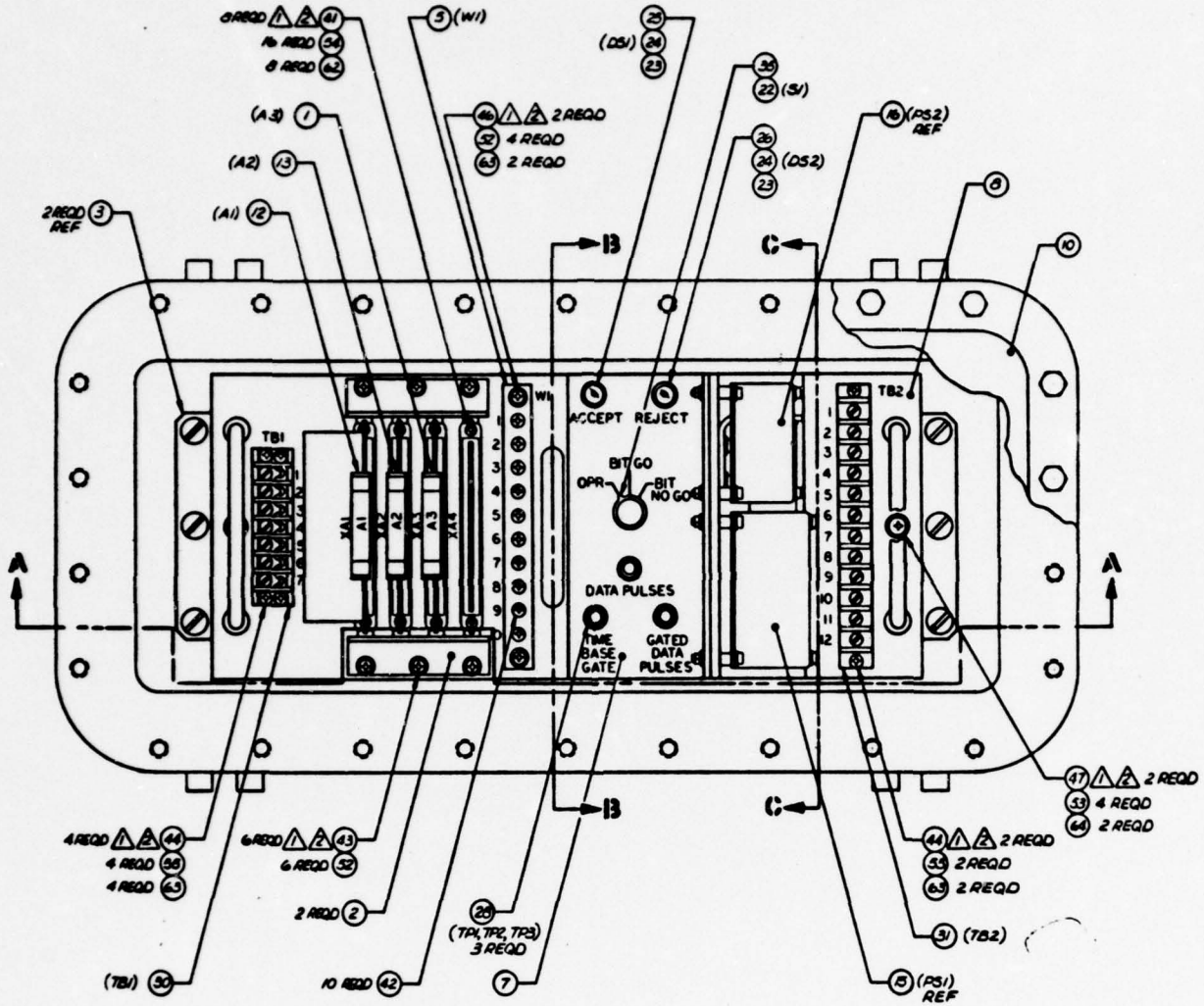


PHOTOGRAPH OF AMPQG SHOWING PROTECTIVE COVER

FIGURE 2.1-7



ELECTRONICS UNIT SHOWING INSTALLATION OF ELECTRONICS

FIGURE 2.1-8

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ELECTRONICS UNIT, SHELL GAGE

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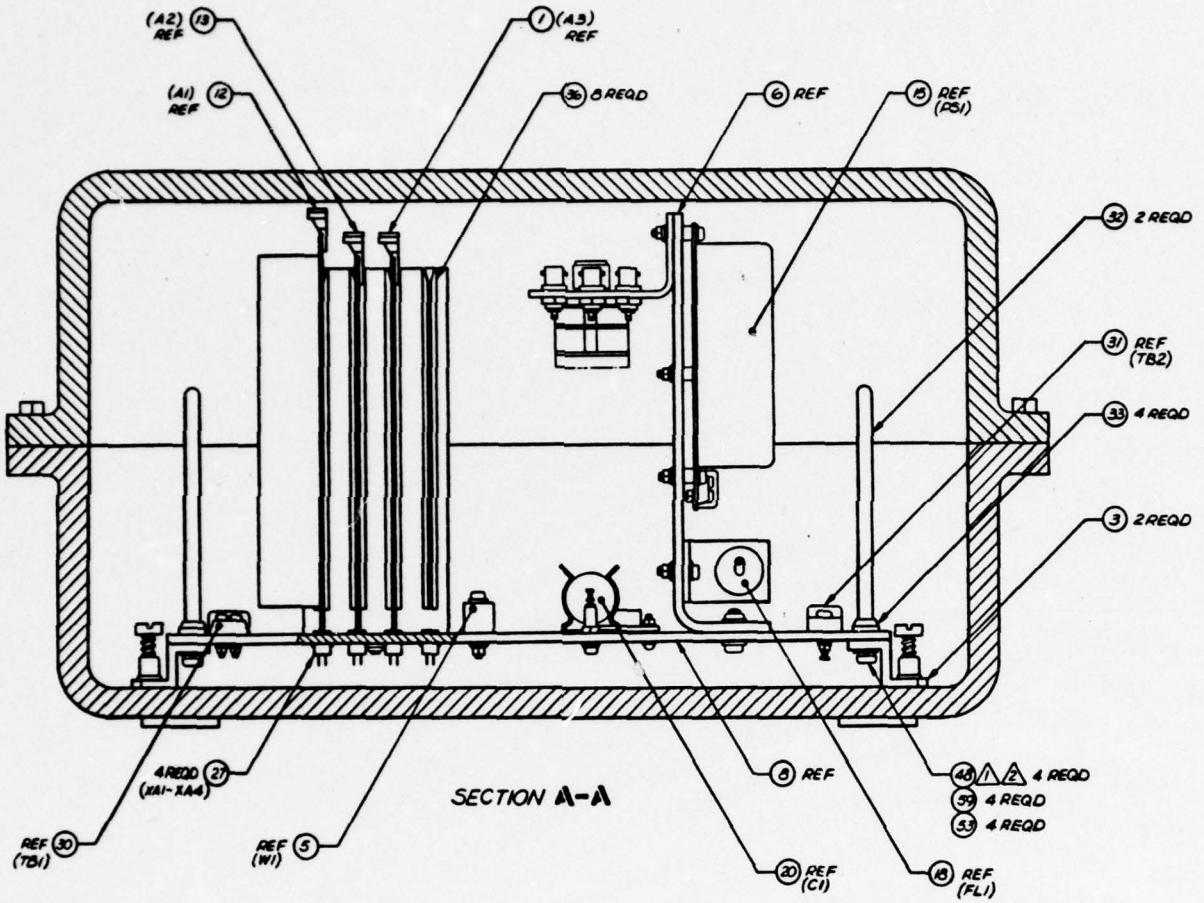

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ELECTRONICS UNIT, SHELL GAGE

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FIGURE 2.1-9

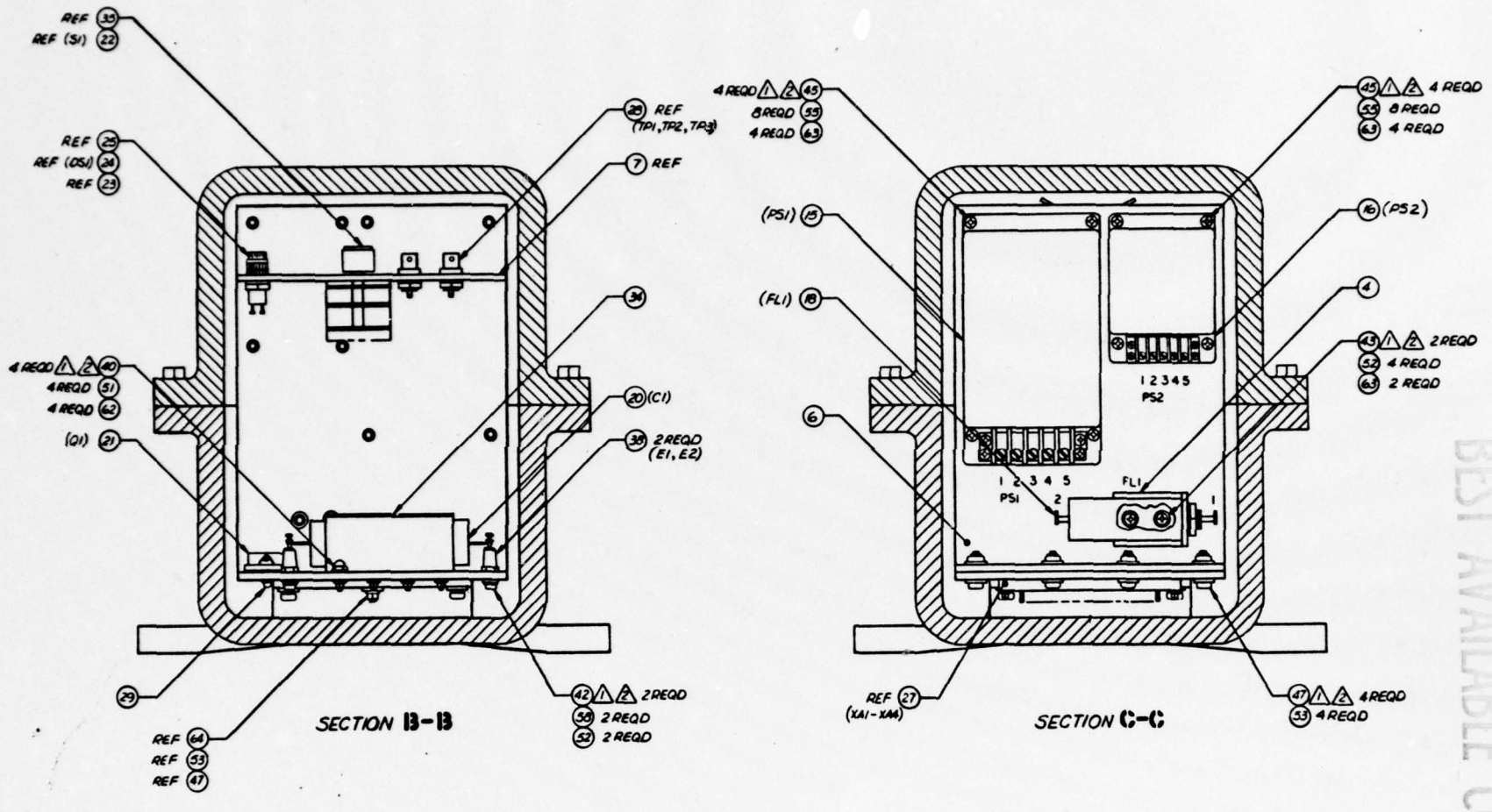

FIGURE 2.1-10

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ELECTRONICS UNIT, SHELL GAGE

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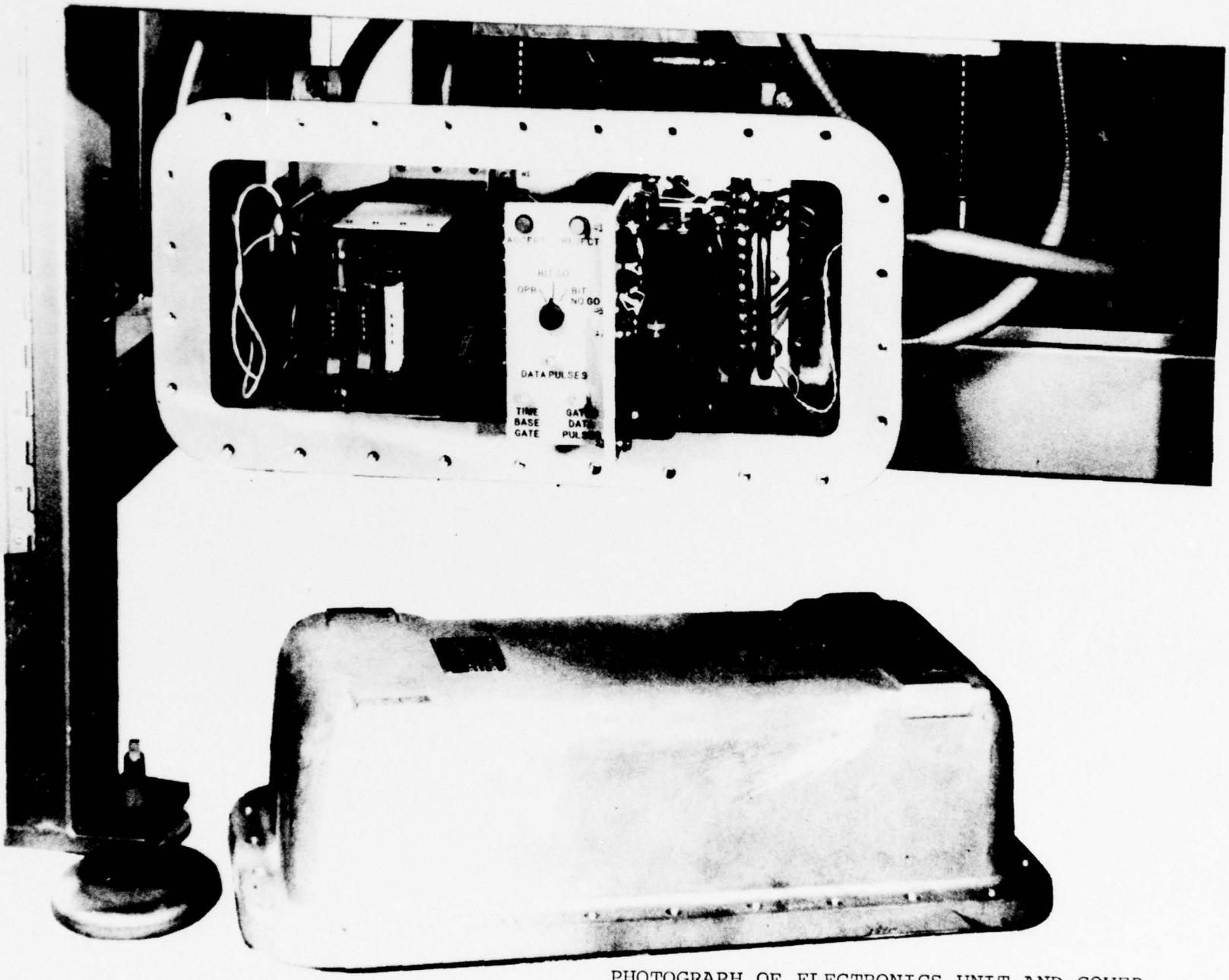


PHOTOGRAPH OF ELECTRONICS UNIT AND COVER

FIGURE 2.1-11

2.2 ELECTRONIC CONSTRUCTION AND OPERATION

2.2.1 General

The electronic system design employed in the on-line equipment is essentially unchanged from the original development equipment. All circuitry is on printed circuit boards and is enclosed in an explosion proof housing. The actual circuit design of the data handling modules remains identical to that employed for the developmental model of the instrument and employs digital techniques almost exclusively. As explained in the original proposal for the development equipment, the nucleonic measurement technique is inherently digital in nature since the output signal from the sensor is a pulse train. Incremental changes in the signal information are manifested as pulse rate changes in the output from the sensor.

2.2.2 Principles of Operation

Since the nucleonic sensor signal information is contained in the pulse rate of the output, the operating principle of the electronics is based upon accumulating the total counts over a fixed interval of time (the duration of the time base gate). The sampled counts are then compared to a preset binary number and if they exceed that number, the cartridge case under test is accepted. Should the counts accumulated be less than the preset number, the cartridge case is rejected.

In order to make the system fail-safe, the "GO-NO-GO" decision

for each cartridge case is assumed to be NO-GO prior to the measurement. The logic design is implemented with that premise, so that a power failure or any type of equipment failure will result in 100% rejection of the cases on the line.

The electronic measuring sequence and decision making actions are initiated by a signal from the automatic handling mechanism. The cartridge cases are inspected at the rate of one case per second. Further details of the system operation are discussed more completely in the ensuing paragraphs.

2.2.3 Input Discriminator

As shown in the block diagram (Figure 2.2-1), the PMT (Photomultiplier Tube) supplies the input signal to three discriminators. These discriminators are amplitude sensitive pulse comparators (μA710 integrated circuits), each of which is set to trigger at a different amplitude on the input pulse voltage waveform. Three discriminators are required in order to "sort out" the appropriate count rate from the automatic gain control (AGC) source and the measure source. Two of the discriminators are used to bracket the signal pulse amplitude while the AGC discriminator is set at the highest amplitude and passes only those pulses from the AGC source.

The count rate through this channel is approximately 100 pulses per second (PPS). The purpose of the AGC channel is to conteract any gain change in the PMT or electronic drift in the signal discriminators which might introduce and error in the signal count rate.

The AGC control loop is shown in the lower portion of Figure 2.2-1. It consists of the AGC discriminator, the rate converter, the high voltage DC to DC converter, and the photomultiplier tube itself. Its operation is described briefly as follows:The AGC source is held in close proximity to the NaI crystal. This source provides a strong photo peak which is well above the signal pulse amplitude and at a much lower counting rate. These AGC source pulses are extracted from the composite signal by measns of a high level discriminator which passes only the AGC pulses to the analog rate convertor. The output voltage of this rate converter is proportional to the input AGC count rate. This voltage is compared to a stable reference voltage and any difference between the two is amplified by a high gain error amplifier. The amplifier error voltage is used to drive a high voltage DC to DC converter which supplies power to the detector.

With the loop closed, any drift mechanism causing a decrease in detector conversion gain results in a drop in the AGC count rate and increases the detector high voltage, thus

re-establishing the correct conversion gain. Similarly, an increase in conversion gain produces a decrease in high voltage and re-establishment of the correct conversion gain.

Two discriminators are used to select the signal channel pulses in order to inhibit false information from noise on the input (low threshold) and the AGC pulses (high threshold). Only those pulses having an amplitude between these two levels are counted by the following logic circuitry. In this manner the counting rate from the measurement source is bracketed precisely and only these pulses are used to make the accept-reject decision.

2.2.4 Digital Threshold

The signal pulses are inputted to a binary counter through a control gate so that they may be accurately counted. The time base gate input controls the beginning and total interval for which the counting is accomplished. The interval has been chosen to be 500 milliseconds. If during this interval the input count rate from the PMT sensor is sufficient to exceed the preset minimum, an output pulse from the counter will set the decision flip-flop immediately following the counter. When the decision flip-flop is set the ensuing interrogate pulse will cause the output relay to be closed, which activates the accept solenoid.

Conversely, if the input count rate to the counter is insufficient to trip the binary threshold circuit the decision flip-flop will not be set. Then the interrogate pulse will not set the accept flip-flop, the output relay will not be closed, the accept solenoid will not be energized and the faulty cartridge case will be delivered into the reject tray. Note that the faulty casing was rejected because the accept mechanism was not energized, which is in conformance with the fail-safe design requirements. The criteria for an accept decision requires several successful events to occur; i.e., the insertion of the sensor into the cartridge case, proper generation of timing pulses by the logic circuitry and an accept decision pulse to energize the accept solenoid. The failure of any of these events will result in the cartridge being sent into the reject tray. Furthermore, a failure of any of the supply voltages which could affect the decision making elements will result in reject decisions.

The binary threshold is determined rather simply by inputting the desired counter outputs to a NAND gate, so that a logic zero transition is obtained when all inputs are logic "one," signifying that the desired count has been reached. Since each measurement cycle is started from zero, all stages of the counter being cleared prior to the time base gate being generated, it is not necessary to examine the state of all the counter stages. Only those stages which are

determined to be a logic one at the desired threshold count need to be inputted to the NAND gate. This reduces, somewhat, the number of leads which must be changed to effect a change in the threshold. The time base gate is generated by a controlled unijunction transistor oscillator.

2.2.5 Scaler-Timer

A scaler-timer is supplied with the equipment to satisfy the system's calibration requirements. This test instrument is a commercial unit having the capability to measure the system time base gate and the PMT signal pulse train within the system accuracy requirements.

2.2.6 Power Supply

The DC power supply voltages required to energize the electronic circuitry are supplied from two commercial modular units. These modules supply the +12 and -6 volt requirements. A simple, zener regulated transistor reduces the +12 volts to +5 volts, which powers the integrated circuit logic modules.

2.2.7 Module Construction

The electronic circuitry utilizes modular construction to enhance maintenance and repair of the equipment. Using the

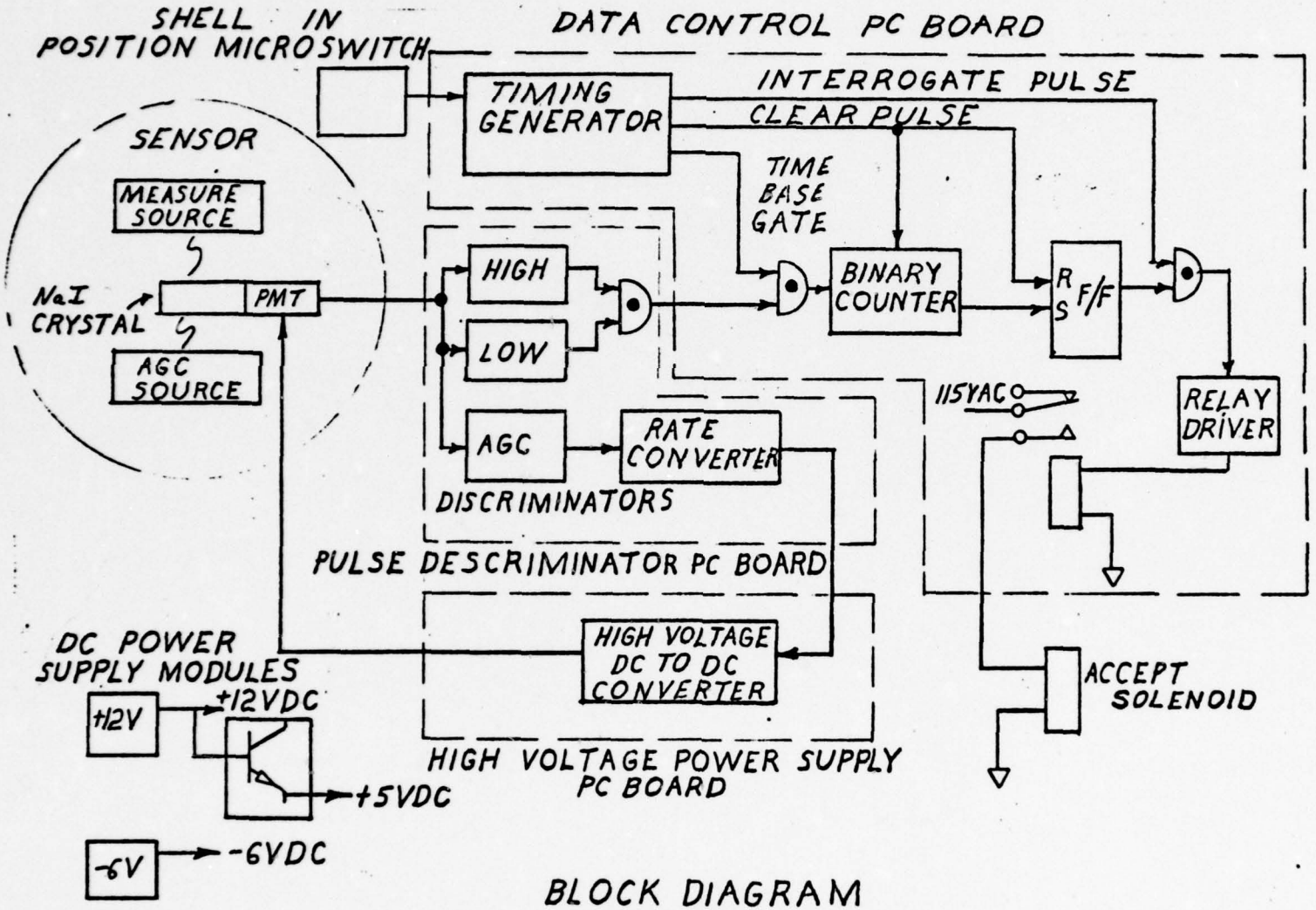
same basic layouts as were developed for the prototype model, three printed circuit boards have been designed and constructed. These boards contain the control and logic circuitry. The printed circuit boards plug into press-fit connectors and are mounted inside the explosion-proof housing.

2.2.8 Interface Connections

Figure 2.2-2 is an interconnection diagram for the printed circuitboards, the power supply modules, the detector and the various switches, solenoids and indicator lights in the electronics bay. The hard-wire interconnections between the electronic data handling system and the automatic handling mechanism are purposely kept at the very minimum. This is, of course, due to the hazardous environment at the point of actual measurement.

Only two operations in the handling and testing sequence are interconnected in this design. The first is the "start" signal, which is a low level DC pulse generated by a micro-switch located on the carrousel drive mechanism, and second the accept signal which is generated by the electronics after the conclusion of the electronic timing sequence. In the latter case, the electrical signal is used to energize the accept solenoid which activates the accept pin mechanism. The accept solenoid itself is located under the carrousel. One other microswitch is utilized in the

cartridge inspection sequence. This microswitch is activated by the carrousel mechanism and is closed during the time the sensor head is being withdrawn from the cartridge under test. Power can only be applied to the accept solenoid when this microswitch is closed. This interlock action thereby inhibits activation of the solenoid when the carrousel is indexing and eliminates the possibility of jamming the solenoid.



BLOCK DIAGRAM
FIGURE 2.2-1

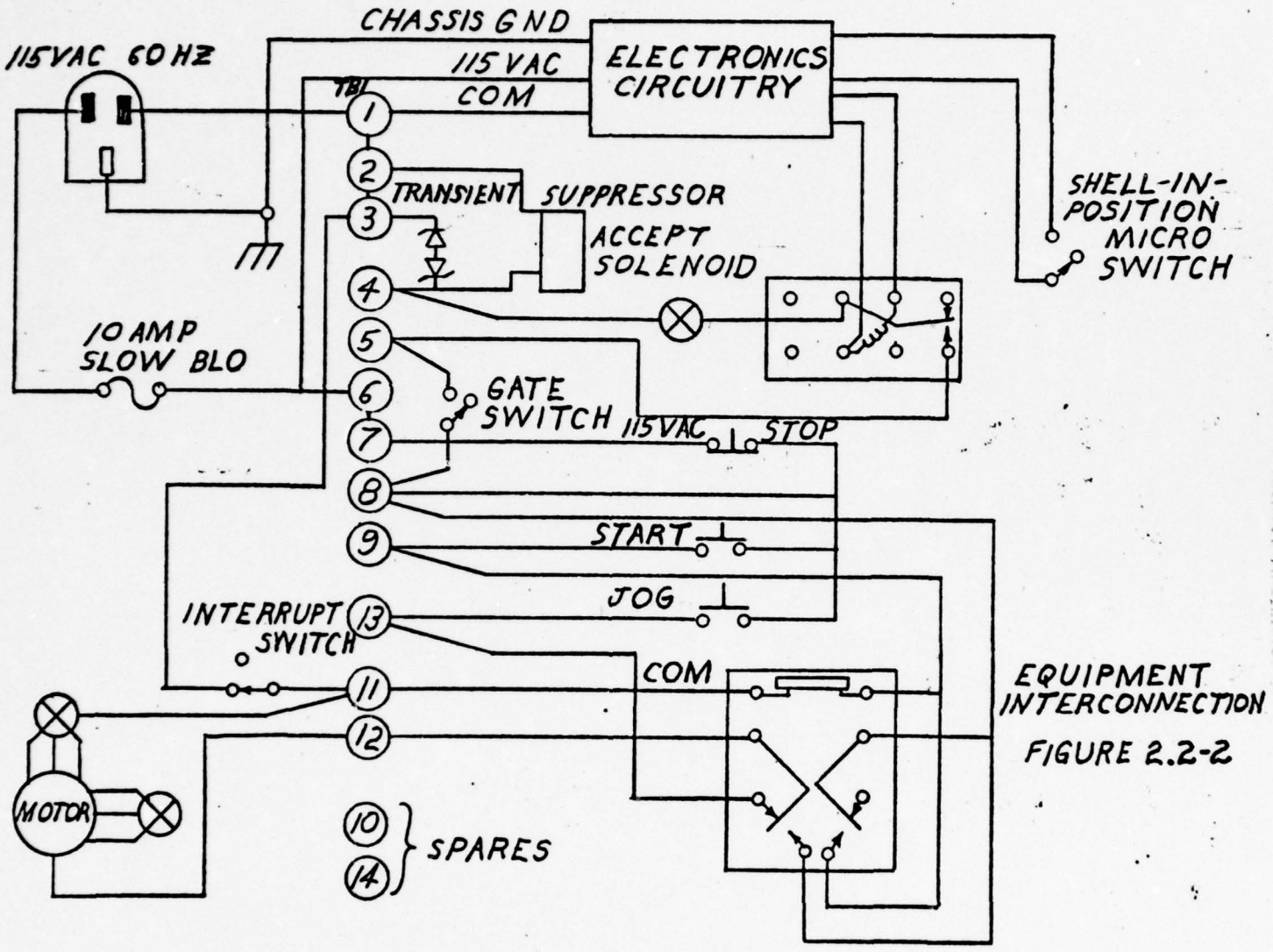

CHASSIS GND
115VAC 60HZ
115 VAC
COM
ELECTRONICS CIRCUITRY
TB1
1
2
3
4
5
6
7
8
9
13
11
12
TRANSIENT SUPPRESSOR
ACCEPT SOLENOID
SHELL-IN-POSITION MICRO SWITCH
10 AMP SLOW BLO
GATE SWITCH
115VAC
STOP
START
JOG
INTERRUPT SWITCH
COM
EQUIPMENT INTERCONNECTION
MOTOR
10
14
SPARES

FIGURE 2.2-2

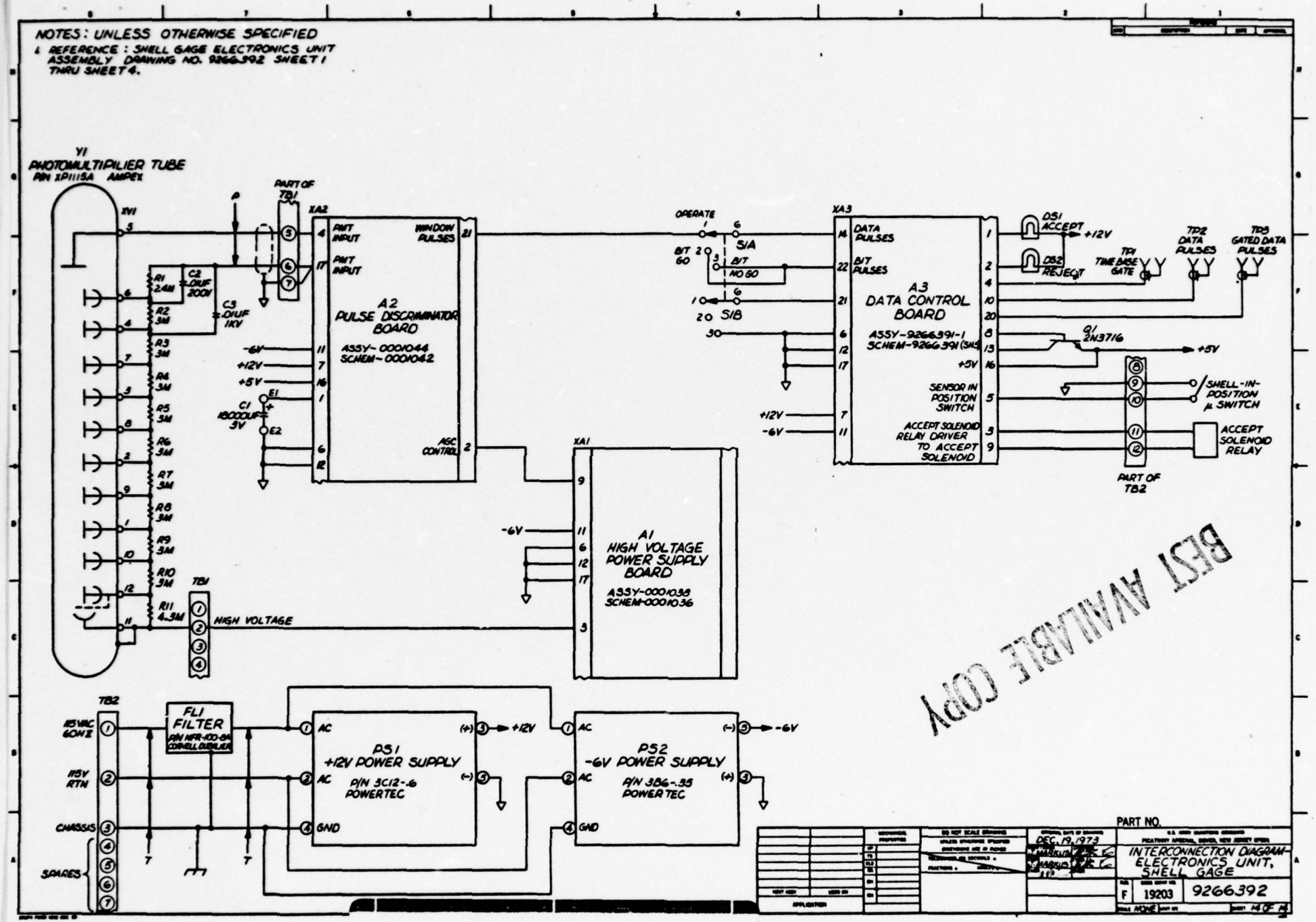


FIGURE 2.2-5

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2.3 DETECTOR CONSTRUCTION AND OPERATION

Construction of the detector is shown in Figure 2.3-1. The active elements of the detector are the Americium 241 (Am-241) radioactive source, the Sodium Iodide (NaI) crystal and the photomultiplier tube (PMT). A spring in the detector housing holds the PMT against the crystal to provide optical coupling through the optical grease at the interface. A "divider chain" of resistors and capacitors on the tube base provides the correct voltage for the PMT. The two cables which feed out through the detector cap provide high voltage to the PMT (red cable) and signal out to the electronics (white shielded cable). The lower part, called the crystal/source housing (shown in Figure 2.3-2) is made of a tungsten alloy and is shaped to fit into a 40 mm cartridge case.

2.3.1 Americium 241 Radioactive Source and Collimator

An annular steel capsule, the Amersham AMCK946, is nestled in the lower part of the source/crystal housing. Figure 2.3-3 shows a sectional view of this source. This source capsule contains 500 millicuries of Americium 241 (Am-241) and is designed so that practically all the emission from the capsule is radially inwards toward the axis of annulus. The characteristics of AM-241 are:

Half Life:	458 Years
Chemical Form:	American Oxide

Emission:	Particle	Abundance	Energy
	Alpha	100%	5.44 - 5.49 Mev*
	Beta	0	---
	Gamma	34%	60 Kev**

*Mev is million electron volts

**Kev is Kilo (thousand) electron volts

The lower part of the detector, the source/crystal housing, is shaped to fit inside the 40 mm cartridge case so that the source annulus is around the propellant charge. The 60 Kev gamma rays penetrate into the propellant from all sides, and part of these rays are scattered up towards the NaI crystal. The housing is made of a tungsten alloy, Kulite Hi Dens Ku-112, which is a very effective absorber of gamma radiation (better than the same thickness of lead). This housing is designed as a collimator for both the source and the crystal; that is, the "look angle" of the source and the "look angle" of the crystal intersect only in the propellant chamber of the cartridge. Thus, when the detector is fully in the cartridge case, the gamma rays scattered by propellants are sorted very effectively from the other gamma rays scattered by the aluminum case, the brass liner and the tungsten housing. This housing also provides excellent shielding for the source to eliminate radiation hazard to operating personnel.

2.3.2 Crystal and Photomultiplier Tube

The NaI crystal, located above the source collimator in the crystal/source housing, contains a Thalium activated Sodium Iodide scintillation crystal. When the energy of a gamma ray is absorbed in the crystal, it emitts a brief pulse of light at about 4,000 angstrums. The energy in the light pulse (number of light phototons) is proportional to the gamma ray energy absorbed. Although the crystal is quite small, the Harshaw 2D1 contains a wafer of NaI 1/2" in diameter and 1/4" thick. It is 90% effecient for 60 Kev gamma radiation.

The pulse of light caused by each gamma ray absorbed emerges from the crystals upper (glass) surface where it is optically coupled to an Amperex XP1115A PMT. The Amperex XP1115A is a ruggedized version of the standard XP1110 PMT; rated at 30 G shock and 25 G vibration. Optical coupling is provided by a thin layer of Dow Corning C-2-0057 Silicone grease. Inside the PMT, the light pulses are converted into a tiny burst of electrons at the cathode. This electron pulse is amplified by a factor of about one million as it cascades up through the 10 dynode stages until a quite respectable electronic pulse is delivered from the tube anode to be outputted on the signal cable to the electronics boards.

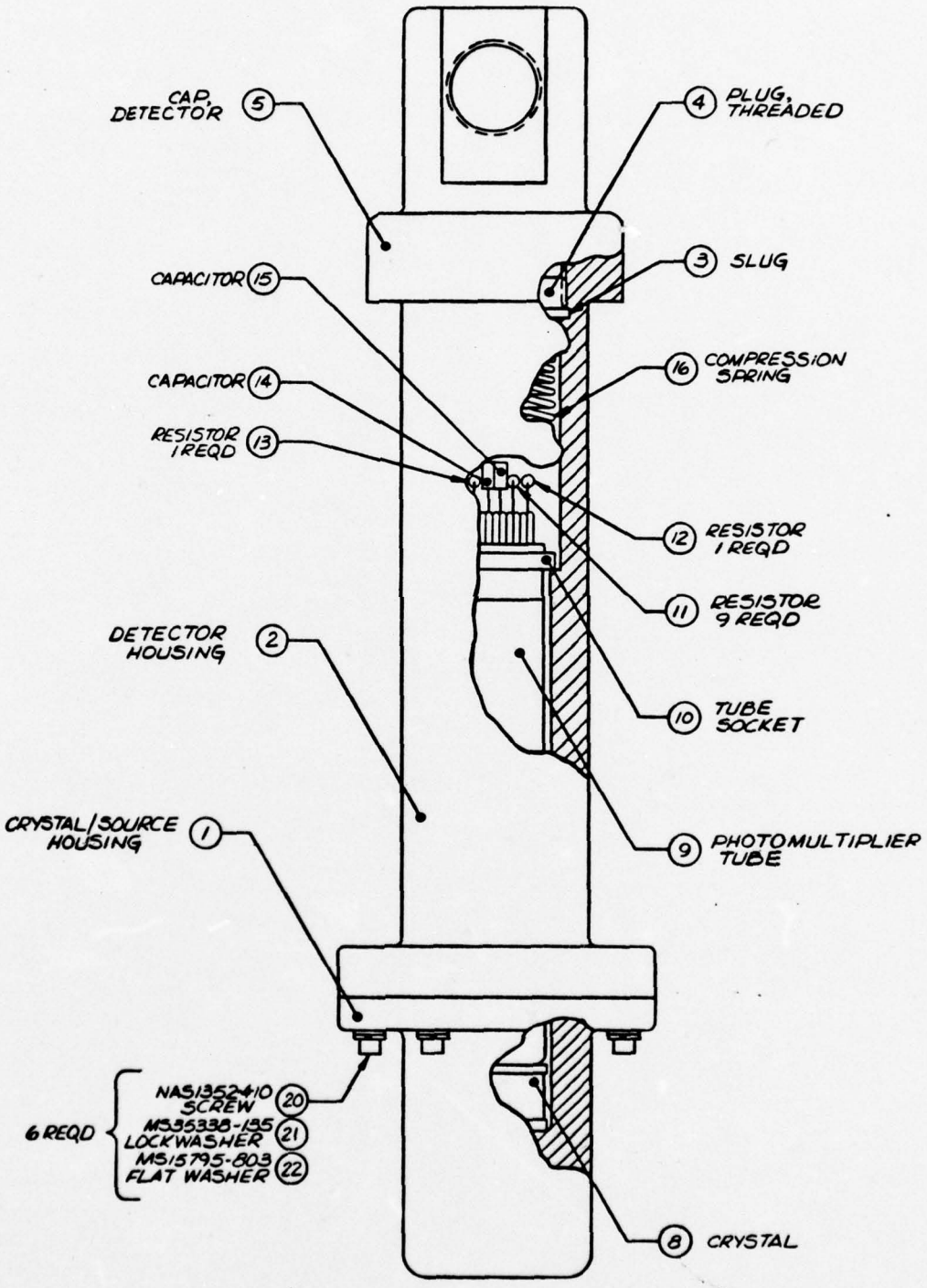
2.3.3 Automatic Gain Control Source

An automatic gain control (AGC) source and filter are wrapped around the crystal. The source is 0.5 grams of U-235 in a think strip which is spiraled into an outside wrap. The inside wrap is a layer of tin about 1/20" thick. U-235 emitts alphas, some weak gammas and x-rays, and very useful gamma at 185 Kev. The tin filter absorbs all the alpha and practically all the weak gamma and x-rays, but lets most of the 185 Kev gammas through. This photopeak from the U-235 source is used for automatic gain control. Figure 2.3-4 shows the pulse height spectrum of the Am-241 peaks from a loaded 40 mm cartridge case and the AGC peak from U-235. The U-235 peak is multiplied by 10 so that it can be plotted on the same graph as the gaging pulses. U-235 has a half-life of 7×10^8 years; it can therefore be considered stable over the lifetime of the gaging system, or the Rocky Mountains for that matter. The electronic operation of the AGC is described in Section 2.2.

2.3.4 Sensor Wiring Diagram

Figure 2.3-5 shows the wiring diagram for the photomultiplier tube (PMT) in the detector. These resistors and capacitors can be seen in the cut-away of the detector in Figure 2.3-1. They are soldered to the PMT socket. The resistors form a "divider chain" which distributes the high voltage to the various stages (dynodes) of the PMT.

Different PMT's, and different applications, require different voltage distributions. There are many ways to optimize the performance. For very fast tubes or for large pulses, the voltage/stage usually is increased gradually from the cathode to the anode. The best pulse height resolution is obtained by using larger voltages on the first two stages (cathode to dynode Number 1 and dynode Number 1 to dynode Number 2). Where high count rates (or large output pulses) are expected, capacitors are placed across the last few stages to increase the charge storage. The voltage distribution used here is designed for good resolution along with moderately high count rates. The AMPQG detector count rate changes very rapidly; the output pulses increase by nearly two orders of magnitude as the detector enters a cartridge case. This makes the charge storage near the output even more important; if the voltage distribution varies because of changing current drain as the detector enters or leaves a cartridge case, the PMT gain will vary - both as a function of time and as a function of propellant quantity. Thus the capacitors must maintain short term stability in the detector as the load current makes its cyclic variation.



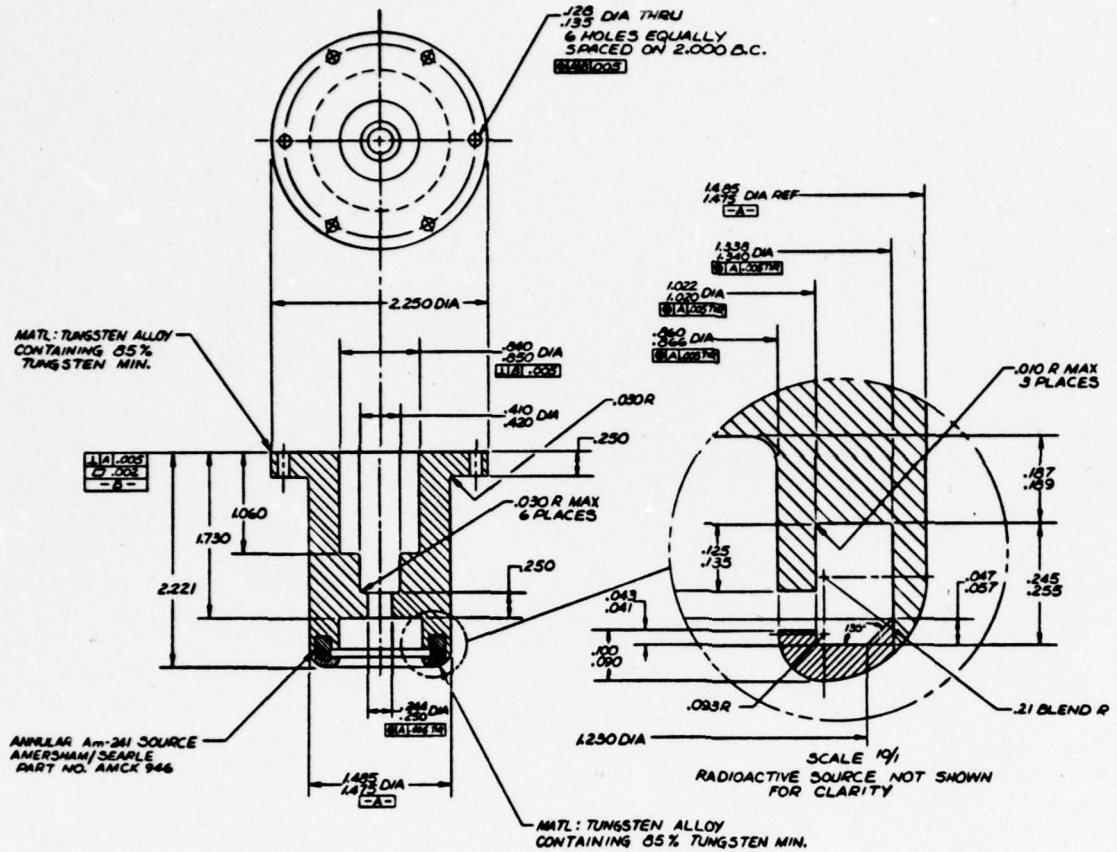
NOTES: UNLESS OTHERWISE SPECIFIED

DETECTOR CONSTRUCTION

FIGURE 2.3-1

NOTES: UNLESS OTHERWISE SPECIFIED

1. REMOVE ALL BURRS AND BREAK SHARP EDGES.



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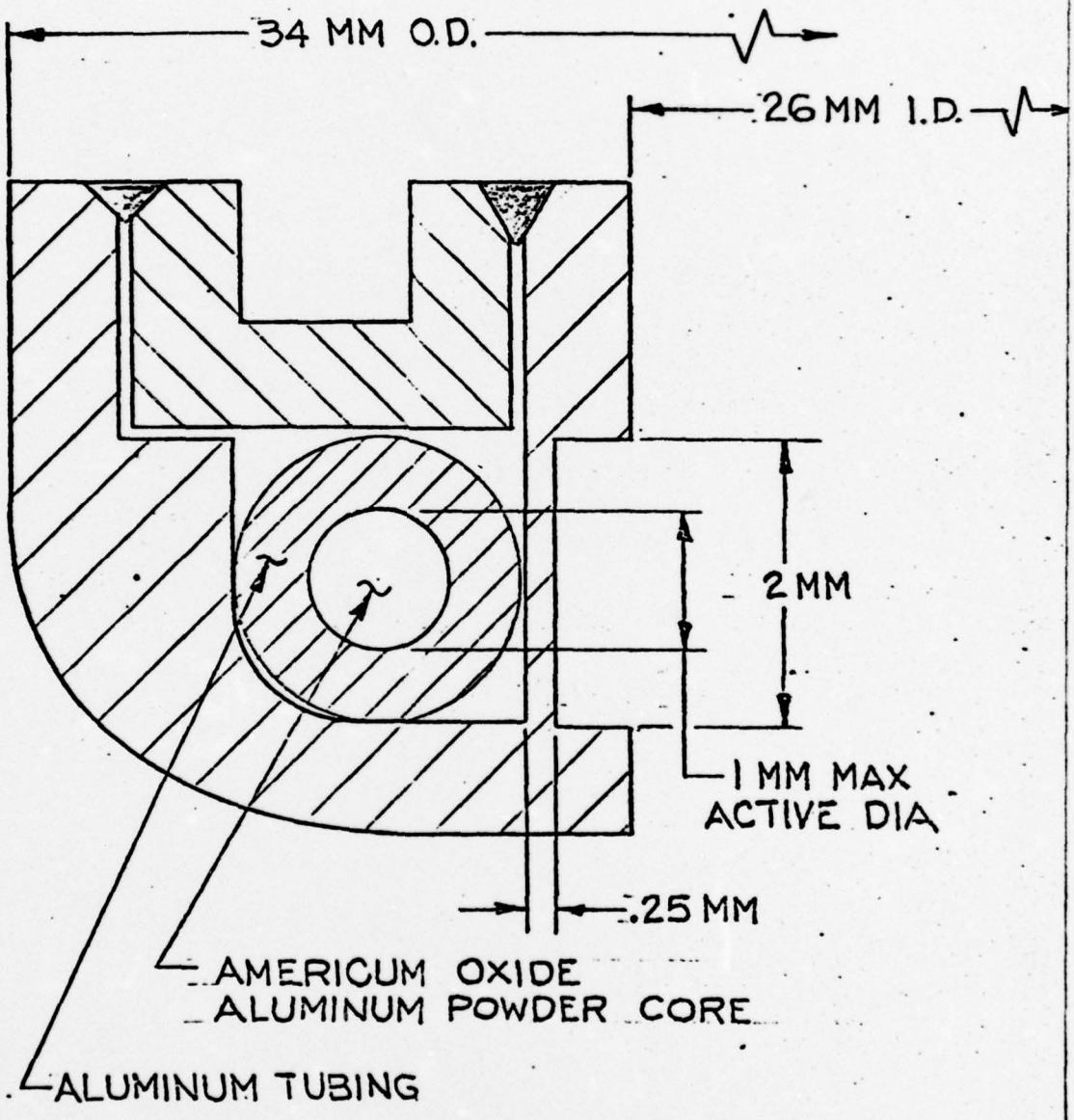
(1) SOURCE/CRYSTAL HOUSING

		DO NOT SCALE DRAWING	JUNE 12, 1975	PART NO.
				DETAILS - DETECTOR ASSEMBLY, SHELL GAGE UNIT
				F 19203 9266394

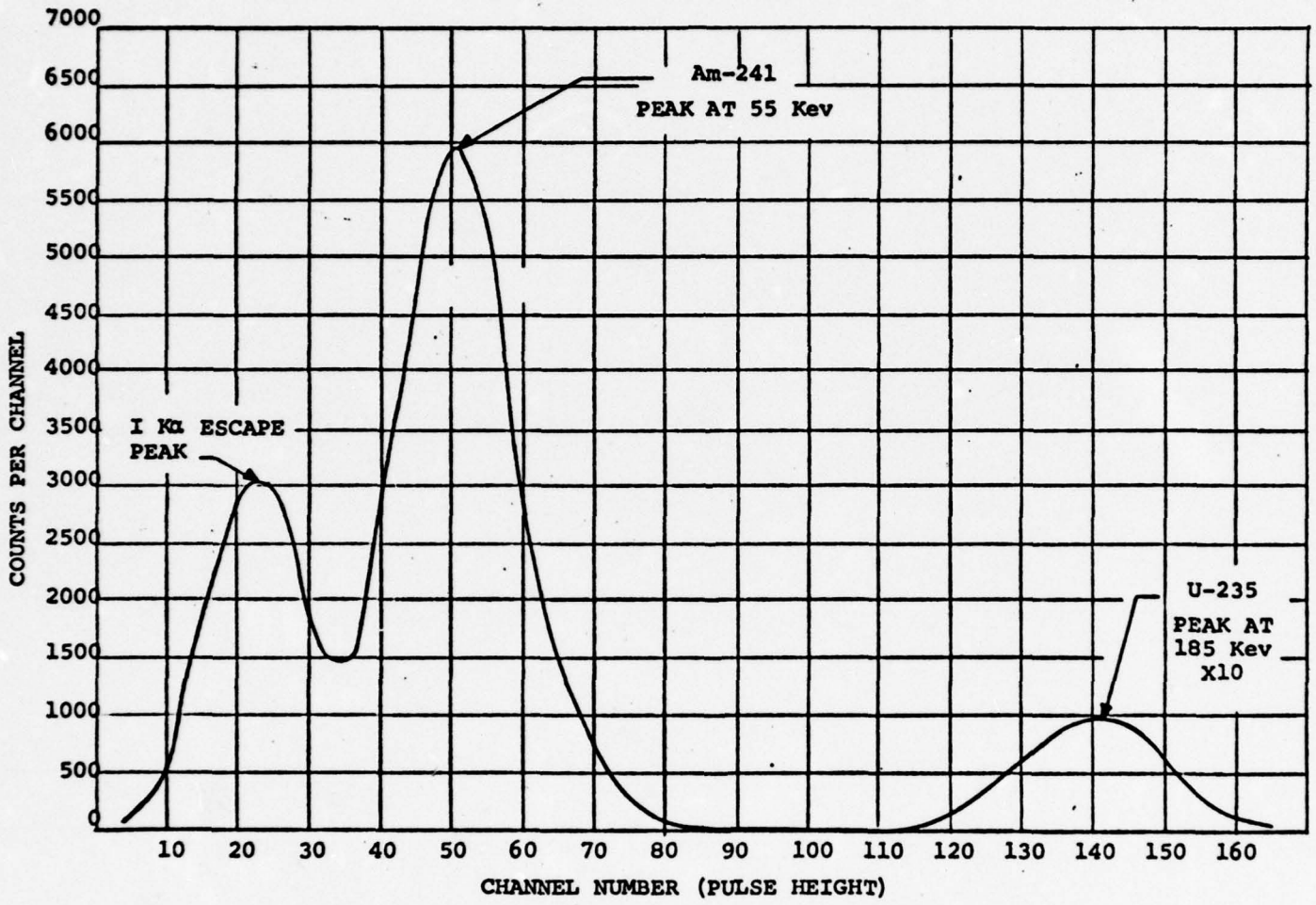
FIGURE 2.3-2

ANNULAR Am-241 SOURCE



SECTION OF ANNULUS

FIGURE 2.3-3



Am-241 BACKSCATTER AND U-235 AGC SPECTRUMS

FIGURE 2.3-4

3.0 SYSTEM TESTS

Test of the AMPQ Gage were scheduled in two phases; the first an acceptance test at General Nucleonics Division in Pomona, California prior to delivery, and the second a final test at Milan Army Ammunition Plant, Milan, Tennessee after delivery. The first was to be primarily a demonstration of the equipment performance using a "variables" testing procedure and the second was to include an 8-hour production run of cartridges.

3.1 DEVELOPMENT TESTS

General Nucleonics Division had on hand a set of 23 cartridge cases with calibrated fill levels furnished by the Milan Ammunition Plant with fill levels of 50% (164 gms), 55% (180 gms), 60% (197 gms), 65% (213 gms), 75% (246 gms), 85% (279 gms), and 100% (328 gms). These cartridge cases had been used in development of the Bench Model Propellant Quantity Gage (Picatinny Contract DAAA21-71-C-0484) and a series of careful measurements had been made on them with the bench model gage (four separate measurements of 100 seconds each to reduce statistical errors and determine repeatability). Figure 3.1-1 shows a plot of these measurements. Some cartridges with the same propellent weight, particularly at 60% and 75%, gave widely different count rates. Measurement of the metal thickness of each cartridge case revealed that in four of them (Numbers 9, 14, 8 and 25) the thickness of

the brass powder cup exceeded the maximum thickness allowed in the cartridge case drawings. Also, in four other cases, the thickness of the aluminum node (the part of the case just over the propellant chamber) was out of tolerance. For Numbers 10, 4, 21 and 24, the thickness was less than the minimum in each case.

The data for these eight cases are circled on Figure 3.1-1. The four with thicker propellant cups all had lower count rates than the average; the four with thinner nodes all had lower count rates than the average. If these eight cases are eliminated from the plot, the remainder of the data shows good agreement for cases of the same propellant weight, and the best fit curve drawn through the data for different weights is a very smooth curve showing good sensitivity.

To calibrate the AMPQG, a representative cartridge of each fill level was chosen from the group:

50%	55%	60%	65%	75%	85%	100%
#12	#7	#26	#15	#13	#5	#22

Figure 3.1-2 shows a plot of the count rate data from these cartridge cases.

3.2 DEMONSTRATION TEST AT GENERAL NUCLEONICS DIVISION

The demonstration tests were conducted during July 1974

with a representative from Picatinny Arsenal present.

The Picatinny Arsenal representative chose 11 of the 23 calibrated cartridge cases to be used in the test. The cases chosen for the test were:

55%	60%	85%	100%
#7	#4	#5	#11
#10	#9	#18	#6
#19	#17		
	#26		

One of the 55% cartridges and two of the 60% cartridges were out of tolerance. Number 10 and Number 4 both had aluminum nodes out of tolerance and Number 9 had a brass powder cup 36% thicker than the maximum. These out-of-tolerance cases could have had a significant effect on the test results. The gage was modified so that the same 11 cases would stay in the carrousel and continuously cycle through the machine. An empty slot in the carrousel thus served as an index to the data. The gated data output was fed into a TMC 400 channel (pulse height) analyzer (PHA) which has a multiscaler mode. In this mode, each of the 400 channels can be used as a separate scaler and an external gating pulse can be used to advance from channel to channel. When 400 pieces of data had been run (334 cartridge samples and 66 empty slots), the gage was stopped and the 400 channels printed out on the TMC printer. Figure 3.1-3 shows the test set-up. After

considerable difficulty in getting the PHA to work with the gage output, the data was recorded in a few hours. This data was analyzed at Picatinny Arsenal; the conclusion was that the gage would not meet the requirements.

3.3 ACCEPTANCE TESTS AT MILAN ARMY AMMUNITION PLANT

The AMPQG was delivered to Milan, Tennessee in July, 1974. It had been planned to test the gage by running an 8-hour production run of 40 mm cartridge cases, with a few known "good" and "reject" cases interspersed (see Part B, Section 5 of the Statement of Work). A different technique for testing was directed by the Picatinny representative, however.

Milan Army Ammunition Plant prepared sets of cartridge cases at predetermined fill levels: 50 at 55% full, 50 at 65% full, 50 at 85% full, 50 at 100% full, and 50 empty cases. These cases were to be intermixed and run randomly through the gage. Picatinny requested that GND bring the 400 channel PHA to Milan for the acceptance test so that data could be recorded for each cartridge case as had been done in the demonstration tests (see Section 3.2 above). When the equipment was hooked up at Milan, it was found that the PHA would not accept the data from the gage "Gated Data Pulse"

output as it had in the GND demonstration tests. Two days were lost in trying because the PHA seemed to work with different inputs and the AMPQG was also working well. Finally, an effort was made to run the AMPQG with groups of cartridge cases and observe the fill level of those accepted or rejected -- an effort to salvage something. At this point, mechanical problems in the AMPQG ended the tests.

3.3.1 Mechanical Problems with the Gage

There were several mechanical problems in the gage which were found during these tests; however, all but one were relatively minor. These problems were:

1. Reject Gate - Running groups of reject cartridges (a condition unlikely in actual use) caused the side walls to loosen and finally to jam.

2. Feeder Tray - Several times the cartridges jammed at the place where they enter the carrousel, either because two would be side-by-side or because they would be picked up above the lower guide ring.

3. Carrousel - The carrousel developed slack after several hours of operation. Even 1^{o} of slack gives .17" of misalignment at the sensors which is more than enough to cause the Number 1 sensor to contact

the side of a cartridge case and turn the power off.

It was thought that both the first two problems could be corrected by some minor shop work in about a day, which would not require moving the entire gage. However, the third was more serious; it would require disassembly of the main carrousel drive unit.

3.3.2 Action by Martin-Marietta Aluminum Sales

Transportation of the AMPQG back to GND in Pomona, California for repairs and later shipping it back to Milan, Tennessee would have been both costly and non-productive. Since Martin-Marietta had the necessary shop facilities at Milan, and personnel experienced in cartridge handling devices, they were asked if they would examine the gage and quote GND the cost of the necessary repair and/or alterations. In the interest of expediting the program, Martin-Marietta agreed and a purchase order was subsequently released by GND for Martin-Marietta to dismantle the gage and repair the known problems. When they had dismantled the carrousel drive unit however, they found additional problems. The 12 cam followers were all either bent or broken. This could not be repaired at Milan. It was necessary to ship the carrousel drive unit to GND, who then returned it to the manufacturer, Swenco Engineering, for replacement of the cam followers. Swenco also beefed up the contact

area to prevent the same thing happening again.

3.3.3 Final Acceptance Test at Milan, Tennessee

3.3.3.1 Preparation for Test

The final acceptance testing was done during the last two weeks of March, 1976. Martin-Marietta Aluminum Sales had reassembled the gage and checked it out mechanically. A modification to the feeder tray to prevent jamming of the incoming cartridge cases was also equipped with a microswitch which would cut gage power if the cases did jam. The sensor had not been reassembled, however. The crystal/source housing had been removed so that people could work on the gage without film badges, etc., and the PMT was also removed to lessen the chances of breaking it.

The test plan was similar to that of the first trip. Using the known propellant weight cases, Picatinny wanted to accumulate 4, 100 pieces of data consisting of:

1,000 pieces at 55% fill
1,000 pieces at 65% fill
1,000 pieces at 85% fill
1,000 pieces at 100% fill
100 pieces at empty

The difference from the earlier test was that the cases

would be run systematically, instead of randomly. That is, each run of up to 400 cases would consist of all the same fill level so there would be no question of which data point corresponded to which fill level.

When the sensor was reassembled and the gage turned on, there was no signal output. Considerable time was spent trouble-shooting before the trouble was located. The spring which holds tension on the PMT was shorted to the high voltage connection at the base of the tube. During the trouble shooting, the data board output had been accidently shorted to the power input pin; there was now no output from the board. A spare data board was available which required only a wiring change to the same decision number as the first board. The gage now operated and with the right connections to the PHA (after some operator problems) permitted recording of data. It was found that disassembling and reassembling the carrousel and sensor bar had changed the sensor height adjustment. A new sensor calibration height was determined and a new decision number calculated using five cartridges of each fill level chosen randomly from those prepared by Milan for the test. These data, plotted in Figure 3.3- 4 , gives a different operating curve and therefore a different decision number than that used in the first test at Milan.

The count rate numbers plotted in Figure 3.3- 4 are twice

the number of counts accumulated in the data board (0.500 second measure time). The decision number N_D = 5500 wired into the data board corresponds to a count rate of 11000 counts per second. This count rate in Figure 3.3-4 indicates that a cartridge of 80% full will be right at the decision point, 50% accepts and 50% rejects.

3.3.3.2 Acceptance Test

The test was conducted by running groups of 200 cartridges of each fill level: 55%, 65%, 85%, and 100%, and printing the results out before proceeding to the next fill level. It was found that the man feeding the cartridges in would sometimes miss a slot, so that an empty slot would be measured and printed out, so an extra 10 or 15 cases were measured in each group to assure that the total would be at least 200. After the first complete run of cartridges with propellant, a group of 100 empties were run. A second run of groups of 200 was started, but midway in the third group the output became unsynchronized with the mechanical motion of the gage. That is, the gage would initiate a "measure" cycle when the detector was not in a cartridge or just before it lifted out. There are two possible causes of this type of malfunction. Either a component failure in the digital section of the data board, or the cam that operates the SIP (Sensor in Position) microswitch slipping on its shaft. The second

was easy to check, and the SIP switch proved to be operating correctly.

Trouble-shooting the data board digital logic was not feasible at Milan. An attempt was made to trade components from this board to the original one (see Section 3.3.3.1 above). It was thought that only the ouput transistor had been blown while trouble-shooting the sensor short, so that component was removed and replaced from the second board. When that failed to fix the problem, it was decided to take both boards back to GND for repair. Board Number 1 was repaired at GND and air mailed back to Milan the next day. The personnel at Milan ran 550 cartridges to check out the gage.

3.3.3.3 Summary of Test Results

A total of 1886 cartridge samples were measured on the AMPQG in the final acceptance tests at the Milan Army Ammunition Plant during the last weeks of March, 1976.

Tests at Milan on March 24 and 25, 1976

In the first part of the final acceptance test, when the pulse height analyzer was used to record the count data for each cartridge, a total of 1336 samples were tested. The results were as follows:

		PRINTER DATA		GAGE ACTION	
FILL LEVEL	NUMBER TESTED	NUMBER ACCEPTED	NUMBER REJECTED	NUMBER ACCEPTED	NUMBER REJECTED
Empty	104	0	104	0	104
55%	409	0	409	1	408
65%	412	2	410	2	410
85%	205	175	30	175	30
100%	206	206	0	203	3

The printout data showed that all 55% cases were rejects and all 100% cases were accepts. However, one 55% case came out the escapement (accept) tray, three 100% showed up in the reject tray. The electronics unit has two lights, a red for reject and a green for accept, which can be observed when the cover is off. An observer watched the lights throughout these test runs. Green lights were observed for all of the 100% cartridges, which agrees with the printed record. The three 100% cartridges found in the reject tray must have resulted from a mechanical malfunction, possibly the memory pins slipped back down or were inadvertently pushed down by the operators.

The cause of the 55% cartridge that was accepted is a bit clearer. In this case, one blink of the green light was observed during this run of 55% cases. The highest data point in the printout was 5499, one count less than the 5500 decision number. It is quite possible that the AMPQG electronics is enough faster than the pulse height

analyzer to account for a difference of one or two counts out of 5500, so the count to the data board could have been 5500 or 5501. This cartridge (the one accepted) was retested in the AMPQG several times. The count data was consistently high (for a 55% case), around 5200, but never close to the accept level.

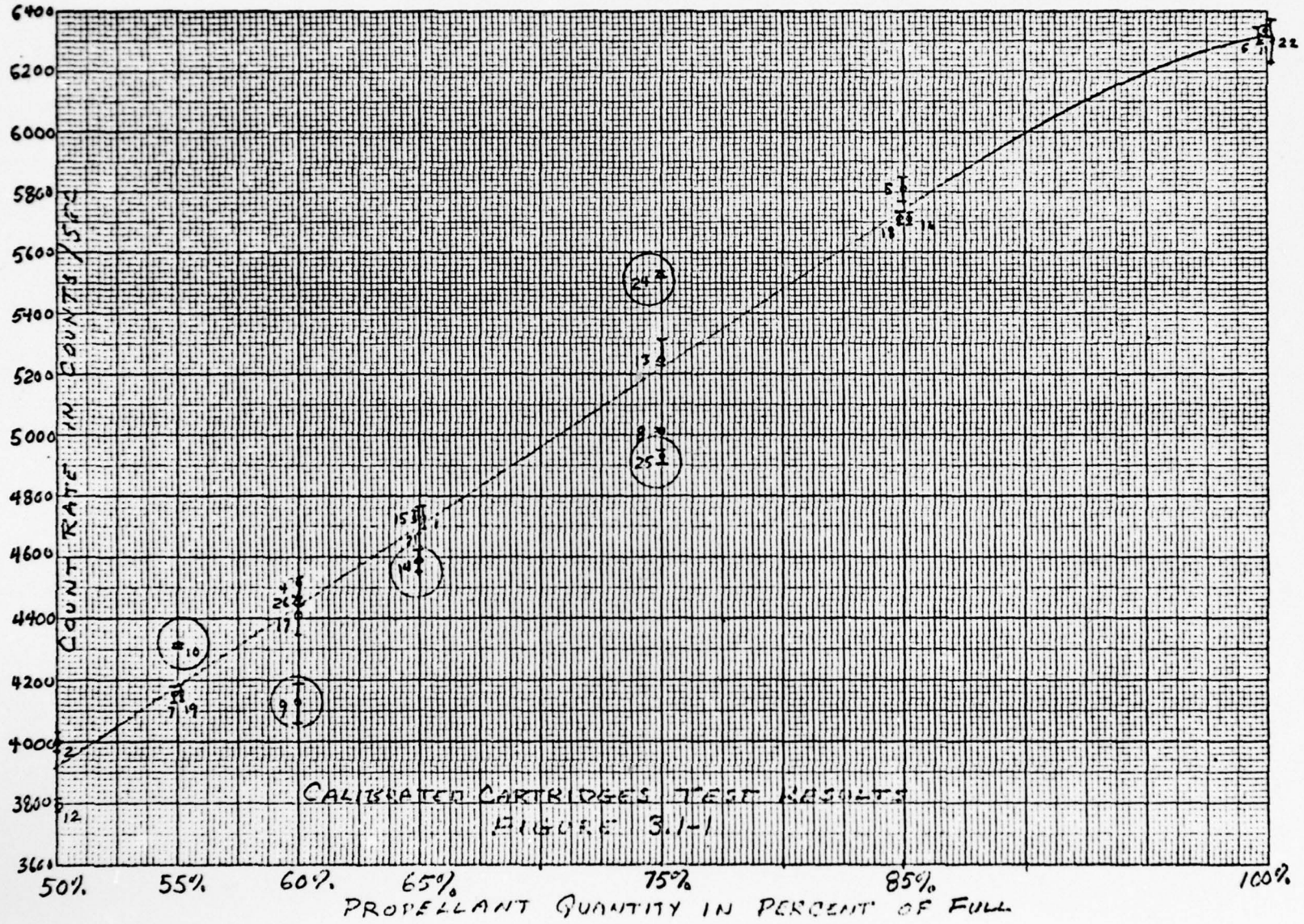
Tests at Milan on March 30, 1976

Milan Army Ammunition Plant personnel replaced the repaired data board and operated the gage on March 30, 1976. One hundred and ten samples of each fill level were run with the following results:

FILL LEVEL	NUMBER RUN	NUMBER ACCEPTED	NUMBER REJECTED
Empty	110	0	110
55%	110	0	110
65%	110	2	108
85%	110	109	1
100%	110	110	0

This data was transmitted to Picatinny Arsenal along with the readout data from the earlier tests for analysis. This completed the acceptance tests.

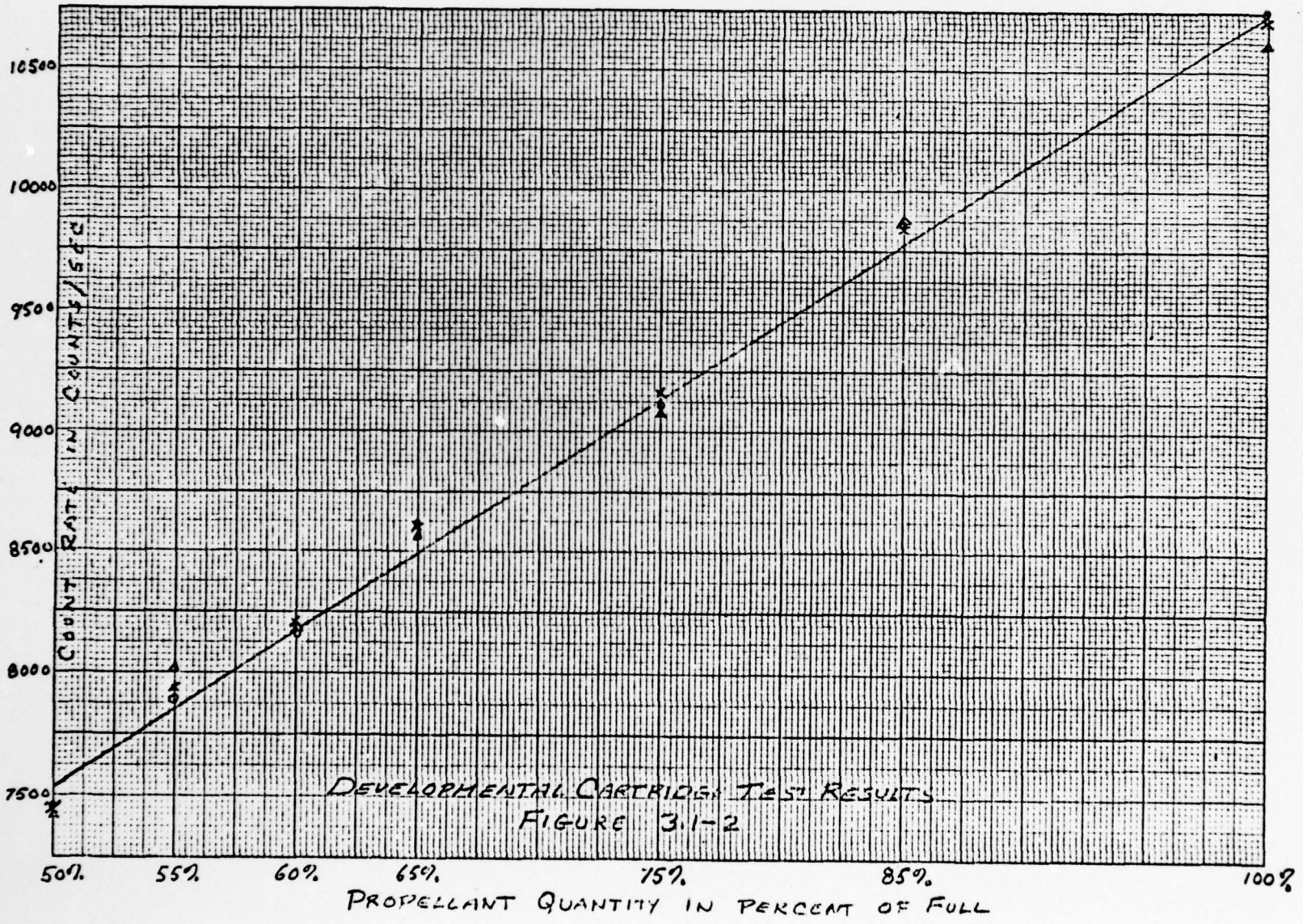
K•Σ 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



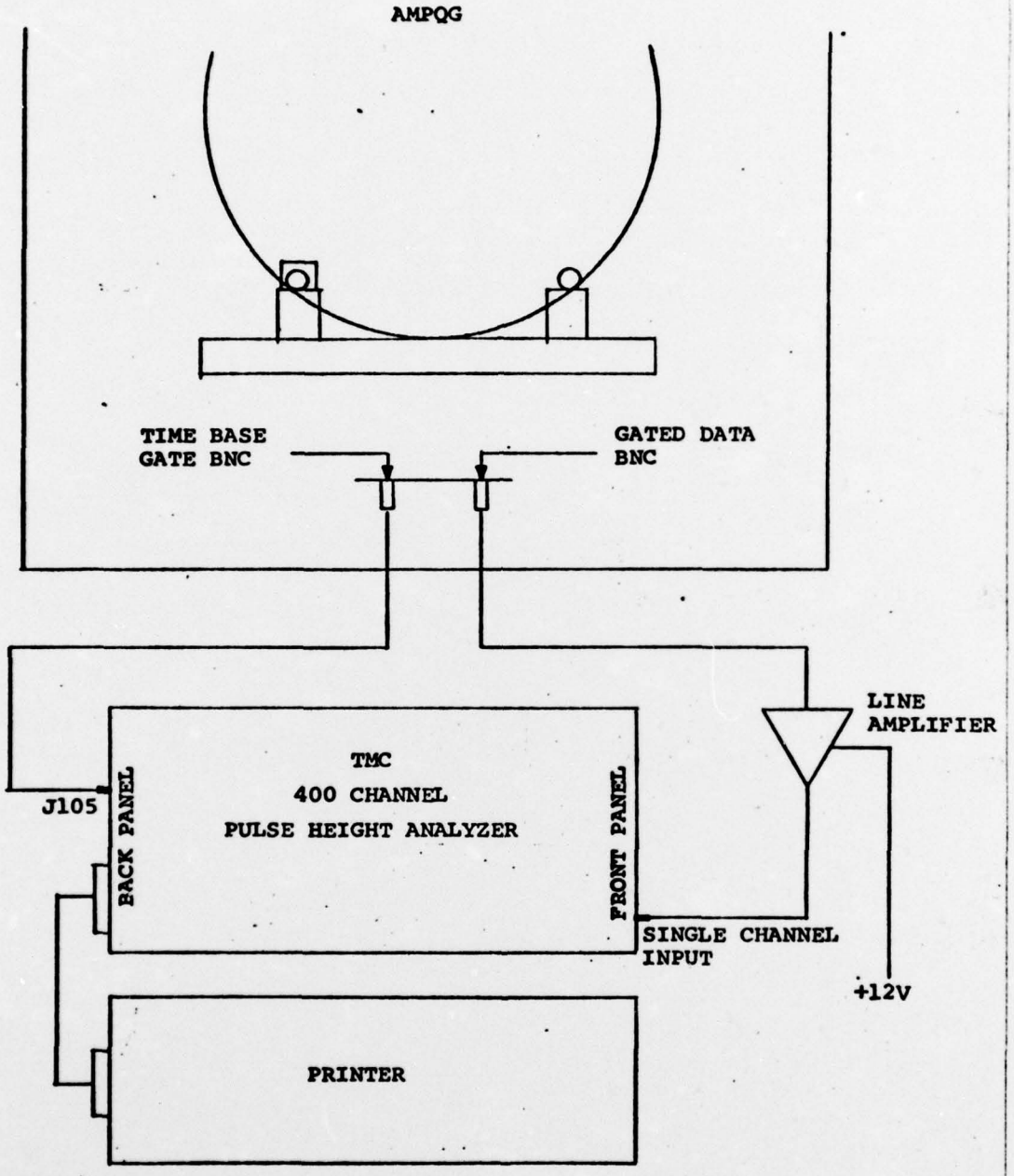
CALIBRATED CARTRIDGES TEST RESULTS

FIGURE 3.1-1

K•E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



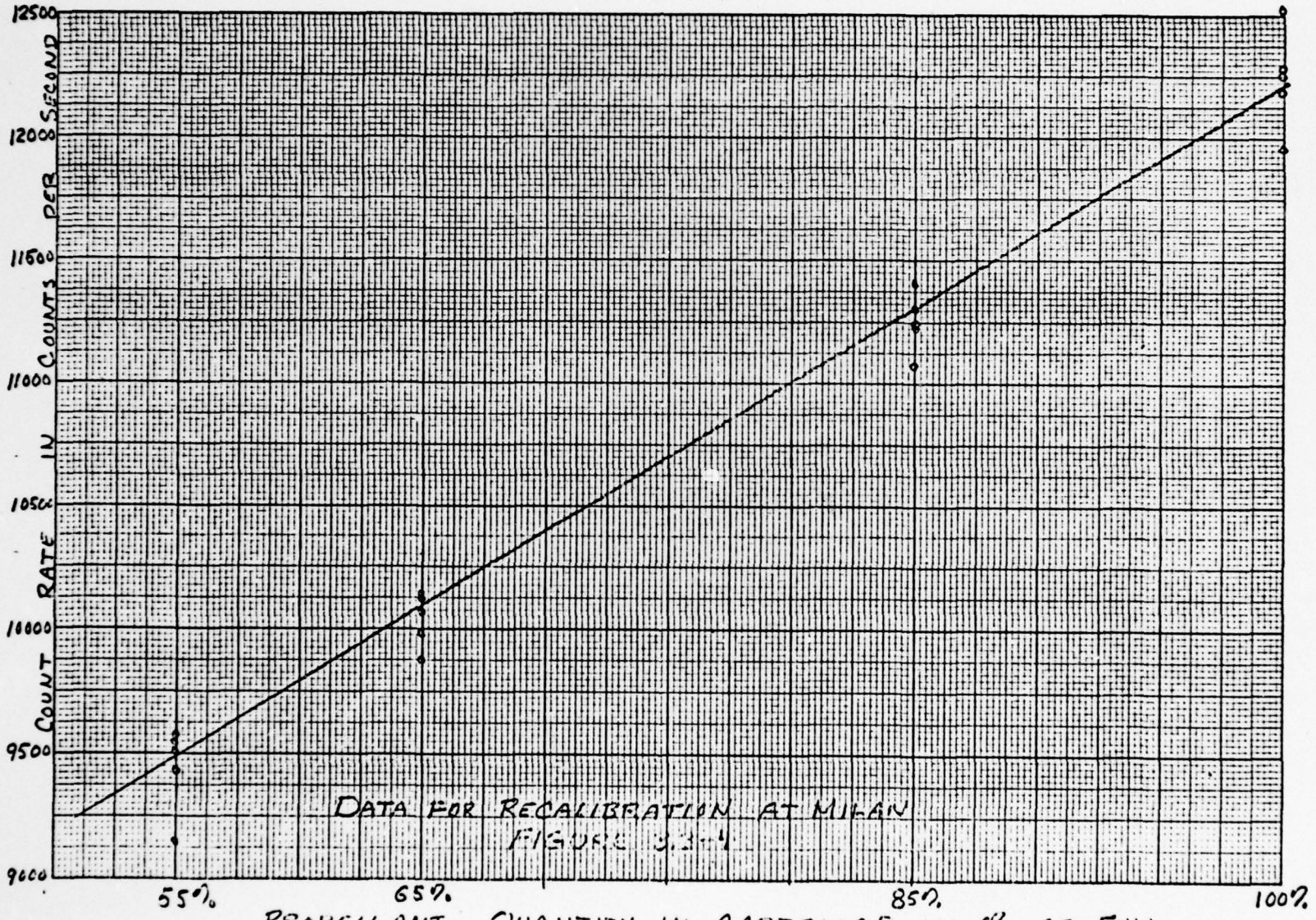
DEVELOPMENTAL CARTRIDGE TEST RESULTS
FIGURE 3.1-2



TEST SET-UP USING TMC 400 CHANNEL ANALYZER

FIGURE 3.1-3

K·E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



4.0 SYSTEM ANALYSIS AND CALIBRATION

Analysis of the AMPQG operation must take into account all possible causes of signal variations including statistical variations, electronic drift, metal thickness differences (within tolerance) of the brass powder cup and the aluminum case, positioning error and variations in propellant packing and slope. The purpose of this analysis is twofold; first to determine whether the system sensitivity is adequate and, second, to determine the optimum decision number No, which must be hard-wired into the data boards.

4.1 SYSTEM ANALYSIS

The final system sensitivity is that measured at the Milan Army Ammunition Plant during the final acceptance test. Figure 3.3-4 is a plot of the count rate data for five cartridges at each of the four fill levels. The average count rates for 55% and 100% for calculating the decision number No are:

55% - 4758
100% - 6109

The system requirements are:

Less than one accept per 10^6 cartridge case at 55% full
Less than one reject per 500 cartridge cases at 100% full

To determine the decision number N_D we calculate:

$$N_{100} - N_D = 3\sqrt{N_{100}} + E_t N_{100} \qquad (1)$$

$$N_D - N_{55} = 4.8\sqrt{N_{55}} + E_T N_{55} \qquad (2)$$

Where N_{100} and N_{55} are the number of counts accumulated in the data board for average cartridges of 100% and 55% fill levels,

$3\sqrt{N_{100}}$ is the 3 sigma statistical variation from N_{100} which will occur once per 500 samples.

$4.8\sqrt{N_{55}}$ is the 4.8 sigma statistical variation from N_{55} which will occur once per 10^6 samples.

E_T is the sum of all non-statistical errors:

E_1 - Electronic stability.

E_2 - Cartridge case positioning with respect to the sensor head.

E_3 - Propellant packing and slope within the cartridge case.

E_4 - Metal tolerances in the cartridge case assembly parts.

Electronic stability

Tests of the gage have shown the electronic errors from all sources (temperature, zero drift, etc.) to be within ±2%

$$E_1 = .02$$

Positioning errors

Repeated measurements of the same cartridge case where other errors are eliminated as far as possible (long count times to reduce statistical error, etc.) show that the positioning of the cartridge contributes less than 2% error.

$$E_2 = .02$$

Propellant packing and slope error

The errors caused by differences in propellant packing and slope of the surface were difficult to assess and nearly impossible to test. The original estimate of ±1.5% seemed to be sufficient as far as could be determined.

$$E_3 = .015$$

Cartridge Metal tolerance error

Tests of cartridge cases with maximum and minimum thicknesses showed that the count rate varied 5% from the minimum to the maximum, or ±2.5% about the mean value. Several out of tolerance cases were found, however all the powder cups (which had the largest effect) which were out of tolerance were too thick -- which is an error on the safe side, as it would cause rejects if anything.

$$E_4 = \pm.025$$

All of the error sources discussed are independent. Therefore the total error is the root-sum square of the individual errors:

$$E_T^2 = E_1^2 + E_2^2 + E_3^2 + E_4^2 \qquad (3)$$

$$E_T = (.02^2 + .02^2 + .015^2 + .025^2)^{\frac{1}{2}} = .041$$

Substituting the values of E_T, N_{100} and N_{55} into equations (1) and (2)

$$N_D(100) = 6109 - 3\sqrt{6109} - .041(6109) = 5624$$

$$N_D(55) = 4758 + 4.8\sqrt{4758} + .041(4758) = 5284$$

the decision number can be set anywhere between these two numbers. The value wired into the data board was:

$$N_D = 5500$$

4.2 SYSTEM CALIBRATION

Calibration of all voltage levels, timing pulses, and height adjustment of the detector are covered in the calibration manual. This section discusses setting the data board to the decision number calculated above. The data board, shown in Figure 4.2-1, has a series of 21 solder posts numbered, left to right, E1 through E21 (Note E1 marked under the first post, and E21 marked under the last one at the far right). The seven posts on the left, E1 through E7, and the six on the right,

E16 through E21, each correspond to a binary number as follows:

Post Number	Binary Number*
E1	4 (2^2)
E2	2 (2^1)
E3	8 (2^3)
E4	64 (2^6)
E5	32 (2^5)
E6	128 (2^7)
E7	16 (2^4)
E16	1024 (2^{10})
E17	512 (2^9)
E18	2048 (2^{11})
E19	256 (2^8)
E20	8192 (2^{13})
E21	4096 (2^{12})

*Only even numbers can be selected, since $2^0 = 1$ is not available.

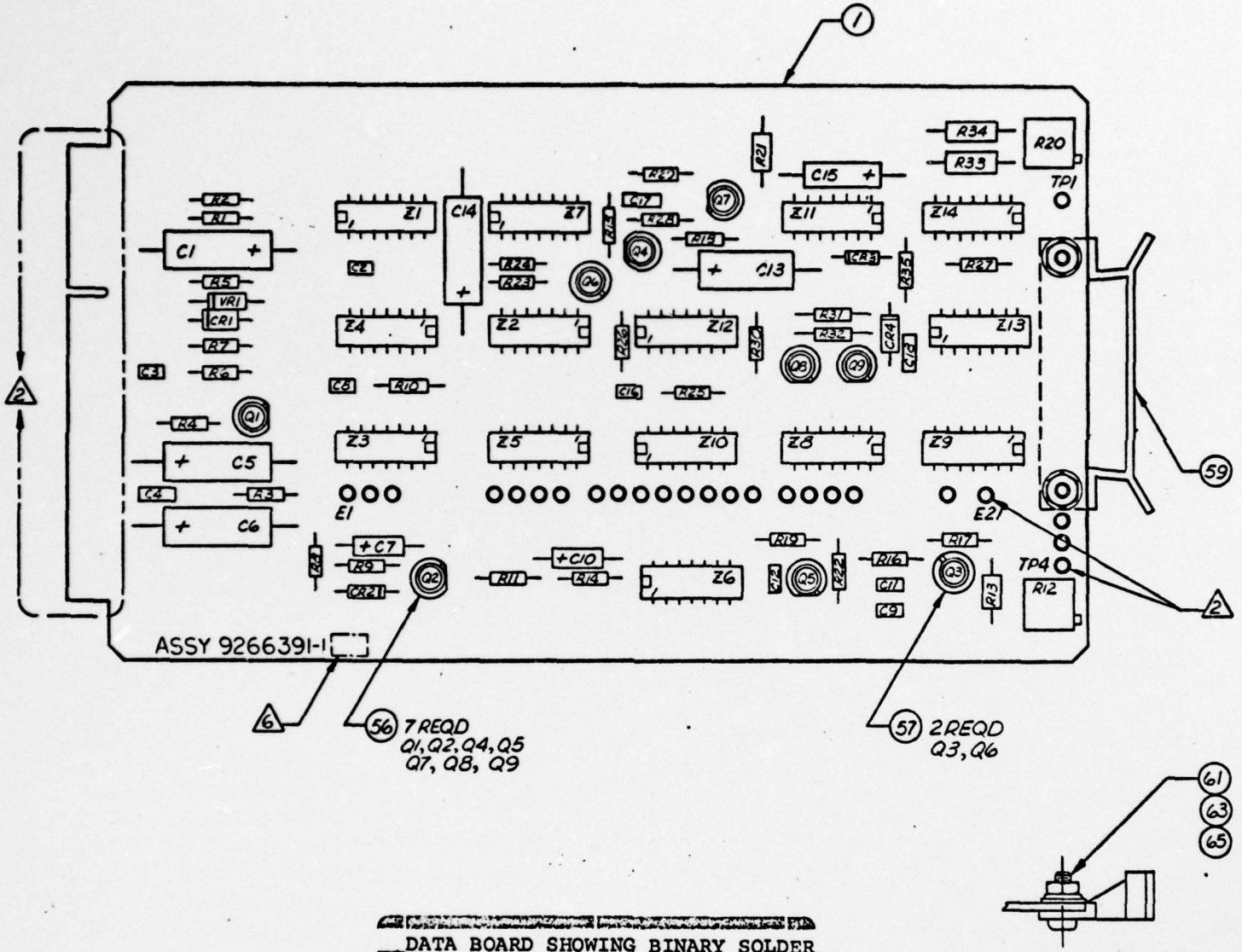
The posts in the center, E8 through E15, are inputs to the binary counter. To set a decision number into the board, first the group of binary numbers that total the desired decision number must be found (the same as converting the decision number to binary). For N_D = 5500, first subtract the largest binary number less than N_D from it (5500-4096 = 1404) and check off E21 as one of the posts to be used. Proceed in the same way, subtracting the largest binary number from the results of the last calculation (1404-1024 = 380, check off E16, 380-256 = 124, check off E19, etc.). The result is E1, E3, E4, E5, E7, E16, E19 and E21, or

5500 = 101010101111 in binary notation

Each of the posts selected must be hard-wired to one of the binary counter inputs (Posts E8 through E15) using only one counter input post for each of the binary number posts. It doesn't matter which counter input post is connected to which binary number post. For N_D5500, the wiring might be:

E1 to E8
E3 to E9
E4 to E10
E5 to E11
E7 to E12
E16 to E13
E19 to E14
E21 to E15

Some binary numbers might require more than eight counter input posts. For instance, 6142 and 4096 each require 11 non-zero binary numbers. In these cases, adding two to either number results in numbers that use only one or two binary posts. There is always a number within ±6 that can be wired with eight posts.



DATA BOARD SHOWING BINARY SOLDER POSTS

FIGURE 4.2-1

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 RESULTS OF FINAL ACCEPTANCE TESTS

The data from the final acceptance test at Milan, Tennessee were sent to Picatinny Arsenal for analysis. The results are not available at this time. A plot of this data (using data from 120 cartridges at each fill level) is shown in Figure 5.1-1. This plot gives a pictorial view of the gage operation. This data indicates that the gage does meet the requirements of:

1. Accept not more than one in one million at 55% full.
2. Reject not more than one in five hundred at 100% full.

These requirements were directed by Picatinny Arsenal after statistical analysis of the demonstration test data.

5.2 MECHANICAL PROBLEMS

While the personnel at Milan Army Ammunition Plant who assisted with the acceptance tests were satisfied that the gage would accept or reject the cartridges properly, they were apprehensive from the start concerning the mechanical durability of the gage. Their misgivings were born out by the mechanical problems that ensued. Even after repairs and modifications at Milan and in California, the gage continued periodically to jam and

stop operating. Most, perhaps all, of these problems could be eliminated for short term operation by redesign of the cartridge pick-up and eject mechanisms. However, a more fundamental problem exists. The rapid start-stop motions of the carrousel and sensor mounting bar cause heavy loads on the drive mechanisms. The gage started to develop slack in the carrousel drive after only a few hours operation. It appears that it's the design concept, that of indexing the entire cartridge carrying mechanism within .25 seconds, that is at fault. If the carrousel rotated smoothly with the cartridges shuttled in and out at the measure position, these heavy loads would be avoided. Alternately, the sensor could move with the cartridge carrier (rotating with the carrousel or following a linear motion). Either of these different design concepts would have avoided the basic problem with the AMPQ Gage.

5.3 RECOMMENDATIONS

The electronic and nucleonic aspects of the AMPQG were quite successful. The mechanical section was not. If an automatic inspection device is needed in the future (the 40 mm cartridge production line is presently closed down), it is recommended that the detector and electronics from the AMPQG be incorporated in a different cartridge positioning/moving device that avoids the problems encounted with the present gage.

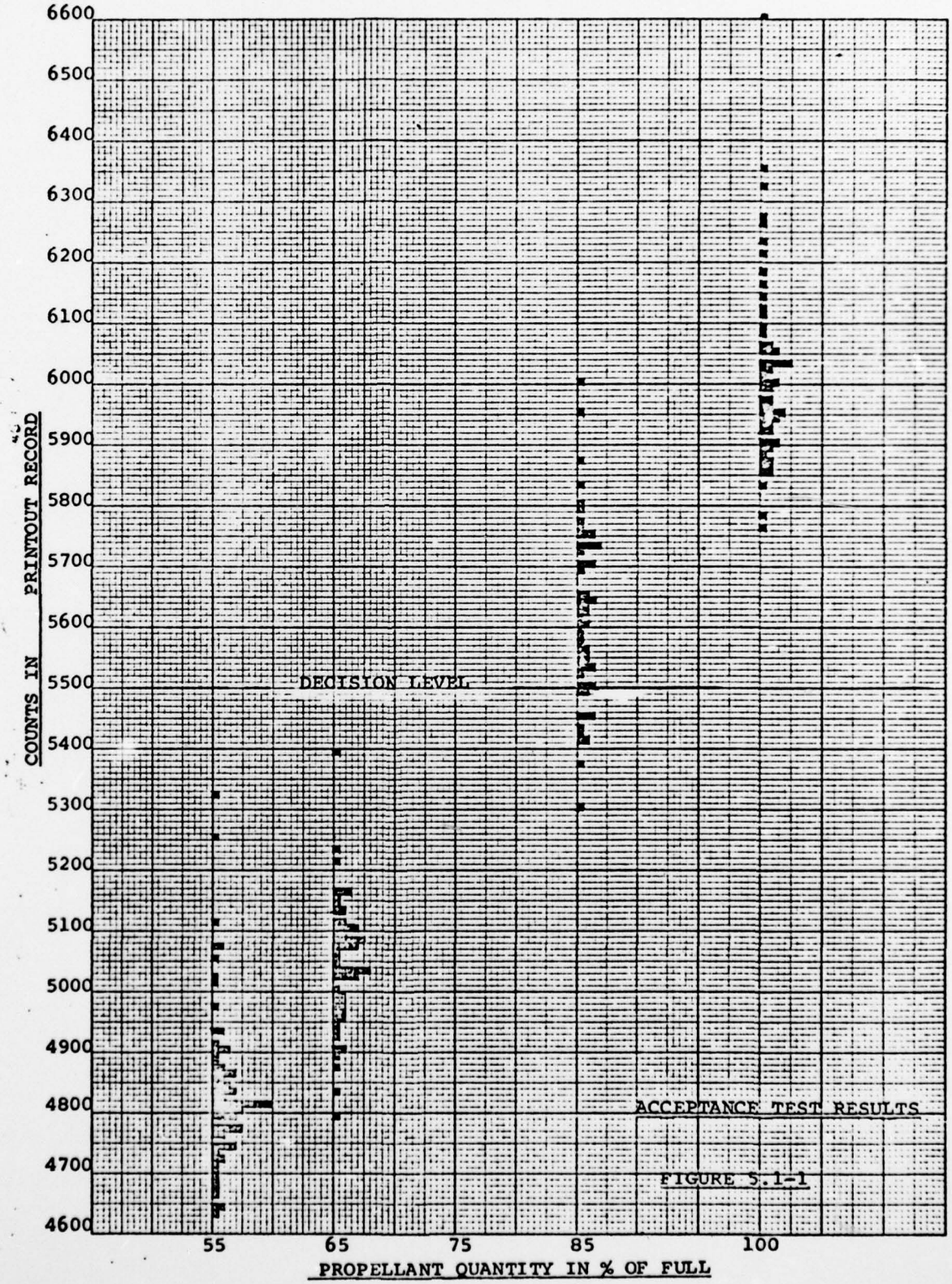

6600
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
COUNTS IN PRINTOUT RECORD
DECISION LEVEL
ACCEPTANCE TEST RESULTS
55
65
75
85
100
PROPELLANT QUANTITY IN % OF FULL

FIGURE 5.1-1

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