HALLIBURTON SERVICES

DRAWER 1431, DUNCAN, OKLAHOMA 73536-0100

GOVERNMENT REGULATIONS DEPARTMENT

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January 29, 1986

RECEIVED JAN 30 1986

RECEIVED '86 FEB -5 A10:33 U.S.N.R.C. FEE MGMT BRANCH

Mr. Jack Whitten
Nuclear Materials Safety Section
United States Nuclear Regulatory Commission
Region IV
611 Ryan Plaza Drive
Suite 1000
Arlington, Texas 76011

Re: Amendment to Radioactive Materials License Number 35-00502-03

Dear Mr. Whitten:

These amendment requests and a check in the amount of $170.00 are being submitted with no intention of delaying the completion of our referenced license renewal. Please act on this separately.

1) It is requested that the license be amended to include an Amersham standard reference source Model AM2404, 2 microcurie Americium 241 on an X240 holder. This source will be used by Electrical Research for development and research of downhole logging and detection tools.

2) Research has also requested an amendment to include a neutron generator. Our sister company Welex is proposing to transfer to Halliburton Services a Model A520, Bore Hole configured neutron generator, manufactured by Kaman Sciences Corporation. If this transfer is not consummated Halliburton will purchase a Model A-801, neutron generator, also manufactured by Kaman Sciences Corporation. The technical data for both pieces of equipment is enclosed. The technical Bulletin No. 104 "Shielding Consideration as Applied to Fast-Neutron Generator Application" will be followed in detail or even made more adequate. Copies of the

Applicant: ...
Check No. 7946322
Amount/Fee Category 170.00
Type of Fee Amendment
Date Check Rec'd 2/5/86
Received By ...

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35-00502-03 PDR

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technical and instruction manuals are enclosed for your consideration. I suggest that both models be included in the amendment.

3) It is requested that Eu-154, Eu-155 and Sb-125, as gamma calibration point standards be added to our license. No source to exceed 10 microcuries with a maximum possession limit of 10 sources each. Again Electrical Research will use the calibration point standards for research, design and development of down hole logging and detection tools. The National Bureau of Standards set SRM #4275B will purchased for this purpose.

4) Please add Gold-198, any form, with a maximum possession limit of 1 curie. This will be used for tracer sand manufacture and liquid isotope supply for our field operations.

Respectfully submitted,

Dan G. Kelly

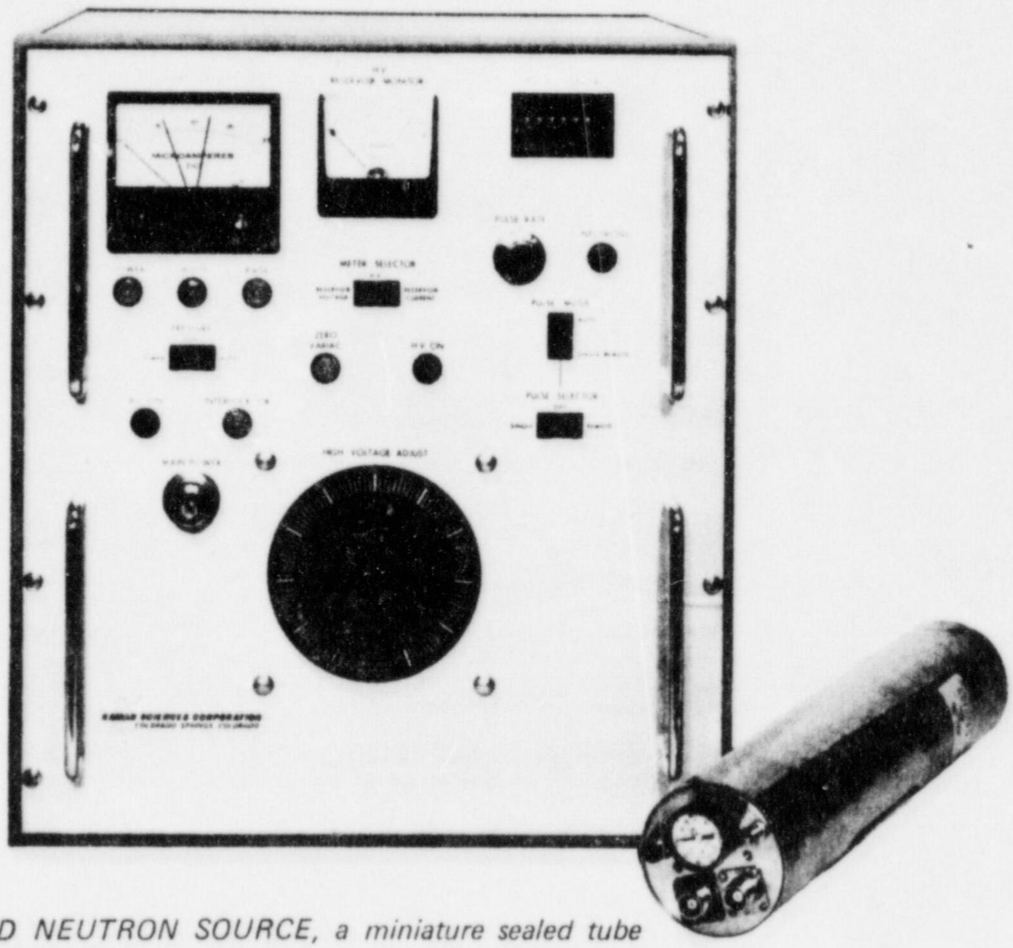
DGK/cdd
Enclosures

cc: Mr. Richard A. Leonardi, Jr.
Mr. Steve Hook

#354

TECHNICAL DATA

Neutron Generator



PULSED NEUTRON SOURCE, a miniature sealed tube accelerator that produces neutrons by the deuterium-tritium or deuterium-deuterium reaction. Neutron outputs of 10^8 neutrons per pulse are obtainable in pulses of 2 to 5 microseconds duration. Average yields of 5×10^8 neutrons per second are obtainable at pulse frequencies up to 10 Hz.

KAMAN SCIENCES CORPORATION

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KAMAN SCIENCES' Model A-801 pulsed neutron source is a miniature sealed-tubed accelerator that produces 14.3 MeV neutrons by the deuterium-tritium reaction. Tubes which utilize the deuterium-deuterium reaction to produce 2.5 MeV neutrons are available on special order. The neutron yield per pulse from the d-d tube is approximately 1% of the yield specified for the d-t tube.

Principal applications for the 801 generator include neutron transport experiments for reactors, reactor core assemblies, and subcritical assemblies; neutron shielding and moderation experiments; calibration of neutron detectors capable of fast time response, and response to high instantaneous neutron flux; activation analysis experiments concerning radionuclides having very short half-lives; and elemental determinations by means of neutron lifetime. It is also recommended for teaching and classroom demonstrations.

The system consists of two separate units: a compact, portable accelerator assembly (the basic neutron generating equipment), and a tabletop control console. The standard accelerator head is a 24 in. long, 4 in. diameter cylinder. Control console and accelerator are interconnected by 30 ft. cables to allow completely remote non-hazardous operation. The system requires a 115 V-ac, 60 Hz (50 Hz optional).

Within the stainless steel housing of the accelerator head are the sealed neutron-generating tube and step up transformer. The tube is a vacuum-tight miniature ion accelerator containing a Penning ion source, gas occlusion elements, accelerating section, and tritium-impregnated titanium target. The head is pressurized with sulfur hexafluoride, an insulating gas, to allow application of high voltage. The HV power supply is a thyratron switched capacitor discharge modulator which drives the autotransformer to provide accelerating power.

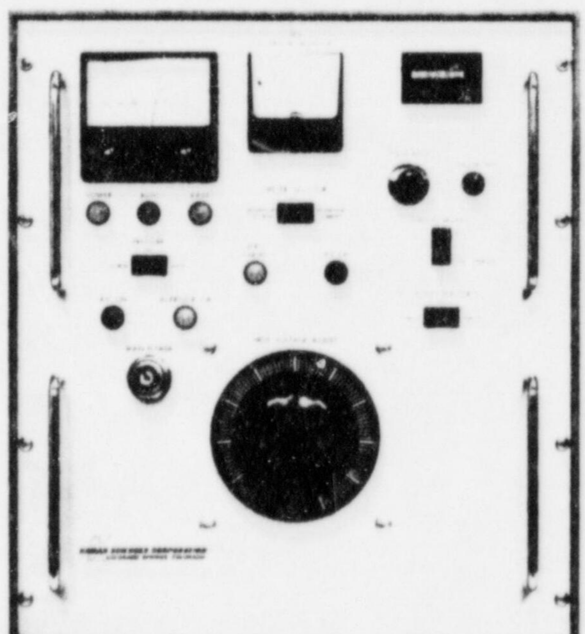
The deuterium gas pressure within the sealed tube is regulated by a servomechanism in the control console. The console also contains a dual pulse generator which supplies power to the accelerating unit. Pulse repetition frequency can be adjusted between 1 and 10 pps by controls on the console panel. In addition to internal control of the pulse rate, the console controls permit external triggering and single pulse generation.

A safety interlock circuit is built into the 801, and a connector is provided on the control console for customer-furnished interlock switches. Continuity must exist in this circuit before high voltage can be applied to the accelerator.

Accelerator tube for the 801 neutron generator is replaced in accordance with Kaman head-rebuild policy. The entire accelerator assembly is returned to the factory for tube change, inspection of other components, checkout of the complete assembly, and calibration tests.

MEASURED NEUTRON OUTPUT	$>10^8$ 14.3 MeV n/pulse
ACCELERATOR ASSEMBLY	
DIMENSIONS	4" diameter x 24" long
WEIGHT	~20 lbs
SOURCE	Penning Ion Gage
BEAM CURRENT	3 amps peak
PULSE LENGTH (nominal)	3.5 μsec at half amplitude
PULSE RATE	1-10 pulses/sec, adjustable or external trigger. Duty cycle 100% up to 5 pps; 50% at 10 pps, with maximum of 5 minutes continuous operation at 10 pps.
PULSE SHAPE	Approximately Gaussian
PULSE LIFE*	200,000
TARGET MATERIAL	Tritium in titanium
TARGET POSITION	7⅜" from lower end of accelerator assembly
ACTIVE TARGET AREA	5 cm^2 (approx. 7 curies of tritium)
CONTROL CONSOLE	
DIMENSIONS	22"H x 19"W x 18"D (nominal)
WEIGHT	~170 lbs
CONTROL CABLES	30 ft. (optionally longer)
INPUT	115 Vac, 60 Hz, 20 amps 115 Vac, 50 Hz, 20 amps (opt.)
POWER SUPPLY OUTPUT	Pulse of 5 kV peak amplitude supplied to transformer in accelerator assembly by control unit power supply

* The A-801 accelerator assembly is warranted for a maximum of one year from date of delivery, or for the specified operating time (pulse life), whichever occurs sooner.

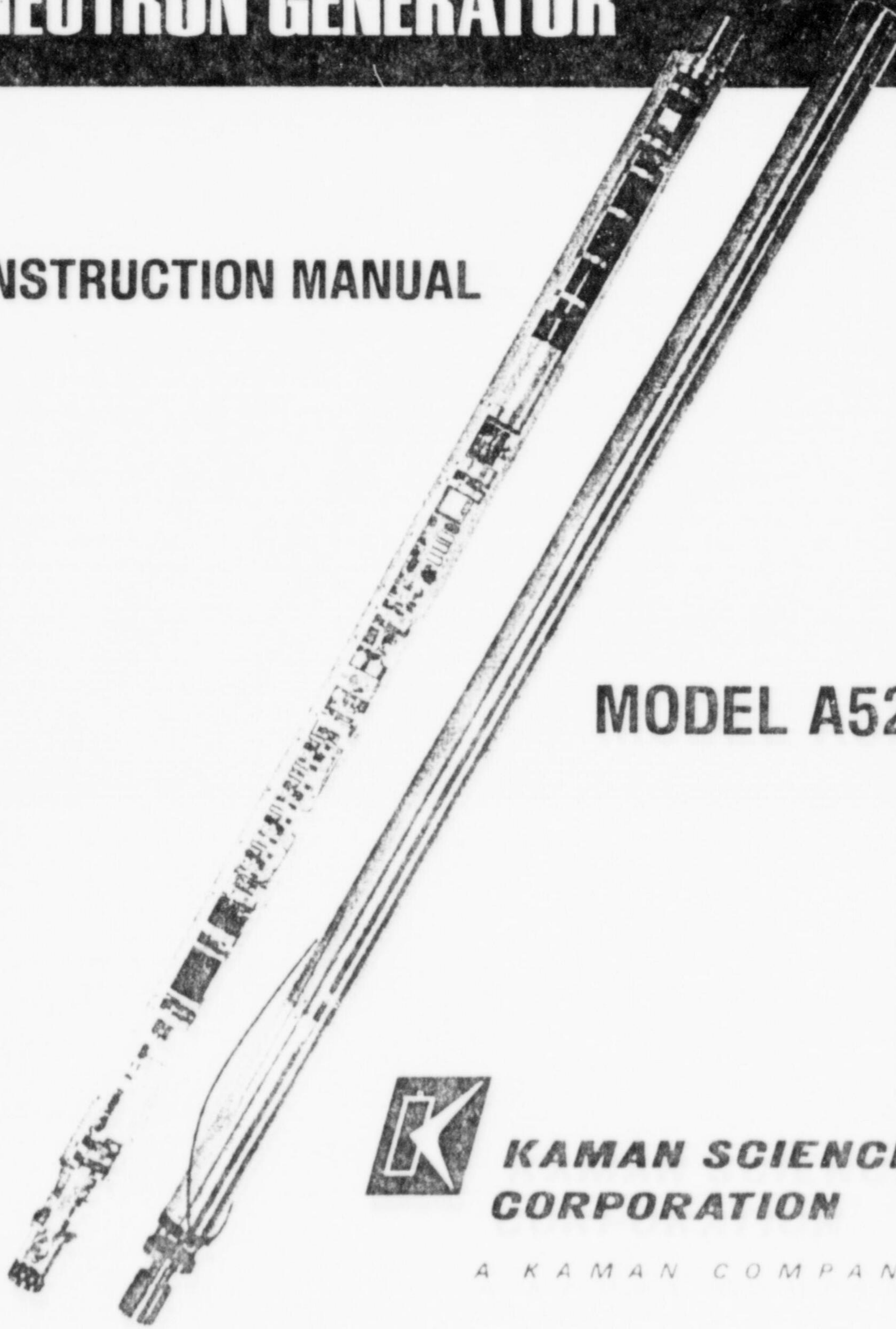


KAMAN SCIENCES CORPORATION

1500 Garden of the Gods Rd. • Tel. (303) 599-1500 • Telex 452412

a Kaman Company Mailing Address: P.O. Box 7463 • Colorado Springs, Colorado 80933

Bore Hole Configured NEUTRON GENERATOR



INSTRUCTION MANUAL

MODEL A520

KAMAN SCIENCES CORPORATION

A KAMAN COMPANY

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APPROVAL AND CHANGE RECORD

PROJECT ENGINEER — J. W. Valentine

PRODUCT MANAGER — J. Reichardt

QUALITY ASSURANCE MANAGER — D. Hair

MANUAL PREPARED BY — J. W. Valentine

CHANGE RECORD

DATE	DESCRIPTION	EFFECTIVITY

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ILLUSTRATIONS &
INTRODUCTION

LIST OF ILLUSTRATIONS

FIGURES

UNPACKING THE A-520 SYSTEM

The components of an A-520 system will be shipped from Kaman Sciences in two wooden boxes, each approximately six feet long. The cylindrical subassemblies are sealed in polyethelene bags and then supported in the boxes by foam packing material. When unpacking, remove the cover screws from the boxes and carefully take out each generator subassembly. After removing the polyethelene bags, inspect each unit visually for evidence of shipping damage. Tip the HIGH VOLTAGE/GENERATOR SECTION (the longer, heavier unit), back and forth and listen for broken or loose parts. This unit holds the neutron generator tube which contains five (5) curies of radioactive tritium gas, and a broken tube envelope presents a possible hazard.

CAUTION!!

DO NOT PRESSURIZE OR DEPRESSURIZE THE SEALED GENERATOR SECTION IF THERE IS EVIDENCE OF INTERNAL DAMAGE. DO NOT HANDLE A DAMAGED GENERATOR WITH BARE HANDS. REPACK AND RETURN THE SEALED UNIT TO KAMAN SCIENCES, AFTER NOTIFICATION OF THE KAMAN REPRESENTATIVE.

INTRODUCTION

This instruction manual provides the basic information necessary to operate and maintain the borehole configured Kaman Sciences model A-520 neutron generator. Operation and maintenance are safe, simple and straightforward when performed according to the procedures. It is emphasized, however, that operation without the appropriate state or federal license and by untrained personnel is illegal and may also be extremely hazardous. To avoid these potential hazards, it is essential that all personnel responsible for operation or maintenance be thoroughly familiar with the material in this manual.

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DEFINITIONS &
ABBREVIATIONS

1.0 DEFINITIONS AND ABBREVIATIONS

1.1 Definitions

Authorized personnel - trained operators who are thoroughly familiar with the material in this manual.

Kaman Representative - The Kaman sales representative for the area.

Card - An electronic printed circuit assembly.

Complementary Switch - An electronic switch composed of complementary (PNP/NPN) transistors.

1.2 Abbreviations

Psi - Pounds per square inch (gage)

kV - Kilovolts

Vp-p - Volts, peak-to-peak

SF_6 - Sulfur hexafluoride

H.V. - High voltage

n/sec - neutrons per second

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GEN. & SPECIFIC
SYSTEM INFO.

2.0 GENERAL AND SPECIFIC SYSTEM INFORMATION

2.1 System Description

The A-520 Neutron Generator consists of three functional pieces, the Neutron Generator Head Assembly, the High Voltage Power Supply and the Power and Control Electronics.

2.1.1 Neutron Generator Head Assembly

The Neutron Generator Head Assembly, referred to as the Generator Section, contains the neutron generator tube, item 10, as shown in Figure 2-1.

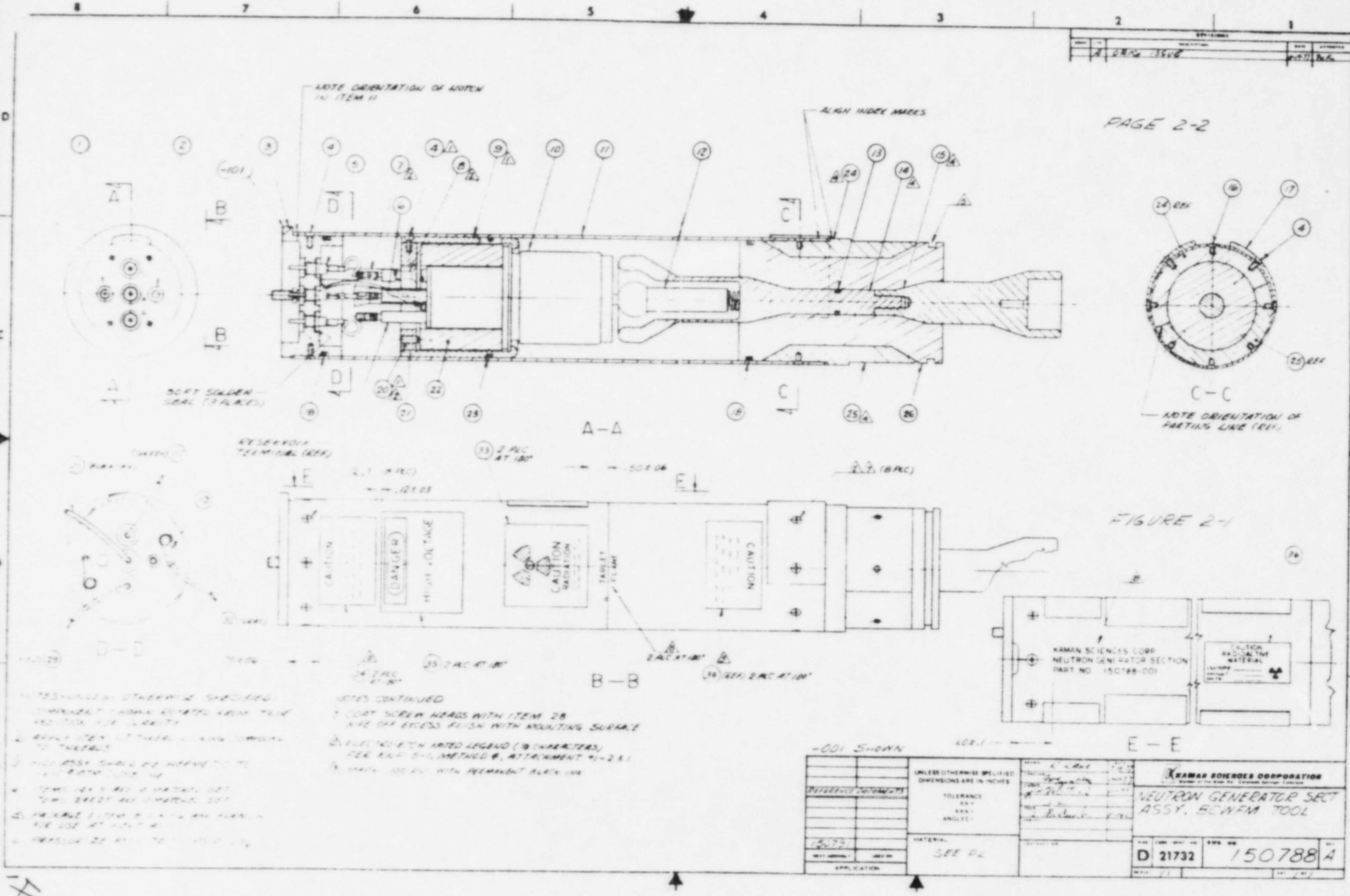
CAUTION!!

THIS IS A PRESSURIZED CONTAINER

THE UNIT IS SEALED TO PROTECT OPERATING PERSONNEL AND PRESSURIZED TO ASSURE PROPER OPERATION OF THE EQUIPMENT. UNAUTHORIZED DISASSEMBLY BY UNTRAINED PERSONNEL COULD RESULT IN INJURY AND RADIOACTIVE CONTAMINATION OF THE PERSONNEL AND THE WORK AREA. KAMAN'S WARRANTY OF THE GENERATOR SECTION IS VOID IF THE UNIT IS OPENED BY UNAUTHORIZED PERSONNEL.

Referring to the figure, the neutron tube's ion source elements are the Reservoir, Anode and Getter, and are connected to feedthru terminals at one end of the assembly. They are orientated as indicated by the initials, R, A and G. The target element is connected thru the current limiting resistor, item 12, to the feedthru center conductor at other end of the Generator Section.

When operating, either the reservoir or getter in the Penning ion source is heated by the replenisher current and liberates a cloud of Deuterium and Tritium gas. Then, by the action of the +1600 volt anode potential and the magnetic field created by the cylindrical magnet, gas



PAGE 2-2
NOTE ORIENTATION OF NOTCH IN ITEM 11
ALIGN INDEX MARKS
SOFT SOLDER SEAL (3 PLACES)
A–A
C–C
NOTE ORIENTATION OF PARTING LINE (REF)
RESERVOIR TERMINAL (REF)
D–D
B–B
FIGURE 2-1
CAUTION
DANGER
HIGH VOLTAGE
CAUTION RADIATION
TARGET PLANE
KAMAN SCIENCES CORP
NEUTRON GENERATOR SECTION
PART NO. 150788-001
CAUTION RADIOACTIVE MATERIAL
E–E
-001 SHOWN
NOTES CONTINUED
7. COAT SCREW HEADS WITH ITEM 28. WIPE OFF EXCESS FLUSH WITH MOUNTING SURFACE
ELECTRO ETCH NOTED LEGEND (⅛ CHARACTERS) PER KNF 5-1, METHOD 4, ATTACHMENT #1-2.8.1
REFERENCE DOCUMENTS
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCE
ANGLES
MATERIAL
SEE PL
APPLICATION
KAMAN SCIENCES CORPORATION
NEUTRON GENERATOR SECT ASSY. BCNFM TOOL
D 21732 150788 A

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molecules are converted into ions. Some of these ions are accelerated into a tritium/deuterium filled target by the -110 kV target potential, where the bombarded target emits neutrons by virtue of the D-T reaction.

2.1.2 High Voltage Power Supply

The High Voltage Power Supply consists of two subassemblies, the High Voltage Driver and the COCKCROFT-WALTON voltage multiplier. During operation and when a new system is delivered, the High Voltage Power Supply is attached to the Generator Section. (See Figure 2-2)

CAUTION!!

THIS IS A PRESSURIZED CONTAINER

DO NOT OPEN OR DECOUPLE FROM THE GENERATOR SECTION WITHOUT FIRST READING SUBSECTION 2.6.

The High Voltage Driver Circuit is an inverter, which provides a high voltage ac square wave output from the input provided by the "50" volt power supply. A +44V dc input to the Driver provides a 6 kV ac to operate the voltage multiplier. The Cockcroft-Walton voltage multiplier rectifies and multiplies the 6 kV ac from the driver to produce the 110 kV dc target voltage for the Generator Tube.

2.1.3 Power and Control Electronics

The Power and Control Electronics, referred to as the Electronics Section, is a five (5) foot long assembly which provides the power and signals to operate the Generator ion source and High Voltage Power Supply (see Figure 2-3). The unit operates to provide the following voltages, signals and timing functions: NOTE: The circuits of this system are protected by U.S. Patents.

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ORIG ISSUE	6-1-77	[illegible]

PAGE 2-4

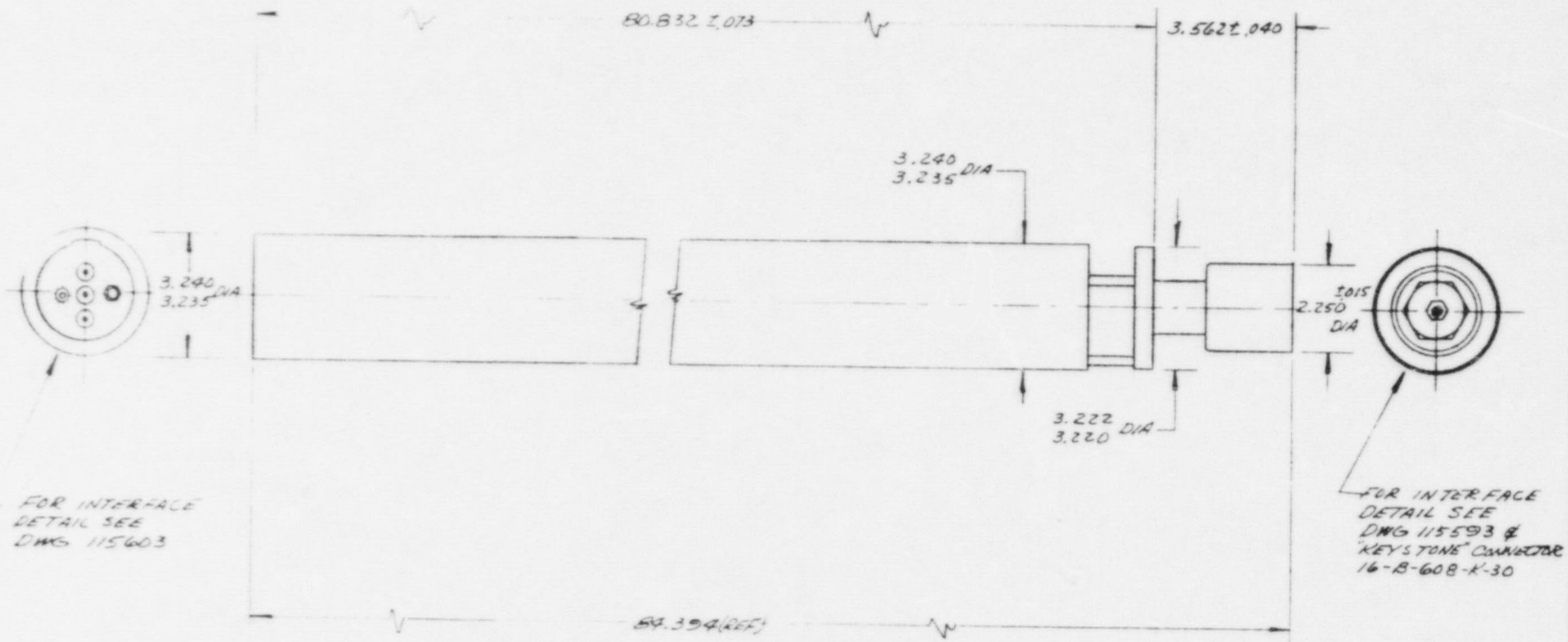

FIGURE 2-2

(S 22331)

INTERPRET THIS DRAWING PER ANSI Y-14

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCE
XX ± N/A
XXX ±
ANGLES ±
SURFACE ROUGHNESS √ MAX

DO NOT SCALE THIS DRAWING

MATERIAL

NEXT ASSEMBLY | USED ON
APPLICATION

KAMAN SCIENCES CORPORATION
Garden of the Gods Rd. Colorado Springs, Colorado

OUTLINE DRAWING
H.V. POWER SUPPLY

SIZE C | CODE IDENT NO 21732 | DWG NO 104075 | REV A

SCALE 1/2

UNLESS OTHERWISE SPECIFIED
VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. ALL EDGES AND CORNERS .005 - .020 APPROX RAD OR CHAM. ALL FILLETS .005 - .020 APPROX RAD. SCREW THREADS PER ASA B1. PIPE THREADS PER ASA B2. SURFACE ROUGHNESS PER ANSI B46. SURFACE ROUGHNESS ON HOLES 250. ALL DIMENSIONS CORRECTED TO 68°F.

104075

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PAGE 2-5

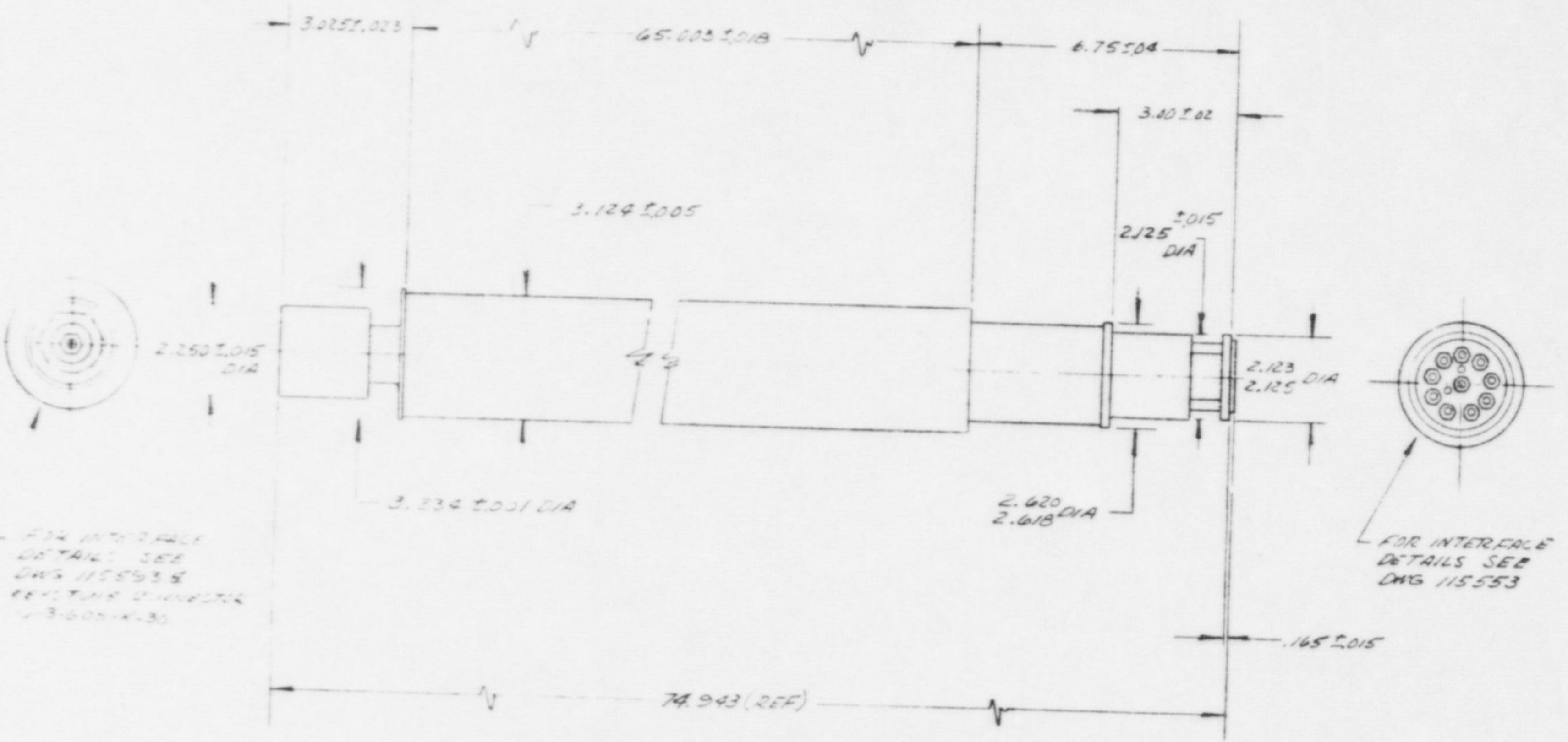

FIGURE 2-3

(Ø20075)

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ORIG ISSUE	6-77	JMK

INTERPRET THIS DRAWING PER ANSI Y-14

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCE
XX ±
XXX ± N/A
ANGLES ±
SURFACE ROUGHNESS √ MAX

DO NOT SCALE THIS DRAWING

MATERIAL

APPLICATION

KAMAN SCIENCES CORPORATION

OUTLINE DRAWING, FLAT PACK DESIGN (ELECTRONICS)

SIZE C | CODE IDENT NO 21732 | DWG NO 104074 | REV A

SCALE 1/2 | SHT 1 OF 1

104074

UNLESS OTHERWISE SPECIFIED
VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. ALL EDGES AND CORNERS .005 - .020 (APPROX RAD OR CHAMF) - ALL FILLETS .005 - .020 (APPROX RAD) - SCREW THREADS PER ASA B1.1 - PIPE THREADS PER ASA B2.1 - SURFACE ROUGHNESS PER ANSI B46.1 - SURFACE ROUGHNESS ON HOLES 250/ MAX - ALL DIMENSIONS CORRECTED TO 68°F ±2°

a. +1600 volt pulses required to power the neutron generator tube ion source.

b. A controlled "+50" V dc required as the input to the 110 kV neutron generator tube target supply.

c. A controlled replenisher current which regulates the neutron generator tube gas pressure.

d. "Sync" pulses coinciding with the start of each neutron pulse, and "Background" pulses for thermal neutron decay operation. (Low dc voltages such as +5, +12, -12 are also available to power ancillary equipment.)

e. The ELECTRONIC SECTION safeguards the operator and the neutron generator system by the use of Time Delays and Interlocks. (Refer to Section 3.)

2.1.3.1 Power Inverter

The power supply for the entire neutron generator system, including the HIGH VOLTACE SECTION, is housed in the ELECTRONICS SECTION. It consists of a +265V dc - 200V p-p ac power inverter. All other power supply voltages are derived from the well regulated 200V p-p ac output. (Refer to drawing KSC-130607, Appendix B). The circuit operates by regulating the dc input to the inverter circuit at +245V $\pm$1V. This voltage then controls the 200V p-p ac output.

2.1.3.2 Control and System Logic Power Source

The voltage regulator circuits for the control and system logic power supplies are mounted on circuit board #4 (see KSC-130608, Appendix B). The input power to the voltage regulators come from step down transformers which are connected to the 200V p-p supply. The power supply output lines are each fused for 0.3 amp.

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2.1.3.3 Oscillator/Cable Driver

Pulse width and pulse repetition rate of the system's neutron output originate from the Oscillator and Initial Cable Driver, Circuit Board #1. (See drawing 130605, Appendix B). The output frequency of the crystal clock is selectively divided by 1, 2, 20 or 200 to determine the system pulse repetition rate. An Initial and a Final pulse are generated to initiate and terminate each neutron pulse, thus determining pulse width. The circuit also shapes and amplifies the initial pulse for the user's sync applications.

2.1.3.4 50 Volt Build-Up/Regulator

The "50" volt power supply circuit is mounted on circuit board #5 (KSC-130611, Appendix B). When activated by the STANDBY DECODE level, the power supply output climbs slowly (time constant, 5.7 minutes) to 44 volts, when fully loaded. With this input the HIGH VOLTAGE SECTION will develop 110 kV and supply a generator tube beam current of 100 microampere maximum. In the event that the generator tube does not draw the rated current, the "50" V supply output drops to 40 volts, thus preventing the output of the HIGH VOLTAGE SECTION from exceeding the 110 kV and possibly reducing the generator tube life.

The "50" volt power supply has one additional feature. The 1600 volt ion source voltage is applied to the generator in the STANDBY MODE only after the "50" volt buildup has reached 15 volts (45 kV out of the HIGH VOLTAGE SECTION). This feature assures that a low acceleration voltage is applied to the tube before activation of the ion source reservoir.

2.1.3.5 1600V Complementary Switch

The 1600V complementary switch and control flip flops are located on the card assembly composed of cards 7, 8 and 7A/8A. The initial and final pulses, originating from the oscillator card, alternately turn on the HIGH SIDE switch while turning off the LOW SIDE switch, then turn on the LOW SIDE switch while turning off the HIGH SIDE switch (see KSC-130606, Appendix B). The resulting output of the assembly is a series of 1600V pulses when the system is operating in the PULSED MODE. When operating in the STANDBY MODE, the HIGH SIDE switch is continuously on while the LOW SIDE switch is off.

2.1.3.6 Decoder

The decoder circuitry, which is mounted on card #6 (KSC-130612, Appendix B), is the "receiver" end of the operator/generator communication link. Components for two decoders only are normally mounted on board #6 (there is space for three more). Decoder #1 is used to initially activate the system for operation in the STANDBY MODE. Decoder #2 may be used to switch the system to a PULSED MODE operation once a 1600V dc has been applied to the source and after 110 kV is applied to the target. The decoders are activated by application of a continuous single frequency signal to the inner shield of the triax instrument cable attached to the generator system. Decoder #1 is tuned to operate at 550 Hz while decoder #2 operates at 680 Hz. The decoder circuits are relatively immune to accidental activation or deactivation by spurious noise signals. The required operating signal, 550 Hz or 680 Hz must be applied for at least 20 seconds before the decoder output will switch states. Once

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the switching has occurred, however, a latching circuit prevents deactivation. Deactivation of the decoders occurs only when the system is powered down by the operator or automatically in the event of excessive (>200 μA) generator tube beam current.

2.1.3.7 Replenisher

The control circuits for the replenisher supply are mounted on card #10 (see drawing 130609, Appendix B). The replenisher supply is the generator tube gas pressure control and employs a feed back loop to perform its function. All other things being equal, the generator tube beam current increases as the tube gas pressure increases.

2.2 System Specifications

The following is an abridged list of system specifications which are considered potentially useful for operation and maintenance.

2.2.1 Performance Specifications

Neutron Output - 1×10^8 n/sec. minimum.

Neutron Pulse Rate - The crystal oscillator frequency (C.O.F.), which determines the pulse rates, is specified by the customer on the purchase order. The pulse rate is manually switchable to four discrete predetermined frequencies as follows:

PULSE RATE	X C.O.F.
No. 1	1.
2	0.5
3	0.05
4	0.005

Neutron Pulse Width - 15 microsecond nominal at 1 KHz pulse rate.

2.2.2 Electrical Specifications

Power Input -

Voltage	+265 Vdc
Current	
a. Idle mode	210 mA
b. Standby mode	315 mA
c. Pulsed mode (full load)	470 mA

Control Signal Inputs -

Mode Switching

a. Idle to Standby	- Frequency	550 Hz
	- Voltage/waveform,	2.2 Vpp/triangle
b. Standby to pulsed mode	- Frequency	680 Hz
	- Voltage/waveform,	2.2 Vpp/triangle

Subsystem Inputs/Outputs

Source Voltage	+1600V
Replenisher Current Range	1.5 to 4 amps dc
High Voltage Generator Output	-110K volts dc
High Voltage Generator Input	+44 Vdc
Nominal Beam Current (pulse mode)	100 μ amps ave.

2.2.3 Mechanical Specifications

Electronic Section	- Length	75 Inches
	- Diameter (max.)	3.24 Inches
	- Weight	30 lbs.
High Voltage Section including Generator	- Length	84.4 Inches
	- Diameter (max.)	3.24 Inches
	- Weight	54 lbs.

SF_6 Pressure in H.V. and Generator Sections - 100 psi

2.2.4 Environmental Specifications

- Maximum Continuous Operating Temperature $125^{\circ}C$

2.3 System Interface

The A-520 system as delivered to the customer consists of two cylinderical subassemblies, the Electronics Section and the High Voltage/Generator Section. These units are interconnected and have provisions for connections to the customer supplied detector package. Power and operator control signals are connected to the Electronics Section.

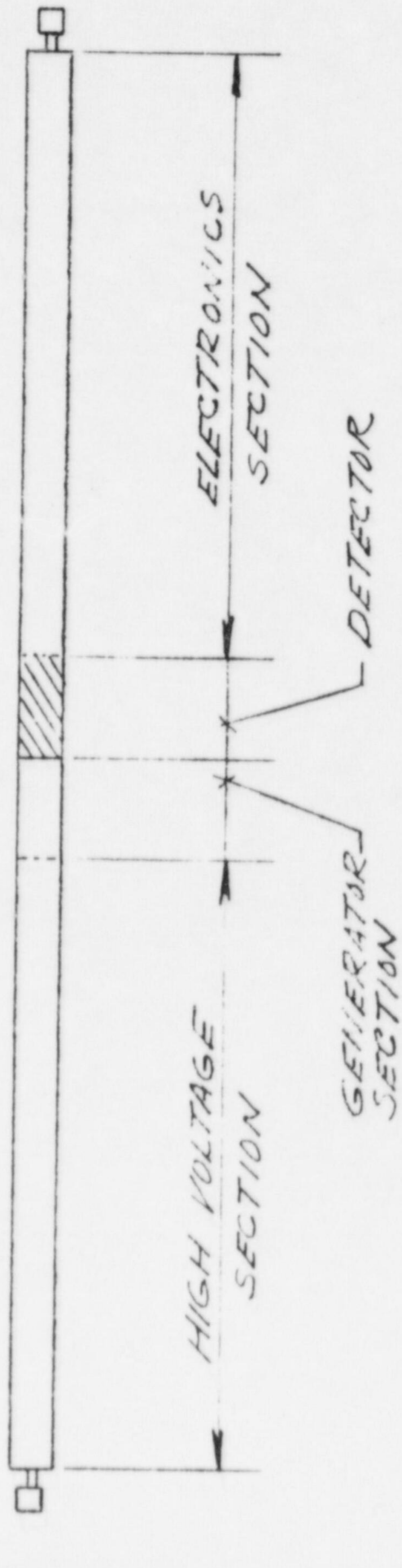
2.3.1 System/Detector Interface

During operation, the -110 kV target voltage is applied at one end of the generator tube, while the source signals are connected at the other end. When using the A-520 neutron generator system in a logging tool, the customer's detector package is usually required to be relatively close to the Generator Tube. The A-520 is therefore delivered in two sections so that the customer may insert his detector between the Generator tube and the Electronics Section, see Figure 2-4. In addition to a detector power circuit for connecting to an up-hole power source, 100 mA of dc current is available from the Electronics Section at each of the following voltages; +5V, +24V, +12V, -12V for detector use. Refer to drawing 130617 for connections.

2.3.2 System/Logging Truck Interface

The A-520 system was designed to operate using a standard triax logging cable for connecting the downhole electronics with the logging truck instrumentation. Other cable configuration are also useable, providing there are at least three conductors, of which two must be insulated from ground and from each other.

With the original A-520 cable configuration, the outer shield of the triax is ground and circuit common. The inner shield carries the primary system power supplied by



RECOMMENDED LOGGING TOOL CONFIGURATION

FIGURE 2-4

the logging truck in the form of +265V dc ±10V, 0.47 amps, at the Electronics end of the cable. Multiplexed with the power on the inner shield are the 550 Hz and 680 Hz mode switching signals which are generated by the Encoder circuit, also located in the logging truck. The center conductor of the instrument cable is used for bringing the sync pulses, which are generated in the Electronics Section, uphole for operator use. The center conductor may also be used for supplying high voltage to the customer's detector package, if desired. In addition, with minor modification, the turning on and off of the detector high voltage may be used to activate and de-activate the Replenisher supply. This feature could be used for stopping and starting the production of neutrons during operation, without shutting off the entire system and then repeating the turn-on sequence.

2.4 Unpacking and Packing the A-520 System

2.4.1 The components of an A-520 system will be shipped from Kaman Sciences in two wooden boxes, each approximately six feet long. The cylindrical subassemblies are sealed in polyethelene bags and then supported in the boxes by foam packing material. When unpacking, remove the cover screws from the boxes and carefully take out each generator subassembly. After removing the polyethelene bags, inspect each unit visually for evidence of shipping damage. Tip the HIGH VOLTAGE/GENERATOR SECTION (the longer, heavier unit), back and forth and listen for broken or loose parts. This unit holds the neutron generator tube which contains five (5) curies of radioactive tritium gas, and a broken tube envelope presents a possible hazard.

CAUTION!!

DO NOT PRESSURIZE OR DEPRESSURIZE THE SEALED GENERATOR SECTION IF THERE IS EVIDENCE OF INTERNAL DAMAGE. DO NOT HANDLE A DAMAGED GENERATOR WITH BARE HANDS. REPACK AND RETURN THE SEALED UNIT TO KAMAN SCIENCES, AFTER NOTIFICATION OF THE KAMAN REPRESENTATIVE.

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2.4.2 Spare Neutron Generator Heads or refurbished heads are shipped from Kaman in shorter (2 foot long) wooden boxes. Unpack and inspect these units in the same manner as the complete High Voltage/Generator Section.

NOTE

KAMAN SCIENCES RECOMMENDS THAT THE WOODEN BOXES BE REUSED BY THE CUSTOMER WHEN RETURNING EQUIPMENT TO KAMAN FOR SERVICE, OR WHEN SHIPPING EQUIPMENT TO THE FIELD FOR LOGGING USE. IT SHOULD ALSO BE NOTED THAT KAMAN SHIPS ALL SF_6 FILLED SYSTEMS PRESSURIZED WITH LESS THAN 5 PSI OF DRY CLEAN SF_6. WHEN RESHIPPING TO THE FIELD, OR FOR REPAIR, HIGHER PRESSURES REQUIRED DURING OPERATION SHOULD BE REDUCED TO THIS LEVEL.

2.5 System Set-Up and Operation

CAUTION!!

ADEQUATE RADIATION SHIELDING OF PERSONNEL IS REQUIRED WHEN OPERATING THE A-520 NEUTRON GENERATOR SYSTEM. REFER TO TECHNICAL BULLETIN NO. 104 IN APPENDIX 2 FOR SHIELDING CONSIDERATIONS. IN ALL CASES, HOWEVER, THE APPROPRIATE STATE OR FEDERAL LICENSE GOVERNS THE USE OF THE GENERATOR.

For new A-520 systems or newly repaired systems follow the Initial Set-up and Adjustment Procedures outlined in subsections 3.2, 4.2 and 5.2 before proceeding with the following instructions. Otherwise, proceed as follows:

2.5.1 Pressurize the High Voltage Section and the Generator Section per the instructions in Section 2.6. DO NOT ATTEMPT TO OPERATE THIS EQUIPMENT UNPRESSURIZED. ANY ATTEMPT TO DO SO WILL VOID KAMAN'S WARRANTY. Next, connect the Electronics and High Voltage/Generator Sections of the A-520 to each other and to the Cable Box and Encoder circuit as shown in Figure 2-5.

2.5.2 Turn on the 265 V dc supply and allow the voltage to come up gradually (approximately 3 sec.) The Idle current will stabilize at 210 mA and the system is now operating in the Idle mode.
NO NEUTRONS ARE BEING PRODUCED AT THIS TIME.

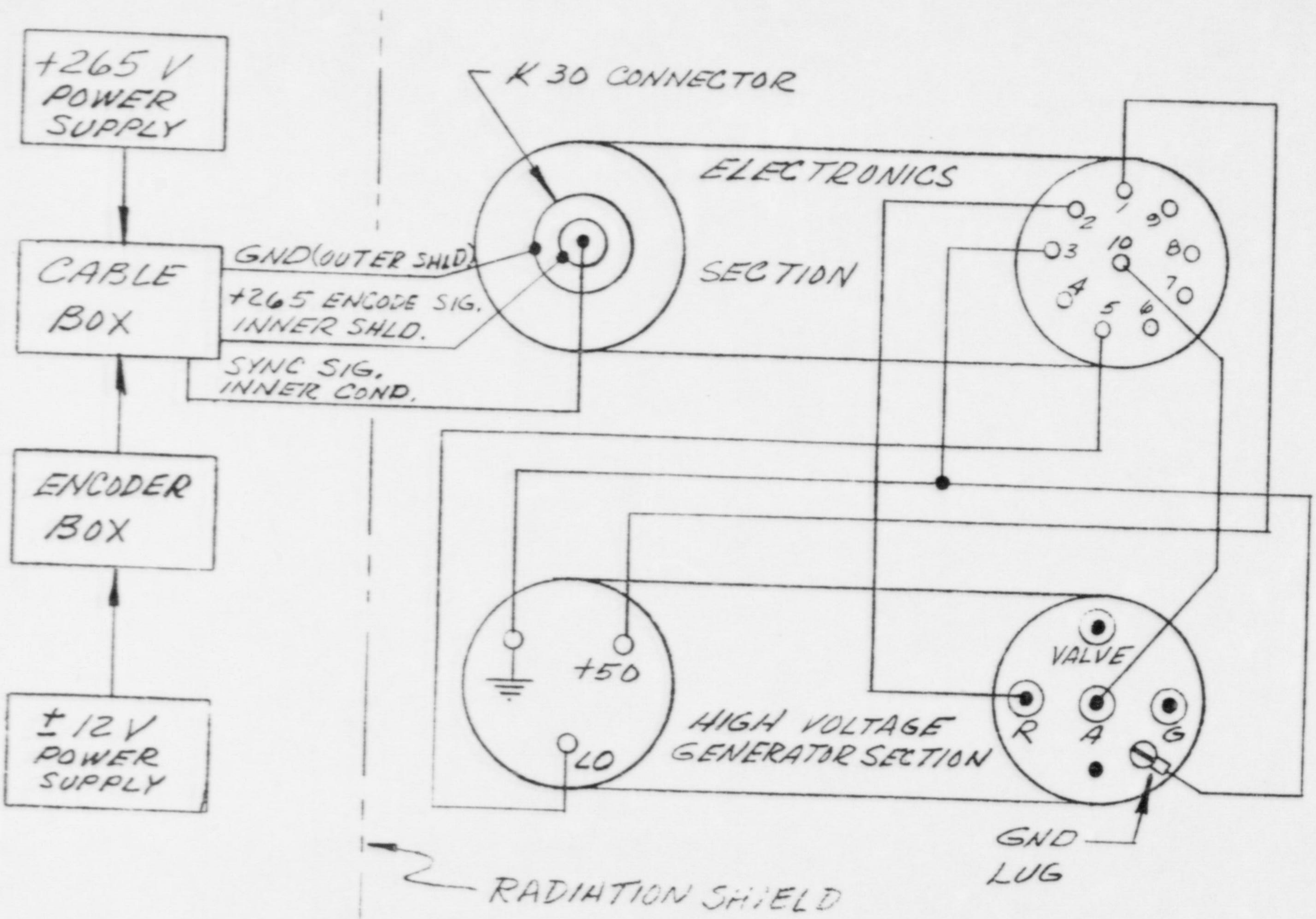
2.5.3 Set the "ON-OFF" switch on the ENCODER Box T2 to "ON". Set the MODE switch to CONT. (Standby).

2.5.4 Press the ENCODE/LOG switch on the CABLE BOX T3, and hold down for 30 seconds. After a minute or so, the 1600 V dc source voltage will come on, and this will be indicated by the 265 volt current shifting upward from 220 mA to 280 mA. After another 5 minutes or so, the High Voltage supply output will reach 110 kV, which will be indicated by a stabilized 315 mA reading of the +265V dc current. The system is now operating in the Standby mode.

CAUTION!!

THE A-520 SYSTEM IS NOW PRODUCING NEUTRONS AT THE RATE OF 5×10^6 n/sec OR LESS. ALTHOUGH THIS IS A RELATIVELY LOW RATE, OVER EXPOSURE IS STILL POTENTIALLY LETHAL.

2.5.5 Set the MODE switch on T2 to the Pulsed position and again depress the T3 ENCODE/LOG switch for 30 seconds. The system will not switch to the Pulsed mode of operation, and the +265V operating current will increase to 470 mA.



WIRING DIAGRAM, SYSTEM OPERATION
FIGURE 2-5

CAUTION!!

THE A-520 SYSTEM IS NOW PRODUCING PULSES OF NEUTRONS AT AN AVERAGE RATE OF 1×10^8 n/sec. OR GREATER.

2.5.6 To stop neutron generation turn off the +265 V dc supply. Due to built-in latching circuits, reactivation of the generator can be accomplished only by repeating steps 2.5.2 thru 2.5.5.

2.6 System Maintenance and Repair

2.6.1 For maintenance instructions, refer to the Maintenance Subsections for the individual A-520 subassemblies in this manual. See 3.3, 4.3 and 5.3.

2.6.2 Repair service for any component of the A-520 system is available at Kaman Sciences. However, repair of the Electronics and the High Voltage Sections may be accomplished in the field at the customer's option.

2.6.3 No special precautions are necessary for field repair of the Electronics Section, and a competent electronic technician with some system experience can perform any necessary field repair. A troubleshooting guide is provided in Section 3.4 of this manual to aid in the location of possible problem areas.

2.6.4 The High Voltage Section may also be repaired in the field. However, the need to observe the following precautions can not be over stressed.

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CAUTION!!

THE HIGH VOLTAGE SECTION IS DESIGNED AS A PRESSURE VESSEL AND CONTAINS SULFUR HEXAFLUORIDE (SF_6) GAS AT PRESSURES UP TO 100 PSI.

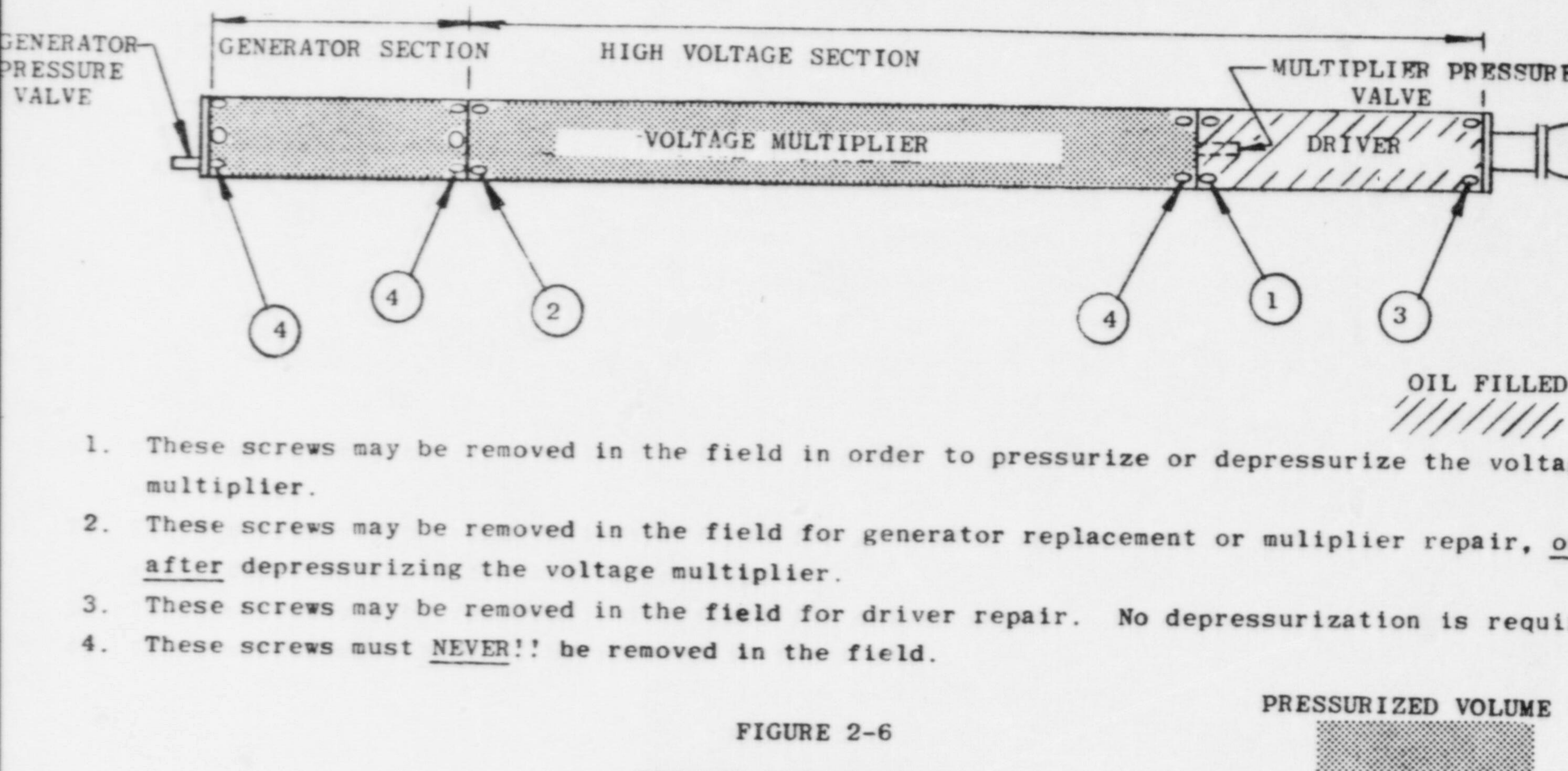
2.6.4.1 Depressurizing the High Voltage/Generator Section

It is important to remember that this assembly contains two separate pressurized volumes in addition to one filled with oil (not pressurized), see Figure 2-6. Before depressurizing ,remove the screws noted with the (1) on Figure 2-6. Then slide the Driver and Voltage Multiplier apart, and release the SF_6 thru the Multiplier Pressure valve and thru the Generator Pressure valve. Bleed the pressure down to approximately 5 psi above atmospheric in both sections. Only then should the Generator and Multiplier be separated.

2.6.4.2 Pressurizing the High Voltage/Generator Section

For systems depressurized for shipment from the factory, or to the field, repressurize by reversing the procedures of 2.6.3.1. Fill both the Generator and the Multiplier with a 100 $^{+20}_{-10}$ psi of dry, clean SF_6 gas. Exhaust some SF_6 thru the pressure hose before connecting it to the Generator or Multiplying sections.

If the Voltage Multiplying assembly has been opened to the atmosphere for the purpose of exchanging the Generator Section, but the cleanliness of the inside of the Multiplier tube has not been compromised, proceed as follows: Reassemble the Generator Section with the Voltage Multiplier to complete the seal. Next, connect a good mechanical vacuum pump and cold trap along with the source of pressurized SF_6 to the Multiplier using high pressure hose and valves. Evacuate the multiplier volume to



1. These screws may be removed in the field in order to pressurize or depressurize the voltage multiplier.
2. These screws may be removed in the field for generator replacement or muliplier repair, <u>only after</u> depressurizing the voltage multiplier.
3. These screws may be removed in the field for driver repair. No depressurization is required.
4. These screws must <u>NEVER</u>!! be removed in the field.

FIGURE 2-6

PRESSURIZATION DIAGRAM
HIGH VOLTAGE/GENERATOR SECTION
A-520 NEUTRON GENERATOR

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100 microns or less and then backfill with the dry SF_6 to 100 $^{+20}_{-10}$ psi. Replace the Driver assembly as the final step.

If the Voltage Multiplying assembly has been opened for repair such as the replacement of a diode, it will first be necessary to clean the inside walls of the Housing and the electronic components before reassembly. Dip bathe the parts in Freon TF and scrub if necessary to remove all traces of oil and dust. (The technician must wear rubber gloves during this operation.) After cleaning, coat "O" rings with a small amount of Dow Corning 11 compound for lubrication, and then re-assemble the unit. After cleaning, proceed as in the foregoing paragraph.

2.6.4.3 Driver Oil Replacement

When repairing the Driver assembly, first remove the K-30 connector housing and than lift out the three terminal connector. Unscrew the drain plug which is positioned beneath the connector plate and pour out the transformer oil into a clean vessel. Seal the vessel to prevent the oil from absorbing moisture. Next, remove the screws noted with a (3) in Figure 2-6, and slide off the aluminum cover.

After performing the necessary repairs, reverse the above procedure to reassemble. The transformer oil should fill 90% of the volume, leaving a 10% void which should be backfilled with dry nitrogen or SF_6. Before backfilling the void with the dry gas, connect a mechanical vacuum pump to the Driver, thru the drain hole, and pump for 30-45 minutes. This procedure will tend to remove moisture which may be entrapped in the system.

2.7 Troubleshooting

Troubleshooting of the A-520 Neutron Generator should be performed on a module basis. Refer to Sections 3.4, 4.4 and 5.4.

ELECTRONICS
SECTION

3.0 ELECTRONICS SECTION

CAUTION!!

DO NOT ATTEMPT TO OPERATE THE ELECTRONIC SECTION IN AN UNSHIELDED SPACE UNLESS THE GENERATOR AND HIGH VOLTAGE SECTION HAVE FIRST BEEN DISCONNECTED.

3.1 Unit/System Interface

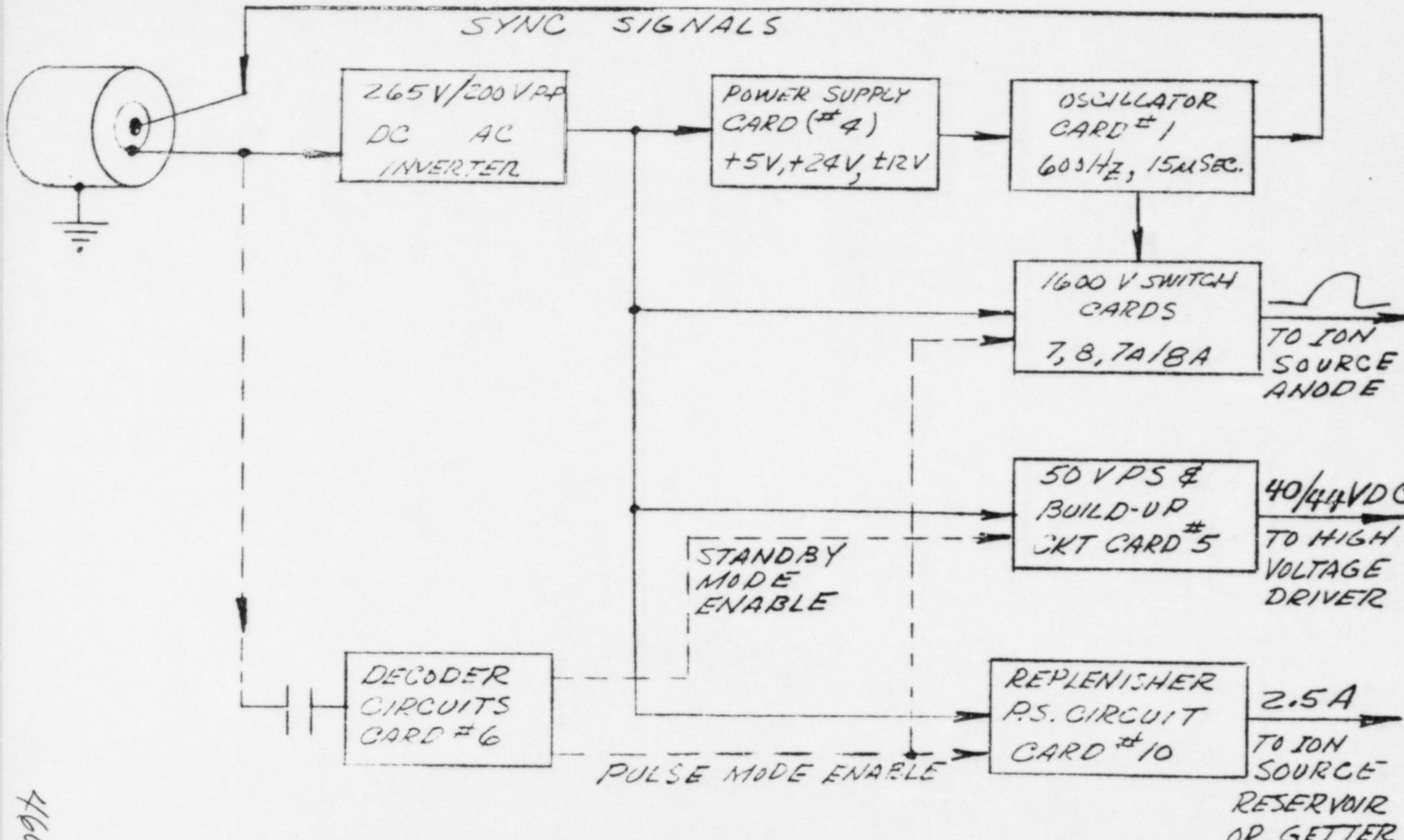
The electronic section of the A-520 interfaces with other elements of the system as indicated by the block diagram, Figure 3-1 (refer to drawing 130617 appendix B for interconnecting terminal identification.)

3.1.1 +1600V Anode Supply

The output pulses from the +1600V switch (terminal #10) are connected to the ion source anode of the generator tube (the center terminal as shown on drawing 150788, Figure 2-1.) When the tube reservoir and/or getter elements are activated, D^2 ions are formed during the period of the +1600 volt pulse.

3.1.2 Replenisher Current Supply

The output of the replenisher supply (Terminal #2) is connected to the Reservoir and/or Getter element of the generator tube (the two outside terminals as shown on drawing 150788 Figure 2-1.) When approximately two amps dc current are supplied to one or both elements, D^2 gas is released in the tube. The Reservoir/Getter current from the Replenisher Supply is automatically controlled by the neutron generator tube beam current. Since the tube beam current flows thru the 110 kV high voltage supply, the low voltage side of the supply is connected to ground thru the input of the Replenisher Control circuit (Terminal #5).



BLOCK DIAGRAM - ELECTRONIC SECTION
MODEL A-520 NEUTRON GENERATOR

FIGURE 3-1

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3.1.3 "50" Volt Power Supply

The output of the "50" Volt Power Supply and Build-up Circuit (Terminal #1) is connected to the High Voltage Driver (see Drawing 130616, appendix B.) The "50" volts is the input to the 110 kV high voltage supply.

3.1.4 +265 V dc System Power Input

The entire system is powered by +265V dc which is connected to the outer conductor of the K-30 connector.

3.1.5 Mode Switching Tone Encoder Signals

The tone encoder signals used to switch from Idle to Standby mode and then from Standby to Pulse operate mode are multiplexed on the +265V dc line and connect thru the outer conductor of the K-30 Connector.

3.1.6 Sync Signals

The neutron pulse sync signals and the background sync pulse developed by the electronics section are connected to the center pin of the K-30 connector.

3.2 Initial Set-up and Adjustment

CAUTION!!!

WHEN OPERATING, LETHAL VOLTAGES ARE PRESENT ON THE FOLLOWING EXPOSED TEST POINTS AND TERMINALS OF THIS EQUIPMENT: BJ1-10, TB1-C 7-2, 7-3, 7-4, 2-7, 2-14, 7-16, 8-13, 8-14, 8-15, 8-16.

The purpose of this sub-section is to provide the operator with procedures and methods to perform the initial set-up of new equipment and an adjustment of used equipment after maintenance repair.

3.2.1 Connect the Electronics Section to the Test Boxes T1, T2, and T3, and connect the power supplies and Oscilloscope to the test boxes and Electronics Section as shown in Figure 3-2.

CAUTION!!!

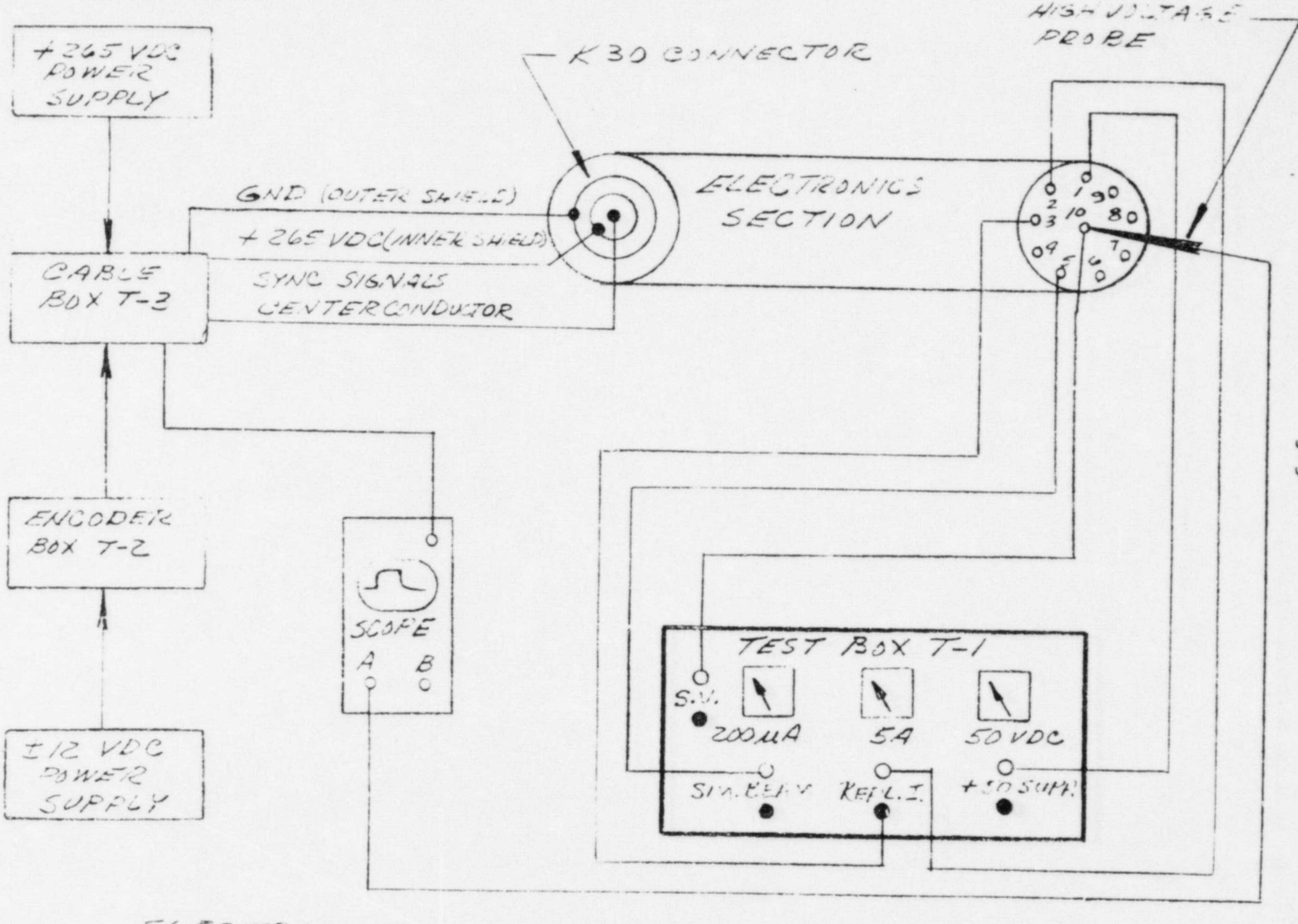
THE SOURCE VOLTAGE AT TERMINAL #10 IS +1600 VOLTS AND THE SCOPE PROBE OR AMPLIFIER INPUT MUST BE RATED FOR THAT VOLTAGE.

3.2.2 Turn on and adjust the scope for a vertical sensitivity (including probe attenuation) of 1000 V/cm. Set the sweep speed for 5 sec/cm.

3.2.3 Turn on the ±12 dc supply to activate the Encoder Box T2. Turn the T2 Box "ON" and set the MODE switch control to Standby (continuous).

3.2.4 Turn on the +265 V dc supply and allow the voltage to come up gradually (approximately 3 sec). Note that the 265V Idle current will stabilize at approximately 210 mA.

3.2.5 Set the LOAD switch on Test Box T1 to "OUT" and set the 100 microampere source switches to OFF and V. Press the ENCODE/LOG switch on the Cable Box T3, and hold it down for 30 seconds. Observe that on the Test Box T1, the 50 VOLT POWER SUPPLY TEST meter begins to rise slowly. Observe also that when the "50" volt supply output exceeds 16 volts dc, the +1600 volt source voltage comes on as indicated by a 160 microamp reading on Test Box T1 and a 1.6 cm shift in the oscilloscope display. (The +265 volt current should read 220 mA just prior to the source voltage turn on and 280 mA just after.) After approximately five minutes, the "50" volt supply output will stabilize at 40 V dc and the 265 V current will read 315 mA. (The electronics are now in the standby mode.)



ELECTRONICS TEST WIRING DIAGRAM
FIGURE 3-2

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3.2.6 Set the MODE switch on the Encoder Box T2 to the PULSED position and set the 100 microampere source switches to ON and I. Adjust the simulated source current to 100 microampere. Again depress the T3 ENCODE/LOG switch for 30 seconds. The system will switch to the pulsed mode of operation as will be evidenced by the oscilloscope trace. The Replenisher circuit will also be activated at this time and the REPLENISHER CURRENT meter on Test Box T1 should indicate approximately 2 amps. (The meter reading could vary ±.5 amps or more depending on the setting of R1016 on the Replenisher card.) Note that an increase in the simulated source current will cause a decrease in replenisher current, and vice versa.

3.2.7 Turn off the Electronics by turning off the +265 V dc. Successful completion of the foregoing subsection indicates proper operation of the A-520 Electronics section.

3.3 Maintenance

The A-520 Electronics is a precision electronic instrument and should be handled as such by experienced and trained personnel. Beyond this, no special maintenance is required since the A-520 is designed for long, maintenance free operation.

3.4 Troubleshooting

This sub-section presents the troubleshooting instructions for the A-520 Electronics Section. These procedures focus mainly on isolating problems to a specific plug-in circuit or functional unit since repair in the field will normally be accomplished on a module replacement basis. Before resorting to the following troubleshooting procedures, perform the normal Initial Set-up and Adjustment outlined in subsection 3.3. If the Electronics continue to malfunction, follow these procedures:

3.4.1 The general troubleshooting scheme (for any problem or symptom) is to first verify that the test power supplies are functioning properly at the correct voltages. The next step is to make resistance measurements at the input power terminals of the Electronics (K-30 connector, outer conductor to ground). The final step is to begin again the procedure specified in 3.3, and then refer to the following guide:

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TROUBLESHOOTING GUIDE

ELECTRONICS SECTION

ITEM	MAJOR SYMPTOM	TEST OR CHECK	PROBABLE PROBLEM IF TEST NOT TRUE
1.	After step 3.3.4, idle current to low	a. Check T.P. 9-1 for +245V dc ±1 V.	a. Card #9 regulator circuit faulty*, 12 supply faulty
		b. Check 200V P-P ±15V square wave, terminal TB	b. Faulty Inverter*
		c. Check +5V, +24V, +12V and -12V supplies, TP	c. Faulty supplies. Replace Card #4.
2.	After step 3.3.4, idle current too high	a. Remove card covers, disconnect and remove cards 1,3,4,5,6. Disconnect cards, 7, 7A/8A,8. Repeat step 3.3.4.	a. Faulty inverter*.
		b. Replace cards in the following order while monitoring idle current: 4,1,3,6,5, connect 7,7A/8A,8.	b. Replace card resulting in high current reading.
3.	After step 3.3.5, "50" volt supply does not build up.	a. Check for 550 Hz trianglar wave from ENCODER BOX T2.	a. Faulty encoder ckt., replace.
		b. Check TP 6-5 level. Should switch from +12 to gnd. after pressing ENCODE/LOG switch for 30 seconds.	b. Faulty Decoder card #6. Replace.
		c. Check the output of the 50 V. Build up Card #5 for voltage build up.	c. Faulty 50V build up circuit, replace Card #5.
4.	"50" Volt supply begins to build-up prior to pressing of ENCODE/LOG switch.	a. Check level at TP-6-5 for +12 Vdc.	a. Faulty Decoder Card. Replace.
		b. Check input level of Card #5 at TP 5-1 for +12 Vdc.	b. Faulty 50V build-up Ckt. Replace Card #5.
5.	After step 3.3.5, +1600V is not switched on when "50" V build-up reaches +16V.	a. Listen for relay closure on Card #5 as 50 volt build-up advances. Switching should occur in the neighborhood of 16 Vdc. Check for +1600 V at TP 7-4.	a. Faulty 50V build-up ckt. Replace Card #5.

ITEM	MAJOR SYMPTOM	TEST OR CHECK	PROBABLE PROBLEM IF TEST NOT TRUE
5.	Contd.	b. After verifying that there are +1600 Vdc at TP 7-4 and 1 μ sec. 12V "<u>initial</u>" pulses at TP 8-3, check for +1600V at TP 8-13.	b. Faulty 1600V switch. Replace Cards 7, 7A/8A, 8.
6.	After step 3.3.5, source voltage comes on but is low (~500V).	a. After verifying that there is +1600 V at TP 7-4, check for 1 μ sec. 12V pulses at TP 8-3.	a. Faulty Oscillator Card. Replace Card #1.
7.	After step 3.3.6, the +1600V source voltage does not switch from dc to the pulsed mode.	a. Check that the voltage level at TP 6-6 switches from gnd. to +12, after pressing ENCODE/LOG switch for 30 seconds.	a. After verifying that the Encoder is generating 680 Hz triangular waves, replace faulty Decoder Card #6.
		b. Check for initial and final pulses at TP's 8-3 and 8-2 respectively.	b. Replace Oscillator Card #1 and/or TND Card #3.
		c. After successfully completing a. and b. above, test for TP's 7-8 and 8-6. <u>CAUTION</u>!! TP 7-8 is 1600 volts above ground.	c. Replace faulty 1600 volt switch, Cards, 7, 7A/8A and 8.
8.	After step 3.3.6, the Replenisher current fails to come on.	a. Listen for relay closure on card #3 after pressing the ENCODE/LOG switch for 30 seconds.	a. Faulty TND Card #3, Replace card.
		b. Check for 4.8Vdc at TP 10-7 after relay closure.	b. If test is true, replace faulty replenisher supply, Card #10*.

*The entire electronics section must be returned for repair.

HIGH VOLTAGE
SECTION

4.0 HIGH VOLTAGE SECTION

4.1 Omit/System Interface

When delivered from the factory as part of an A-520 system, or when operating, the High Voltage Section is assembled with the Generator Section.

4.1.1 The high voltage feedthru, which connects the 110 kV output of the High Voltage Section to the Generator target, also provides a common pressure barrier. The three terminals at the other end of the High Voltage Section, see schematic 130616, appendix B, connect to the Electronics Section.

4.1.2 The "50" V terminal is the input power to the High Voltage power supply. The ground terminal connects to the Electronics system ground, and the third terminal is the low side terminal of the high voltage output. This terminal is grounded thru the input of the Replenisher Supply control circuit. Since the Generator tube beam current flows thru the low side terminal to ground, the Replenisher Supply control senses the beam current and thereby controls the Replenisher Supply output.

4.2 Initial Set-Up and Adjustment

4.2.1 Pressurize the High Voltage Section with SF6 as described in 2.6. DO NOT ATTEMPT TO OPERATE THIS UNIT UNPRESSURIZED. ANY ATTEMPT TO DO SO WILL VOID KAMAN'S WARRANTY FOR THIS UNIT

4.2.2 Connect the High Voltage Section to the Generator Section or a 1.2G ohm, 120 kV resistor. (A special adapter is required if a resistive load is used. Request information from K.S.C.) Refer to Section 5.2 for initial test instructions.

CAUTION!!

DO NOT ATTEMPT TO OPERATE THE HIGH VOLTAGE SECTION WITHOUT A LOAD. ANY ATTEMPT TO DO SO WILL VOID KAMAN'S WARRANTY FOR THIS UNIT. SEE APPENDIX A.

4.3 Maintenance

No special maintenance procedures are required for the High Voltage Section, other than the pressurization with SF_6 prior to operation.

4.4 Troubleshooting

This sub-section presents the troubleshooting instructions for the A-520 High Voltage Section. The procedures focus mainly on isolating problems to a specific functional unit since repair in the field will normally be accomplished on a module replacement basis.

TROUBLESHOOTING GUIDE

HIGH VOLTAGE SECTION

ITEM	MAJOR SYMPTOM	TEST OR CHECK	PROBABLE PROBLEM IF TEST NOT TRUE
1.	High Voltage Section draws significantly more or less than 380 mA from the "50" Volt supply.	a. Remove the Driver from the Voltage Multiplier and check Driver input current for 180 mA, at 48V dc, and no output load. Check Driver output for 6.2 kV ac.	a. Replace faulty Driver. b. If test (a) is true, replace or repair faulty Voltage Multiplier. CAUTION!! DEPRESSURE BEFORE OPENING FOR REPAIR.

GENERATOR SECTION

5.0 GENERATOR SECTION

5.1 Unit/System Interface

When delivered from the factory as part of an A-520 system, or when operating, the Generator Section is assembled with the High Voltage Section.

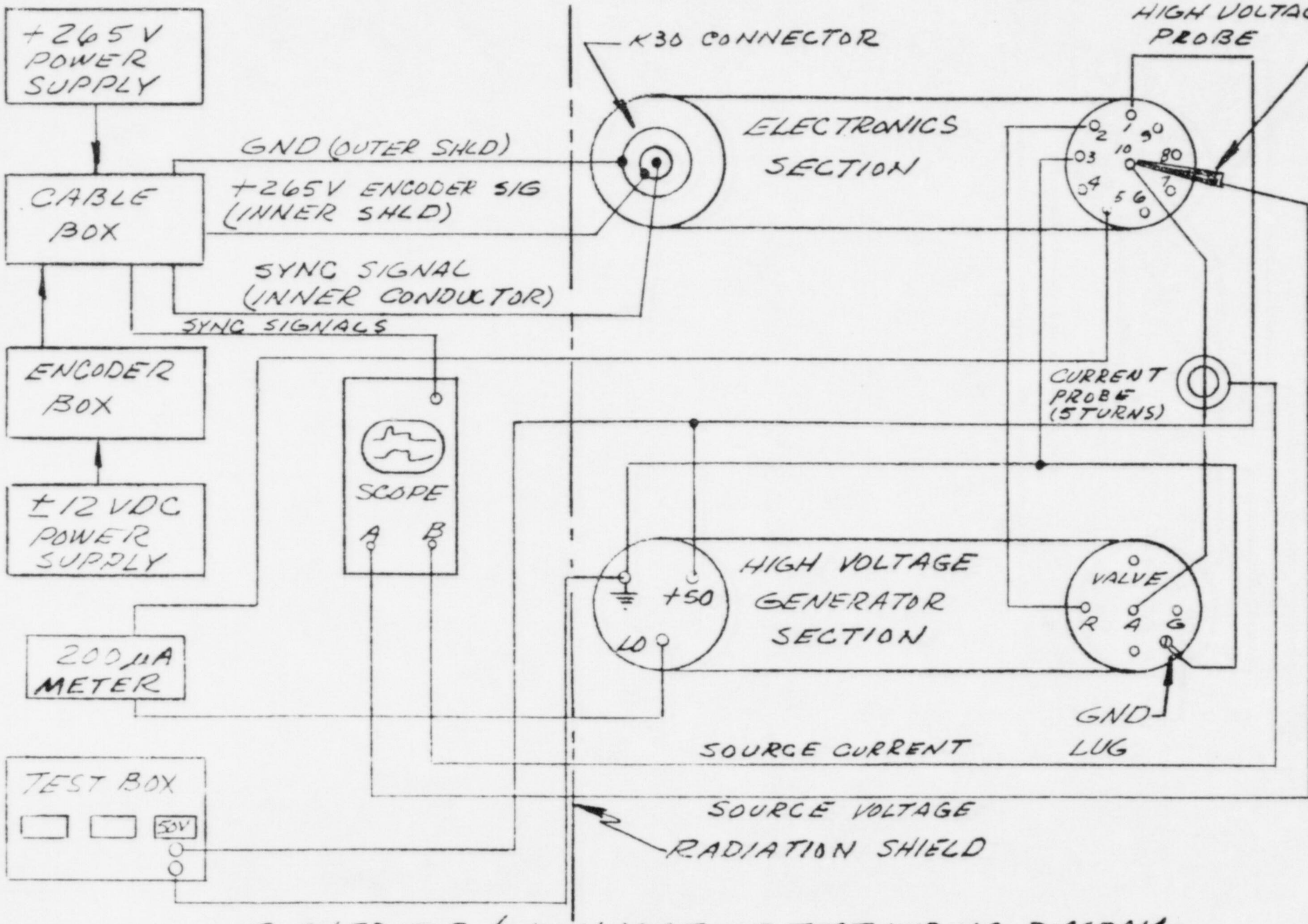
5.1.1 The high voltage feedthru which connects to the Generator Target and to the -110 kV output of the High Voltage Section, also provides a common presure barrier. The three terminals at the other end of the Generator, R, A, and G, see Figure 2-1, connect to the Electronics Section as shown in Figure 2-5.

5.1.2 When operating the +1600 volt pulses and Replenisher current from the Electronics Section, activate the Generator source producing deuterium and tritium ions. The ions are then accelerated into a tritium-deuterium loaded target by the -110 kV supplied by the High Voltage Section.

5.2 Initial Set-Up and Adjustment

Before proceeding with the set-up and adjustment of the Generator and High Voltage Section, verify that the Electronics Section operates properly by performing the procedure of 3.2.

5.2.1 Pressurize the High Voltage/Generator Section as specified in 2.6.3.2, then connect this assembly to the Electronics Section as shown in Figure 5-1. Temporarily, however, disconnect the +"50" volt lead from terminal #1 of the Electronics Section to the input of the High Voltage Section. This will preclude generation of neutrons.



GENERATOR / HIGH VOLTAGE TEST WIRING DIAGRAM
FIGURE 5-1

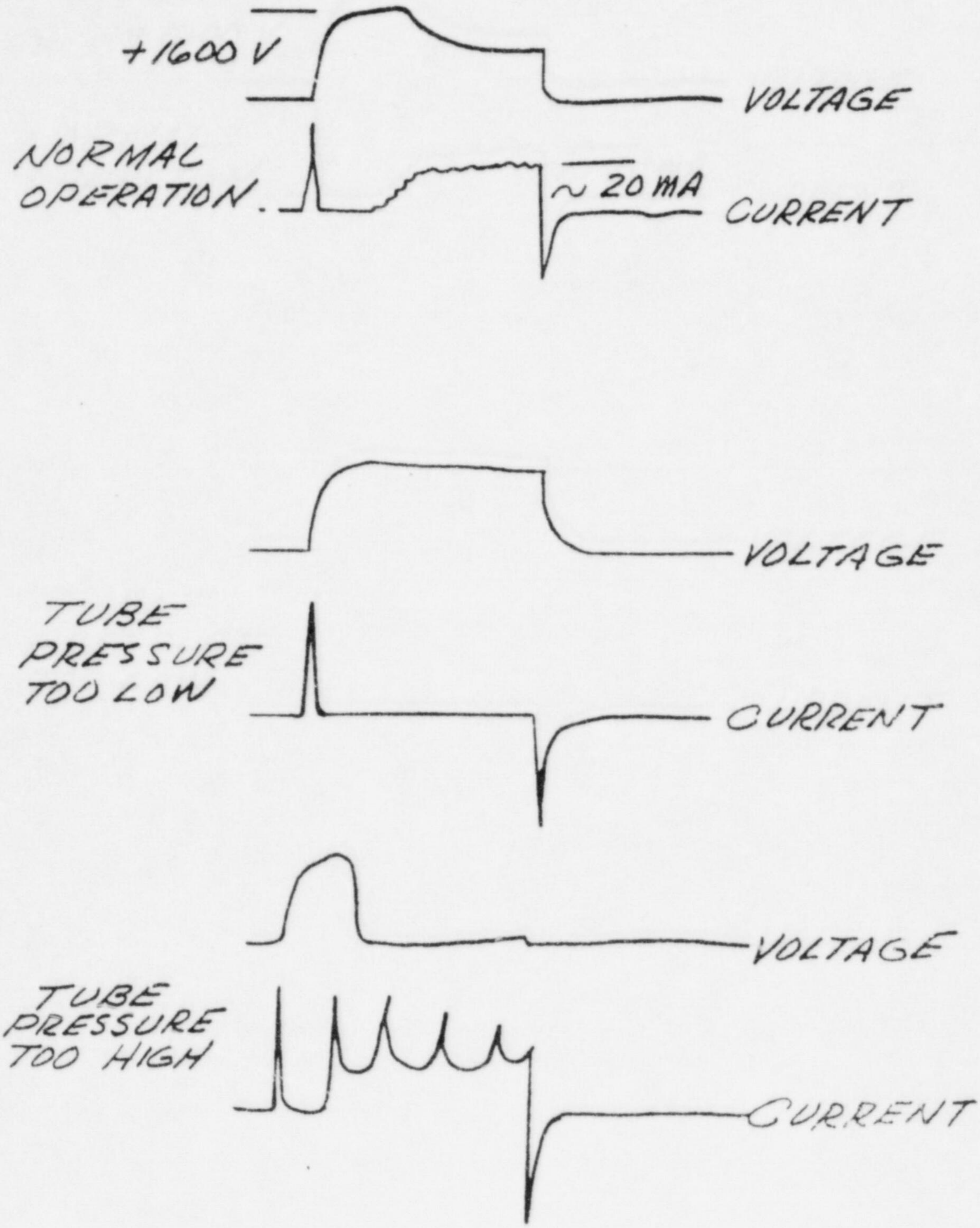
5.2.2 Turn on the 265V dc supply and allow the voltage to come up gradually (approximately 3 sec.) The Idle current will stabilize at 210 mA, and the A-520 system will now be operating in the Idle mode.

5.2.3 Set the "ON-OFF" switch on the ENCODER Box T2 to "ON". Set the MODE switch to "CONT" (Standby).

5.2.4 Press the ENCODE/LOG switch on the Cable Box T3, and hold down for 30 seconds. Observe on Test Box T1 that the "50" volt supply begins to rise. When the "50" volt supply output exceeds 16 volts dc, observe on the oscilloscope that the 1600 volt source voltage comes on.

5.2.5 Set the MODE switch on T2 to the PULSE position and again depress the T3 ENCODE/LOG switch for 30 seconds. The system will switch to the pulsed mode of operation as will be evident from the oscilloscope traces. At this time, the Replenisher circuit will also be activated and within ten seconds the neutron tube gas pressure will begin to rise. (The Replenisher current will be approximately 2.1A). The increase in gas pressure will result in an increase in source current, and a change in the scope traces, see Figure 5-2.

5.2.6 Adjust pot. R1016 located on the Replenisher circuit board (board #10) for a current and voltage wave form similar to trace "A" of Figure 5-2. Increasing the resistance of R1016 by turning the control to the right (clockwise) will decrease the tube gas pressure.



TYPICAL ION SOURCE VOLTAGE AND CURRENT WAVE FORMS

FIGURE 5-2

CAUTION!!

DO NOT OPERATE THE SOURCE IN THE HIGH PRESSURE MODE FOR MORE THAN 10 SECONDS AT A TIME. OVER PRESSURING OF THE TUBE MAY OCCUR WHICH WOULD RESULT IN PERMANENT DAMAGE. ATTEMPT TO ADJUST THE REPLENISHER SUPPLY AS QUICKLY AS POSSIBLE FOR THE CORRECT RANGE OF TUBE PRESSURE AS INDICATED BY THE GENERAL SHAPE OF THE SOURCE VOLTAGE AND CURRENT WAVE FORMS.

5.2.7 After the initial adjustment of the Replenisher circuit, turn off the 265V dc, and reconnect the +"50" volt line which was disconnected in 5.2.1. Prepare now to operate the Generator in a neutron producing mode.

CAUTION!!

ADEQUATE RADIATION SHIELDING OF PERSONNEL IS REQUIRED WHEN OPERATING THE A-520 NEUTRON GENERATOR SYSTEM. REFER TO TECHNICAL BULLETIN NO. 104 IN APPENDIX A FOR SHIELDING CONSIDERATIONS.

5.2.8 Turn on the 265V dc supply and allow the voltage to come up gradually (approximately 3 sec.) The Idle current will stabilize at 210 mA, and the A-520 system will be operating in the Idle mode.

THE A-520 NEUTRON GENERATOR IS NOT PRODUCING NEUTRONS UNDER THESE CONDITIONS.

5.2.9 Set the "ON-OFF" switch on the ENCODER Box T2 to "ON". Set the MODE switch to "CONT" (Standby).

5.2.10 Press the ENCODE/LOG switch on the Cable Box T3, and hold down for 30 seconds. Observe on Test Box T1 that the "50" volt supply begins to rise. When the "50" volt supply output exceeds 16 volts dc, observe on the oscilloscope that the 1600 volt source voltage comes on. (The 265 volt "Standby" current should now read 220 mA just prior to the source voltage turn on and 280 mA just after.) After approximately 5 minutes, the "50" volt supply output will stabilize at 40V dc and the 265V current will read 315 mA (110 kV is now applied to the neutron tube target).

CAUTION!!

THE A-520 SYSTEM IS NOW PRODUCING NEUTRONS AT A RATE OF 5×10^6 n/sec OR LESS. ALTHOUGH THIS IS A RELATIVELY LOW RATE, OVER EXPOSURE IS STILL POTENTIALLY LETHAL.

5.2.11 Set the MODE switch on T2 to the PULSE position and again depress the T3 ENCODE/LOG switch for 30 seconds. The system will switch to the pulse mode of operation as will be evident from the oscilloscope traces. At this time, the Replenisher circuit will also be activated and within ten seconds the neutron tube gas pressure will be stabilized at near normal operating pressure (the Replenisher current will be approximately 2.1A).

CAUTION!!

THE A-520 SYSTEM IS NOW PRODUCING PULSES OF NEUTRONS AT AN AVERAGE RATE OF 1×10^8 n/sec. OR GREATER.

5.2.12 Verify that the beam current as read on the micro-ampmeter is ± 10 microamps. If the beam current is incorrect, adjust R1016 pot. located on the Replenisher control board #10.

CAUTION!!

TURN OFF THE A-520 SYSTEM BEFORE ADJUSTING THE R1016 POT.

5.2.13 The initial set-up and adjustment of the Generator Section is now complete. Verification of the neutron output may be made at this time at the user's option.

Kaman uses the "Texas Convention" technique outlined in Technical Bulletin No. 109 which is included in appendix A. At the conclusion of these tests, the equipment is ready for field use.

5.3 Maintenance

No special maintenance procedures are required for the Generator Section other than the pressurization with SF6 prior to operation, see subsection 2.6. No attempt should be made to open or repair this unit in the field.

When returning the Generator Section to Kaman for repair or rework, install the dust cover provided over the high voltage feedthru, and pack the unit for shipment. Use the original wooden shipping box or an equivalent. Be sure to depressurize the Generator unless there is evidence of internal damage such as loose parts.

5.4 Troubleshooting

This sub-section presents the troubleshooting instructions for the A-520 Generator Section. Before resorting to the following procedures, perform the normal Initial Set-up and Adjustment outlined in 5.3 above. If the Generator Section continues to malfunction, follow these procedures.

CAUTION!!

CONTACT KAMAN REP FOR INSTRUCTIONS IF TUBE APPEARS TO BE DAMAGED.

NOTE

THE SEALED GENERATOR SECTION IS NOT TO BE OPENED UNDER ANY CONDITIONS. VIOLATION OF THIS CONDITION RESULTS IN A SAFETY HAZARD AND INVALIDATES THE SEALED TUBE WARRANTEE.

TROUBLESHOOTING GUIDE

GENERATOR SECTION

ITEM	MAJOR SYMPTOM	TEST OR CHECK	PROBABLE PROBLEM IF TEST NOT TRUE
1.	Low neutron output. ($<1 \times 10^8$ n/sec.)	a. Replace High Voltage Section and retest per 5.2 for 1×10^8 n/sec. or greater.	a. Return Generator Section to Kaman for repair or refurbishing. b. If test (a) is true, the High Voltage Section is defective. Refer to Section 4.4 for further isolation of defective subassembly.

APPENDIX A

KAMAN SCIENCES CORPORATION

A KAMAN COMPANY

TECHNICAL BULLETIN no. 104

Shielding Considerations as Applied to Fast-Neutron Generator Application

High output, fast-neutron generators require careful considerations of the shielding required to protect personnel from x-rays and 14 Mev neutrons produced during operations. An introduction to these shielding considerations is offered as a guide to individuals responsible for neutron generator facilities.

Shielding must be designed to meet the requirements of the Nuclear Regulatory Commission Regulations 10 CFR 20. Complete familiarity with these regulations by all concerned with neutron generator operation is essential.

Almost any material can be used for shielding. To be completely effective, however, shielding for 14 Mev neutrons should contain both heavy and light elements. Ordinary and heavy aggregate concrete have distinct advantages for most neutron generator facilities; therefore, concrete is the most commonly used shielding material for these applications. Three typical examples of calculating the amount of shielding for specific conditions are presented in this bulletin as a guide for meeting the requirements of NRC Regulation 10 CFR 20.

NEUTRON GENERATOR SHIELDING CONSIDERATIONS

When planning a neutron generator facility, the first item considered should be shielding. This technical bulletin presents an introduction to the shielding considerations associated with Kaman Sciences neutron generators. It should be noted, however that the shielding for a particular facility depends on many parameters that may vary from facility to facility. Each application, therefore, must be considered for its particular requirements.

Although almost any material can be used for shielding, depending only on the amount of material and space available, ordinary or heavy aggregate concrete or earth are the recommended materials for most installations. The shielding for each facility must be designed to meet the Nuclear Regulatory Commission Regulation 10 CFR Part 20, Standards for Protection Against Radiation. The U. S. Department of Commerce Handbook No. 63, "Protection Against Neutron Radiation up to 30 Million Electron Volts," also is recommended as a valuable reference document. In addition to these, there are many other shielding documents and books available which can be used as reference material. The technical advice of the Kaman Sciences staff also is encouraged if there is any doubt concerning the adequacy of proposed or existing shielding.

NEUTRON GENERATOR OUTPUTS

The first item to consider is the neutron and x-ray output under normal operating conditions. Typical neutron generator outputs for Kaman Sciences' series of neutron generators are given in Table I. (These out-

TABLE I

TYPICAL NEUTRON GENERATOR OUTPUTS

NEUTRON GENERATOR SERIES	NEUTRON OUTPUT	X-RAY OUTPUT (GENERATING NEUTRONS)	X-RAY OUTPUT (OPERATING, BUT NOT GENERATING NEUTRONS)
A-520	2×10^{8} n/sec max	15 mr/hr max	<15 mr/hr
A-620	2×10^{8} n/sec max	<15 mr/hr	None
A-801	10^{9} n/sec max	<15 mr/hr	None
A-710	2×10^{10} n/sec max	450 mr/hr max	250 mr/hr max
A-711	10^{11} n/sec max	750 mr/hr max	450 mr/hr
A-1254	2.5×10^{11} n/sec max	750 mr/hr max	450 mr/hr max

puts assume that the neutron generators are operated according to the instructions given in the appropriate operations manual.) The radiation outputs are listed as 4π yields for neutron outputs and as dose rates for x-ray outputs. The x-ray outputs were measured using a SU-1H Tracerlab survey meter placed at the point of maximum x-ray intensity on the surface of the neutron generator. The x-ray yield does not include the x-ray and gamma rays that result from interactions of neutrons with materials placed near the generator. In most cases, the radiation from neutron-activated materials will be low, and shielding that is adequate for neutrons will suppress the x-rays to a permissible level. Therefore, the shielding in most cases should be designed for neutron output.

In the A-1000 series generators, it is possible to operate the generator for short periods of time with a beam flap intercepting the deuterium beam or for longer periods using the beam deflection technique. This flap, or beam deflector, reduces the neutron production to a negligible level. The x-ray output for either of these methods is approximately one-half of the normal operating level output. Care should be taken to provide proper shielding against x-rays for personnel working near the generator with the generator operating in either of these manners.

FACILITY SHIELDING

The purpose of shielding is to reduce the radiation in any occupied area to a level that meets the requirements of NRC Regulation 10 CFR 20. Any type of material or geometry that will accomplish this is acceptable. Distance from the generator, operating time of the generator, and personnel time near the generator also should be considered in designing the shielding.

The 14 Mev neutrons produced by Kaman Sciences' neutron generators are best attenuated by using a combination of heavy and light elements. Heavy elements absorb most of the energy from the neutrons by inelastic scattering. The light elements further reduce neutron energy by elastic scattering and also absorb a great many of the slow neutrons. A material such as boron, with a high capture cross section for slow neutrons, can be used to increase the number of slow neutrons absorbed.

Concrete, either ordinary or heavy aggregate, is the natural choice for shielding as it contains both heavy and light elements and is economical, reliable, structurally useful and versatile. Under certain conditions, earth also provides a satisfactory economical shield. Where space is restricted, iron-polyethylene or iron-water shielding may prove the most desirable. Other combinations of material can be used to meet particular shielding requirements.

The geometry of the shield can vary from distance only (no shielding) to shielding completely surrounding the generator. Other possible shielding geometries are a labyrinth, cavity, pit or well, and shadow shielding as well as combinations of these.

SHIELDED ROOM – LABYRINTH SHIELDING

A shielded room with a labyrinth geometry provides a convenient design which lends itself very well to concrete construction. The size of the shielded room and labyrinth width and arrangement will depend on particular needs. The wall and arrangement also will depend on particular needs. The wall thickness will depend on the neutron generator output. Figure 1 illustrates a floor plan of a typical shielded room arrangement. This floor plan assumes a room 10 feet square with a $4\frac{1}{2}$ foot entryway. The thickness of the shielding has been indicated as X-feet. This value, X, must be determined by the output of the particular neutron generator. The room is assumed to be 8 feet high with a roof thickness equal to the wall thickness. This structure probably should be built on a concrete slab.

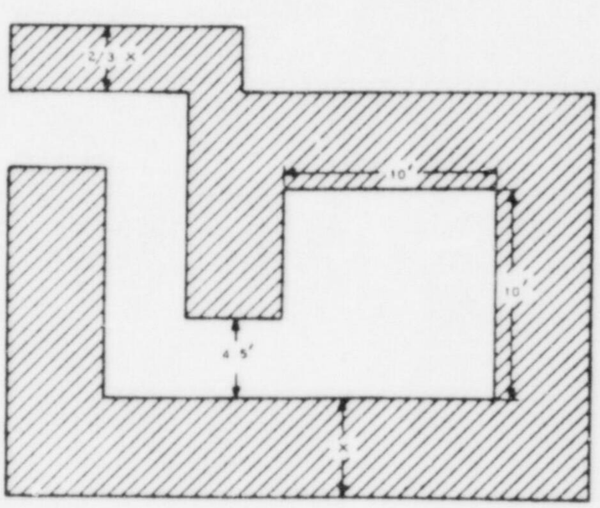


FIGURE 1
SHIELDED ROOM WITH LABYRINTH

Concrete, either poured or solid block, is the natural choice for a structure of this type. In general, a carefully laid unmortared solid concrete block is 90 percent

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as effective as a monolithic, poured structure. An unmortared concrete block structure can be particularly useful where the installation may be temporary. All vertical cracks should be staggered to reduce leakage; gravity is usually sufficient to keep the horizontal cracks closed.

CAVITY SHIELDING

A savings can be effected by providing part or all of the shielding in the immediate vicinity of the neutron source. This arrangement is suitable where the pieces to be irradiated are small and where suitable sample transfer systems are available. The A-500, A-600 and A-800 series neutron generators can be provided with extensions such that only the target section is inserted into the cavity. It should be remembered, however, that the generator itself provides virtually no protection against neutrons, and the hole through which the drift tube is inserted acts as a collimator.

The area behind the neutron generator, therefore, should be restricted to prevent personnel from entering during the operation of the neutron generator, or a shield must be placed behind the neutron generator to shield out the collimated beam of neutrons. Also, entrance and exit ports for the sample transfer system and cables must be designed to eliminate direct streaming.

Some types of neutron generators have exposed high voltage and are, therefore, severely limited as to their location. (They must be located at least 3 feet from walls or floors to prevent voltage arcing to the ground.) There are no such limitations with any of Kaman Sciences neutron generators; therefore, maximum utilization can be made of basements, corners, and similar locations that provide natural shielding.

PIT AND WELL INSTALLATIONS

A pit provides an economical installation in which earth provides shielding in all but the vertical direction. A roll-a-way shield door can be provided over the pit to prevent streaming above the neutron generator. The pit installation lends itself to a basement floor installation where small samples are to be irradiated. Suitable sample transfer systems should be used with this type of installation.

Kaman Sciences neutron generators can be mounted and operated in any position without the loss of efficiency and without danger of voltage breakdown. Therefore, the pit can be designed to meet the needs of the experimenters and experimental equipment.

SAMPLE SHIELDING COMPUTATIONS

As previously stated, shielding must be designed to meet special requirements of facility, equipment and operating conditions. The sample computations presented herein are meant to be used only as a guide and are typical of shielding required to meet NRC requirements. A neutron flux of 10 neutron/cm^2/sec (14 Mev) is the maximum permissible level (not exceeding 100 mrems) for a 40 hour week.

Example 1: Consider a Kaman Sciences A-1254 neutron generator with a 4π yield of 10^{11} neutrons/second. This neutron generator is to be operated in a concrete block room with a labyrinth access as shown in Figure 1. Calculate the thickness X, of the shielding required such that personnel on the exterior of the structure (around 10 feet from source) will receive no more than 100 mrems in a 40 hour week.

At a position of 10 centimeters from the target, the source approximates a point source, and the neutron flux can be calculated using the inverse square law:

$$\varphi = \frac{\varphi_o}{4\pi r^2}$$

where φ_o is the generator output and r is the distance from the source to sample position. Therefore, this flux at 10 centimeters from the source is

$$\varphi = \frac{10^{11}}{4\pi 10^2} = 7.96 \times 10^7 \text{ neutrons/cm}^2\text{/sec.}$$

The neutron flux at a distance of 10 feet (305 cm) from the target, assuming no shielding and using the inverse square law is:

$$\varphi = \frac{10^{11}}{4\pi (305)^2} = 8.55 \times 10^4 \text{neutron/cm}^2\text{/sec.}$$

The flux at 10 feet with no shielding, therefore, is approximately 4 orders of magnitude too high. The 14 Mev neutrons are reduced by a factor of 10 for each 15 inches of solid concrete block. The relaxation length for concrete was taken from Reference 1 and corrected for the reduced shielding effect of concrete block. Therefore, 5 feet of concrete block will reduce the neutron flux to approximately 9 neutrons/cm^2/second, which is within the permissible level.

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Example 2: Consider a cavity concrete shield placed around a Kaman Sciences A-1254 neutron generator with a 4π yield of 10^{11} neutrons/sec. How much shielding, placed at 4 inches from the source, is necessary for personnel to work next to the shielding without receiving more than the maximum permissible dose for a 40 hour week of 10 neutrons/cm^2/second?

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1. AERE-R-3920 A Review of High Intensity Neutron Sources and Their Applications in Industry. G. Olive, J. F. Cameron and C. G. Clayton June 1962.

In order to solve this problem, the amount of shielding which gives the distance of closest approach must be determined. Each 15 inches of concrete will reduce the flux by an order of magnitude. In addition, the inverse square law acts to reduce the flux. A simple approach is to consider two easily solved shielding thicknesses. The results of these shielding calculations, when represented as a flux-versus-distance curve on semi-log paper (this function is a straight line on semi-log paper), illustrates the shielding necessary to reduce the neutron flux to 10 neutrons/cm^2/second.

As a starting point, choose 5 feet of concrete. This is the amount needed for a closest approach distance of 10 feet; therefore, the shielding thickness will necessarily be greater than this value.

Calculate the flux for distance only (5 feet + 4 inches or 163 centimeters) using the inverse square law:

$$\varphi = \frac{10^{11}}{4\pi(163)^2} = 3.02 \times 10^5 \text{ neutron/cm}^2\text{/sec.}$$

Decrease this value by 4 orders of magnitude for the 60 inches of shielding used. Therefore, the neutron flux is 30.2 neutrons/cm^2/second. This flux is greater than the maximum permissible level of 10 neutrons/cm^2/second for a 40 hour week.

As a second point, choose a larger shielding thickness, say 90 inches. Calculate for distance only (239 centimeters):

$$\varphi = \frac{10^{11}}{4\pi(239)^2} = 1.4 \times 10^5 \text{ neutrons/cm}^2\text{/sec.}$$

Reduce this value by 6 orders of magnitude for the 90 inches of shielding. Therefore, the neutron flux is 0.14 neutrons/cm^2/sec.

These two points are plotted on Figure 2 and connected with a straight line. Choosing 10 neutrons/cm^2/second on this curve, we find that 5.5 feet of shielding is necessary.

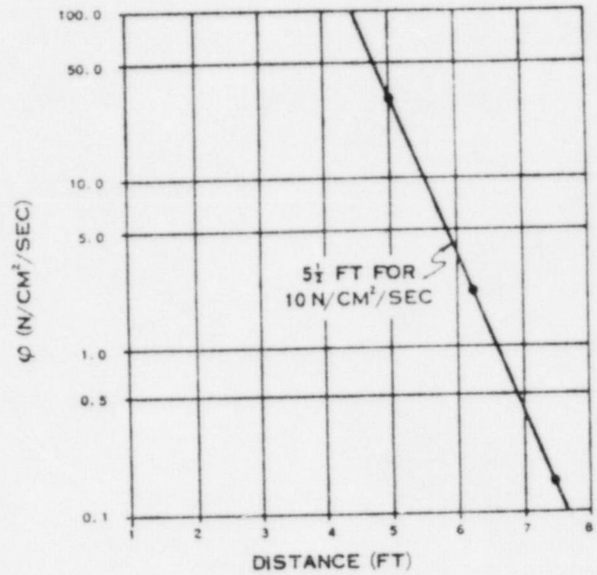

FIGURE 2

FLUX VERSUS DISTANCE FOR CONCRETE

Example 3: What is the minimum approach distance to an unshielded Kaman Sciences A-1254 neutron generator with a 4π yield of 10^{11} neutrons/cm^2/second? The maximum permissible level is 10 neutrons/cm^2/sec, assuming a 40 hour week.

Using the inverse square law in solving for r, we find

$$r = \left(\frac{\varphi_o}{4\pi\varphi}\right)^{\frac{1}{2}}$$

Putting in the values and solving for r, we find that the closest approach distance is 2.82×10^4 centimeters or 925 feet.

CONCLUSIONS

Radiation shielding is an essential part of any neutron generator facility. The neutron flux and x-ray output from high output neutron generators can present a potential hazard and, therefore, adequate shielding must be provided to preclude the possibility of exposure to personnel during operation and maintenance of the equipment.

With proper planning, an adequate shield that meets the requirements set forth in NRC regulation 10 CFR 20 can be constructed at minimal expense. These considerations might include use of distance in combination with earth, concrete or existing structures that provide the proper shielding characteristics.

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August 25, 1975

SEALED ACCELERATOR HEAD LIMITED WARRANTY

Kaman Sciences warrants each sealed accelerator head to be free from defects in material and workmanship for a period of one year or for the specified operating life, as indicated below, whichever shall occur sooner, when operated with non-defective electronic and control equipment supplied by, and in accordance with written instructions provided by Kaman Sciences.

This sealed accelerator head warranty is pro-rated, so that credit against the accelerator head rebuild price will be allowed for any unused portion of the guarantee life at the time of accelerator head failure. Guarantee life is that portion during which the accelerator is warranted to operate above the minimum yield specified below.

Warranty validation records are provided with each sealed accelerator head. Failure to complete and return these validation records to Kaman Sciences will automatically void this Warranty.

This Warranty does not apply to a sealed accelerator head which has become defective, damaged or broken due to misuse, accident, negligence in transit or handling, or operation outside the conditions prescribed in the instruction manual. Opening of a sealed accelerator head without the express approval of the Kaman Sciences Service Department will automatically void this Warranty.

Kaman Sciences' obligation under this Warranty shall be limited to repair or replacement of any components within the sealed accelerator head which, upon our examination, and in our judgment, appear to be defective in material or workmanship, provided the sealed accelerator head is delivered prepaid to the Kaman Sciences plant.

In no event shall Kaman be liable for incidental or consequential damages, including commercial loss, resulting from any article sold under this Warranty.

In the event Buyer fails to limit to Kaman's warranty set forth above any express or implied warranty it may make with respect to any product of which any article sold hereunder is a component, Buyer shall indemnify and hold Kaman harmless from any and all liability, costs and expenses to which Kaman may be subjected as a result of Buyer's failure to so limit its express or implied warranties.

Continued on other side

THIS WARRANTY IS EXCLUSIVE AND IS MADE IN LIEU OF ALL OTHER WARRANTIES; AND THOSE IMPLIED WARRANTIES, INCLUDING SPECIFICALLY THE WARRANTIES OR MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE HEREBY EXPRESSLY LIMITED TO ONE (1) YEAR DURATION.

NO MODIFICATION OR ALTERATION OF THE FOREGOING WARRANTY AND LIMITATION OR REMEDIES PROVISIONS SHALL BE VALID OR ENFORCEABLE UNLESS SET FORTH IN A WRITTEN AGREEMENT SIGNED BY KAMAN SCIENCES AND THE BUYER.

Accelerator	Tube Model	Guarantee Life	Minimum Yield during Guarantee Life
A-700	A-3043	250 hours	5×10^7 n/sec
A-702	A-3043	250 hours	5×10^8 n/sec
A-710	A-3043	200 hours	5×10^9 n/sec
A-711	A-3045/6	200 hours	5×10^{10} n/sec
A-800	A-3041	500,000 pulses	5×10^6 n/pulse
A-801	A-3041-H	200,000 pulses	5×10^7 n/pulse

APPENDIX A-3

RECOMMENDED SPARE PARTS

1. Generator Section, P/N 150788

1. High Voltage Driver, P/N 150787

3. High Voltage Power Supply, P/N 150758

4. Printed Circuit Card #1, P/N 150761

5. Printed Circuit Card #3, P/N 150763

6. Printed Circuit Card #4, P/N 150764

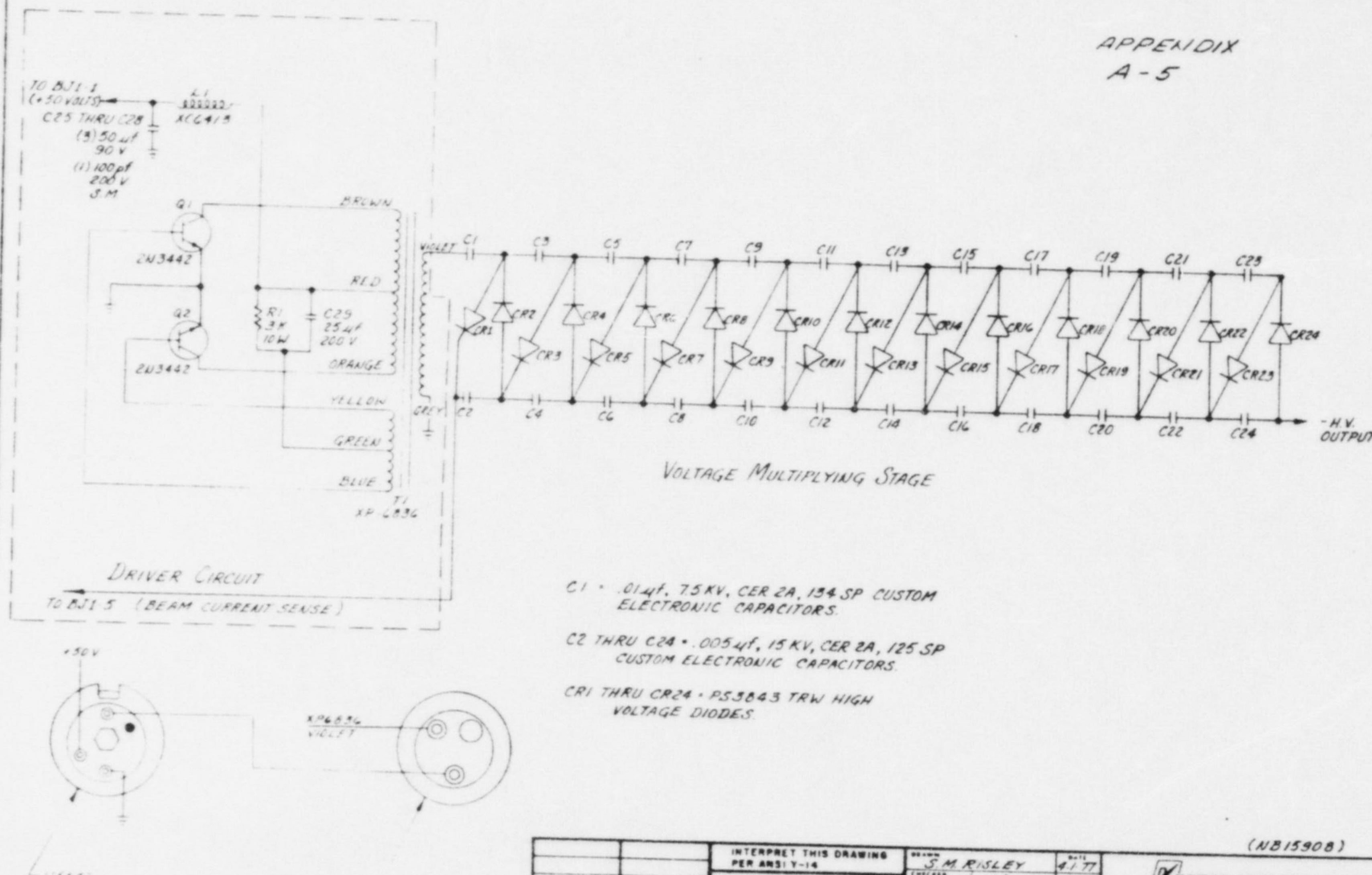
7. Printed Circuit Card #5, P/N 150765

8. Printed Circuit Card #6, P/N 150766

9. 1600 Volt Switch Assembly, P/N 150777

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ORIGINAL ISSUE	4-5-77	JWK
	B	PER E.C.O. # 06719	4-25-77	JWK

APPENDIX A-5



C1 = .01µf, 7.5 KV, CER 2A, 134 SP CUSTOM ELECTRONIC CAPACITORS.

C2 THRU C24 = .005µf, 15 KV, CER 2A, 125 SP CUSTOM ELECTRONIC CAPACITORS.

CR1 THRU CR24 = PS3843 TRW HIGH VOLTAGE DIODES.

(NB15908)

UNLESS OTHERWISE SPECIFIED
VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. ALL EDGES AND CORNERS .005-.020 (APPROX RAD OR CHAM) - ALL FILLETS .005-.020 (APPROX RAD) - SCREW THREADS PER ASA B1.1 - PIPE THREADS PER ASA B2.1 - SURFACE ROUGHNESS PER ANSI B46.1 - SURFACE ROUGHNESS ON HOLES 250/ MAX - ALL DIMENSIONS CORRECTED TO 68°F ±2°

NEXT ASSEMBLY	USED ON
	130758
APPLICATION	

INTERPRET THIS DRAWING PER ANSI Y-14
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCE
XX ± ~
XXX ± ~
ANGLES ± ~
SURFACE ROUGHNESS √ MAX
DO NOT SCALE THIS DRAWING
MATERIAL

DRAWN	S.M. RISLEY	4-1-77
CHECKED	[illegible]	4-4-77
ENGR	W. Valentine	4-4-77
	JD[illegible]	4-4-77
PROD	E. McC[illegible]	4-4-77
PROJECT		
CONTRACT NO		

KAMAN SCIENCES CORPORATION
Garden of the Gods Rd. Colorado Springs, Colorado

CIRCUIT DIAGRAM OF THE 125V HIGH VOLTAGE POWER SUPPLY 3¾ NG ( ) 6.1-2

SIZE	CODE IDENT. NO.	DWG. NO.	REV
C	21732	130616	B

SCALE ~ SHT 1 OF 1

130616

APPENDIX A-4

ANCILLARY EQUIPMENT REQUIRED FOR OPERATION AND MAINTENANCE

1. TEST AND CONTROL MODULES: (Available from Kaman)

   1.1 Electronics Test Box T-1 Model A520T1

   1.2 Encoder Box, T-2 Model A520T2

   1.3 Cable Junction Box, T-3 Model A520T3

2. POWER SUPPLIES:

   2.1 +265V dc, 500 mA - Main system power

   2.2 ±12V dc, 50 mA - Encoder box power.

3. Dual trace oscilloscope with voltage probe rated for measuring 1600V dc and 1600 volt pulses.

4. Current probe, type

5. 200 μ amp dc meter

6. Interconnecting cables

7. Mechanical vacuum pump with cold trap

8. A cylinder of SF_6 and a cylinder of dry nitrogen gas, both with pressures regulators for pressurizing up to 100 psi.

9. Access to licensed facility and equipment therein when making neutron measurements.

TECHNICAL BULLETIN no. 109

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Texas Convention Technique for Measuring Neutron Output

The Texas Convention[1] technique is a suggested standard method for measuring neutron generator output. However, the irradiation time and the cross section are left to the discretion of the experimenter. This Technical Bulletin discusses a set of parameters and correction factors that are convenient for neutron output measurement.

The reaction involved is the $Cu^{63}(n,2n)Cu^{62}$ reaction produced by fast neutrons. Basically, a copper foil is irradiated at a known distance from a neutron producing target and counted for 0.51 MeV gammas from positron annihilation at a known distance from a 3-in. x 3-in. sodium iodide detector of known efficiency.

The cross section for the reaction is a function of deuteron energy and of the angle between the deuteron beam and the line from the target to the detector foil. For Kaman Sciences Models A-1254 and A-711 neutron generators, the accelerating voltage is 180-190 kV and the beam is mostly composed of molecular ions, so the energy is about 90-95 keV per deuteron. The neutron line shape (from Reference 2, pp. 23-24) is used to estimate an average neutron energy of 14.6 MeV for neutrons at 0° to the deuteron beam axis, 14.4 MeV for neutrons at 45° to the beam, and 14.1 MeV for neutrons at 90° to the beam.

Many measurements of the cross section are available[3], so judgment must be exercised and some uncertainty may always remain. In the absence of better information, the use of the solid line on page 29-63-6 of Reference 3 is suggested. This gives 560 mb for the 0° position, 530 mb for 45°, and 480 mb for 90°. Since it is customary in the Kaman laboratory to use 45°, 530 mb is used for these calculations. Even if this cross section were improperly used at other angles in the range 0°-70°, the error would be less than ±6%. Angles near 90° should not be used since the material in the target cap scatters the neutrons near 90°. Even though the neutron output from the $T(d,n)He^4$ reaction is essentially isotropic at low beam energies, the output from an accelerator with the target plane at 90° to the beam is low near 90° due to the scattering. In the forward direction, scattering amounts to only about 2-3%, and part of this is elastic (small energy change), so the correction is usually ignored.

The foils are specified[1] as 99.9% pure copper, 0.25-mm thick by either 1-cm or 2.5-cm diameter. Foils used here weigh 0.17 gm and 1.06 gm, respectively, although the exact weight should be used if any significant variation is found. The foils should be placed far enough away from the target so that the target and foil sizes are small compared to the distance. Since the effective beam size on the target is usually around 2 cm, the distance is chosen as 20 cm.

Times should be chosen to give adequate activity for good statistics without requiring excessive time for the measurement. At Kaman, the usual sequence is 30-second irradiation, 30-second decay, and 60-second count.

The Texas Convention recommends that the foils be counted at 3 cm from the top surface of a 3-in. x 3-in. NaI crystal with a 0.95-cm thick Lucite absorber on each side of the foil to insure that all positrons are annihilated near the foil. The amount of material surrounding the crystal (can plus reflector) should be determined by x ray to measure the distance from the crystal surface to the outside of the can. This distance is typically 2-4 mm. For the detector used at Kaman, this distance has been measured as 4 mm, so the foil is placed on the central axis of the detector at a distance of 2.6 cm from the outer surface of the can.

For the above geometry, Heath[4] has calculated correction factors for the geometrical efficiency, e; the absorption in the Lucite absorber and can, A; the branching ratio, q; and the photopeak efficiency, P. The disintegration rate of the source (N_o in disintegrations per minute at zero decay) is related to the photopeak area (N_p in counts per minute at zero decay) by

$$N_o = N_p / PeAq$$

where $(PeAq)^{-1}$ is 8.591 for the 1-cm foil and 8.703 for the 2.5-cm foil

COMPARISON TO GM COUNTING TECHNIQUE

Several years ago, Kaman Sciences adopted a copper foil technique for measuring neutron output which used a GM counter instead of a scintillator. The other parameters, however, are quite similar to those of the Texas Convention method. The foils are 0.020-in. thick and either ¼-in. or ¾-in. diameter (weights of 0.15 g and 1.3 g, respectively*). The irradiation, decay, and count times are the same (30 seconds, 30 seconds, and 60 seconds). The primary difference is that the foils are counted for positrons with an end-window GM counter in nearly 2π geometry. This technique is simpler to use, and therefore continues in use in preference to the newer Texas Convention technique.

The correction factors for counter efficiency require a knowledge of the self-absorption of the positrons in the copper and the geometric efficiency of the detector. Baker and Katz[4] have studied the self-absorption factors for several isotopes and show graphs for these isotopes. The factor is 0.50 for Cu^{62} positrons and a foil thickness of 0.020 in. An angular distribution of the positrons given in Reference 4 shows that very few are emitted at large angles. Consideration of this distribution and the efficiency of the GM detector for positrons that enter the tube (≈98%) indicates that the geometric efficiency of the counting system is about 47%.

From the earlier calculation, we can obtain N_a for the number of activated nuclei present at the end of irradiation, and λN_a for the disintegration rate. Thus

$$N_a = 2.15\text{x}10^{-5}\, Y \text{ x } \frac{W}{1.06}$$
$$= 2.635\text{x}10^{-5}\, Y$$

where W is the weight of the ¾-in. x 0.020-in. foil (≈1.3 grams), and 1.06 is the weight of the 2.5-cm x 0.25-mm foil used earlier.

The number of counts (corrected for background) obtained in the 60-second count at 30 seconds decay is

$$C = 2.635\text{x}10^{-5}\, \lambda Y f_a f_g e^{-\lambda t_d}$$

where f_a is the self-absorption factor (0.50) and f_g is the geometry factor.

$$C = 2.635\text{x}10^{-5} \text{ x } 0.0701 \text{ x } Y \text{ x } 0.50 \text{ x } 0.47 \text{ x } 0.932$$
$$= 4.04\text{x}10^{-7} Y.$$

The equivalent result for the ¼-in. foil (0.15 gram) is.

$$C = \frac{0.15}{1.3} \text{x} 4.04\text{x}10^{-7}\, Y$$
$$= 4.67\text{x}10^{-8}\, Y$$
$$\text{or } \; Y = 2.14\text{x}10^{7}\, C.$$

The ¼-in. foils are used for high yield generators to minimize the dead-time effects in the GM tube. Thus for neutron outputs of 10^{10} n/sec, $5\text{x}10^{10}$ n/sec, and 10^{11} n/sec, the counts are, respectively, 467, 2335, and 4670.

The precision of this measurement is about the same as the precision of the Texas Convention method. The main difference is in the counting technique, where the calculation of PeAq is replaced by the calculation of the self-absorption and geometry factors. Since the product $f_a f_g$ can be determined to about the same ±5% uncertainty as PeAq, both methods should have about the same uncertainty.

Several checks have been made over a two year period by simultaneously irradiating foils for both methods. The agreement has ranged from 2% to 12%.

References

1. "The Texas Convention on the Measurement of 14-MeV Neutron Fluxes from Accelerators", with appendix by R. L. Heath, *Proceedings of the 1965 International Conference on Modern Trends in Activation Analysis*, College Station, Texas. April 1965.
2. Seagrave, John D., *D(d,n)He³ and T(d,n)He⁴ Neutron Source Handbook*, LAMS-2162. 24 January 1958.
3. Goldberg, M. D., et al, *Neutron Cross Sections*, BNL 325, 2nd Ed., Supp. No. 2, Vol. II-A. February 1966.
4. Baker, R. G. and L. Katz, "Absolute Beta Counting of Thick Planar Samples", *Nucleonics*, Vol. 11, No. 2, pp. 14-19. February 1953.

The number of atoms, N_a, of Cu^{62} present at the end of the irradiation is given by

$$N_a = N_{63} W \phi \sigma f_o \, t_i$$

where N_{63} is the number of atoms of Cu^{63} per gram of copper, W is the foil weight, ϕ is the neutron flux on the foil, σ is the reaction cross section (530 mb), f_o is the correction for decay during irradiation (0.98 for 30 seconds), and t_i is the irradiation time (30 seconds). The neutron flux, ϕ, is given by $Y/4\pi r^2$, where Y is the neutron yield in neutrons per second, and r is the target-to-foil distance.

If we assume a 2.5-cm foil (1.06 gm*), and a distance of 20 cm, the number of activated nuclei present at the end of irradiation is

$$N_a = \left[\frac{(6.02 \times 10^{23}) \times 0.691}{63.54}\right] \times 1.06 \times \left(\frac{Y}{4\pi \times 400}\right)$$
$$\times (0.53 \times 10^{-24}) \times 0.98 \times 30$$
$$= 2.15 \times 10^{-5}\, Y.$$

The disintegration rate is λN_a, where

$$\lambda (0.0701 \text{ min}^{-1})$$

is the decay constant for the Cu^{62} half-life of 9.9 minutes.

Thus the relation between photopeak area and disintegration rate becomes

$$N_p = N_o PeAq$$
$$= \lambda N_a PeAq$$
$$= 0.0701 \times (2.15 \times 10^{-5}) Y \times \frac{1}{8.703}$$
$$= 1.73 \times 10^{-7}\, Y$$

The photopeak area can be determined from the spectrum as recorded on a multichannel analyzer and corrected for bremsstrählung. However, it is often more convenient to use a window on a single channel analyzer to obtain total count, since it is easier to use and requires no dead time correction for rates up to 200,000 counts per minute. The window is set with the lower limit at the low point of the valley between the photopeak and the Compton edge, and the upper limit an equal amount above the photopeak† A graphical integration for a multichannel spectrum as compared to this window indicated that the window count was 5% higher than the true photopeak count corrected for bremsstrählung.

Finally, the window count needs to be corrected for the average decay time ($t_d \approx 1$ min). Thus the window count corrected for background, C_w, is related to the neutron yield by

$$1.73 \times 10^{-7}\, Y = N_p = C_w e^{\lambda t_d} \times 0.95$$
$$= C_w \times 1.073 \times 0.95$$
$$\text{or,} \quad Y = 5.90 \times 10^{6}\, C_w.$$

For example, neutron outputs of 10^{10} n/sec, 5×10^{10} n/sec, and 10^{11} n/sec should give, respectively, 1695, 8480, and 16,950 counts.

The Texas Convention technique, with the parameters defined above, is useful for neutron outputs of 10^{10} n/sec or above (Kaman Sciences's A-710, A-711, and A-1254 neutron generators), since the counting statistics are adequate for the desired precision.

The precision of the above measurement is determined by several factors. On an absolute basis, the cross section is the largest uncertainty. The quoted value is estimated to be accurate to ±10%, although various measurements differ by more than a factor of 2. The value of PeAq has to be calculated, and Heath[1] estimates the uncertainty to be ±5%. Neither of these uncertainties applies to relative measurements, which depend primarily on precision in positioning, timing, and window setting. These errors can be as low as ±2%, although errors as high as 10% can occur if adequate care is not taken with the measurement. Thus it is concluded that the absolute accuracy of the method is better than ±20%, and the relative accuracy (including inter-laboratory comparisons) is 2% - 10%, depending on the care taken with the experimental setup.

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*All foils should be weighed to make sure that the weight is within 2% of the nominal value. Variable width copper sheets and dull punches frequently cause variations of 10% or more.

†The half-width is approximately 20% of the peak height; i.e., if the peak is in channel 102, the window should extend from channels 82 to 122.

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