DP-1501

NUCLEAR INCIDENT MONITOR

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SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29801

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT AT(07-2)-1

Printed in the United States of America
Available from
Technical Information Center
U. S. Department of Energy
P. O. Box 62
Oak Ridge, Tennessee 37830

Price: Printed Copy $4.50; Microfiche $3.00

725934 ✓

DP-1501

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by

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Approved by

Equipment Engineering Department
Works Technical

Publication Date: January 1979

ISSUED BY E. I. DU PONT DE NEMOURS AND COMPANY
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ABSTRACT

This report describes an improved instrument to detect radiation that would be emitted by the accidental assembly of a critical mass of fissionable material. The instrument is a solid-state model designed to supersede a vacuum-tube-circuit model that has been in use for several years. The new instrument provides audible and visible alarms within 4 seconds after exposure to gamma radiation exceeding 1 R/hr. The instrument alarms within 0.3 second after exposure to a 50 microsecond burst of radiation that induces a dose of 0.6 mR.

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NUCLEAR INCIDENT MONITOR

INTRODUCTION

The Savannah River Plant has a number of locations where fissionable materials are stored or processed in sufficient quantity for a potential critical configuration. Technical Standards specify that these locations be monitored by instruments that would alarm promptly in the event of a criticality accident. The instruments are called Nuclear Incident Monitors or NIM's. The purpose is to warn personnel to evacuate the area as rapidly as possible thereby minimizing their exposure to radiation.

NIM's should never fail to alarm when an alarm condition exists. Independent instruments are installed in pairs within 100 feet of each potential incident location, and the operation of either will initiate an evacuation alarm. Of equal importance is the absence of false alarms. False alarms are minimized by routine maintenance at 25-day intervals, yearly calibration, and a fail indicating design. The dose rate at which the NIM is set to alarm is well above normal radiation levels tolerated in routine operations with radioactive materials. This eliminates false alarms caused by radioactive materials being moved in the vicinity of the instruments.

The NIM design now in use was developed about 15 years ago based on vacuum-tube circuits. Replacement parts are difficult to obtain. This report describes a redesigned NIM based on solid-state components. Design objectives are to improve reliability and reduce maintenance costs.

The new NIM is a gamma detector with an air-filled ionization chamber as the radiation sensor. Solid-state electronics are built into a compact package attached to the ion chamber. Audible and visible alarms are actuated when the radiation rate exceeds 1 R/hr. Self-checking monitoring circuits sense malfunction of several critical components, and an output meter indicates the radiation level. The NIM normally operates on 110 VAC, 60 Hz, but automatically transfers to battery power if normal power is lost.

Five prototypes have been built. Tests of the prototypes at Savannah River, Oak Ridge, and White Sands showed that:

- NIM's responded to criticality incidents of 4.7×10^{16} fissions within a radius of 2300 feet.

- NIM's alarmed within 0.3 second after a 50 microsecond nuclear burst when the total dose received exceeded 0.6 mR.

- The change in meter indication due to temperature was less than 10% over a range of -5 to 150°F.

- The alarm setpoint varied less than 1% over a 1-year test period.

INSTRUMENT DESCRIPTION

The NIM is a gamma radiation monitor with audible and visible alarms that are actuated when the monitor is exposed to a radiation rate exceeding one roentgen per hour (1 R/hr). The instrument is AC powered with a backup self-contained battery. The radiation detector is an air-filled ionization chamber. Current from the chamber is amplified and converted to a voltage signal by an electrometer amplifier. A voltage comparator monitors the voltage signal and energizes an alarm relay when chamber current exceeds a preset value. The relay actuates local and remote alarm bells and lights.

A fault detector monitors critical circuits and initiates a trouble alarm if a fault is detected. Operation of the trouble alarm prevents operation of the evacuation alarm and vice versa. A manual reset is required following actuation of either alarm. The instruments are "fail-indicating" in that most component failures will result in a trouble alarm and not an evacuation alarm. Most probable failure modes of electronic components, connector pins, wiring, and power supplies were simulated in the laboratory to test this feature. In all tests, a trouble alarm was generated.

Radiation intensity to 1.5 R/hr is indicated by a 0-5 VDC meter (Figure 1). Output is set at 1 VDC in a radiation field of less than 1 mR/hr. Overall dimensions are 20 in. length × 12 in. width × 17 in. height. Figures 2 through 5 show front, side, back, and inside views of the NIM.

Indicators

NIM conditions are displayed on external indicators (Figures 2, 3, and 5).

- Evacuation alarm light and bell

  The flashing red light and continuous bell are actuated by 1 R/hr radiation rate.

- Trouble light and audible signal

  The amber light and pulsating horn are activated by any one of seven abnormal instrument conditions.

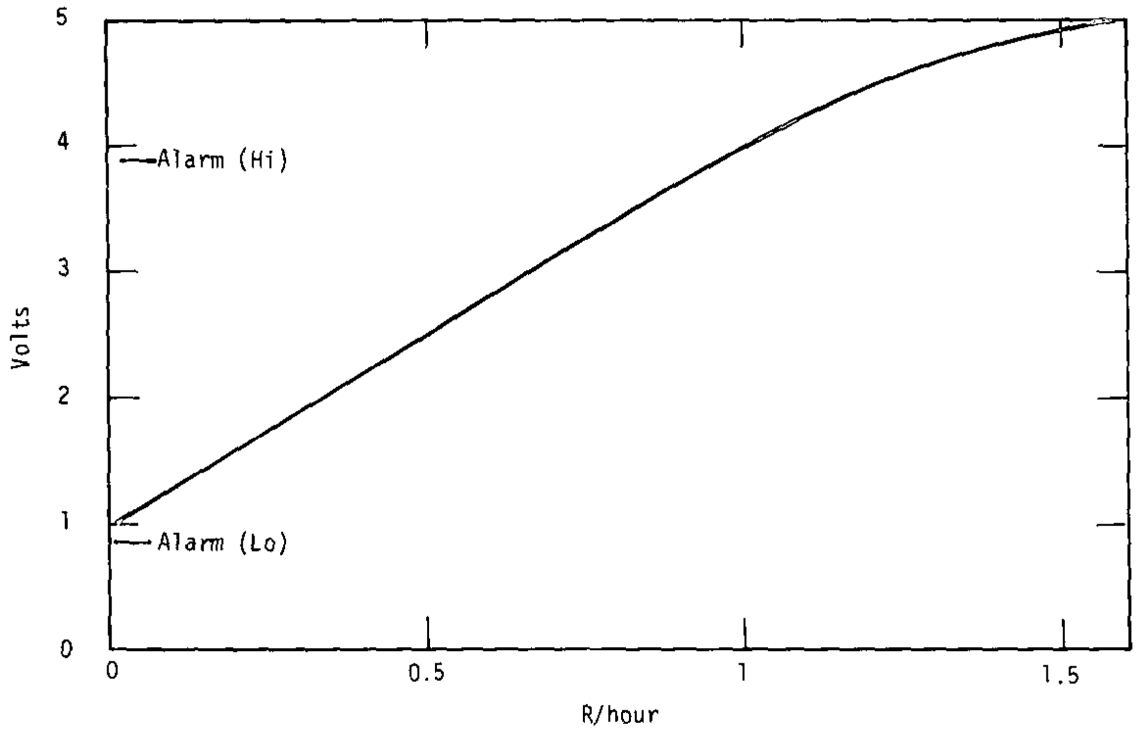

Figure 1. Typical NIM Sensitivity

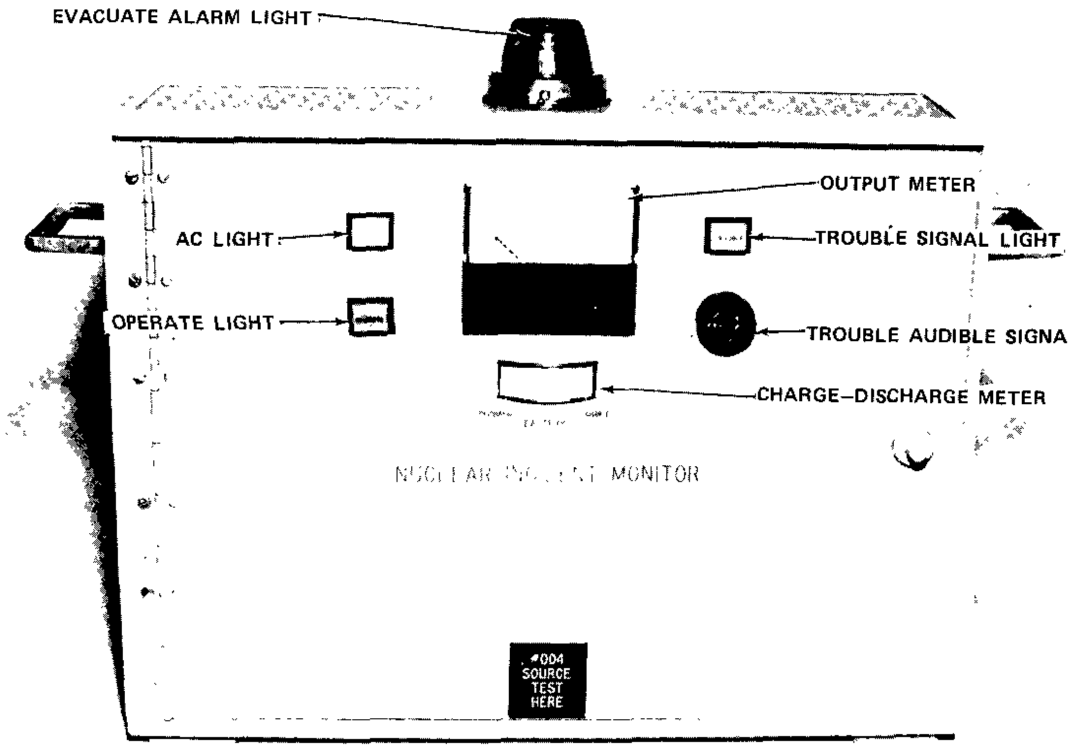

Figure 2. NIM Front View

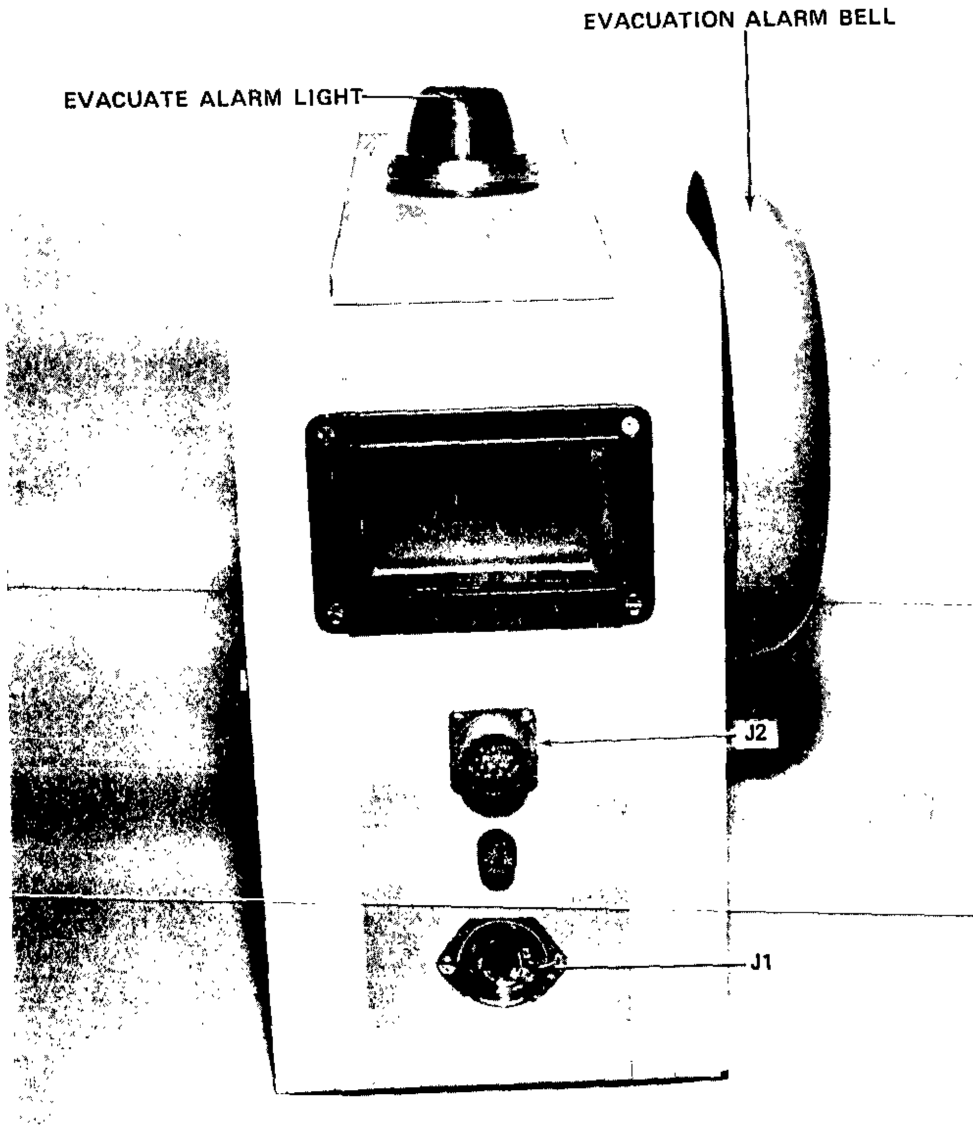

Figure 3. NIM Side View

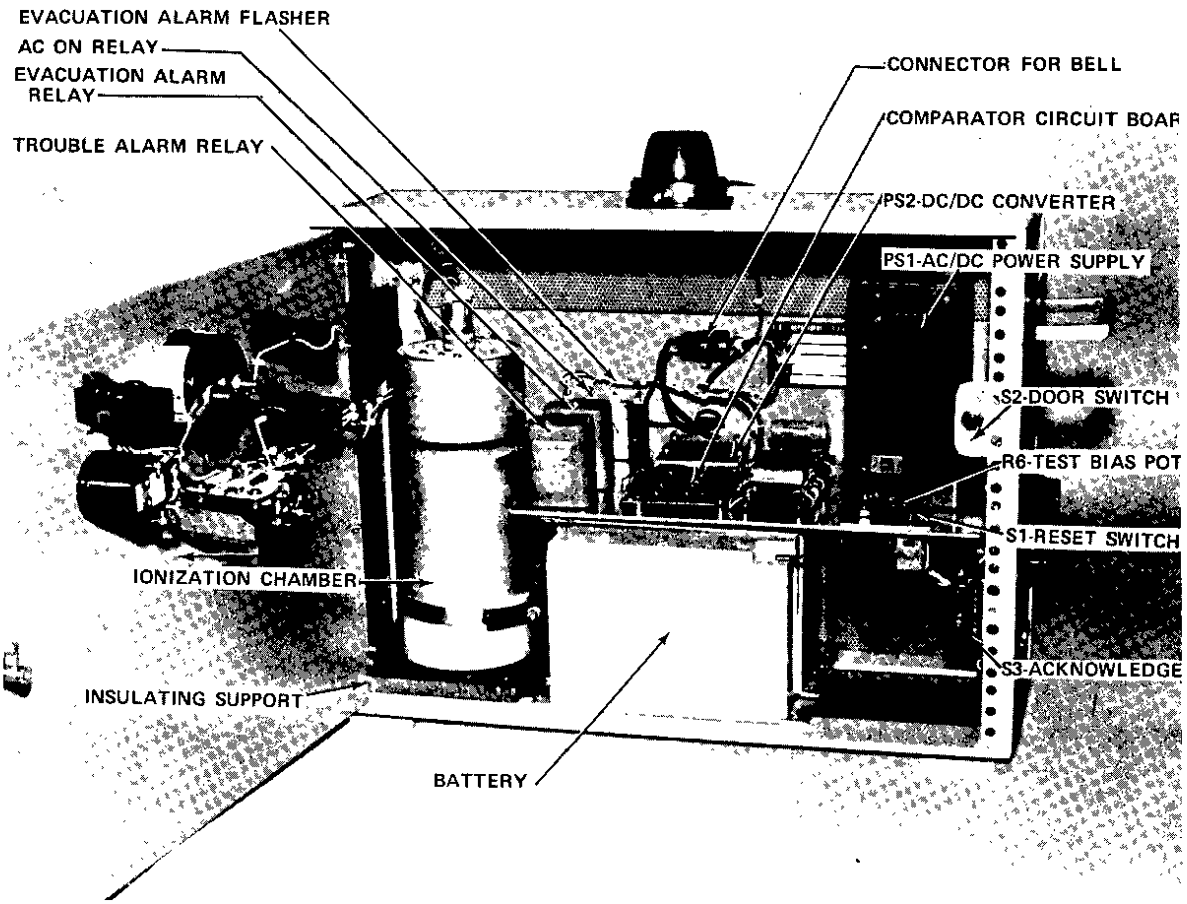

Figure 4. NIM Inside View

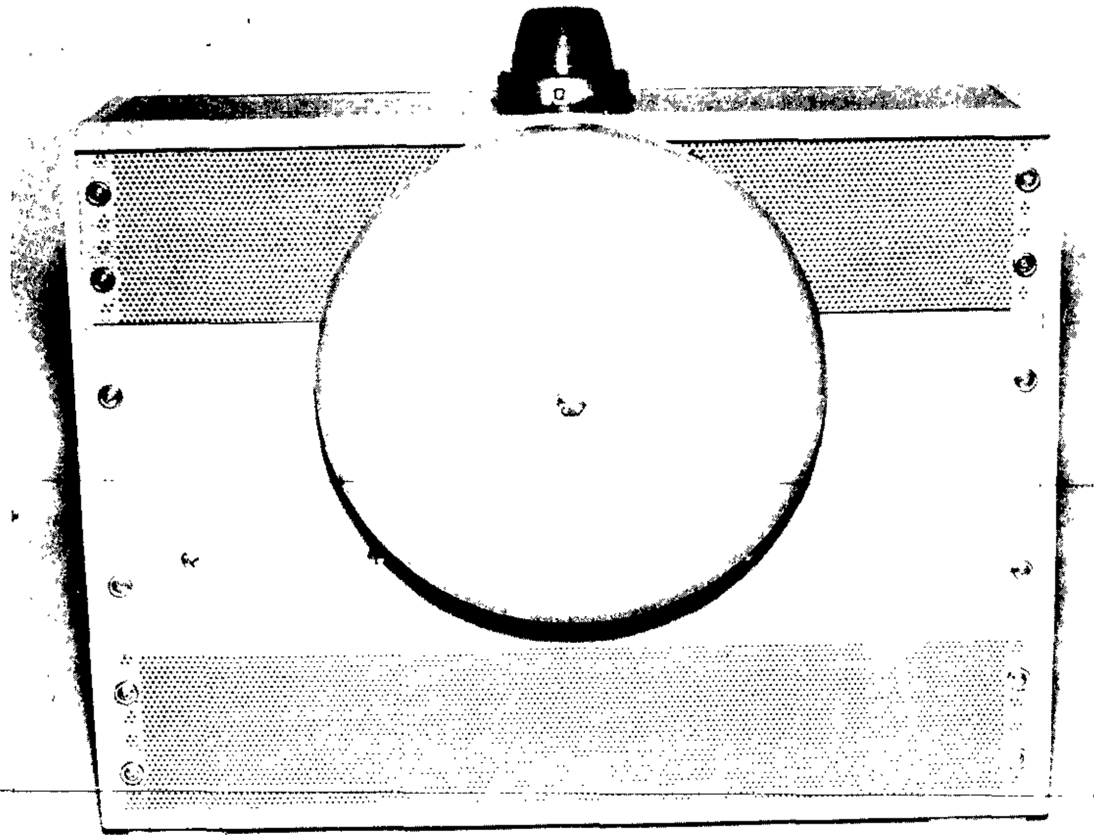

Figure 5. NIM Rear View

- Operate light

  The green light is on when conditions are normal.

- AC power

  The white light is on when the NIM is operating from 120 VAC line power.

- Output meter

  The 0 to 5 VDC meter indicates amplifier output voltage (response from 0 to 1 R/hr is 1 to 4 VDC).

- Charge/discharge meter

  Indicates battery charge/discharge current.

Remote Outputs

Relay contacts can be used to provide remote indication of an evacuation alarm, trouble, and loss of AC power through signal connector J2 (Figure 3). An internal jumper (Figure 6) is provided to allow external circuits to verify that the remote signal cable is connected to the NIM. A trouble alarm will cause K1 to drop out. Loss of AC power will cause K3 to drop out. K1 will initiate a remote trouble alarm through a contact closure between connector pins J2-E and J2-F. A loss of AC power or a malfunction may be detected by an opening of the circuit between connector pins J2-E and J2-D. Continuity between connector pins J2-B and J2-C provides a remote evacuation alarm when K2 is energized *and* the cabinet door is closed.

Radiation Detector

The radiation detector is an air-filled ion chamber (Figure 7). The outer wall of the chamber is energized to -15 VDC. Gamma radiation produces ionization in the air inside the chamber and the charge is collected by the inner electrode. The chamber current is approximately linear with radiation from 0-1 R/hr (Figure 8). Current at 1 R/hr is 3×10^{-11} A and leakage is less than 1×10^{-12} A. Chamber current is proportional to electrode length. At 1 R/hr, a 1/4-inch reduction in electrode length decreases the current by 17%. Proper choice of electrode length can be used to select a greater than 1 R/hr alarm point. Figure 9 is a plot of NIM voltage response versus radiation rate for various electrode lengths between 5-3/8 inch and 1/4 inch. For example, the use of a 1/2 inch electrode will cause an otherwise standard NIM to alarm at 25 R/hr and a 3/8 inch at 50 R/hr. (The amplifier's maximum output is 14 V.

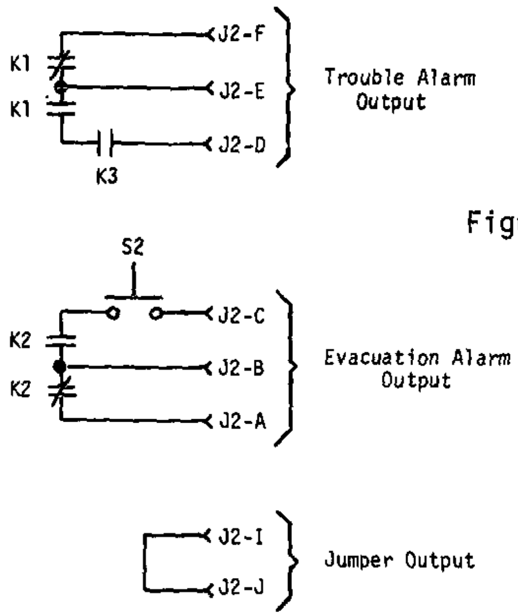

Figure 6. Output Circuits

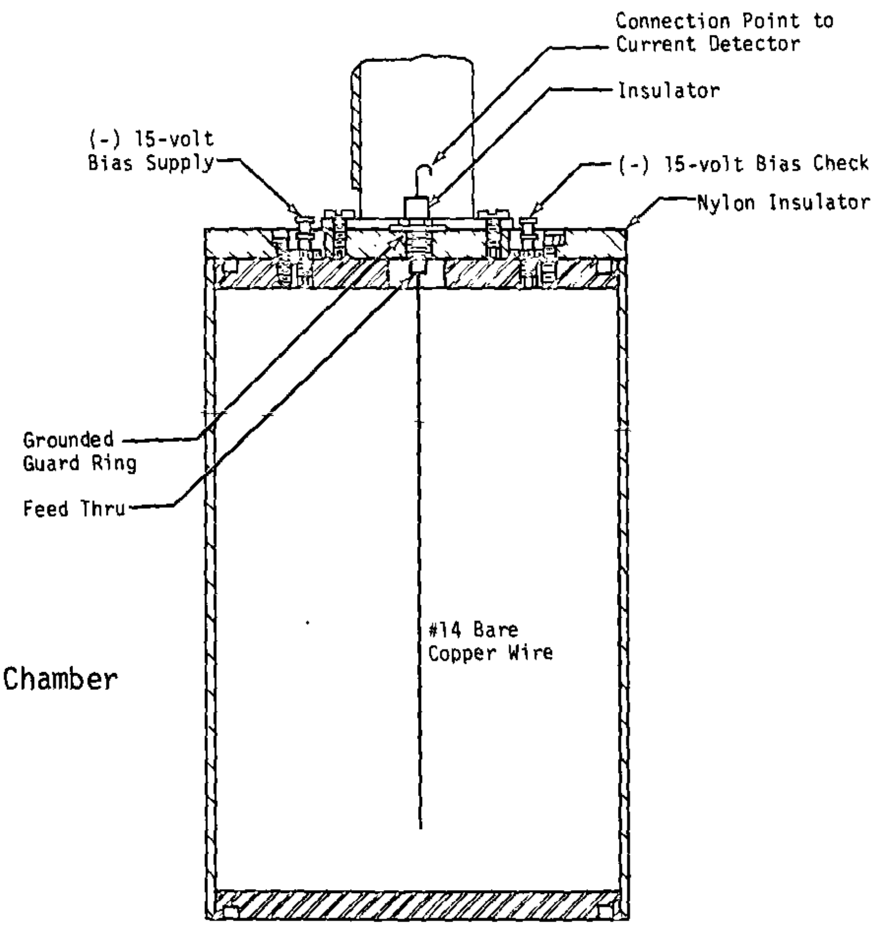

Figure 7. Ionization Chamber

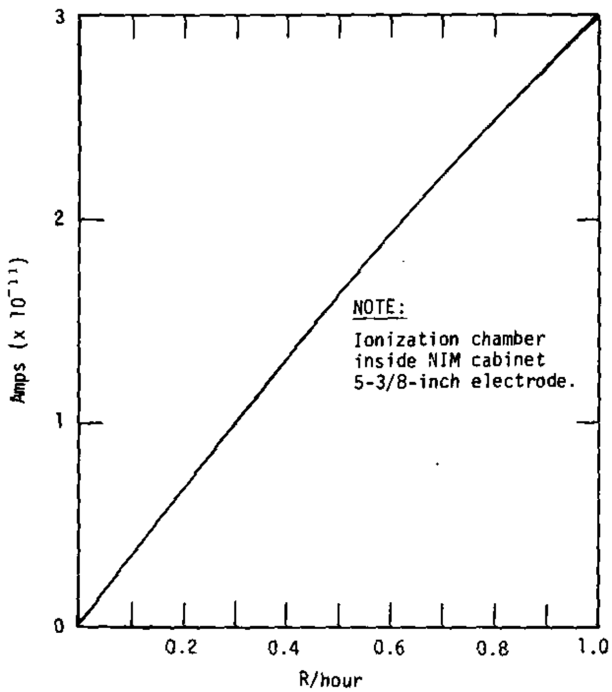

Figure 8. Typical Chamber Sensitivity

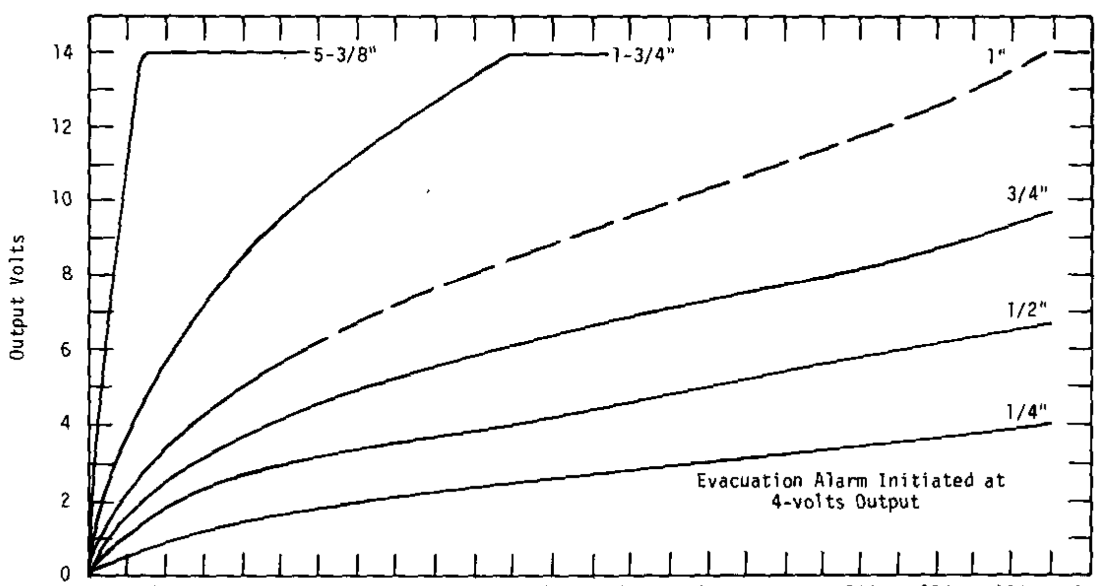

Figure 9. NIM Response Versus Electrode Length

The standard chamber is a 3-1/2-inch diameter by 6-inch tall aluminum canister with a 5-3/8-inch long, No. 14 AWG copper inner electrode. The insulated outer wall of the canister forms the outer electrode and is biased to -15 VDC. A grounded guard ring isolates the inner electrode from the outer electrode. The inner electrode is held at ground potential by the electrometer amplifier.

The chamber is insulated at the top and bottom. A polyester glass support is attached to the chamber bottom. The electrode to amplifier connection is isolated by grounded guard rings at the feedthrough and at the amplifier input. Two solder terminals are staked in place before assembling the ion chamber/amplifier. One terminal supplies the -15 VDC chamber bias and the other supplies -15 VDC to the test bias circuit. Loss of chamber bias results in a trouble signal initiated by the test bias circuit.

Amplifier

The amplifier is enclosed and shielded by a grounded aluminum cover and mounted on top of the chamber (Figure 10). A short length of wire connects the chamber electrode to circuit board input. A connector allows easy replacement of the amplifier assembly.

Chamber electrode current is converted to voltage by the amplifier at the ratio of 1×10^{-11} A per volt. A second source of current is supplied to the amplifier by the test bias circuit (Figure 11). This current provides a means of testing instrument response and alarm set points; it is normally adjusted so that the output meter reads 1 V in a radiation field of less than 1 mR/hr.

The test bias circuit is a current source which is electrically parallel with the ion chamber. It is powered from the -15 VDC bias on the ionization chamber; loss of ion chamber bias will cause the amplifier output to drop below 1 V. The fault comparator monitors the amplifier output and will initiate a trouble signal when the amplifier output goes below the 0.83 VDC set point. The test bias circuit provides a current source to the amplifier input which can be varied manually (R6) to test instrument response and alarm set-points. The test bias circuit has an output current range of 0 to 12×10^{-11} A and is normally adjusted so the amplifier output is 1 VDC in a radiation field <1 mR/hr. Ionization chamber current (I_S) and test bias circuit current (I_B) are summed and converted to a voltage signal (V_O) by the electrometer amplifier according to the equation:

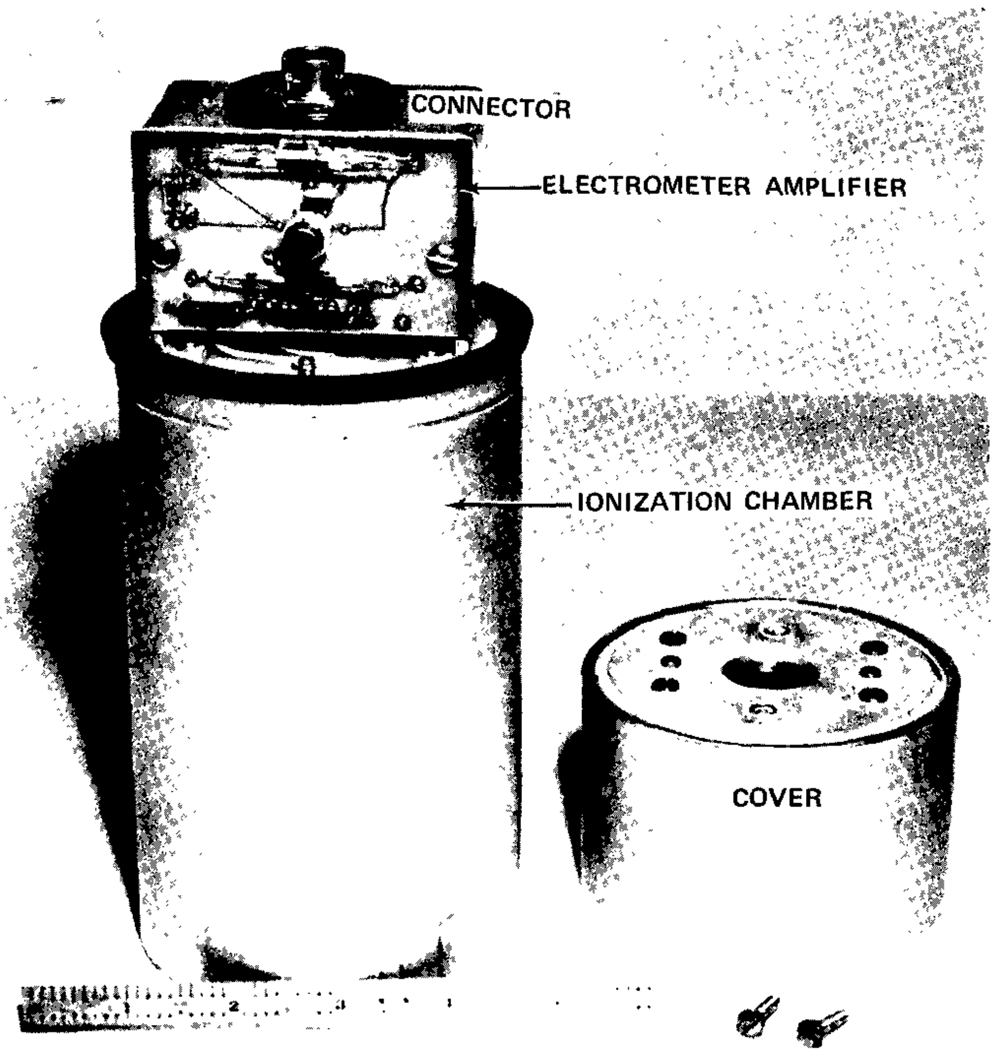

Figure 10. Ionization Chamber - Electronics

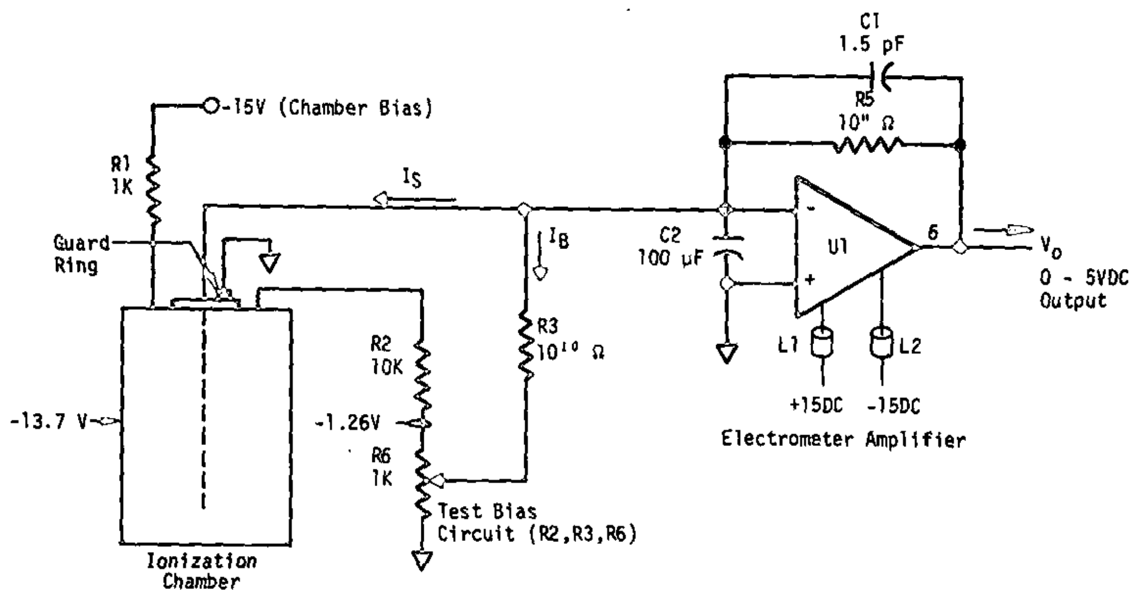

Figure 11. Simplified Chamber and Amplifier Diagram

$$V_O = (I_S + I_B)\ (1 \times 10^{11})$$

$$I_S \simeq 0$$

$$I_B = 1 \times 10^{-11} A$$

$$V_O = (0 + 1 \times 10^{-11})\ (1 \times 10^{11}) = 1\ V$$

In a 1 R/hr radiation field:

$$I_S = 3.0 \times 10^{-11} A$$

$$I_B = 1 \times 10^{-11} A$$

$$V_O = (3.0 \times 11^{-11} + 1 \times 10^{-11})\ (1 \times 10^{11}) = 4.0\ V$$

The amplifier holds the chamber inner electrode at virtual ground potential. The output voltage changes to equalize the potential between its inverting (-) and non-inverting (+) inputs. Since the non-inverting input is grounded, the amplifier holds the inverting input (which is connected to the inner electrode) at ground potential. The feedback resistance (R5,10^{11} ohms) establishes the magnitude of output voltage needed to produce the equalizing current at the inverting input.

The amplifier is a Burr Brown Model 3523L and was chosen for low bias current (1×10^{-13}A) and high input impedance ($>10^{13}$ ohms). C1 and C2 are low leakage glass type capacitors with $>10^{13}$ and $>10^{12}$ ohms leakage resistance, respectively. R3 and R5 are glass enclosed resistors, R1 and R2 are wire-wound resistors, and R6 is a 10-turn wire-wound potentiometer. Chokes L1 and L2 are used to provide RF isolation.

Evacuation Alarm and Trouble Signal

Comparator Circuits

Amplifier output voltage is supplied to the comparator board (Figure 12). Three integrated circuit comparators are used to initiate the evacuation alarms and trouble signals. Comparator U2 initiates the evacuation alarm when input voltage to pin 5 exceeds that to pin 4. Comparator U4 initiates the trouble signal, when the instrument door is opened, the bell circuit opens, or low battery voltage is detected. Comparator U3 initiates the trouble signal when voltage at input U3-5 is less than that at reference input U3-4 (0.83 V).

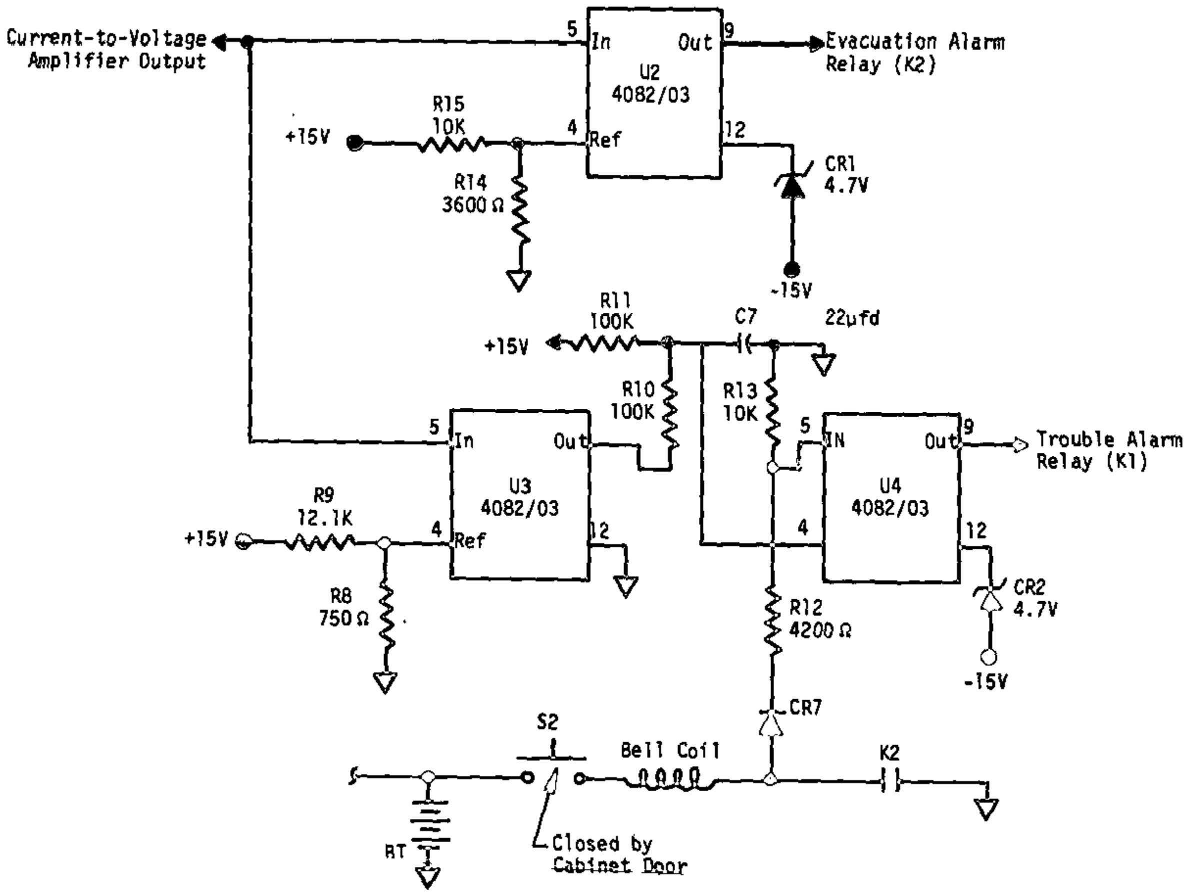

Figure 12. Simplified Alarm Circuits

U2, U3, and U4 are Burr Brown Model 4082/03, integrated circuit, voltage comparators. Each comparator is an electronic switch which energizes a relay coil when the signal at the input exceeds the reference voltage. The comparators are rated to carry a load of up to 100 mA. Maximum relay coil current is 16 mA.

The evacuation alarm relay, K2, operates the alarm bell and light when it is energized by comparator U2. The reference voltage (pin 4) for U2 is set to 3.95 V by R14 and R15. K2 is energized when the input voltage at U2-5 (amplifier output) exceeds 3.95 V.

The trouble signal is initiated when relay K1 is de-energized by the action of U3 or U4. This occurs when the 1 V (<1 mR/hr radiation) input to U3 drops below the 0.83 VDC reference voltage (set by R8 and R9). A 7.5 VDC reference is established for U4 (voltage divider R11, R10). U3 de-energizes the trouble signal relay (K1) when the amplifier output is less than 0.83 VDC. The input to U4 is the battery (BT) voltage (13.8 V nominal) divided to 9.7 VDC by R12 and R13. Normally the input (9.7 VDC) to U4 exceeds the reference voltage (7.5 VDC) and the trouble relay is energized through U4 and CR2. If the signal voltage to U3 drops below the reference voltage, U3 will operate to increase the U4 reference to 15 VDC and U4 will de-energize K1. A decrease in battery voltage from 13.8 to 10.7 V will also cause the signal to U4 to decrease below the reference and K1 will be de-energized. The signal to U4 is connected through a cabinet door switch and alarm bell circuit such that an open bell circuit or open cabinet door will remove the U4 input and de-energize K1. Pin 12 of U2 and U4 is connected to the -15 VDC power supply through a zener diode (CR2). This arrangement will cause K1 to de-energize and prevent K2 from energizing if either half of the ±15 VDC power supply fails. Capacitor C7 and resistors R10 and R11 provide a time delay to reduce trouble alarm response to transients.

Relay and Switch Logic (Figure 13)

Relay K1 is normally energized. De-energizing K1 operates the audible (DS3) and visible (I3) trouble signals through the acknowledge switch (S3). Relay K2 is normally de-energized. Energizing K2 operates the evacuation alarm bell DS2 and flashing light (I1). When K1 is de-energized (trouble signal) the evacuation alarm circuit is disabled.

To reset the evacuation or trouble signal, the Acknowledge switch (S3) is pulled out and the Reset button (S1) is depressed. S2 is held closed by the cabinet door. When the door is opened, S2 interrupts the evacuation alarm bell and remote evacuation alarm circuits. Closing the door automatically resets the Acknowledge switch S3. The Operate light is lit when the door is closed,

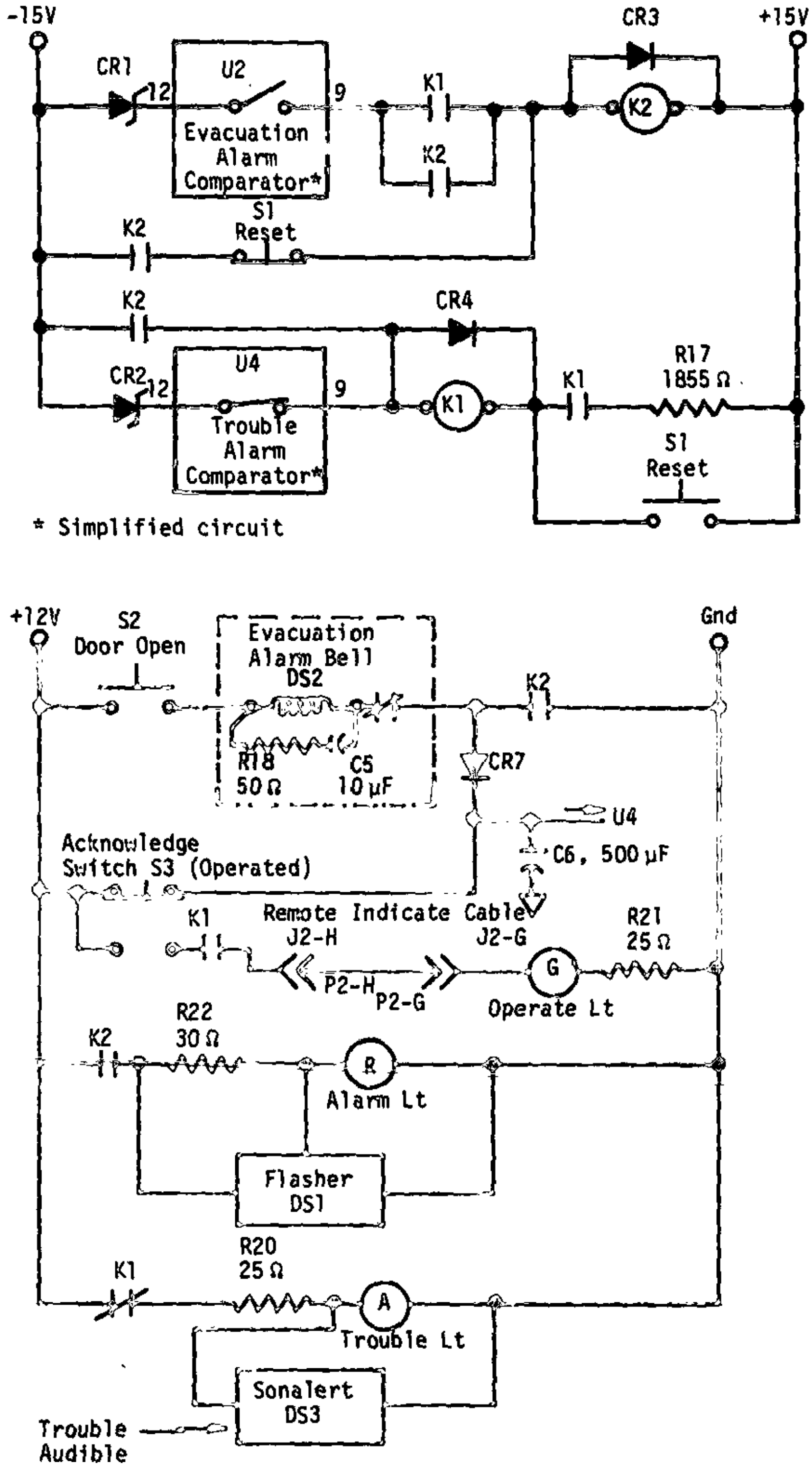

Figure 13. Relay Logic

K1 energized, and the remote indicating cable connected to J2. Capacitor C6 provides a short (<1 sec) time delay to prevent the trouble signal while the door is being closed.

K2 is energized by U2 for an evacuation alarm condition and sealed in by a set of its contacts through reset switch S1. K2 energizes the bell (through door switch S2), flasher, and evacuation alarm light.

The trouble signal relay is normally energized through U4. When energized, K1 contacts complete the evacuation alarm circuit and turns on the Operate light through Acknowledge switch S3. When K1 is de-energized, the evacuation alarm circuit is disabled and the trouble audible signal and light are turned on.

K1 and K2 are 6 PDT, hermetically sealed relays with bifurcated, gold plated-over-silver contacts. Nominal operating voltage is 30 VDC with pickup at 16 VDC and dropout at 5.5 VDC. The normally energized voltage relay, K1, is picked up at 30 VDC but is held in at 15 VDC through resistor R16 to extend relay life and reduce power consumption. R20, R21, and R22 are resistors that limit the power consumption of the indicating lights.

Power Supply

The power supply system (Figure 14) consists of two power supplies and a rechargeable battery. The 120 VAC to 15 VDC supply (PS1) will operate the NIM and charge the battery simultaneously. PS2 is a DC/DC converter supplying regulated ±15 VDC. The battery is a 12 VDC gelled electrolyte lead acid type. When voltage from PS1 decreases below battery terminal voltage, diode CR5 is back biased and the NIM is powered from the battery; when normal supply voltage is restored, the battery accepts charging current. PS3 is a voltage limiting device which shorts the output of PS1 if it increases to 16 VDC to prevent damage to the battery and/or PS2. If PS3 operates, light I4 will be turned off, relay K3 will be de-energized to indicate remotely the loss of AC power, and the battery will operate the NIM.

PS1 is a 120 VAC to 15 VDC, adjustable, 2.5 A power supply. The manufacturer's input voltage rating is 105 - 132 VAC. During laboratory tests, the supply output did not change significantly until the input had been decreased to less than 85 VAC. PS1 is adjusted (with battery disconnected) to provide 13.8 VDC to the battery terminal. The load on PS1 is about 300 mA plus battery charging current of from 0.02 to 1.8 A. Current load is limited to 2.5 A maximum and will operate the NIM and charge a "dead" battery simultaneously.

The negative battery terminal is grounded through a meter which indicates charging current or battery output. CR6 protects the meter from damage by high charging currents. The meter is 500-0-500 μA movement shunted with a 0.04 ohm resistor (R5) to change the range to 500-0-500 mA. R5 also provides a parallel current path in the event the meter coil opens. With the NIM reset to normal conditions and AC power off, the meter should indicate about 270 mA. The battery generates hydrogen at 1.8 cm^3/mA/hr while charging, and the NIM case is vented to prevent accumulating a dangerous hydrogen concentration.

Expected battery life is 4 to 6 years. To maximize shelf life, spare batteries should be stored fully charged and kept at a temperature between 0 to 40°F. Installed batteries should be tested yearly to assure operable condition. With AC power disconnected, the battery should be replaced if the trouble alarm is initiated within 24 hours because of low battery voltage. The battery should also be replaced if the trickle charge current varies from its normal charging characteristic.

PS2 is a DC/DC converter supplying regulated ±15 VDC (150 mA maximum). Output is constant at 15 ±0.011 VDC for input 10.7 - 13.8 VDC (11.0 VDC is the low battery fault point). Regulation is lost if the input drops below 9.5 VDC. Input current to PS2 is about 150 mA. The load on the +15 VDC output is about 40 mA and about 30 mA on the -15 VDC output. At a room temperature of 79°F, the surface temperature of PS2 is about 95°F. Thermal compound is used between PS2 and the top mounted heat sink to assure adequate cooling.

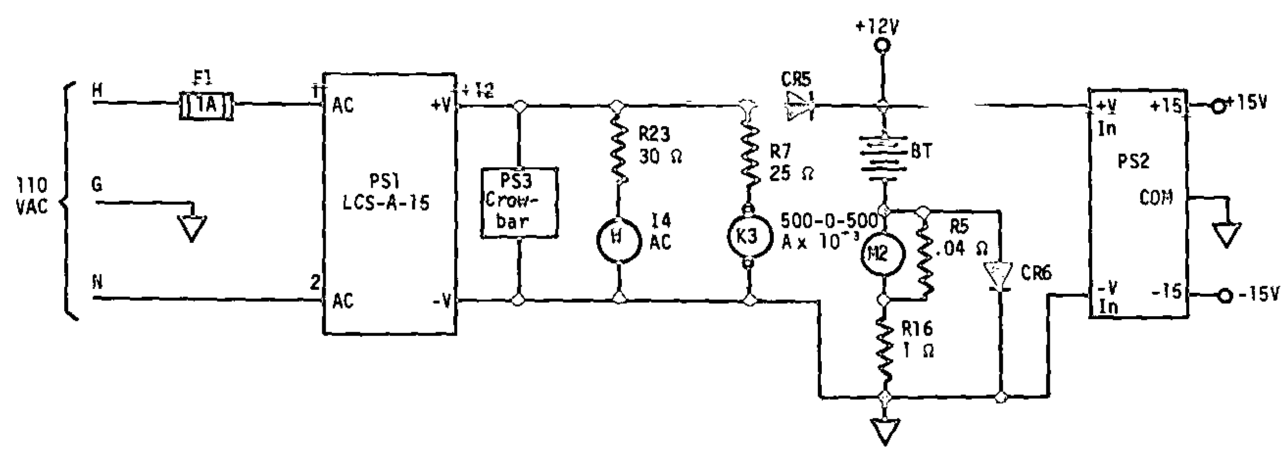

Figure 14. Power Supply

COMPONENT LIFE EXPECTANCY

The estimated mean time between failures (MTBF) for major components are listed below. All other components are estimated to have a MTBF greater than 50 years.

Part No.	Description	MTBF (yrs)	Information Source
U1	Operational Amplifier	10	Vendor
U2-U4	Comparators	10	Vendor
K1,K3	Relay-Normally Energized	10	Estimated
K2	Relay-Normally De-energized	50	Du Pont
PS1	Power Supply - AC/DC	10	Vendor
PS2	Power Supply - DC/DC	9	Vendor
BT	Battery	4	Vendor
I2,I4	Lamp Bulb - Normally on	3	Vendor
R6	Variable Resistor	20	Du Pont

NIM's should be checked monthly using the procedure in Appendix 1.

Note: Opening the door actuates the trouble signal. To silence the trouble signal, pull out the Acknowledge switch (S3) and press Reset switch (S1). When the door is reclosed, the Acknowledge switch is automatically reset and the NIM is ready for service.

CALIBRATION

The evacuation alarm calibration should be verified at least once per year using a 1 R/hr gamma source. The NIM (containing the ion chamber) should be centered over the source. Failure to alarm at 1.0 ±0.1 R/hr from a ^{60}Co gamma source indicates a malfunction in the instrument.

A 1.0 R/hr radiation field causes a 3.0 VDC increase in the amplifier output. The amplifier output is normally biased to 1.0 VDC. The trouble (low) signal and evacuation (high) alarm set points are preset to 0.83 and 3.95 VDC, respectively. The set points may be tested by using the test bias control (R6). Instrument output voltage at meter M1 terminals should respond to potentiometer R6 wiper voltage adjustment at the ratio of 10 to 1 (Figure 15). Reducing the amplifier output to 0.83 ±0.05 VDC as indicated by the front panel meter should actuate the trouble signal. Increasing the output to 4.0 ±0.1 VDC should actuate the evacuation alarm.

In a radiation field of <1 mR/hr, the amplifier output should be set to 1.0 V. If the test bias circuit is adjusted for an amplifier output less than 1.0 VDC, more than 1 R/hr will be required to initiate an alarm.

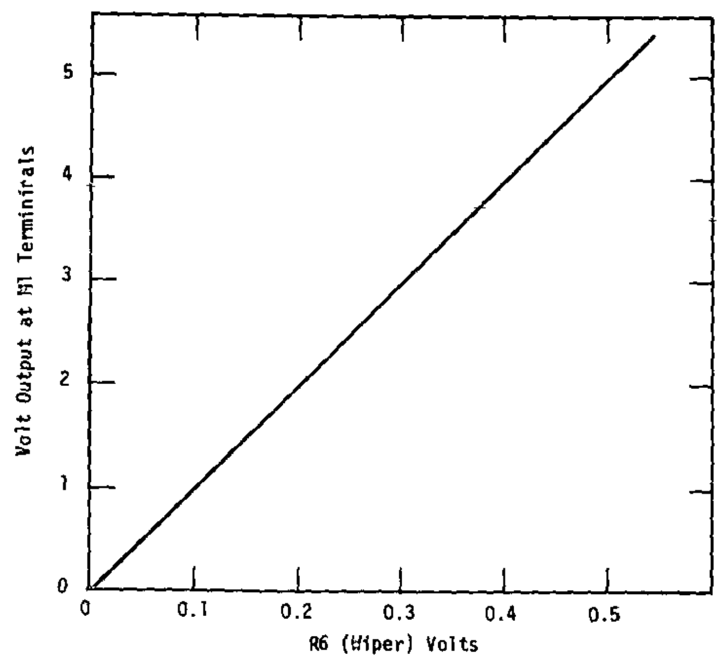

Figure 15. Output Versus R6 Wiper Voltage

LABORATORY TESTS

The five prototype NIM's have been tested for drift, set-point accuracy, gamma response, X-ray burst, temperature stability, AC supply variation, battery performance, and response due to single component or connection failure.

Long-Term Stability

Conservative design precludes the necessity of component selection or individual instrument adjustment. Among the 5 prototypes, there was virtually no instrument-to-instrument variation in calibration. Following assembly, the gamma response and alarm point accuracy was periodically tested over the 14-month evaluation period. Test results indicated negligible drift with time.

X-ray Burst Test

A 3.6 R, 0.1 second x-ray burst caused each NIM to alarm within 0.3 second (Figure 16). The instruments were exposed to 30 consecutive 0.1 second bursts. Thermoluminescent dosimeters (TLD) were used to determine the average dose per burst.

Temperature Stability

Tests were made to determine temperature sensitivity of the NIM. Amplifier output may shift 1-6% of full scale (FS equals 5 VDC over a temperature range of -5 to 150°F). The test/bias circuit was used to set the output to 2.5 VDC (approximately equivalent to 0.6 mR/hr) at room temperature. The output shift is caused partly by electrometer amplifier bias current changes. Bias current is about $\pm 0.1 \times 10^{-12}$A at 77°F and doubles every +18°F.

AC Supply Variation

Tests showed that the response is not affected by AC supply variation. Transients are filtered by the AC/DC power supply. Reducing the AC voltage causes the AC/DC output voltage to drop below its normal 14.5 VDC and at that point the battery automatically supplies the NIM.

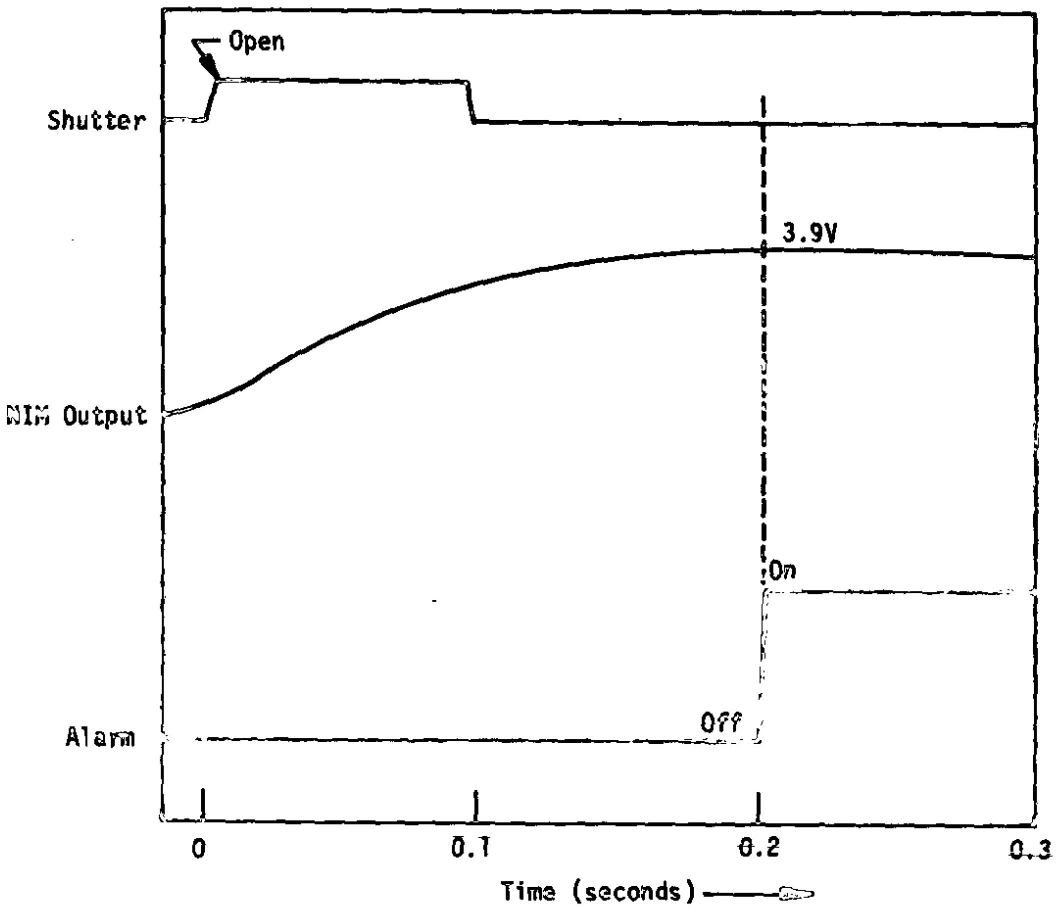

Figure 16. Shutter Test – X-ray Burst

Battery Performance

A fully charged battery will operate the NIM for about 60 hours (Figure 17). When the terminal voltage reaches 11 VDC the NIM trouble signal is initiated. At a battery voltage of 10 VDC, an evacuation alarm (bell and flashing light) can still be sustained for 8 hours. A discharged battery (<10 VDC terminal voltage) will fully recharge in 24 hours when AC power is applied (Figure 18).

Fail Indicate Criterion

Prevention of false alarms is an important design criterion. To reduce the probability that a component or wiring failure could cause an evacuation alarm, the instrument was designed to indicate such failure by initiating a trouble signal. This fail-indicate criterion determined much of the wiring arrangement as well as the schematic design. All of the fail-indicate circuits were tested in the laboratory to assure proper performance.

A trouble alarm or fail indication is provided for the following conditions:

- The alarm relay is normally not energized. To initiate an alarm, the relay requires both +15 VDC and -15 VDC. Loss of either +15 VDC or -15 VDC will drop out the normally energized trouble relay and the power loss will be indicated. The alarm relay cannot be energized until the trouble is cleared.

- Ion chamber excitation is monitored by the test/bias circuit to assure that adequate collection potential exists. Chamber voltage of less than a negative 11.45 VDC initiates a trouble signal.

- An open bell circuit, open door, or amplifier failure also are indicated by the trouble alarm.

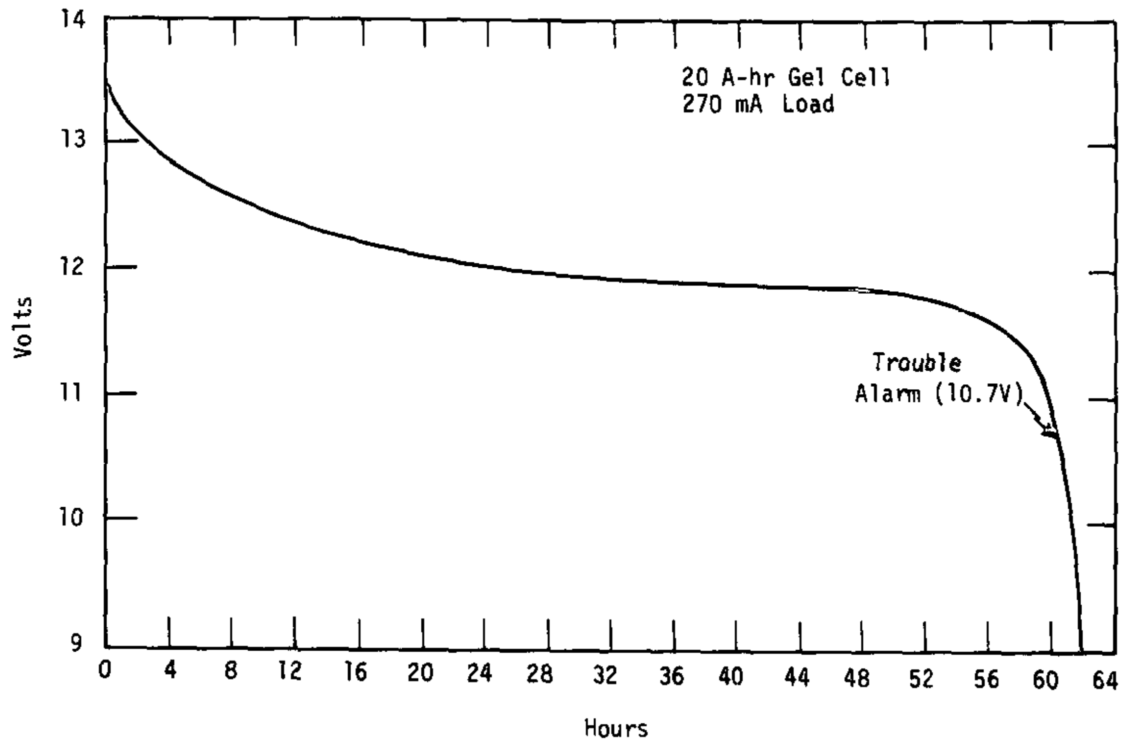

Figure 17. Battery Discharge Curve

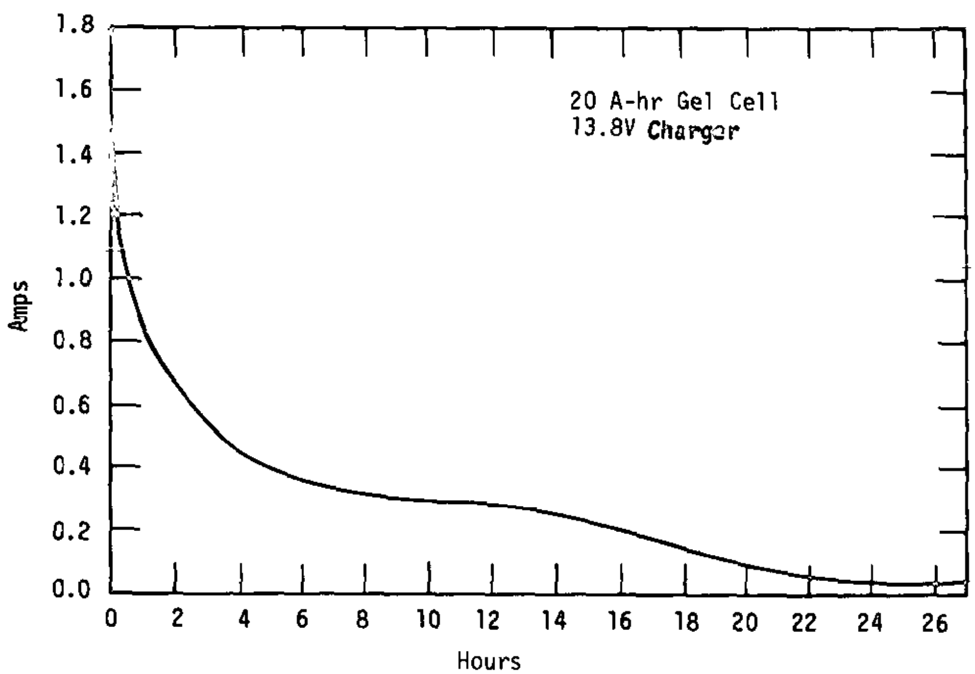

Figure 18. Battery Charging Current

FIELD TESTS

The five prototype NIM's were installed in plant locations chosen to subject the instruments to worst-case field environmental conditions. The prototypes were checked monthly by the E & I personnel using the field check procedure. One failure was experienced during six months of field testing. A rechargeable battery failed due to insufficient acid fill by the manufacturer. Failure was indicated by the trouble signal when the 120 VAC power was disconnected as part of the routine monthly inspection.

Burst Reactor Tests

The ultimate test of a NIM is the demonstration of proper operation during a fission burst. The existing "vacuum tube type" NIM was tested at the White Sands Fast Burst Reactor Facility (FBRF) in 1970. Tests confirmed that instruments set to alarm in a constant radiation field of 1 R/hr would alarm in about 1 second, 1200 feet from a burst of 5.24×10^{16} fissions, and alarm in 0.38 second at 4.5 feet from a burst of 5.24×10^{16} fissions.

Following development of the new NIM, tests were necessary to determine that it also would respond reliably to a criticality accident. The objectives of the tests were to determine the maximum distance from a criticality accident at which the NIM would alarm, and demonstrate that it would alarm and survive when exposed to a close burst of neutrons and gamma radiation typical of those having accidentally occurred at other nuclear processing sites.

Oak Ridge Test

One of the prototype NIM's was exposed to a 3.9×10^{16} fission burst at a position two meters from the Oak Ridge National Laboratory burst reactor. No recordings were made, but audio visual monitoring indicated no delay in the initiation of the evacuation bell and flashing light following the 130 microsecond duration burst.

White Sands Test

The five prototypes were then tested at the FBRF. The NIM's were located in line of sight with the burst reactor. A 50 microsecond duration burst of 4.7×10^{16} fissions was sufficient to cause a NIM 2300 feet away to alarm. Elapsed time between burst and alarm was 0.2 second. Three NIM's 15 feet from the reactor each alarmed in 0.025 second and were not damaged by the burst. The total dose exposure of NIM's resulting in alarms ranging from 0.7 mR to 1R gamma radiation. At the conclusion of the tests, four of the prototypes had each been exposed to three bursts. The fifth NIM (previously tested at Oak Ridge) was exposed to four bursts, two of which were close to the reactor. The five NIM's were each subjected to extensive inspection and testing following the burst tests. The NIM's were not damaged by the burst tests, and the instruments were unchanged from their initial calibrations. The reactor/NIM test arrangement is shown in Figure 19. NIM response was recorded with an oscillograph located in a cell below the reactor. Thermoluminescent dosimeters (TLD) placed at 100-foot intervals from the 100 to the 1000 foot mark and at each NIM location provided accurate gamma dose data during each burst (Figure 20). Neutron dose was measured using a neutron dosimeter strapped to a polyethylene bottle filled with two gallons of water and placed at the 1000 foot mark.

Burst test data are summarized in Table 1 and plotted in Figure 21. The five NIM's were exposed to three reactor bursts of varied size and duration. Out of 15 exposures, there were two "no alarm" conditions. During test number one, a pre-burst trouble condition prevented the NIM at 700 feet from alarming. During test number 3, dosage was 15% less than the alarm setpoint at the NIM located 2550 feet from the reactor. Dosage at the 2300 feet location was 15% greater than the alarm setpoint. The minimum time to alarm following initiation of a burst was 0.025 second (the operating time of the relay). The maximum alarm delay recorded was 0.2 second (test 3 at 2300 feet).

The total dose calculated was verified by total dose measured (Table 2). The calculations are based on measured reactor temperature rise, and the measured burst time. Beyond 1000 feet, the TLD data became scattered (Figure 20).

Reactor power in fissions is calculated based on ΔT (°C). Reactor time is measured. The number three burst test included three NIM's spaced 15 feet from the reactor. Each alarmed within 0.025 second. Subsequent tests at SRP indicated that the NIM's were not damaged by proximity to the burst.

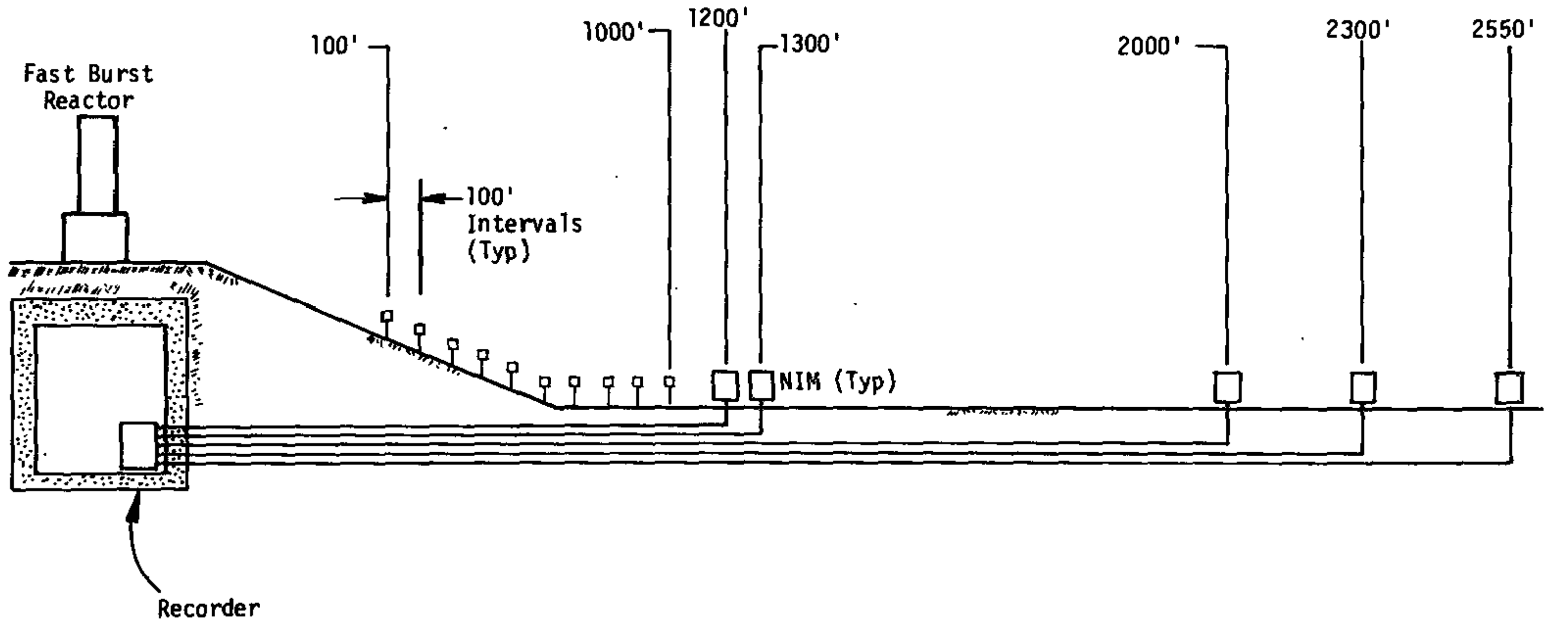

Figure 19. White Sands Test Arrangement

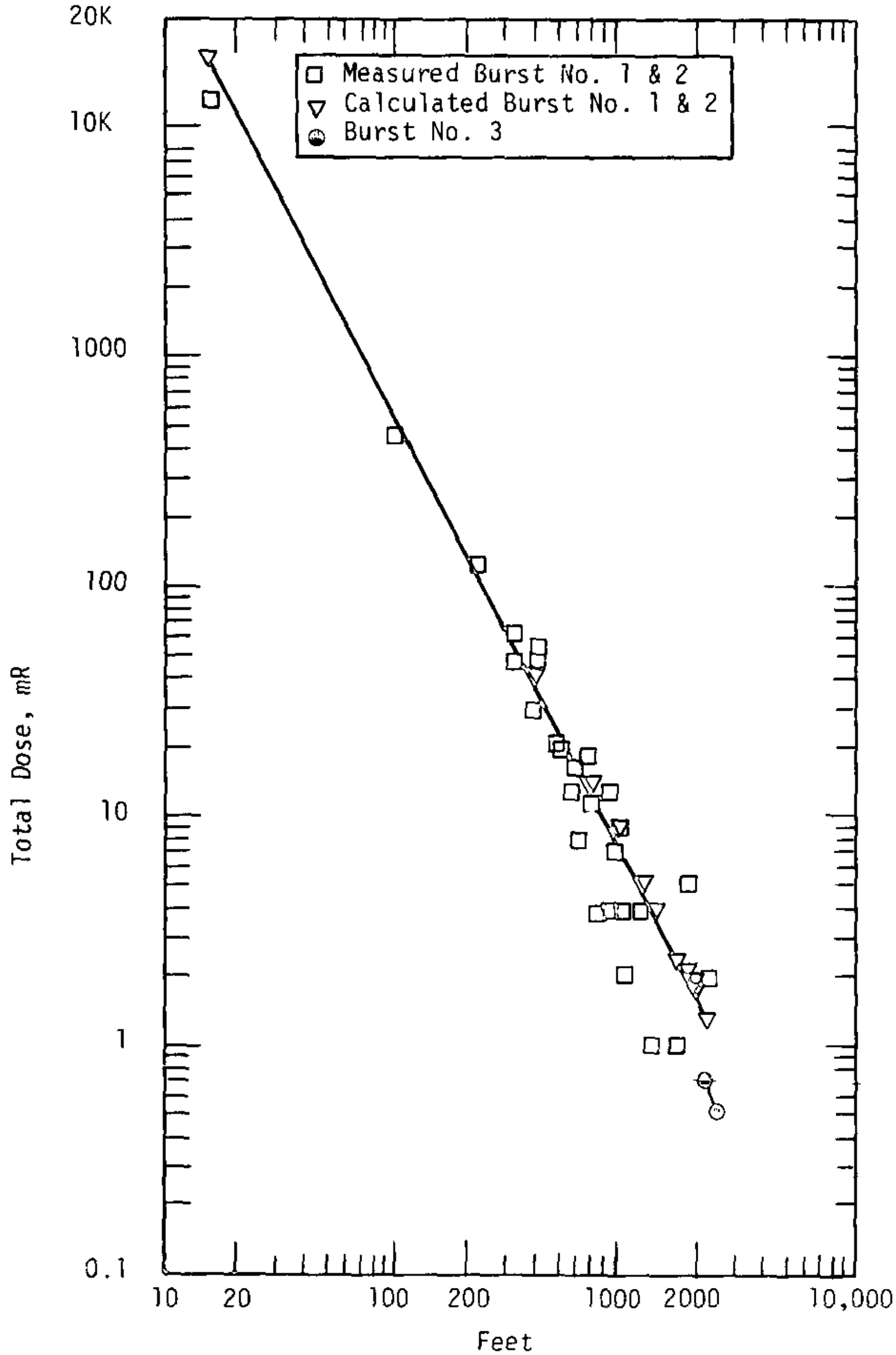

Figure 20. TLD Data

TABLE 1

White Sands Burst Test Data Summary

Test No.	*Distance of NIM from Reactor (feet)*	*Exposure Rate (R/sec)*	*Total Dose (mR)*	*Time to Alarm (sec)*	*Reactor Power (fissions)/time*
1	400	868	43	0.025	7.25×10^{16}/45 μsec
	700	283	14	No alarm	
	900	171	9	0.025	
	1200	96	5	0.025	
	1300	82	4	0.025	
2	1700	48	2.4	0.025	7.20×10^{16}/47.5 μsec
	1800	43	2.2	0.025	
	1900	39	2.0	0.025	
	2000	35	1.8	0.025	
	2300	26	1.3	0.10	
3	15	3×10^5	15 R	0.025	4.7×10^{16}/58 μsec
	15	3×10^5	15 R	0.025	
	15	3×10^5	15 R	0.025	
	2300	14	0.7	0.20	
	2550	11	0.5	No alarm	

TABLE 2

Fast Burst Reactor Calculation Technique

Test No.	*Burst Reactor ΔT, °C*	*Effective Burst Width, μsec*	*Total Dose at 200 in.*	*Dose Rate at 1000 ft*	*Total Dose at 1000 ft*
1	241	47	24.1 R	140 R/sec	6.6 mR
2	235	47.5	23.5 R	136 R/sec	6.5 mR
3	156	58	15.6 R	75 R/sec	4.45 mR

Dose rate = $(0.1)\ (\Delta T)\ R = (0.1)\ (241)\ R = 24.1\ R$ at 200 in.

Dose rate = $24.1/47 \times 10^{-6} = 5 \times 10^5$ R/sec. at 200 in.

Dose rate = $(5 \times 10^5)\ (200/12{,}000)^2 = 140$ R/sec. at 1000 ft.

Total dose = $(140)\ (47 \times 10^{-6}) = 6.6$ mR at 1000 ft.

During each test, the NIM output signal was maximum about 0.3 second after burst initiation and independent of dose rate. The five curves shown (Figure 21) correspond to dose rates from 11 to 82 R/sec. The delay in response to the burst is caused by ion chamber collection and recombination rates, and circuit time constants. Circuit time constants require that the NIM output exceed the 4 V (1 R/hr) set point for at least 0.025 second to guarantee operation of the alarm. A longer response time would result in a reduction of sensitivity. The 1.3 mR total dose (Figure 22) produced a signal which was above the set point for almost 1.0 second. Significant short-lived radioactivity was induced in NIM's exposed to those bursts. The AC/DC power supply and three relays remained radioactive for the longest period of time. The immediate effect, estimated to have been several R/hr, had decayed to normal background within about 3 hours.

After the burst tests, the five prototypes were re-tested for gamma response, set point accuracy, and temperature sensitivity. The tests indicated no significant change in specifications.

- Alarm set points were within 1% of the original values.
- The evacuation alarms operated when exposed to 0.98 R/hr gamma radiation.
- Output variation due to ambient temperature was less than 10% of full scale over a (-) 5 to (+) 150°F change.

Three of the five instruments tested at White Sands had alarm bell failures. In each case the bells rang normally for at least 15 minutes. An improved bell design submitted by the manufacturer has been tested and found to operate for 8 continuous hours without failure. The improved type bell is presently being used as a spare part for the existing NIM's.

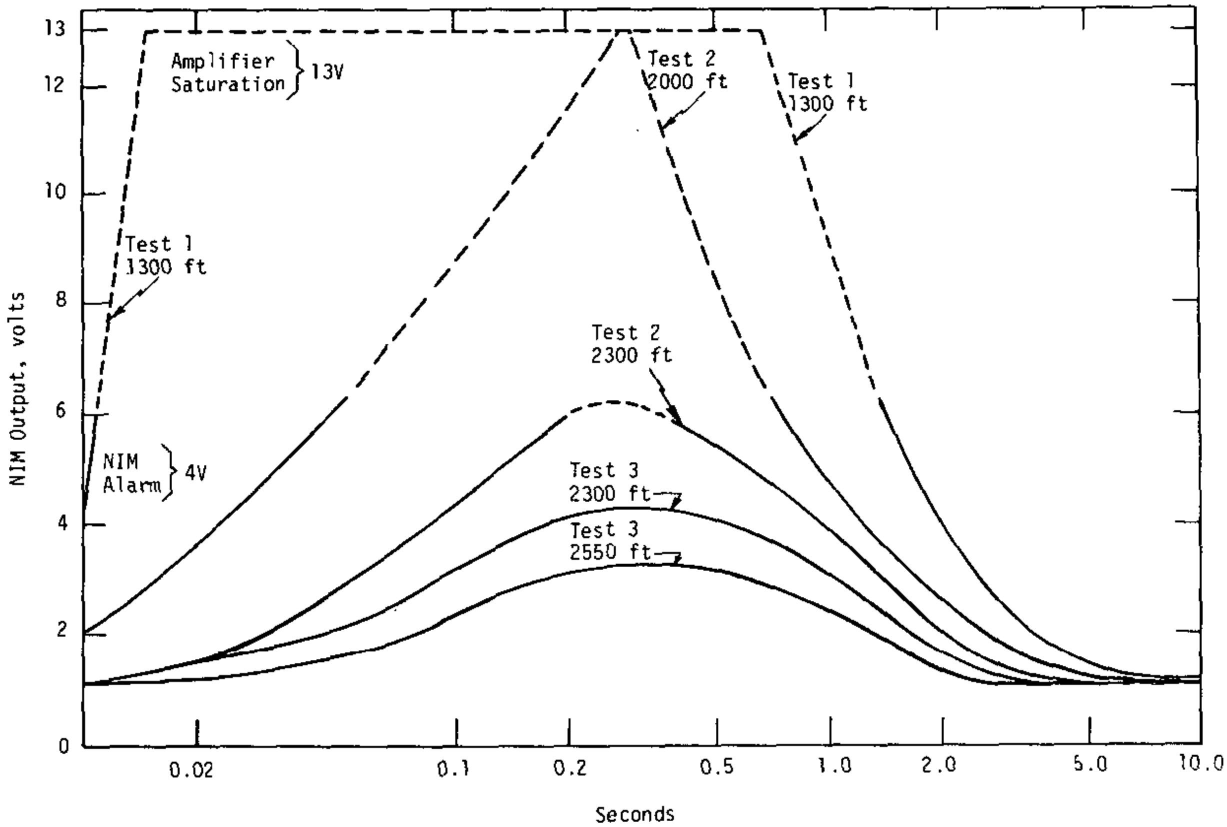

Figure 21. NIM Response Versus Distance

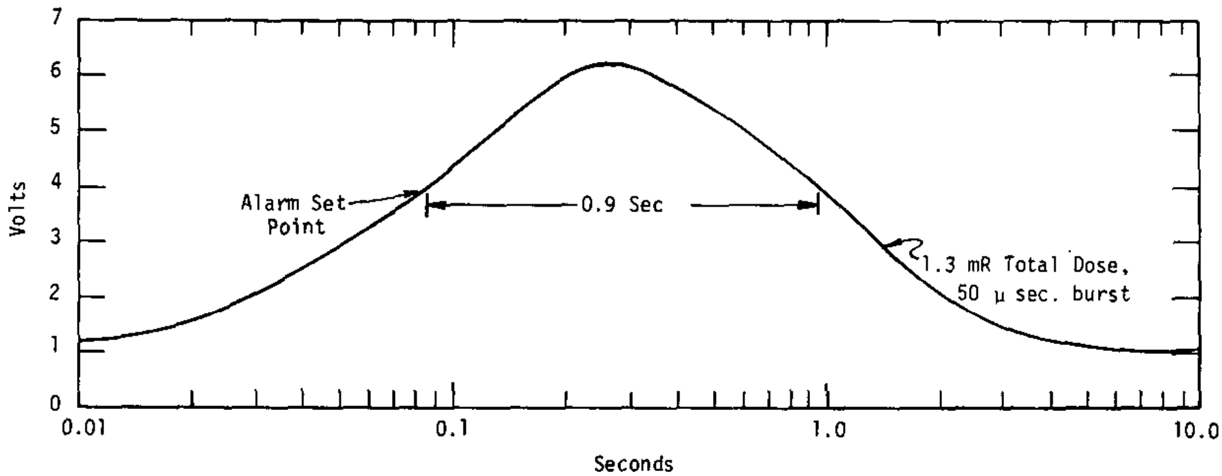

Figure 22. NIM Response to 58 Microsecond Burst

Appendix A

FIELD CHECK PROCEDURE

1. Record the following:

   a. AC light on ________.

   b. OPERATE light on _______.

   c. DC Voltmeter reading________V.

   d. BATTERY METER reading ______DISCHARGE
CHARGE

   e. NIM Serial Number____________

   f. Tested by____________________

2. Open door on NIM. Trouble light should come on and alarm should sound.__________
   Using the bias potentiometer, adjust the DC voltmeter reading to 1.2 volts.

3. Lifting slightly, pull out door switch and depress reset pushbutton. Trouble alarm should cease.___________

4. Slowly turn bias potentiometer counterclockwise and observe DC voltmeter reading when trouble alarm sounds. The alarm must sound between 0.7 and 1.0 volt. Record _________ V.

5. Adjust bias potentiometer for voltmeter reading of 1 volt. Depress reset pushbutton. The alarm should cease.

6. Connect negative test multimeter lead to NIM ground.

7. Connect positive test multimeter lead to power supply side of CR5 (right side of first diode on component board). Voltage must read 14.4 ± 0.5 VDC. Record __________V.

8. Move positive test multimeter lead to battery (left) side of CR5. Voltage must read 13.7 ± 0.3 VDC. Record __________V.

9. Unplug AC cord. Voltage must read 13.2 ± 0.2 VDC. Record __________V. Plug AC cord into NIM.

10. Move positive test multimeter lead to left side of R17 (first resistor on component board). Voltage must read ±15.0 ± 0.1 VDC. Record +__________V.

11. Move positive test multimeter lead to left rear wire terminal of comparator P. C. board. Record__________V.

12. Remove both multimeter test leads, <u>leave door open</u>. If low alarm sounds, repeat step 3.

13. Position source to produce 500 mR/hr near center of chamber.

14. Slowly move source toward NIM until red light on top starts flashing.

15. Verify and record radiation dose rate required to activate light. ________mR/hr (Must be between 900 and 1200 mR/hr.)

16. Remove source.

17. Lift door switch plunger and pull to OUT position. Depress reset pushbutton and close door.

18. Observe that voltmeter reads 1 volt and AC and OPERATE lights are on.

19. Remove from service any NIM that is out of tolerance.

Appendix B

DRAWING LIST — SOLID STATE NUCLEAR INCIDENT MONITOR

Drawing No.	*Title*
S5-G-352	Schematic Diagram
S5-G-353	Connection Diagram
S5-G-354	Details — Sheet No. 1
S5-G-355	Subassembly and Component Layout
S5-G-356	Enclosure Cutout Details
S5-G-357	Assembly
S5-G-358	Ion Chamber — Subassembly and Details

Appendix C

NIM PARTS LIST

Component	Print/Part Number	Description	Required/ NIM
Switch S1	357/18	Series PB Pushbutton, Cat. #202PB3-T 2PDT Microswitch - Honeywell	1
S2	357/17	Series PB Pushbutton, Cat. #3PB12 3PDT Microswitch - Honeywell	1
S3	357/37	Door Interlock Switch, Cat. #2AC57 SPDT operate on manual pull Microswitch - Honeywell	1
Potentiometer R6	357/19	1000 ohm, 10 turns, bushing mount sealed, Nichrome wirewound Part #3500S 21-102, Bourns Trimpot Div.	1
	357/19	1/4 inch Shaft lock, James Millen 10061	1
Resistor R4	358/15	100,000 megohm, 1%, Precision Glass Encapsulated Type RX-1, Hi-Meg, Victoreen VLN Corp.	1
R3	358/18	10,000 megohm, 1%, Precision Glass Encapsulated Type RX-1, Hi Meg, Victoreen VLN Corp.	1
R9	355/2	12,100 ohm wirewound 1% RS-2B, 3 watt Dale	1
R2	358/3	10,000 ohm wirewound 1% RS-2B, 3 watt Dale	1
R10	355/3	100,000 ohm wirewound 1% MFS, 1/2 watt Dale	1
R11	355/3	100,000 ohm wirewound 1% MFS, 1/2 watt Dale	1
R13	355/3	10,000 ohm wirewound 1% RS-2B, 3 watt Dale	1
R15	355/3	10,000 ohm wirewound 1% RS-2B, 3 watt Dale	1
R12	355/4	4,200 ohm wirewound, 1% RS-2B, 3 watt Dale	1
R14	355/5	3,600 ohm wirewound, 1% RS-2B, 3 watt Dale	1
R17	359/47	1,855 ohm wirewound, 1% RS-2B, 3 watt Dale	1
~~R1~~	~~357/4~~	~~1,000 ohm wirewound, 1% RS-2B, 3 watt Dale~~	~~1~~
R8	355/1	750 ohm wirewound, 1%, RS-2B, 3 watt Dale	1
R7	357/44	25 ohm wirewound, 1% RS-2B, 3 watt Dale	1
R20	357/44	25 ohm wirewound, 1% RS-2B, 3 watt Dale	1
R21	357/44	25 ohm wirewound, 1% RS-2B, 3 watt Dale	1
R19	357/19	20 ohm wirewound, 1% RS-2B, 3 watt Dale	1
R16	357/16	1 ohm wirewound, 1% RS-2B, 3 watt Dale	1
R22	357/63	30 ohm wirewound, 1% RH-10, 10 watt Dale	1
R23	357/55	30 ohm wirewound, 1% RS-5, 5 watt Dale	1
R18	357/47	50 ohm wirewound, 1% RH-10, 10 watt Dale	1
R5	357/67	0.04 ohm wirewound, 1% RH-10, 10 watt Dale	1

(Continued)

Component	Print/Part Number	Description	Required/ NIM
Relay K1, K2	357/69	Type ML-4422, 1855 ohm coil, 6PDT Bifurcated Contacts 100 to 200 micro inches of gold over silver. Hermetically sealed, hook type solder connections, stud mount. Pick up 24 VDC, hold in 15 VDC, drop out 2.5 VDC, Potter & Brumfield	2
K3	357/6	Series R10 Cat. No. R10-E1-Y4-V185, oomplete with socket 27E126 and spring 20C Potter & Brumfield	1
Meter M1	357/25	Panel type, 5 volt DC, Zero left, Cat. #50-251-320-LSLS General	1
M2	357/30	Panel type, Edgewise 500-0-500 microamp Zero Center Series 100, Type 185 Cat. #50-185-112EMEM complete with mounting kit, Cat. #4149K16G778	1
Indicator I1	357/26	Lamp, Utility Part No. 975R Yankee Metal Products	1
I2	357/24	Lighted Series 4, with Legend - OPERATE - printed on green lens, Cat. #4C11B21AGL, Microswitch - Honeywell	1
I3	357/20	Lighted Series 4, with Legend - TROUBLE - printed on amber lens Cat. #4C11B21AAL Microswitch - Honeywell	1
I4	357/23	Lighted Series 4 with Legend - AC ON - printed on white lens Cat. #4C11B21AWL Microswitch - Honeywell	1
-		Lamp Cat. #4Z221 for I2, I3, I4, Microswitch-Honeywell	3
-		Lamp 6E63, General Electric	1
Audible Alarm DS3	357/27	Sonalert Alarm, Cat. #SC628P Mallory	1
DS2	357/8	Bell, 10 inch, Cat. #435-10-E1 Edwards Co.	1
Flasher DS1	357/33	Model 423, Solid State, Cat. #423-13-1 Sec., Artison Electronics	1
Battery BT	357/39	Gel Cell 20 amp hours, 12 V, Part #GC12200A Glove Union Inc.	1
Enclosure	357/1	Instrument Case, Part #E1419XX. Modified Panel TOPNL Depth of 7 inches. No chassis mounting brackets. Include hinged front panel door. Rear panel to be made up of one part P-7, as the panel center, with a part P-3P above and a part P-3P below the center. Blue Body No. 25189 with gray trim No. 26440 Scientific Atlanta, Optima Division.	1
Capacitor C1	358/14	Glass, 1.5 pF Mil-C-23269/01-7003 Components selected by Corning to exceed 1×10^{13} ohm insulation resistance, Corning Glass Corp.	1

(Continued)

Appendix C, Contd

Component	Print/Part Number	Description	Required/ NIM
Capacitor C2	358/8	Glass, 100 pF Mil-C-2369/01-7091 Components selected by Corning to exceed 1×10^{12} ohm insulation resistance, Corning Glass Corp.	1
C3	358/6	Capacitor Ceramic Monolithic, 0.1 μF, Centralab USCC104KCW	1
C4	358/16	Capacitor Ceramic Monolithic, 0.1 μF, Centralab USCC104KCW	1
C5	357/49	Capacitor, Electrolytic 10 μF, 400 V DC, Cat. #76301-39D Sprague	1
C6	357/52	Capacitor, Electrolytic 500 μF, 12 V Cat. #PRS1170, Aerovox	1
C7	357/69	Capacitor, Tantalum, 22 μF, 15 V, Cat. #196D226X0015K Sprague	1
Connector J1	358/10	Coupling, Push-Pull 750 Series Receptacle Single-Hole Mounting. No. 754-7-OPN, 7-pin, Deutsch	1
P1	357/42	Coupling, Push-Pull, 750 Series Plug-cable with female insert No. 757-7-OSN, Deutsch Electronics Components Div.	1
J2	357/14	Receptacle, Box No. AN3102-20-27P Amphenol	1
Power Supply PS1	357/9	Power Supply, 120 V AC to 15 V DC, Cat. #LCSA15, Lambda Electronics	1
PS3	357/58	Overvoltage, "Crowbar" Cat. #L20-OV-15, Lambda Electronics	1
PS2	357/7	Converter, DC/DC 150 PAC, Input 12 V Dual ±15 V output, Series A, 4.5 watts, case Z, Cat. A12-D15-150-Z Stevens Arnold, Inc.	1
Diode CR5	357/51	3A, 100 V, Motorola MR831	1
CR6	357/51	3A, 100 V, Motorola MR831	1
CR3	357/45	1 amp, 600 V, IN4005	1
CR4	357/45	1 amp, 600 V, IN4005	1
CR7	357/45	1 amp, 600 V, IN4005	1
CR1	355/8	Silicon Reference Diode, 4.7 V, JAN IN-750A	1
CR2	355/8	Silicon Reference Diode, 4.7 V, JAN IN-750A	1
Socket -	357/63	Socket (for PS2) Model 1400 MC Burr Brown	1
Amplifier U1	358/17	Amplifier, Current, Model 3523L, Burr Brown	1
Socket -	358/29	Socket (for Amplifier U1) 8 contact, Teflon, printed circuit terminal style 0.2-inch pin circle, Part #8058-3963, Augat Inc.	1

(Continued)

Appendix C, Contd

Component		Print/Part Number	Description	Required/ NIM
Amplifier	U2	355/6	Comparator, Burr Brown 4082/03	1
	U3	355/6	Comparator, Burr Brown 4082/03	1
	U4	355/6	Comparator, Burr Brown 4082/03	1
Miscellaneous Hardware	-	358/25	Solder Terminal, 4-40 thread mount hex base, Cat. #C40T-B Clover Eng. Co.	2
		358/1	Insulated Terminal, Feedthru Teflon Part #69001-0600 Chemelec Products, Inc.	1
	-	358/20	Rod, 3-3/4 inch dia. Nylon, Cadillac Plastic	1/4 in.
	-	354/2	Stock, 1/2 inch Polyester Glass Sheet	5 × 6 in.
	-	357/29	Handle, Recessed No. H-9149, Bud Radio	1 pr.
	-	358/13	Board, Double side, Kepro No. S2365G	8 × 3 in.
	-	355/7	Board, Double side, Kepro No. S2365G	
	-	357/35	Board, Double side, Kepro No. S2365G	
	-	353/1	Wire, hookup, #22AWG Teflon insulation, 48 color code combinations, stranded	150 ft.
	-	357/43	Plug, male, 3 wire twistlock, recessed No. 7556-G, Hubbell	
		357/11	Fuseholder, No. 342023, Littlefuse	1
Fuse	F1	357/11	1A, 3AG Type, Littlefuse	
Miscellaneous Hardware	-	358/28	Wire, Bare Copper AWG14	6 in.
	-	358/11	O-Ring 1-9/16 OD x 1-5/16 ID, ARP 568-219	1
	-	358/19	Gasket, cut from 1/8" Thick, Natural Soft Rubber (see print)	1
	-	357/60	Ground Pin, Cambion 2051-1	1
	-	357/65	Connector, Cinch Jones S-304-CCT	1
	-	357/66	Connector, Cinch Jones P-304-CCT	1
Choke	L1	358/31	Ferrite Bead, FAIR-RITE No. 2643001401	1
	L2	358/31	Ferrite Bead, FAIR-RITE No. 2643001401	1

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