WSRC-TR-96-0159

Nuclear Incident Monitor Criticality Alarm Instrument for the Savannah River Site

by

J. B. Jenkins

Westinghouse Savannah River Company

Savannah River Site

Aiken, South Carolina 29808

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WSRC-TR-96-0159

NUCLEAR INCIDENT MONITOR
Criticality Alarm Instrument for the Savannah River Site (U)

TECHNICAL MANUAL

J. B. Jenkins

May 21, 1996

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

SAFETY • RESPONSIBILITY • SECURITY
SRS
SAVANNAH RIVER SITE

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Introduction

The Savannah River Site is a Department of Energy facility. The facility stores, processes, and works with fissionable material at a number of locations. Technical standards and United States Department of Energy orders, require these locations to be monitored by criticality alarm systems under certain circumstances. The Savannah River Site calls such instruments Nuclear Incident Monitors or NIMs. The Sole purpose of the Nuclear Incident Monitor is to provide an immediate evacuation signal in the case of an accidental criticality in order to minimize personnel exposure to radiation.

The new unit is the third generation Nuclear Incident Monitor at the Savannah River Site. The second generation unit was developed in 1979. It was designed to eliminate vacuum-tube circuits, and was the first solid state NIM at SRS. The major design objectives of the second generation NIM were to improve reliability and reduce maintenance costs.

The major design objectives of the third generation NIM include maintainability and compliance with DOE orders and ANSI standards. Replacement parts for the second generation NIM are becoming more difficult to obtain. Tedious calibration techniques are becoming more difficult as the instruments age. The existing NIMs also fail to meet several ANSI standards requirements that are required by DOE order 5480.1A. These include requirements for seismic stability and redundant systems to reduce false alarms.

The new NIM has some of the same features and functions as the existing unit. Consistency between the two units accommodates the training of personnel, the writing of procedures, and the reduction of faults and maintenance problems. Designs which were very reliable in the second generation unit are used in the new instrument. Parts and circuits that were not so reliable in the existing unit were modified or replaced. These design modifications generated many improvements in the new Nuclear Incident Monitor. The new NIM units use a two out of three voting system to reduce false alarms due to single instrument failures. The new instrument is more tolerant of harsh environments and electromagnetic noise. It is smaller, lighter, and designed to withstand 3G seismic events.

Ten prototype units have been built and tested. This report describes the design of the new NIM and the testing that took place to verify its acceptability.

Instrument Layout

The front of the NIM provides technicians and personnel with all of the necessary information about the status of the unit. The front panel also provides the field testing team with access to all of the circuits and operations necessary to fulfill their jobs. There is no longer a need to open the instrument to perform routine field tests and calibrations. The design makes entering the NIM difficult for anyone but authorized personnel.

The most important function of the NIM is to alert people of an accidental criticality. An evacuation bell is located on the back of the NIM, and a red flashing light is located at the top of the NIM. Additional bells and lights are located throughout facilities where the NIMs are in use.

The six LED indicators located on the front panel provide important information about the status of the NIM. They allow personnel to determine the operational status of the NIM at a glance. The three LED indicators on the left (looking at the NIM) are green. These indicators should always be illuminated. These LED indicate the proper operation of the AC power, DC power, and the 2 out of 3 voting systems. When one or more of these indicators is not illuminated, action should be taken to correct the problem.

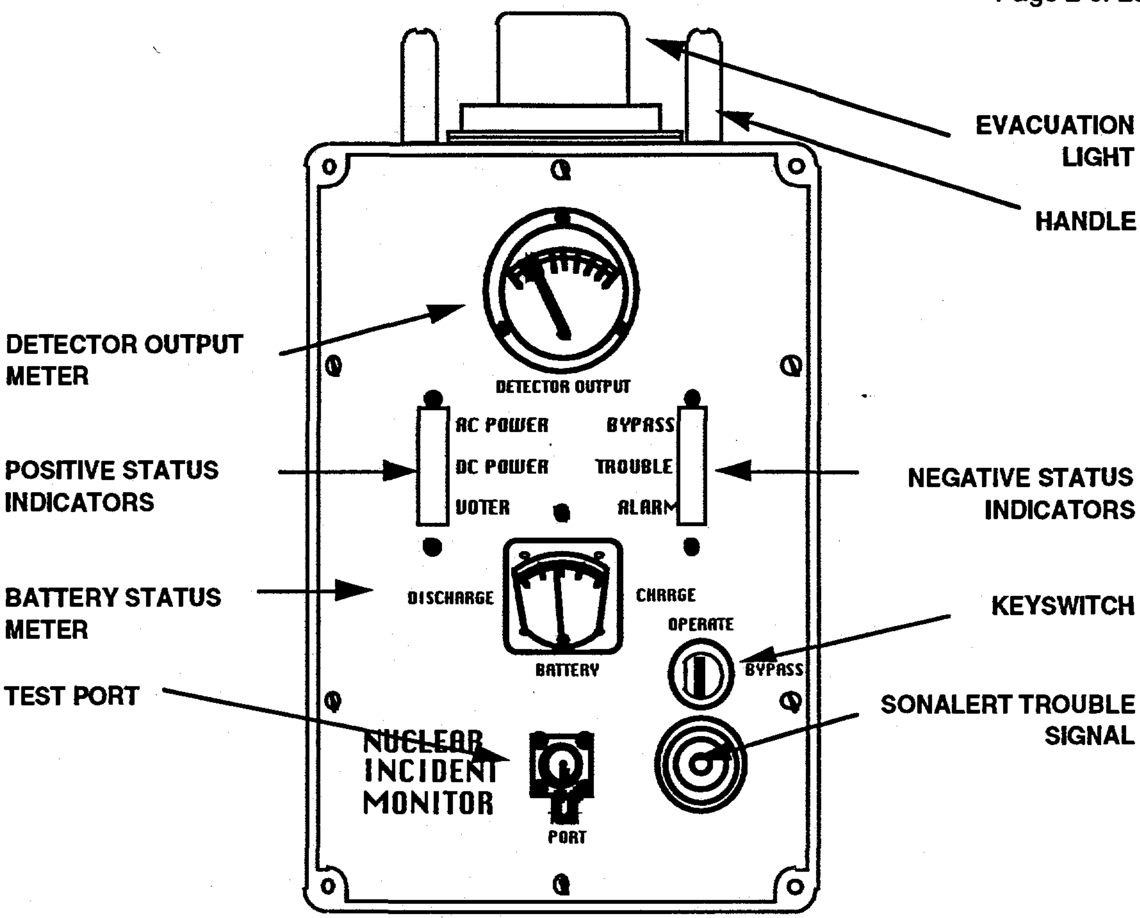


Figure 1
Front View of the NIM

The three indicators on the right side are yellow. These indicators will normally not be illuminated. The top LED of these three indicates a bypass state for the NIM. This occurs when the NIM has been placed into bypass using the key switch or the remote reset line. The middle LED indicates a trouble state for the NIM which means the NIM unit's self testing circuitry has detected a problem with one of the circuits and has sent the NIM into trouble state. The trouble light should always be accompanied by an audible sonalert signal which is located in the bottom right corner of the front panel. The bottom LED indicates an alarm state for the NIM. When the NIM receives an alarm detection input, the alarm vote is latched and this LED is illuminated. When two NIM units illuminate the alarm indicator, the evacuation signals will be activated.

There are two analog meters on the front panel of the NIM. The top meter displays the output of the electrometer circuit. It is the detector output. This meter should normally read 1 volt. A reading of 4 volts corresponds to a dose rate of 1 R/hr which is the trip point for the alarm. The bottom meter displays the status of the battery, indicating the charge or discharge current. During normal operation the meter should read slightly positive.

The key switch located on the front panel allows an operator to place the NIM in the bypass or operate state. Alarms are still displayed in the bypass mode, but the evacuation bell is deactivated. The bypass state is most commonly used for source checking the NIM units.

The test port on the front of the NIM allows operators in the field to span test the NIM. It also allows technicians access to several signals on the control board and electrometer board.

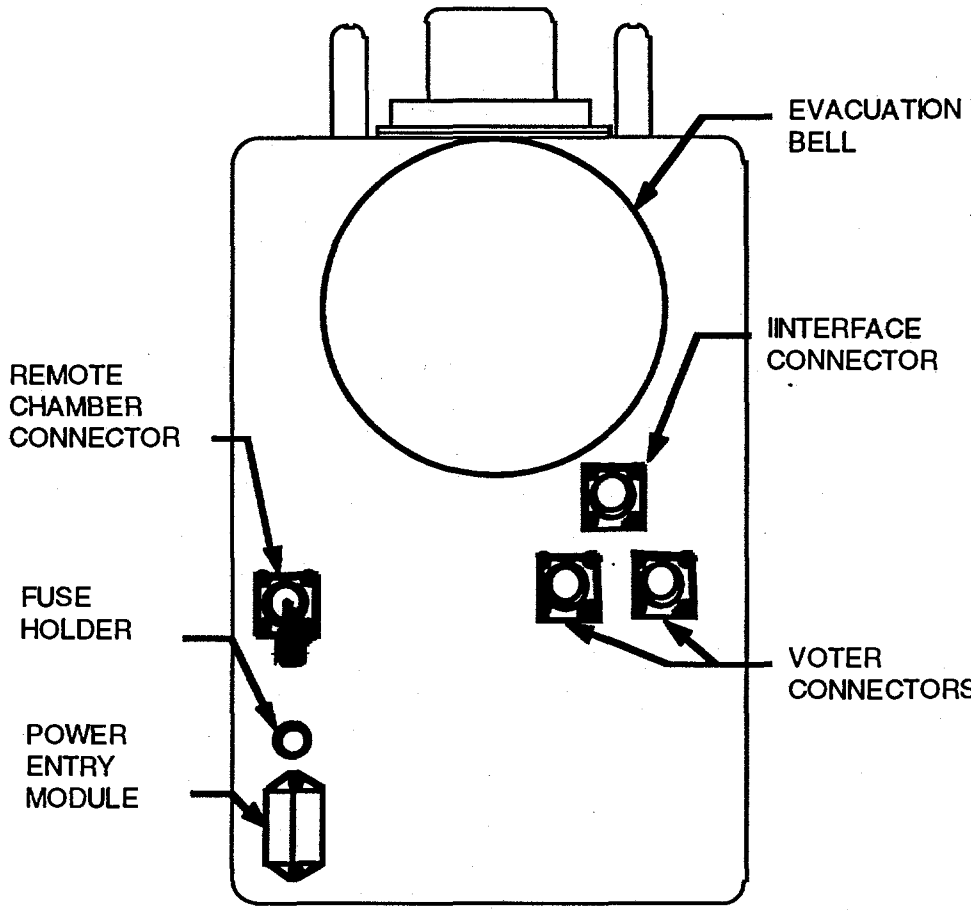


Figure 2
Rear View of the NIM

The rear of the NIM contains the bell, power entry system, and four connectors. The interface connector provides signals and relay contacts for use with a control center and external bell loops. The two voter connectors are used to communicate with each of the other NIM units in a set. The remote ion chamber connector is used only in installations where the ionization chamber is located outside of the NIM chassis. The power entry system includes 2 amp fuse and an on/off switch. The power is on when the switch is pressed in at the bottom.

The inside of the NIM is broken down into six major parts. The ion chamber detector and the 12 VDC battery are secured inside the NIM using 16 G rated Velcro buckled straps. The 15VDC power supply, DC flasher, and the wiring harness are located in the main body of the NIM chassis. The sixth major part is the control printed circuit board, and it is located on the inside front panel of the NIM.

Operation of the NIM

The NIM has four basic states of operation. These states are called operate, trouble, alarm, and bypass. The operate state is the state of normal operation. Six input and three output feedback signals control the status of the NIMs asynchronous state machine. The logic uses two additional input signals to produce some outputs which are not results of the state machine. The state machine is broken into two related state diagrams which result in three output equations. These diagrams and tables are shown in figures 3A, 3B and 4. The program for the logic device provides the interface between the state machine and the physical inputs and outputs of the NIM. It also provides the basis for examining the operation of the NIM through all four states.

The State Machine Inputs: Trouble, Reset, Alarm

There are two trouble inputs into the programmable array logic (PAL). The first trouble input consists of two monitoring circuits which are hard wire "ORed" to result in the power and bell trouble signal. The power trouble signal is activated if the 12 volt power bus drops below 10.75 volts. The bell trouble signal activates if the bell circuit becomes open. The second trouble signal received by the PAL is from the electrometer circuit inside the ion chamber assembly. The output of the operational amplifier is monitored to determine its voltage level. During normal operation this voltage is near 1 volt. If circuit or component failure cause this voltage to drop below .87 volts, the electrometer trouble signal will become active. These two signals are immediately "ORed" together inside the programmable array logic to give one *trouble* input to the asynchronous state machine.

There are three reset signals input to the programmable array logic. These resets are the power on reset, the remote reset, and the reset from the operate/bypass key switch on the front of the NIM. The remote reset is "ANDed" with the alarm input signal inside the PAL. The alarm input signal is used to mask the remote reset line during a criticality. The remote reset circuit contains a photo diode which sometimes activates during high dose rate exposures, causing the remote reset line to become active. The alarm input signal "ANDed" to the remote reset prevents activation of the reset line during the period that the detector is above the trip point voltage. The three resets are "ORed" together inside the PAL and treated as a single *reset* input by the state machine.

Alarm input is the signal from the detector indicating that it has detected a critical event.

The State Machine Outputs: Trouble, Alarm, Bypass

The *trouble* output turns on the front panel trouble indicator, activates the audible trouble signal, and deactivates the trouble relay. This signal also becomes part of the alarm output logic and the vote output equation.

The *alarm* output activates the alarm indicator on the front panel of the NIM. It also is used in the trouble output and bypass output logic. This signal is part of the vote output and the evacuation output signals.

The *bypass* output activates the bypass indicator on the front panel of the NIM and activates the bypass relay which disables the evacuation bell.

Additional PAL Inputs and Outputs

Two inputs besides those used in the state machine are used by the PAL. These two signals are vote signals from the other two NIM units in the set. These vote signals which are called vote1 and vote 2 are active if the other NIM units have an alarm, or are in trouble. These vote signals do not determine the status of the NIM state machine. They are only used in conjunction with the state of the NIM to produce appropriate outputs.

Vote out is the signal which is sent to the other two NIM units. The other units read it as one of the two incoming vote in signals. Vote out is active if the NIM has an alarm output or a trouble output. This allows the NIM set to become a one of two detection system if one of the NIM units fail.

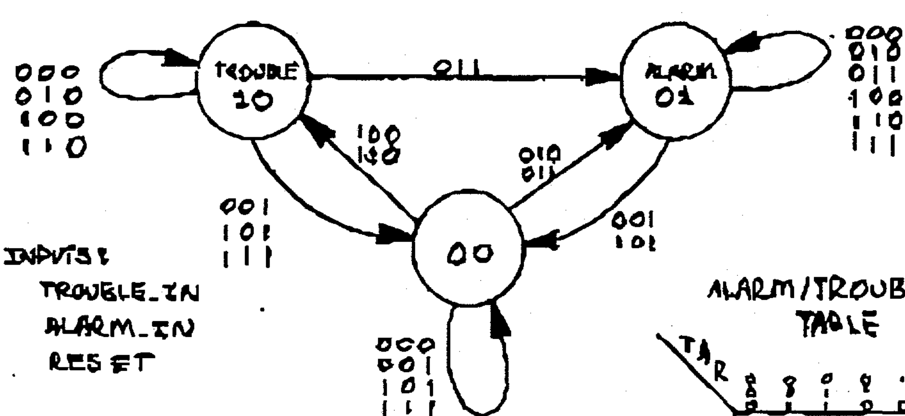
Alarm out is the signal which activates the evacuation alarms. Alarm out is active if the NIM unit has an alarm output and a vote in input.

Calculation Sheet

SRS

Project						Calculation No.		
NIM								
Subject: LOGIC FOR STATE MACHINE						Sheet No. 1		
Rev	Originator	Date	Checker	Date	Rev	Originator	Date	Checker	Date
1	I.B. Jenkins	7-31-92	TR Taylor	7/31/92					

NIM ALARM/TROUBLE STATE DIAGRAM



INPUTS:
TROUBLE_IN
ALARM_IN
RESET

OUTPUTS:
TROUBLE_OUT
ALARM

ALARM/TROUBLE STATE TABLE

TA \ R	000	001	010	011	100	101	110	111	TA
1	(1)	2		3				4	00
2	1	(2)	5				6		00
3	7		5	(3)	8				01
4	9				10		6	(4)	10
5		2	(5)	3		11			01
6		2				12	(6)	4	00
7	(7)	2		3				13	01
8				3	(8)	11		13	01
9	(9)	2		14				4	10
10				14	(10)	12		4	10
11			5		8	(11)	6		01
12			5		10	(12)	6		00
13	7				8		6	(13)	01
14	9		5	(14)	10				10

REDUCED STATE TABLE

(1)	(2)	5	3	10	(12)	(6)	4	00
(7)	2	(5)	(3)	(8)	(11)	6	(13)	01
X	X	X	X	X	X	X	X	11
(9)	2	5	(14)	(10)	12	6	(4)	10

Figure 3A
Alarm/Trouble State Machine Notes

Calculation Sheet

Project	Calculation No.
NIM	
Subject: LOGIC FOR STATE MACHINE	**Sheet No.** 2

Rev	Originator	Date	Checker	Date	Rev	Originator	Date	Checker	Date
1	J.R. Jenkins	7-31-92	TR TeDaal	7/31/92					

TA \ TR								
00	0	0	0	0	1	0	0	1
01	0	0	0	0	0	0	0	0
11	X	X	X	X	X	X	X	X
10	1	0	0	1	1	0	0	1

$$TROUBLE = TROUBLE \cdot \overline{RESET} + \overline{ALARM} \cdot TROUBLE\_IN \cdot \overline{RESET}$$

$$= \overline{RESET}\,(TROUBLE + \overline{ALARM} \cdot TROUBLE\_IN)$$

00	0	0	1	1	0	0	0	0
01	1	0	1	1	1	1	0	1
11	X	X	X	X	X	X	X	X
10	0	0	1	0	0	0	0	0

$$ALARM = ALARM \cdot \overline{RESET} + \overline{TROUBLE\_IN} \cdot ALARM\_IN \cdot RESET + \overline{TROUBLE} \cdot \overline{TROUBLE\_IN} \cdot ALARM\_IN + ALARM \cdot ALARM\_IN$$

$$= \overline{TROUBLE\_IN} \cdot ALARM\_IN\,(RESET + \overline{TROUBLE}) + ALARM\,(ALARM\_IN + \overline{RESET})$$

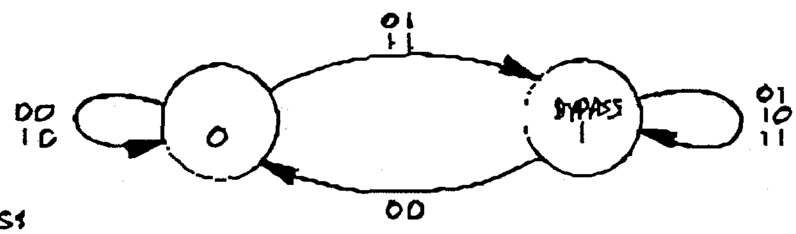
Figure 3B
Alarm/Trouble State Machine Notes

Calculation Sheet

Project	Calculation No.
Subject: NIM — LOGIC FOR STATE MACHINE	Sheet No. 3

Rev	Originator	Date	Checker	Date	Rev	Originator	Date	Checker	Date
1	J.B. Jenkins	7-31-92	TR Talbot	7/31/92					

NIM BYPASS STATE DIAGRAM



INPUTS:
ALARM
RESET

OUTPUT:
BYPASS

BYPASS STATE TABLE

	AR 00	01	11	10	B
1	(1)	2		3	0
2	1	(2)	4		1
3	1	2		(3)	0
4		2	(4)	5	1
5	1		4	(5)	1

REDUCED STATE TABLE

(1)	2	X	(3)	0
1	(2)	(4)	(5)	1

B \ AR	00	01	11	10
0	0	1	X	0
1	0	1	1	1

BYPASS = RESET + BYPASS • ALARM

Figure 4
Bypass State Machine Notes

The Programmable Array Logic Program

The programmable device used by the NIM is a 20 pin P16L8. The device receives 8 inputs as described above. The device produces 8 outputs and feedbacks to be used by the NIM. The PAL program is given below.

```
Name        NIM_LOGIC
Partno      P16L8
Revision    2.6
Date        5/19/92
Designer    J. B. JENKINS
Company     WSRC
Location    Site Wide
Assembly    NIM

/*INPUTS*/

Pin 1 = trouble_pb         /* asserted high     */
Pin 2 = trouble_el;        /* asserted low */
Pin 3 = alarm_in;          /* asserted low      */
Pin 4 = reset_sw;          /* asserted low      */
Pin 5 = reset_ct;`         /* asserted low      */
Pin 6 = reset_po;          /* asserted high     */
Pin 7 = vote1`_in;         /* asserted low      */
Pin 8 = vote2_in;          /* asserted low      */

/*OUTPUTS*/

Pin 12 = vote_out;         /* asserted low      */
Pin 13 = bypass_fb;        /* asserted high     */
Pin 14 = trouble_fb;       /* asserted high     */
Pin 15 = alarm;            /* asserted high     */
Pin 16 = reset;            /* asserted high     */
Pin 17 = bypass_out;       /* asserted high     */
Pin 18 = trouble_out;      /* asserted low      */
Pin 19 = alarm_out;        /* asserted high     */

/*EQUATIONS*/

reset = !((reset_ct # !alarm_in) & reset_sw & reset_po);

bypass_fb = reset # (bypass_fb & alarm);

bypass_out = bypass_fb;

trouble_fb = !reset & (trouble_fb # (!trouble_el # trouble_pb) & !alarm);

trouble _out = !trouble_fb;

alarm = ((!alarm_in & !(!trouble_el # trouble_pb) & (!trouble_fb # reset)) # alarm &
(reset & alarm_in));

vote_out = !alarm & trouble out;

alarm_out = vote & !(vote1_in & vote2_in);
```

Normal Operation

During normal operation the NIM produces no audible signals and illuminates three green LED light bars on the front panel. The detector output meter on the front panel will read about 1 volt in the majority of installations. The reading may be slightly higher based on the level of background radiation.

Normal Operation (Loss of AC Power)

When AC line power is removed from the NIM, the AC Power indicator on the front panel extinguishes and the sonalert audible signal is activated. The NIM functions properly until the battery charge drains below 10.75 volts. At this point the NIM will fail into its trouble state. See the battery performance test results for detailed information on battery operation.

Trouble State

When the NIM has fatal power or circuit malfunctions it transitions into its trouble state. In trouble state, the yellow trouble indicator on the front panel of the instrument is illuminated and the sonalert audible signal is activated. The NIM can not transition into an alarm state from the trouble state without first being manually cleared out of the trouble state. The trouble state causes the NIM unit's vote out signal to activate, so that the other two NIM units in the system receive a vote in signal from the troubled NIM. This allows the system to become a one out of two voting system when one NIM is in trouble.

Alarm State

When the NIM receives an alarm in signal it transitions to the alarm state. The yellow alarm indicator on the front panel of the NIM will become illuminated. The NIM will activate its vote out signal to the other NIM units in the set. If the NIM is receives an alarm in signal, the evacuation bell and light will be activated.

Bypass State

When the NIM receives a reset signal from the remote reset or from the key switch, it transitions into the bypass state. In the bypass state, the yellow bypass indicator on the front panel of the NIM is illuminated. Bypass state will clear the trouble state and prevent any transition to that state. Bypass state will clear the alarm state only if the alarm condition is gone. The bypass state does not prevent transition to the alarm state, it merely masks the evacuation bell and some of the interface signals. The NIM can not be taken out of the bypass state if an alarm condition exists.

Circuit Design

Remote Connections

The interface connector provides access to five groups of conductors. These can provide a remote location with the ability to reset the NIM as well as determine its status. The signals provide information about AC power loss, trouble state, bypass state, and alarm state. Three of the signal groups use relay contacts which are rated for 250 VAC, 48 VDC at 4 amps. A jumper loop is provided in the connector for verification that the interface cable is connected. The final pair of conductors resets the NIM when 120 VAC is placed across the conductors.

K1-ALARM RELAY K2-BYPASS RELAY K3-TROUBLE RELAY K4-AC RELAY

Relays are shown in there normal operation position. K1 and K2 are normally de-energized, while K3 and K4 are normally energized. J4 is the interface connector designation.

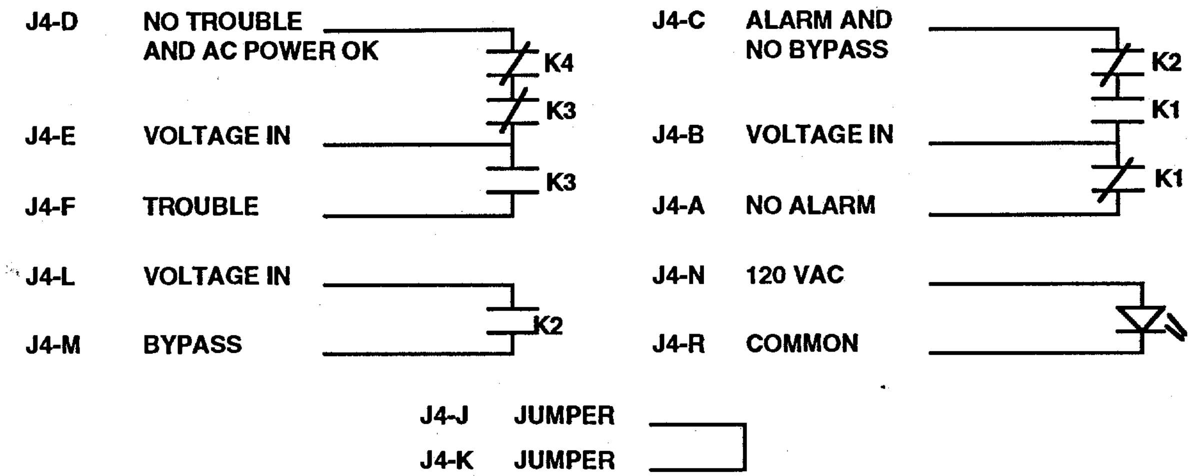


Figure 5
Interface Connector Schematic

The remote ion chamber connector (J6) at the rear of the NIM provides a feedthrough for all of the ion chamber signals. In installations where the ion chamber is be placed outside the NIM chassis, this connector should be used. The cable assembly (W1) which normally connects the control printed circuit board to the ion chamber, will connect to the inside of this through bulkhead connector. A longer external cable will connect to the ion chamber at its remote location.

Radiation Detector

The radiation detector is a dry nitrogen filled ion chamber. The outer shell of the cylinder is energized to a -13.6 VDC potential, while the electrode collector inside the chamber is given ground potential. Gamma-rays passing through the chamber ionize some of the nitrogen causing a current flow from the ground potential electrode to the lower potential cylinder. The chamber current is nearly linear from 0 to 1 R/hr. Figure 6 shows the electrometer output versus R/hr around the trip point for the span of gains available. Each picoAmp corresponds to a tenth of a volt out of the electrometer circuit. The dose rate per volt of the electrometer output is .33R/hr/volt. Due to variations in fabrication and assembly, a calibration potentiometer allows some adjustment of the gain circuit to assure that the 4 volt trip point will correspond to a 1R/hr gamma-ray dose rate.

The ion chamber is 3.5 inches in diameter and has a volume of approximately 48 cubic inches or .8 liters. The center electrode is .060 in diameter and protrudes 4.125 inches into the cylinder. It is isolated from the canister by two concentric rings of ceramic divided by a metallic guard ring

The chamber shell is insulated using a clear shrinkable tubing. A red insulating PVC cap is placed on the bottom of the cylinder. This insulation prevents shorting between the -13.6 VDC canister and other surfaces. The upper cap of the ion chamber assembly is called the electrometer cap. It covers the electrometer circuits and is grounded to protect against electromagnetic noise.

The electrometer circuit has a simple input bias stage and an amplifier stage with an adjustable gain. The output stage consists of two comparators for signaling alarm or trouble, and a voltage follower to isolate the analog signal that goes to the detector output meter.

The input bias signal is powered by the -15 VDC source that supplies the chamber bias of -13.6 VDC. A voltage divider sets the input bias at -.1VDC. The gain stage of the amplifier converts this into a 1 VDC output. If the -15 VDC power source is lost, the ouput will drop below .87VDC causing the trouble comparator to activate. The input stage provides connections for an input bias adjustment mechanism that allows the amplifier output to be span tested. This test can verify the alarm trip point and the trouble trip point. Common, -15VDC, and Op Amp Bias signal are found at the test port on the front panel of the NIM. The span test circuit can be connected as shown in Figure 9.

The amplifier stage of the circuit can produce gains ranging between -9 and -13. Ideally the gain should be set to -10, but variations in production and components may require small gain adjustments. The major concern is that dose rates of 1R/hr correspond to the 4 volt trip point. The amplifier holds the electrode at virtual ground potential. The output of the amplifier changes in order to equalize the potential between the two inputs. The non-inverting input is grounded, so the output of the amplifier will fight to hold the inverting input at this potential. If a current is following from the electrode to the outer shell of the cylinder, the current output of the amplifier will have to equal this current to maintain the ground potential. This current flows across the high megohm gain resistance creating a large voltage at the output of the amplifier.

The gain resistance adjusts between 92GΩ and 131GΩ. The equation for the feedback gain resistance is given below.

Rgain = ((10G//(750+Rpot//750)+9.09K) / 10G//(750+Rpot//750))*10G

The output stage of the electrometer circuit consists of two comparators and a voltage follower. The output stage receives the analog signal from the operational amplifier, and makes decisions based on its voltage level. The alarm comparator is set to have a 4.01 volt trip point. This is 3 volts above the normal output of the amplifier. This produces a low voltage at the comparator output When the amplifier voltage rises from this point, the trigger voltage (threshold) is given as follows:

Vamp = ((4.01- 0)/1M)*10K + 4.01 = 4.05 VDC

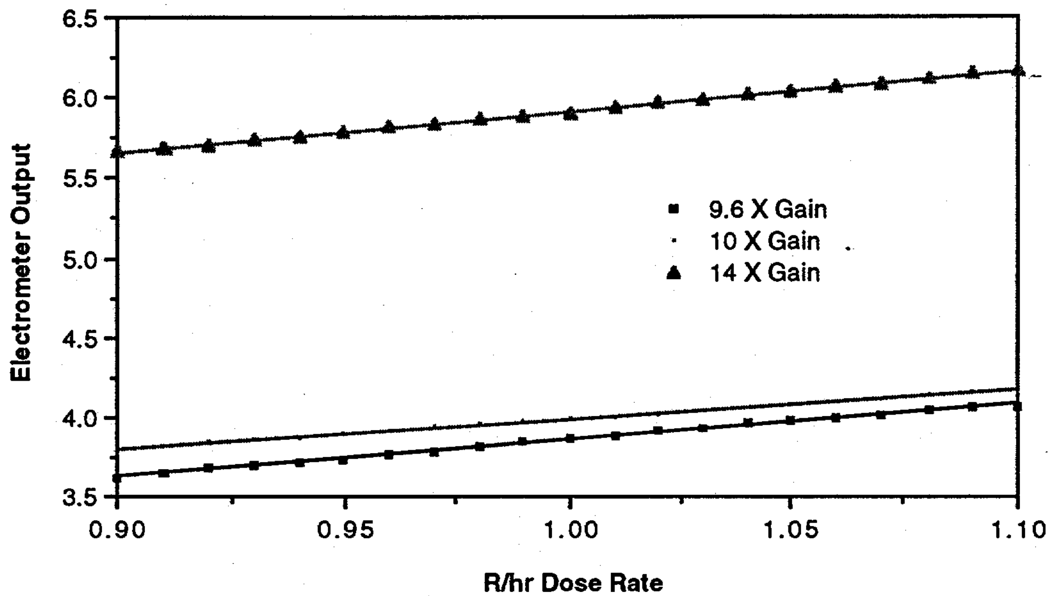


Figure 6
Detector Output Versus Dose Rate for Steady State Events

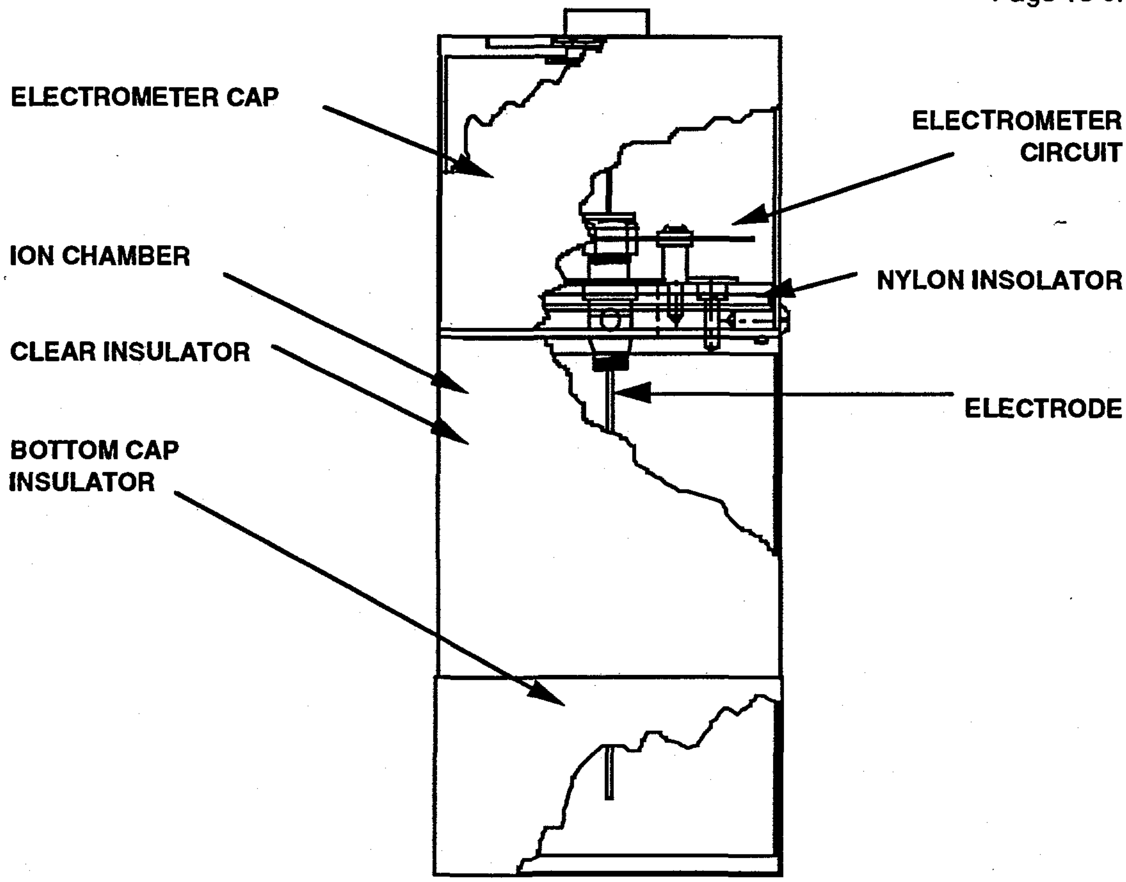


Figure 7
Ion Chamber and Electrometer Housing Details

The amplifier voltage must reach 4.05 volts to trip the 4.01 threshold on the comparator. When this happens, the NIM is sent into alarm state and the output of the comparator is tied high through a 3k resistor to +15 VDC. The voltage normally found at the output pin of the comparator at this point is about 7 VDC due to voltage division within the control circuits. When the amplifier voltage falls from the alarm point, the trigger voltage (threshold) is given as follows:

Vamp = ((4.01 - 7)/1M)*10K + 4.01K = 3.98 VDC

This hysteresis prevents toggling during transitions from one output to the next. The trouble comparator works the same way with a different trip point. Its threshold is set at .875 volts. The amplifier voltage is normally greater than this, so the output of the comparator is tied to +15 through the 3K resistor. When the amplifier voltage drops, the threshold is .86 volts, and the comparator output becomes 0VDC. When the amplifier voltage rises from below .86 volts, the threshold is .88 volts and the output becomes tied to +15 again.

The third component in the output stage is the voltage follower. The analog signal is fed through the voltage follower before it is sent to the detector output meter on the front panel of the NIM chassis. The voltage follower isolates this long analog cable run from the actual amplifier output so that noise on the cable will not interfere with the decision making on the electrometer board.

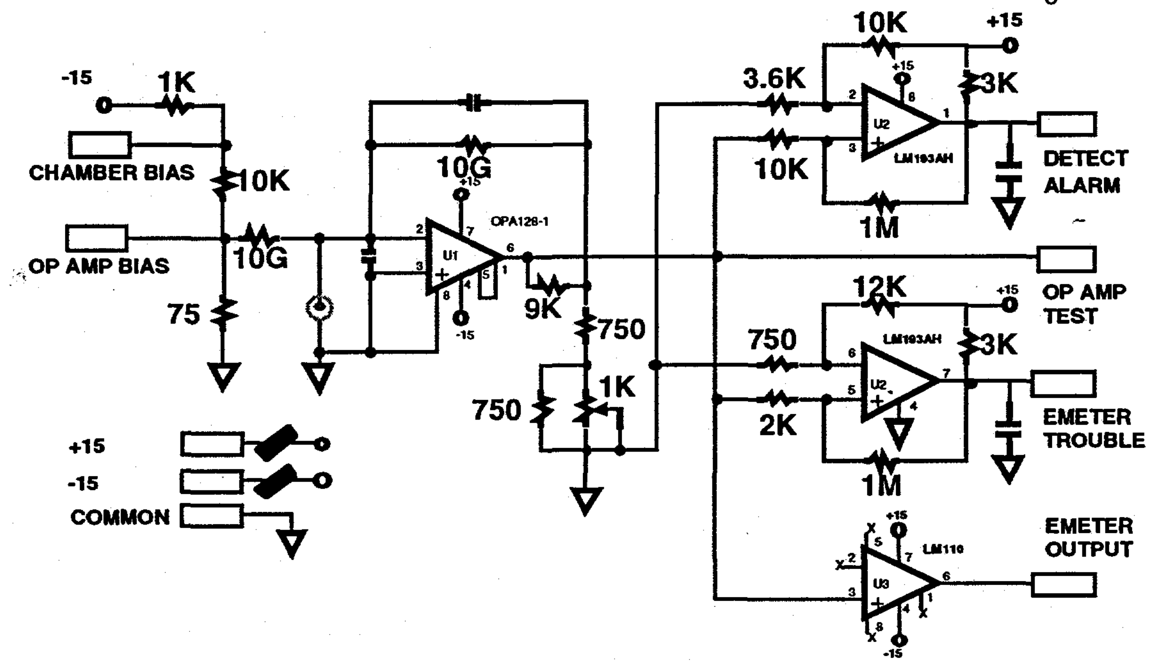


Figure 8
ElectrometerSchematic

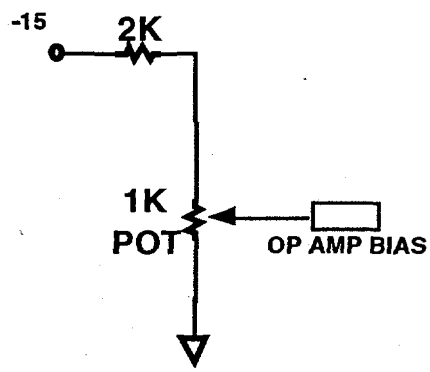


Figure 9
Electrometer Spanning Adjustment Circuit

Power and Bell Trouble Circuits

There are two comparators in addition to those on the electrometer printed circuit board. These comparators are used to detect problems with the bell and the power supply. Both circuits are found on the control printed circuit board. The bell trouble circuit ensures that the bell switch and solenoid have a closed circuit. If the coil or the switch become an open circuit the trouble signal will be activated. The power trouble circuit monitors the 12VDC power circuit. If the 12 DVC power circuit drops below 10.75 VDC the trouble signal is activated. At 10.75 volts, the DC to DC convertors can no longer produce their proper outputs and the integrity of the logic can no longer be assured.

Accelerometer Circuit

The accelerometer circuit prevents the NIM from falling into trouble state during a seismic event. This allows the NIM to detect an alarm, and provide an evacuation signal if there is a criticality. The ion chamber and electrometer are sensitive to seismic events. Severe motion or impact can cause the electrometer output to oscillate by several tenths of a volt. While this is not enough to send the instrument into its alarm state, it is enough to put the NIM into its trouble state. The normal electrometer output of 1 VDC only has to drop by .2 VDC to pass the threshold on the trouble comparator. The accelerometer circuit measures the magnitude of the seismic event, and masks the electrometer trouble signal if the event is large enough to cause a false trouble signal.

The accelerometer produces an output of 15mVDC per 1G. This relationship is linear from -2G to +2G. The output of the accelerometer is amplified by a factor of 100 and sent to two comparators. The first comparator looks for voltages greater than 1.2 volts in order to activate. The second comparator looks for voltages less than -1.4VDC in order to activate. These two signals, which are normally low, are inverted and then "nanded" together. The signal is then sent to a retriggerable one shot whose output indicates the presence of seismic activity above the 1G range. This signal is "nanded" with the electrometer trouble signal, so that during a seismic event the logic circuit cannot receive an electrometer trouble. The seismic signal from the one shot clears 3 seconds after the last event above 1G.

Logic Circuit

The logic circuit consists of the digital components, the optical solid state switches, and the relays. The brain of the logic circuit is the programmable array logic device which contains the burned in logic program. The inputs to the PAL have been described in detail in previous sections. They are all brought into the PAL as TTL logic signals. The outputs of the PAL, and their impact on the logic circuit are discussed here.

The *vote_out* signal is active low. When this signal drops low, the optical switch in U5 is activated causing the vote out signal to the other two NIM units in the set to drop low. These two signal are vote in signals for the other NIM units in the set.

The *alarm* signal is active high. When this signal is high, an optical switch in U4 is activated causing the alarm indicator on the front panel of the NIM to illuminate.

The *bypass_out* signal is active high. When this signal is high, an optical switch on U3 is activated causing the bypass relay to energize and the bypass indicator on the front panel of the NIM to illuminate. The energized bypass relay causes the bypass contacts to the interface connector to close (K2 pins 4 and 5). It causes the alarm and not bypass contacts to the interface connector to open (K2 pins 2 and 3). It causes the evacuation bell activation voltage line to open (K2 pins 8 and 9).

The *trouble_out* signal is active low. When this signal is low, an optical switch in U4 is deactivated causing the trouble relay to de-energize. The de-energized trouble relay causes contacts (K3 pins 8 and 9) to close supplying power to activate the audible trouble signal and illuminate the trouble indicator on the front panel of the NIM. It closes contacts (K3 pins 2 and 3) which complete the trouble circuit to the interface connector. It opens contacts (K3 pins 10 and 11) which complete the no trouble and ac power ok circuit to the interface connector.

The *alarm_out* signal is active high. When this signal is high, an optical switch in U3 is activated causing the alarm relay to energize. The energized alarm relay causes contacts (K1 pins 10 and 11) to close supplying power to the evacuation light and the bypass contacts for the evacuation bell. It closes contacts (K1 pins 4 and 5) which complete the alarm and no bypass circuit to the interface connector. It opens contacts (K1 pins 8 and 9) which complete the no alarm circuit to the interface connector.

The Power Circuit

The power system consists of three power supplies and a rechargeable battery. PS0 converts the 115 VAC to 15 VDC. This power supply is adjusted to give an output of 14.75 VDC and then is dropped across two high power diodes to a give a voltage output of 13.5 VDC. This voltage is used to power the NIM and charge the battery simultaneously. PS1 is a DC to DC convertor which takes an input between 10.75 and 13.5 VDC and supplies +15 and -15 VDC outputs. PS2 is another DC to DC convertor that accepts the same inputs and provides a +5VDC output. When the voltage from PS0 decreases below the battery terminal voltage (approximately 12.5 volts for a fully charged battery) the two diodes are reverse biased and the battery powers the NIM.

The load on the PS0 power supply is about 275mA plus the charge current which can range between 10 and 500 mA. The current supplied by the 5 VDC supply is about 65mA. The current supplied by the +15 output of the PS1 is 25mA and the -15 output is 38mA. The 12 VDC (13.5VDC) supplies the NIM with about 105mA. The NIM circuits use about 233mA of current which requires 275mA into the power supplies. This represents about an 84 percent efficient power conversion rating for the power supplies.

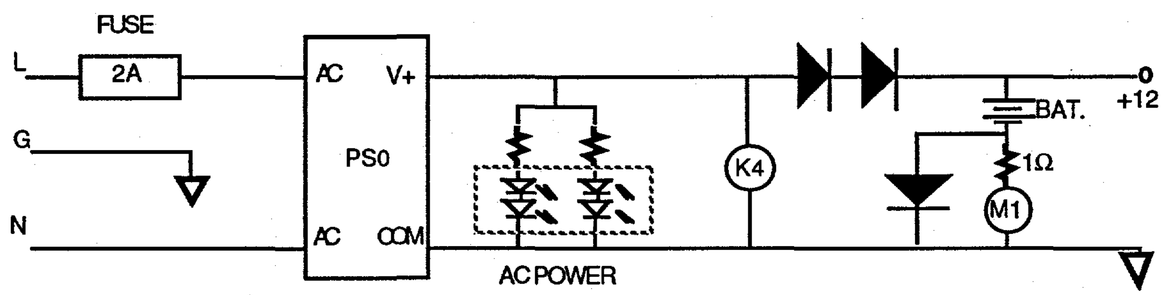


Figure 10
Power Circuit Schematic

Radiation Burst Tests

Radiation burst testing was conducted to verify the NIM unit's compliance with ANSI 8.3 requirements for criticality alarm systems. The testing also verified the effectiveness of all of the new units operating configurations. Seven NIM units were tested at the Sandia Pulse Reactor III, Sandia National Laboratories, Albuquerque, New Mexico. Four calibrated gamma-ray ionization chambers were used for dose rate measurements during the testing. The pulse reactor was operated with its radiation beam port open to allow testing at various distances and field strengths.

Paragraph 4.5 of ANSI 8.3 requires the NIM to alarm and remain alarming when subjected to dose rates of greater than 10 rad/sec. During the initial testing, the NIM units functioned properly in dose rates greater than 50 rad/sec, but failed to function correctly when subjected to hundreds of thousands of rad/sec. A modification was made to the programmable array logic which corrected this failure.

NIM SN-P01 with the modified PAL was placed 3 meters from the reactor assembly inside the containment facility. It was subjected to three radiation bursts, each exceeding a dose rate of 150,000 rad/sec . The relationship between dose rate and burst magnitude at 3 meters is presented in figure 1. Burst magnitude is given in terms of change in temperature (ΔT). As ΔT increases, the pulse width decreases causing the dose rate to increase exponentially. The relationship is based on total dose measurements taken for tests at the 3 meter location using thermoluminescence dosimetry.

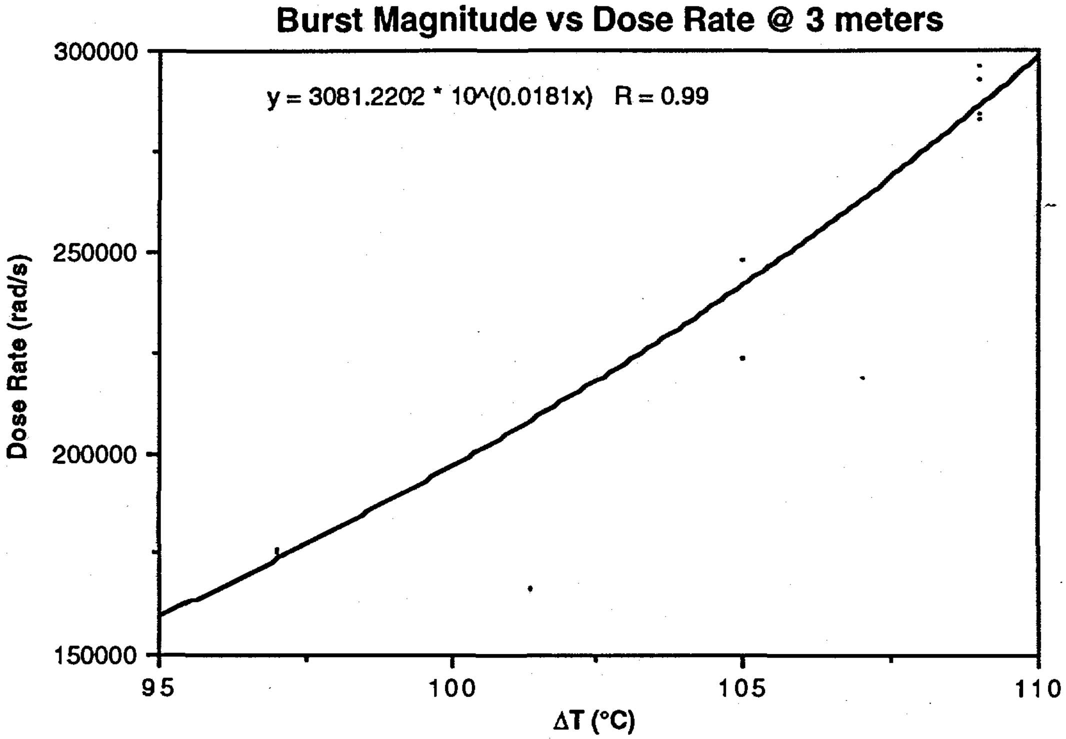


Figure 11
Burst Test Magnitude Versus Dose Rate at 3 Meters

During the tests, NIM SN-P01 and NIM SN-P07 were each exposed to total doses of over 400 rad. Both instruments continued to operate properly, and showed no signs of degradation. The three bursts which verified the NIM unit's survivability are listed below with ΔT and calculated peak dose rate.

SPR III Shot No.	Burst Magnitude (ΔT)	Dose Rate (rad/sec)
8591	109	289,000
8592	94	156,000
8593	94	156,000

Paragraph 5.5 of ANSI 8.3 requires the NIM to produce audible and visible warnings within 500 ms of a detectable criticality accident. Testing at Sandia verified that in the worst case, the NIM unit produces an audible alarm tone within 150ms. The worst case is the lowest detectable dose rate for a transient event lasting less than 500μs. The graph below shows the relationship between dose rate and response time. This graph is not valid above one million rad/hr where the response time levels out at 30 ms. It is also not valid below 3,000 rad/hr where the event is not detected.

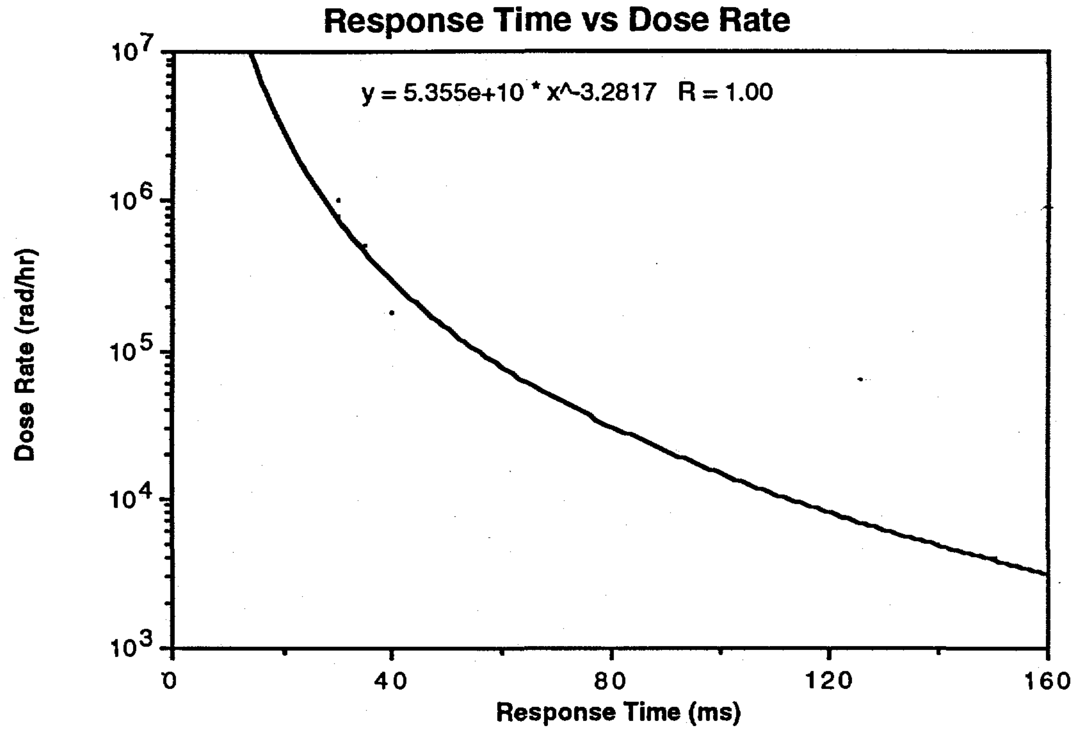


Figure 12
Response Time Versus Dose Rate

Paragraph 5.6 of ANSI 8.3 requires the NIM to alarm for the minimum transient accident of concern. This detection must occur at the NIM unit's maximum radius of coverage. Savannah River limits its NIM radius to 33 meters, so the minimum transient accident of concern must be detected at 33 meters.

For a transient event, ANSI 8.3 assumes a neutron-to-gamma dose ratio of 12. That is to say, for every 12 rad due to neutrons, there is 1 rad due to gamma-rays. The minimum accident of concern is an absorbed dose of 20 rad at 2 meters. For a transient event this would involve 18.5 rad from neutrons and 1.5 rad from gamma-rays. For an event lasting 1ms to deliver an absorbed dose of 1.5 rad from gamma-rays, the peak gamma-ray dose rate at 2 meters would have to be 1.5 rad/ms, or 5.4 million rad/hr. At a distance of 33 meters, this translates to 19,835 rad/hr. ANSI 8.3 therefore requires the NIM to alarm for dose rates of less than 19,000 rad/hr.

Figure 3 shows the output of NIM electrometer circuits when exposed to various dose rates. Output signals going above 4 volts cause the NIM to alarm. The graph indicates that the NIM alarmed in dose rates greater than 3,000 rad/hr. The full width half maximum period of all events in the graph was between 270μs and 380μs.

Paragraph 5.7 of ANSI 8.3 requires the NIM to alarm as a result of a transient criticality of less than 1ms duration. Testing at SPR III verified that the new unit responds properly to transient events lasting less than 300μs. Figure 4 shows the relationship between the burst magnitude ΔT and the full width half maximum pulse width. During testing the burst magnitude ranged between 94°C and 111°C. No full width half maximum pulse widths were greater than 500μs.

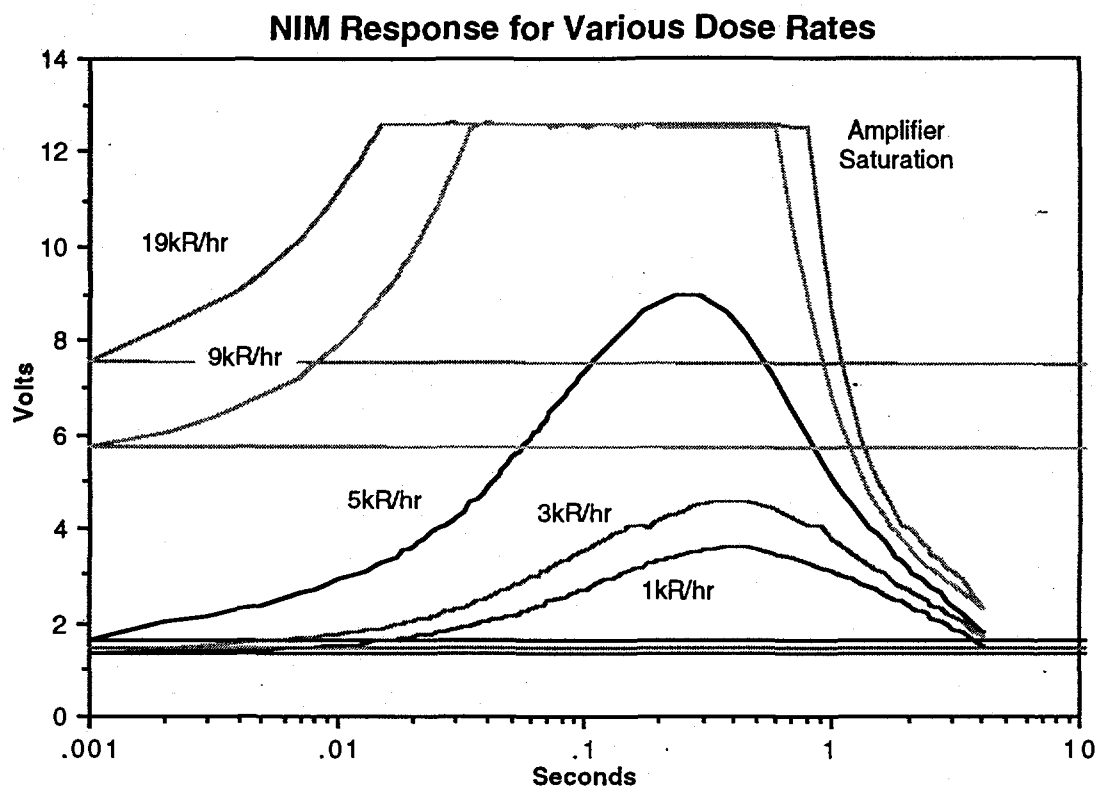


Figure 13
Detector Output Versus Dose Rate for Transient Events

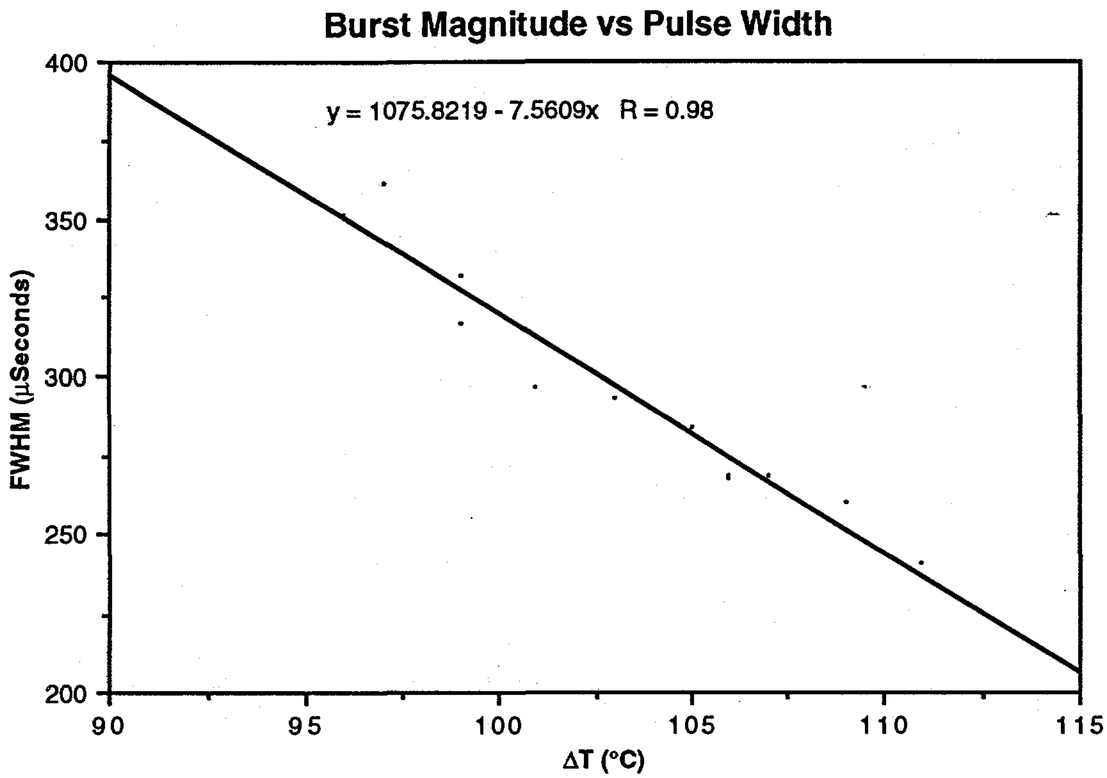


Figure 14
Burst Test Magnitude Versus Pulse Width

The NIM unit's operating configurations were tested during the bursts to verify proper operation. The NIM alarmed properly in all of its configurations. The tests verified proper operation using AC power, DC power, remote ionization chambers, local ionization chambers, voting sets, and stand alone units.

For the remote ionization chamber test, the ionization chambers were attached to 150 foot cables. The cables and the ionization chambers were placed in the path of the gamma-ray beam.

The NIM met or exceeded all of the requirements of the radiation burst testing.

- The NIM functions properly when subjected to dose rates greater than 200,000 rad/sec. This is 20,000 times greater than the ANSI 8.3 standard of 10 rad/sec.
- The NIM produces an alarm signal within 150ms of an event. This is three times faster than the ANSI 8.3 requirement of 500ms.
- The NIM alarms when subjected to dose rates of less than 3,000 rad/sec for less than 500µs. This is six times less than the ANSI requirement for our radius of coverage at Savannah River Site.
- The NIM responds properly to transient criticality events of less than 300µs. This is 3 times less than the ANSI standard which requires detection of 1ms events.
- The NIM functions properly in all of its configurations.

Battery Performance Tests

The NIM uses a 12 VDC, 12 amp-hour sealed-cell lead acid battery for back up power. The terminal voltage of the battery is 13.3 volts during normal VAC operation. When VAC is removed an audible signal on the NIM is activated. The NIM will operate for approximately 45 hours on a fully charged battery. When the terminal voltage drops below 10.8 VDC the NIM will transition to the trouble state, and the trouble indicator on the front panel will be illuminated. Approximately four hours after the trouble state is initiated, the terminal voltage will drop below 9.3 VDC causing the NIM to default into the bypass state. Figure 15 is a graph of the battery terminal voltage during discharge.

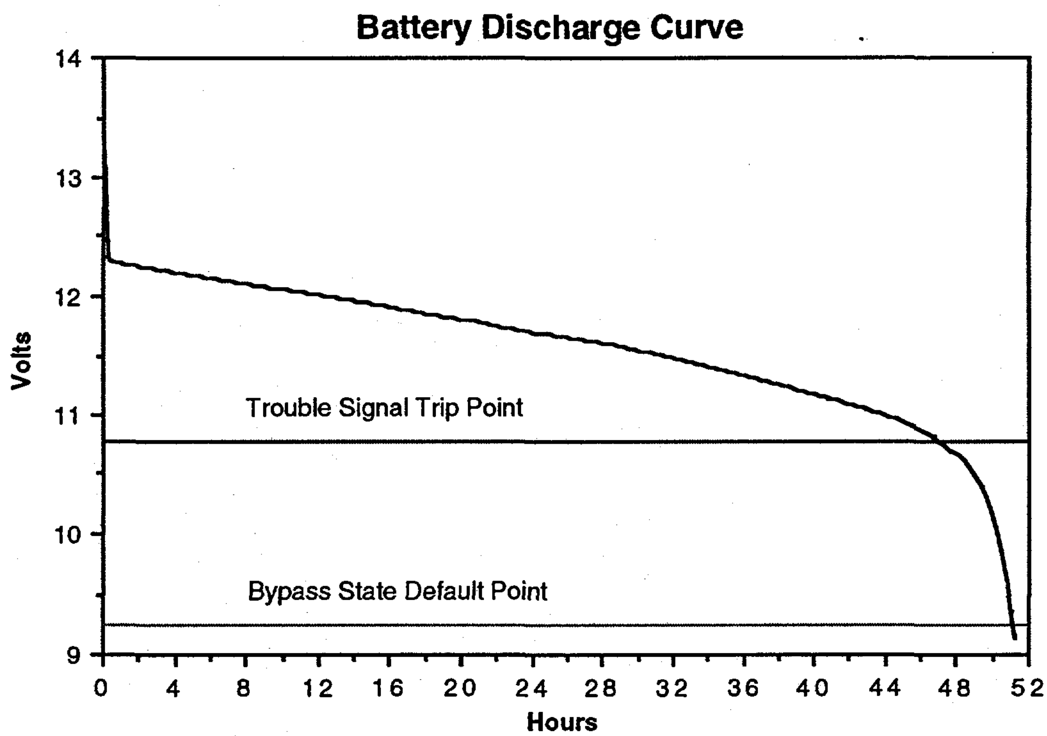


Figure 15
Battery Discharge Curve

A battery which has been discharged to less than 9 VDC requires about 60 hours to fully recharge. The charge current after 40 hours is already less than 50 mAmps. A 10 mAmp leakage current is present even when the battery is fully charged. Figure 16 shows the charging current relative to the charging time.

The inside air temperature of the NIM is 93°F during normal operation with an ambient air temperature of 77°F. The air circulation is marginal around the NIM, and the air temperature around the outside of the NIM increases by 5°F during recharge. This approximates a typical operating environment for the NIM. During the first two hours of battery recharge the internal air temperature peaks at about 25°F above the normal operating temperature. This peak temperature drops off quickly and is within 10°F of the normal operating temperature after 8 hours of charging. Figure 7 shows the relationship between charge time and temperature. The data has been normalized for an ambient air temperature of 77°F. Figure 17 shows the relationship between internal NIM temperature and ambient temperature for a well controlled environment with proper circulation and temperature regulation.

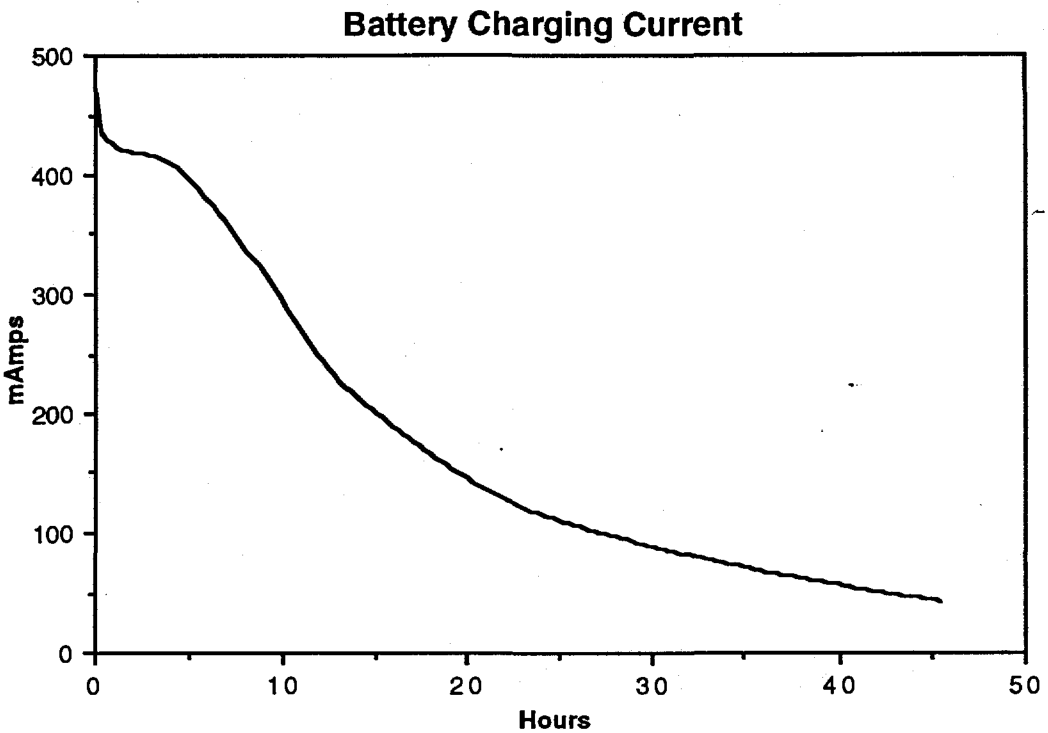


Figure 16
Battery Charging Curve

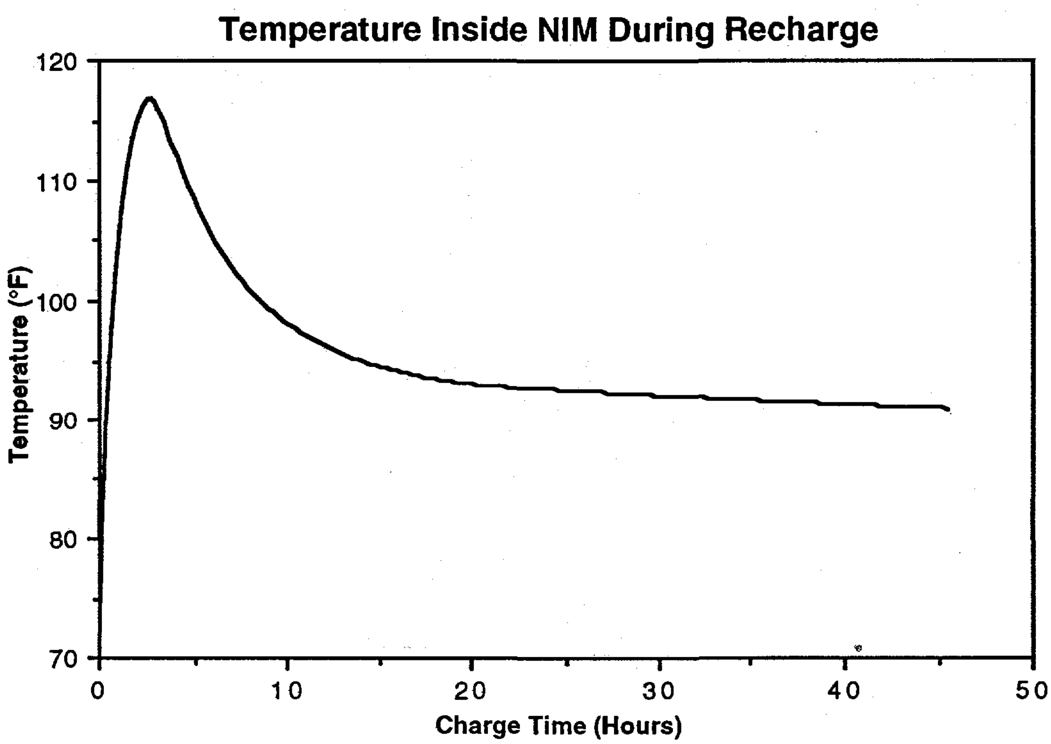


Figure 17
NIM Internal Temperature During Battery Charge

AC Power Variation Tests

Tests verify that the NIM unit's operation is not affected by fluctuations in the AC supply voltage. Variations in the AC supply voltage ranging between 105 and 125 VAC are detectable at the output of the power supply. When the AC supply voltage drops enough to cause the power supply voltage to drop below 14.75 VDC, the battery begins to supply the NIM.

Heat Cycle and Temperature Stability Tests

A heat cycle test was carried out on one set of NIM units over a 100 hour period. The units were cycled between 20°F and 120 °F. At various temperature levels the output of the NIM's detector was measured to determine its variation due to temperature change. Figure 18 provides a graph of the background radiation level detector output versus the internal temperature of the NIM. The output of the detector varies less than ±5 percent around its level at 90°F.

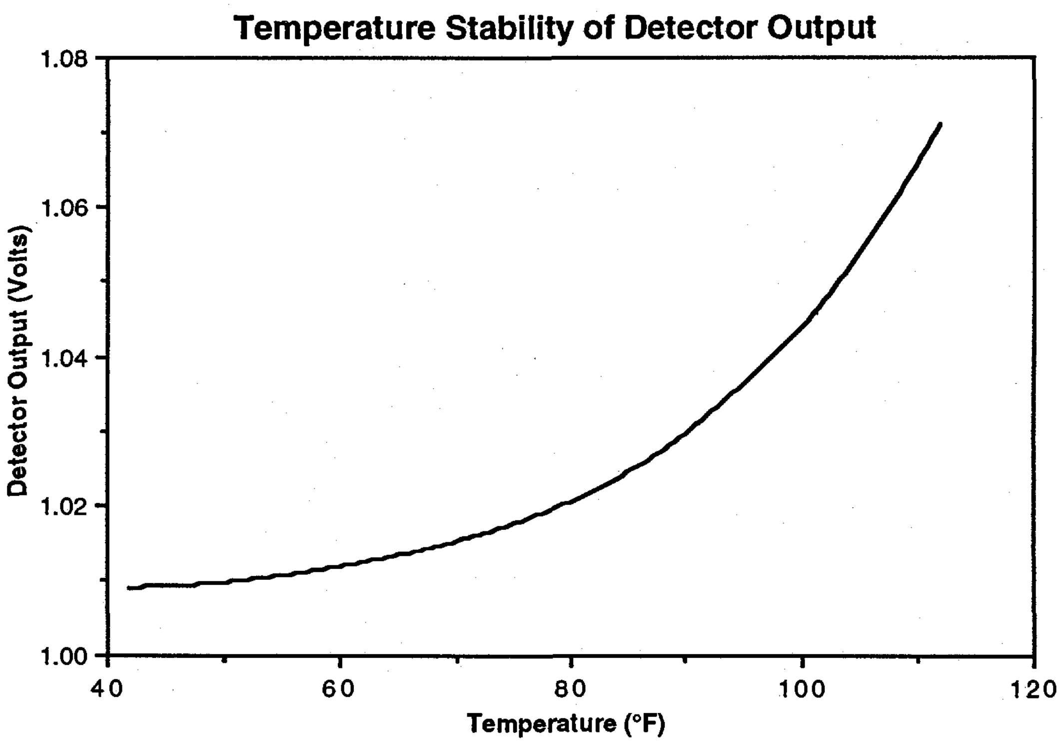


Figure 18
Temperature Stability of Detector Output

Figure 19 is a graph of temperature versus time for the air inside of the NIM chassis and the air inside the environmental chamber. During periods of level environmental chamber temperature, the air inside the NIM chassis was about 13 °F greater. In addition to the heat cycle test, the same units were operated in an ambient temperature of 92°F (internal chassis temperature 105°F) for a period of 4 weeks. After each of these tests, the NIM units were functionally checked and no problems were found.

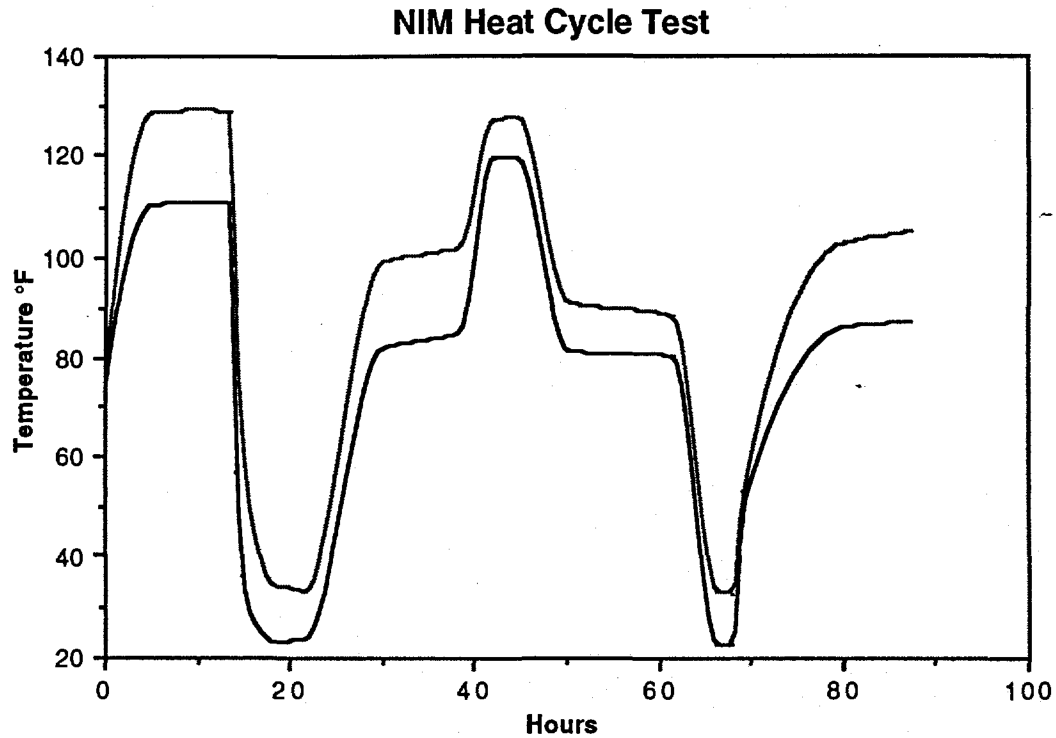


Figure 19
NIM Heat Cycle Test Temperature Curve

NIM Bell Sound Pressure Level and Frequency Spectrum Tests

Three NIM bells were placed 10 feet from a calibrated sound pressure level measurement device and each was tested individually. The NIM bells were then tested with two and three bells ringing. In each case the sound level was tested for five different voltage levels. These levels represent fluctuations in the battery voltage. The results show that the NIM units provide a sound pressure level above 92dB in each of the configurations. Figure 20 shows the results of the tests.

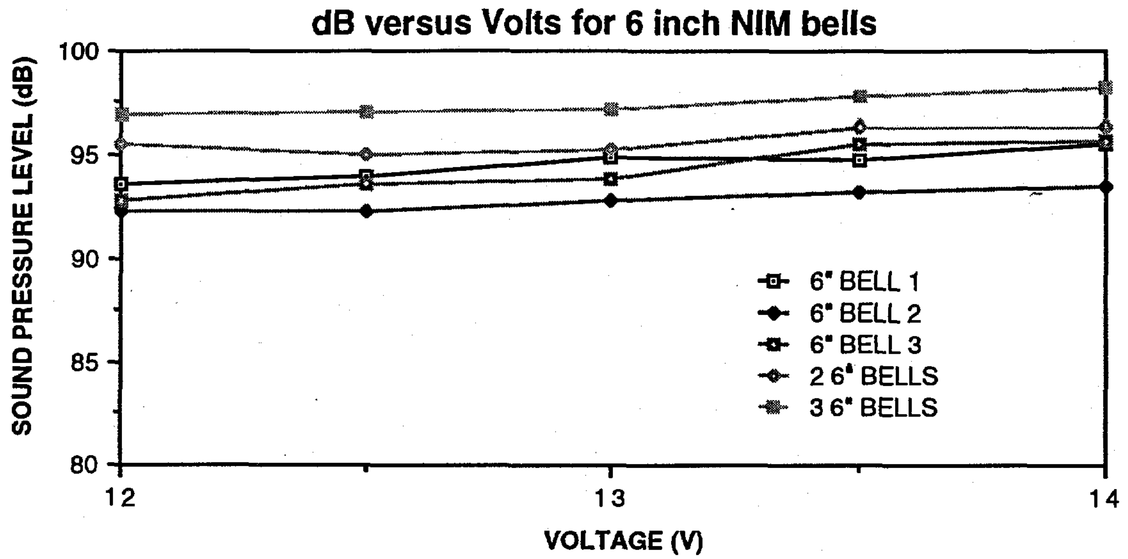


Figure 20
NIN Bell Sound Pressure Level Versus Voltage

A test was conducted to determine the frequency spectrum of the NIM bell. A microphone with a preamplifier was connected to a spectrum analyzer. The bell was rung, and a plot was made of the bell's frequency spectrum. The first peak on the graph in figure 21 is 60Hz noise. The first normal mode frequency peak comes at 605Hz. This is the fundamental frequency of the NIM bell.

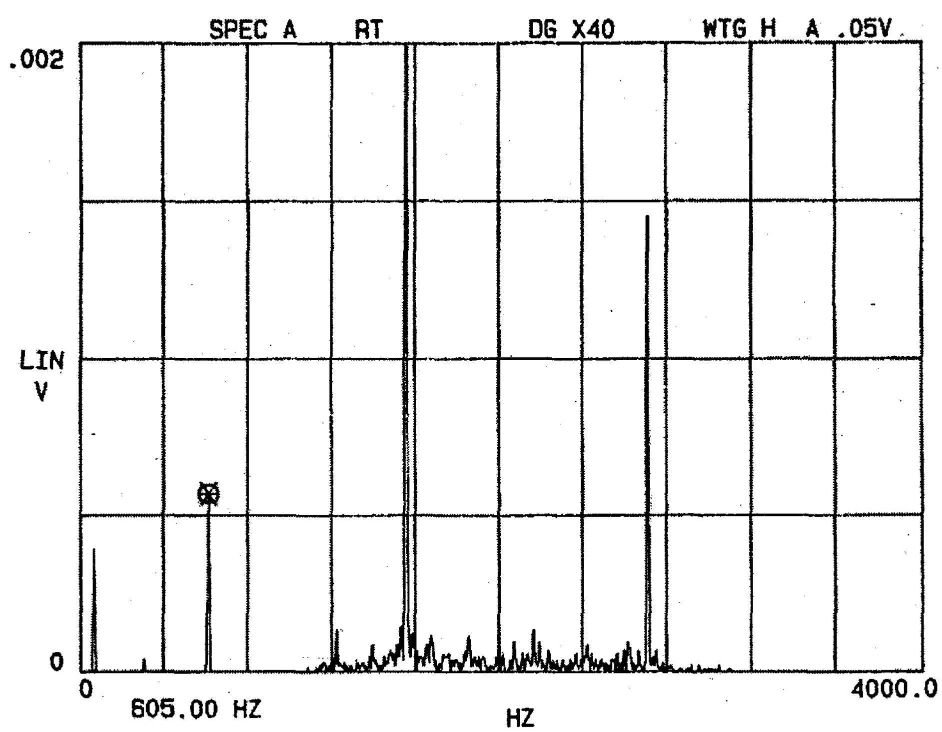


Figure 21
NIM Bell Frequency Spectrum

NIM Reliability Tests

The prototype NIM units were placed through two longevity reliability tests. One involved operating the three NIM units for four months in abnormally high ambient temperatures. The other involved operating as many of the NIM units as possible for as long as possible in normal operating conditions.

Figure 22 shows the environmental conditions from the heat stress duration test. The three NIM units were placed in a temperature chamber. The temperature was varied slowly over time. Humidity was not controlled. The temperature inside the temperature chamber and the temperature inside one of the NIM units was periodically monitored. At the end of the four month cycle, the NIM units were functionally tested, and no problems were found.

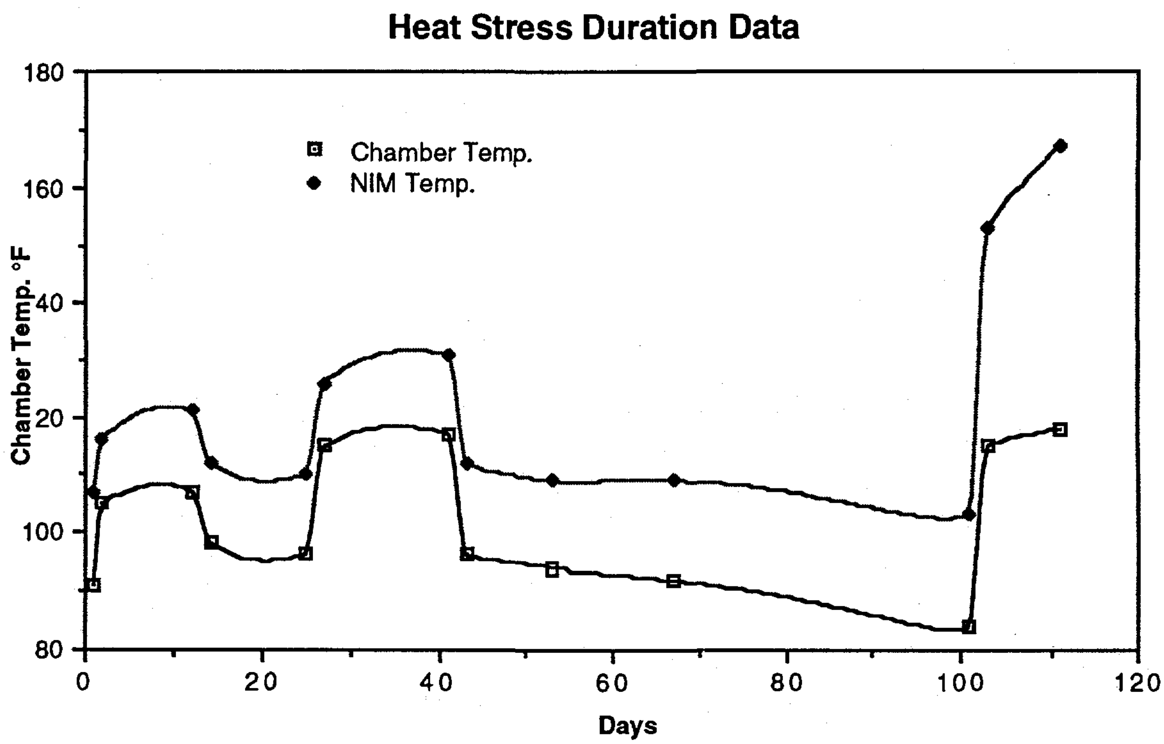


Figure 22
NIM Heat Stress Duration Test Temperature Curve

The duration test carried out under normal operating conditions was successful. The ambient temperatures for this test have ranged between 68°F and 78°F. The NIM units have been subjected to all normal operating conditions including power outages. No failures have been reported on any of the NIM units during this test. The time line data for this test is given in figure 23.

Seven NIM units have been operating for over 6000 hours each with no failures. The NIM units have been operated for a total of over 59,000 hours without a failure.

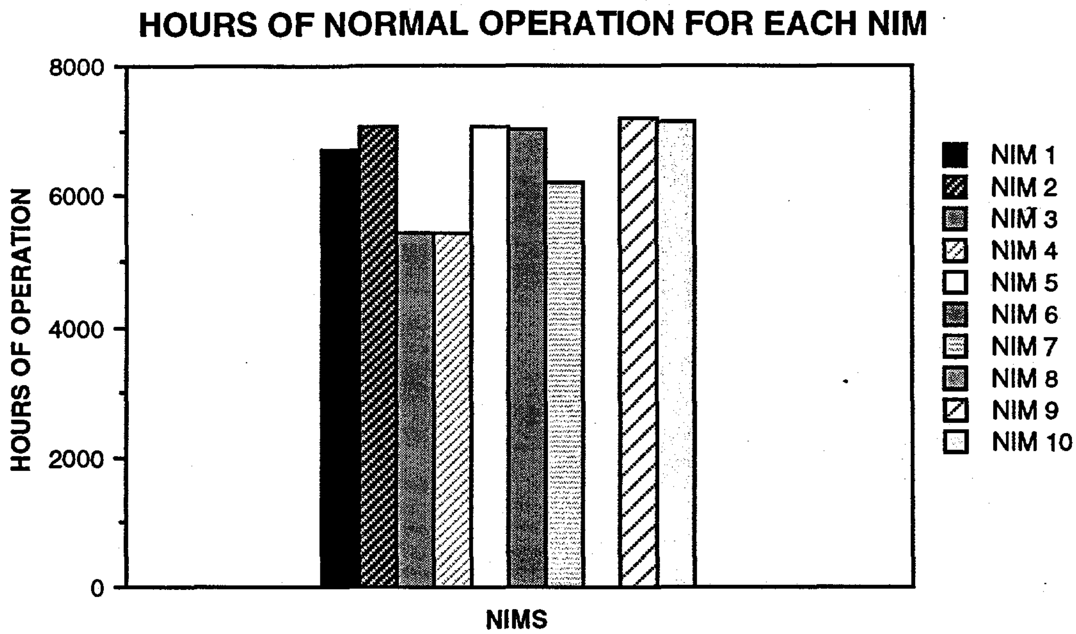


Figure 23
NIM Longevity Test Time Chart

Siesmic Qualification

NIM units were seismically tested to the requirements of the following standards and regulatory documents.

USNRC Regulatory Guide 1.100, "Seismic Qualification of Electric Equipment for Nuclear Power Plants".

IEEE 344-1987, "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations".

Testing was performed using the site developed seismic spectrum for the 5th level of a Separations canyon building. The NIM's were tested as single untis and connected together in triplets. Criteria for acceptance was full functionality before, during and after each test. All of the NIM's tested were accepted.

In addition to the seismic testing, fragility tests were performed to define the levels at which the NIM's would fail. Energy levels six times the design basis peak were applied without failure.

APPENDIX A

DRAWING LIST

Drawing No.	Drawing Title
L-LC-G-0009	NUCLEAR INCIDENT MONITOR (U) ION CHAMBER ELECTROMETER PRINTED CIRCUIT BOARD PC257 REV-0 SCHEMATIC
L-LC-G-0010	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 SCHEMATIC, SHEET 1
L-LC-G-0011	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 SCHEMATIC, SHEET 2
L-LD-G-0013	NUCLEAR INCIDENT MONITOR (U) ION CHAMBER ELECTROMETER PRINTED CIRCUIT BOARD PC257 REV-0 SUBASSEMBLY
L-LD-G-0014	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 SUBASSEMBLY
L-LD-G-0015	NUCLEAR INCIDENT MONITOR (U) CONNECTOR BUSS PRINTED CIRCUIT BOARD PC330 REV-0 SUBASSEMBLY AND SCHEMATIC
L-LE-G-0011	NUCLEAR INCIDENT MONITOR (U) ION CHAMBER ELECTROMETER PRINTED CIRCUIT OBOARD PC257 REV-0 FABRICATION DETAILS
L-LE-G-0012	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 FABRICATION DETAILS
L-LE-G-0013	NUCLEAR INCIDENT MONITOR (U) CONNECTOR BUS PRINTED CIRCUIT BOARD PC330 REV-0 FABRICATION DETAILS & LAYER MAPS
L-LF-G-0010	NUCLEAR INCIDENT MONITOR (U) ION CHAMBER ELECTROMETER PRINTED CIRCUIT BOARD PC257 REV-0 LAYER MAPS
L-LF-G-0011	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 LAYER MAPS, SHEET 1
L-LF-G-0012	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 LAYER MAPS, SHEET 2
L-LF-G-0013	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 LAYER MAPS, SHEET 3
L-LF-G-0014	NUCLEAR INCIDENT MONITOR (U) CONTROL PRINTED CIRCUIT BOARD PC258 REV-1 LAYER MAPS, SHEET 4
L-L1-G-0006	NUCLEAR INCIDENT MONITOR (U) CHASSIS ASSEMBLY
L-L2-G-0004	NUCLEAR INCIDENT MONITOR (U) CHASSIS WIRING HARNESS SUBASSEMBLY
L-L2-G-0005	NUCLEAR INCIDENT MONITOR (U) ION CHAMBER SUBASSEMBLY
L-L3-G-0007	NUCLEAR INCIDENT MONITOR (U) CHASSIS PARTS FRONT PLATE ENGRAVING DETAILS
L-L7-G-0002	NUCLEAR INCIDENT MONITOR (U) CHASSIS WIRING WIRING HARNESS SCHEMATIC
R-R2-G-0007	NUCLEAR INCIDENT MONITOR (U) DETECTOR PARTS ELECTROMETER CAP AND INSULATOR DETAILS, WELDMENT AND SUBASSEMBLY

APPENDIX A

DRAWING LIST (continued)

R-R2-G-0008	NUCLEAR INCIDENT MONITOR (U) DETECTOR PARTS ION CHAMBER AND FEEDTHROUGH DETAILS, WELDMENT AND SUBASSEMBLY
R-R4-G-0004	NUCLEAR INCIDENT MONITOR (U) CHASSIS PARTS BACK PLATE AND BOTTOM PLATE DETAILS
R-R4-G-0005	NUCLEAR INCIDENT MONITOR (U) CHASSIS PARTS FRONT PLATE AND LEXAN PANEL DETAILS
R-R4-G-0006	NUCLEAR INCIDENT MONITOR (U) CHASSIS PARTS GASKET AND BRACKET DETAILS
R-R7-G-0001	NUCLEAR INCIDENT MONITOR (U) CHASSIS PARTS & DETAILS