U. S. NUCLEAR REGULATORY COMMISSION

REGION V

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Docket: 50-530

License: NPF-74

Licensee: Arizona Public Service Company
P. O. Box 53999, Station 9012
Phoenix, AZ 85072-3999

Facility: Palo Verde Nuclear Generating Station
Unit 3

Inspection location: Wintersburg, Arizona

Inspection duration: May 8 - 14, 1992

Approved by: R P Zimmerman 6/4/92
Roy P. Zimmerman, Director Date Signed
Division of Reactor Safety & Projects

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Areas Inspected:

A special announced Augmented Inspection Team (AIT) inspection was performed to determine and evaluate licensee activities and circumstances related to the May 4, 1992, loss of plant annunciator system event at Palo Verde, Unit 3.

The AIT used NRC Inspection Procedure 93800 and the AIT charter (provided as Appendix B).

General Conclusions and Findings:

The AIT's primary findings focused on work order control and equipment and personnel safety. Within these two areas, the team identified several instances in which program barriers were not in place (and opportunities were missed) that could have avoided the event:

These barriers, had they been in place, could have (1) provided the opportunity for the originating engineer to identify to the planner that active breakers did not need to have the contacts verified, (2) identified that the breaker involved in the event had been previously verified, approximately one year earlier, and did not require reverification, and (3) ensured that precautions adequate for protecting equipment and preventing adverse plant effects were specified and implemented when working on energized gear.

The AIT also identified opportunities for licensee improvement in the areas of procedures, training, computer data processing capability, and operator provisions for base-lining instrument data.

The AIT concluded that licensee response to the event was satisfactory in that:

1. The licensee's classification of the event was correct.

2. The required notifications of the event to organizations external to APS were prompt and timely. However, the licensee's internal notification processes were in need of improvement.

3. Emergency response facilities were generally adequate to support event response.

4. The staffing of emergency response facilities was generally adequate to support facility operations during an extended event.

5. The licensee's coordination of recovery efforts and communications generally went well during the emergency.

6. The licensee's short-term corrective actions to support returning the plant alarm systems to operable status were adequate.

However, the AIT concluded that if the licensee had provided program barriers and required that specific personnel and equipment safety precautions be implemented for non-safety-related equipment the event could have been precluded.

Significant Safety Matters:

There were no significant nuclear safety matters identified during this inspection.

Open Items:

No inspector follow-up items were identified during this inspection.

Strengths Noted:

The AIT identified the following licensee strengths in responding to the event:

The licensee demonstrated their ability to adequately respond to the event and coordinate and implement short-term corrective actions to return non-safety-related plant alarm systems to normal. The operator's control room command, control, and communication were effective in avoiding challenges to plant safety systems.

Weaknesses Noted:

The AIT identified the following areas of weakness, including several which could have increased the probability that the event would occur:

The electricians performing the maintenance work order that initiated the event did not take appropriate precautions to prevent accidental damage to equipment, thus creating a condition which (1) significantly degraded the Control Room operators' ability to monitor plant parameters, (2) impacted plant computer capability for automatic calculation of plant safety limits, invoking license requirements for reducing plant power, and (3) called into question the operability of the optical isolation system, which segregates safety-related and non-safety-related devices.

Although the licensee's programs and procedures for controlling safety related and non-safety related work are the same, licensee programs and procedures did not require Engineering Department review or concurrence on revisions, made by other organizations, to Engineering-originated work requests.

Licensee programs and procedures required work planners to review archived work orders. However, the planner did not review archived work orders in this case. Licensee management considered reviews of archived work orders to be unnecessary in the case of simple tasks. Program requirements appeared to be inconsistent with management expectations.

The plant operating procedure for responding to the loss of the plant monitoring system did not cover the total loss of non-safety-related annunciators or annunciators and computer systems.

Emergency plan procedures did not clearly identify criteria necessary for exiting an emergency condition.

Plant operating procedures did not provide a clear threshold for determining computer alarm/printer operability.

Operator training was not provided for the loss of all non-safety-related annunciators during normal and abnormal operating conditions.

The plant computer input buffer overloaded during high input conditions, electrical noise problems existed and there were contentions for access to peripheral devices that result in the loss of information.

TABLE OF CONTENTS

LIST OF ACRONYMS

ac	Alternating Current
AIT	Augmented Inspection Team
AO	Auxiliary Operator
APS	Arizona Public Service Company
ASI	Axial Shape Index
Asst SS	Assistant Shift Supervisor
ATS	Automatic Turbine Startup
AZTILT	Azimuthal Flux Tilt
CEA	Control Element Assembly
CEAC	Control Element Assembly Calculator
CMC	Core Monitoring Computer
COLSS	Core Operating Limits Supervisory System
CPC	Core Protection Calculator
CRDR	Condition Report/Disposition Request
CRS	Control Room Supervisor
CRT	Cathode-Ray Tube
CWP	Controlled Withdrawal Prohibit
dc	Direct Current
DNBR	Departure from Nucleate Boiling Ratio
EAL	Emergency Action Level
EC	Emergency Coordinator
EER	Engineering Evaluation Request
EIS	Electronic Isolation System
ENS	Emergency Notification System
EOC	Emergency Operations Center
EOD	Emergency Onsite Director
EOF	Emergency Operations Facility
EOP	Emergency Operating Procedure
EPIP	Emergency Plan Implementing Procedure
GCC	Generation Control Center
Generex	Generator Exciter
HPN	Health Physics Network
Hz	Hertz
I&C	Instrumentation and Control Group
JCO	Justification for Continued Operation
LCO	Limiting Condition for Operation
LED	Light Emitting Diode
LPD	Linear Power Density
MI	Multiple Input
MSR	Moisture Separator Reheater
MST	Mountain Standard Time
NUE	Notification of Unusual Event
PC	Plant Computer
PDIL	Power Dependent Insertion Limit
PIU	Process Input Unit
PMS	Plant Monitoring System
PPC	Plant Process Computer
PRA	Probabilistic Risk Assessment
PRB	Plant Review Board
PVNGS	Palo Verde Nuclear Generating Station
RCP	Reactor Coolant Pump

RCS	Reactor Coolant System
RJ	Plant Computer Alarm System
RK	Main Control Board Alarm System
RPS	Reactor Protection System
SEAS	Safety Equipment Actuated Status
SESS	Safety Equipment Status System
SS	Shift Supervisor
STA	Shift Technical Advisor
STSC	Satellite Technical Support Center
TBD	Technical Basis Document
TEC	Technical Engineering Coordinator
TS	Technical Specification
TSC	Technical Support Center
vac	Volts of Alternating Current
vdc	Volts of Direct Current
VP	Vice President
WO	Work Order
WR	Work Request

NOTE: All times are given in Mountain Standard Time.

I. Introduction - Formulation and Initiation of the AIT

A. Background and Formation of AIT

On Monday, May 4, 1992, at 0819 MST, following the loss of the non-safety-related alarm annunciator and computer alarm systems, Palo Verde Unit 3 declared an ALERT.

The unit had been operating at about 100% power when, at about 0436, an electrician, performing a wire de-termination in a non-safety-related motor control center in the turbine building, failed to control a disconnected lead from the plant annunciator system power supply and allowed the lead to momentarily come in contact with one phase of a 480 vac bus. This momentary shorting applied 480 vac to a 24 vdc plant annunciator system power supply, resulting in a loss of the plant alarm annunciator system and portions of the associated computer recording capability.

The potential for significant generic implications of this event suggested the need for further evaluation by an NRC AIT.

On the morning of Friday, May 8, 1992, after detailed regional and resident staff briefings and consultation with senior NRC Headquarters management, the Region V Regional Administrator directed the dispatch of an AIT.

B. AIT Inspection Plan - Initiation of Inspection

Based on the AIT charter (included as Appendix B to this report), an inspection plan was prepared by the Region V staff and promulgated by the Regional Administrator on May 7, 1992. The AIT members arrived at PVNGS on May 7 and 8, 1992. To initiate the special inspection, an entrance interview was held with licensee management on the morning of May 8, followed by an afternoon tour of areas of the facility affected by the event. This tour allowed the team to personally view the equipment involved in the event.

The following Unit 3 areas were toured by the team inspectors during the inspection:

* Turbine Building (with specific attention to the load center where the event was initiated)

* Control Room, Unit 3

* Control Boards and the back of the main control panels, Unit 3 (including Bays 1 through 8 of the plant annunciator system)

C. Persons Contacted

Refer to Appendix A.

D. Executive Summary

In response to the May 4, 1992, loss of non-safety-related plant annunciator and computer alarm systems at Palo Verde Unit 3, the NRC dispatched an Augmented Inspection Team (AIT) to Palo Verde Nuclear Generating Station (PVNGS). The purpose of the AIT was to determine the circumstances leading to the event, establish a sequence of events, evaluate the licensee's (management and operations) effectiveness in response to the event, and assess the effectiveness and appropriateness of the licensee's corrective actions to re-establish confidence in the reliability and operability of the plant alarm systems.

The AIT's primary findings focused on two areas: (1) work order control, and (2) equipment and personnel safety. The team also pointed out several areas worthy of licensee evaluation for improvement.

The loss of alarm annunciator event was precipitated by a circuit breaker trip alarm verification that inadvertently created a short circuit from 480 vac load center power supply to the annunciator system 24 vdc. In review of the specific circumstances leading up to this event, the team found that the licensee's work control programs lacked certain "barriers" which, if in place, could have precluded the event. As a key example, if work planning controls had been more stringent, the planner might have identified that the circuit breaker alarm verification that precipitated the event had been previously performed, and that a repeat check was not necessary.

The AIT's findings identified several instances in which program barriers were not in place (and opportunities were missed) that could have avoided the event:

1. Finding: A work planner modified Engineering Department instructions (originally requiring trip alarm verification on spare breakers only) to require trip alarm verification on active breakers, as well, without obtaining Engineering concurrence on the modification.

   Missing Barrier: The licensee's program for maintenance planning does not require the work planner to obtain Engineering review and concurrence for work orders which slightly modify Engineering instructions.

   Missed Opportunity: The AIT noted that Engineering had known the active breakers to be satisfactory when they specified the trip alarm verification on the spare breakers, and, for this reason, had excluded the active breakers from the work scope. The AIT concluded that the licensee missed an opportunity to preclude the event by not requiring the above "barrier."

2. Finding: The work planner did not review archived work documents that showed the active breaker trip alarms to have been verified about one year earlier.

   Missing Barrier: The work planner is allowed, by provisions of the maintenance program, to not review archived work orders under certain circumstances.

   Missed Opportunity: A review of archived work documents for the active breakers could have identified that the planner-specified work on the active breakers was not necessary, having already been performed (for the breaker being worked on) about April 23, 1991.

3. Finding: The electrician performed work (disconnecting of a lead) that was not specified by the work order.

   Missing Barrier: Workers are not procedurally precluded from deviating from the precise implementation of work order specifics in the case of non-safety-related work.

   Missed Opportunity: The AIT noted that management had not presented consistent expectations to workers regarding the rigor to be used in implementing non-safety-related and safety-related work orders, although the programs and procedures governing both safety related and non-safety related work are the same.

4. Finding: Adequate equipment safety precautions were not implemented by the electrician.

   Missing Barrier: Equipment safety considerations were not adequately delineated by electrical safety instructions. The licensee had previously identified this finding, and was engaged in a program to upgrade personnel and equipment safety instructions.

   Missed Opportunity: The electricians failed to use appropriate equipment safety practices (such as rubber or canvas blankets to drape over high-energy bus work, or insulated tongs to capture and restrain a disconnected lead). The operators indicated their understanding had been that a canvas blanket would be draped over the high-energy bus work.

The AIT identified a number of areas for the licensee's consideration where additional improvements, although not mandated by regulatory requirements, could be made:

1. Procedure Improvements

   a. The process for notifying internal licensee management of events could be improved by clearly identifying internal notification responsibilities and priorities.

b. The procedure for dealing with a loss of the plant monitoring system does not cover the total loss of the non-safety-related alarm systems. Procedure improvements could provide the operators with considered guidance in dealing with the circumstances of the event in question.

c. Emergency plan procedures do not clearly identify criteria necessary for exiting an emergency condition. The process used (management discussion and consensus) was not considered flawed by the team; however, the team noted that the process might be improved by a clearer definition of criteria.

d. The methods for operator assessment of computer alarm printer/computer operability are not clear. The operations staff expressed interest in having a clearer threshold of acceptability defined.

2. <u>Training Improvements</u>

The licensee's training program could be improved by providing training on a loss of the non-safety-related plant alarm systems during normal and abnormal plant shutdowns or reactor trips.

3. <u>Improved Ability in Early Detection of Trends</u>

The AIT noted that operators are not allowed to mark Control Room indicators with the relative reading of a process variable, and observed that this prohibition puts the operators at a higher risk of missing trends. The operators indicated interest in being allowed to mark indicators in a non-permanent manner, at some point in their shift, to provide quick visual indication of process variable changes.

4. <u>Improved Ability to Capture Alarms and Reconstruct Events</u>

The AIT's discussions with operators indicated that the computer buffer quickly overloads during high input situations, resulting in a loss of information. In addition, the alarm screen cathode-ray tube display scrolls too rapidly to be meaningful under those situations. These observations suggest the prudence of assessing the need to upgrade the computer buffer.

The team concluded that:

1. The licensee's classification of the event was correct.
2. The required notifications of the event to organizations external to APS were prompt and timely. However, the processes used by the licensee for APS-internal notifications needed improvement.
3. Emergency response facilities were generally adequate to support event response.

4. The staffing of emergency response facilities was generally adequate to support facility operations during an extended event.

5. The licensee's coordination of recovery efforts and communications generally went well during the emergency.

6. The licensee's short-term corrective actions to support returning the plant alarm systems to operable status were adequate and thorough.

II. Description of Unit 3 Event

A. Event Summary

On May 4, 1992, at 0436, with Unit 3 operating at 100% power, a licensee electrician was performing work on a 480 vac electrical load center in the Turbine Building. The electrician was disconnecting a lead from a terminal board above two breakers. The lead was energized from a 24 vdc power supply in the plant annunciator system (RK system), Cabinet 2. The electrician lost control of the lead when the attaching screw became disengaged from the terminal board, and the lead came in momentary contact with one phase of the 480 vac bus bars in back of the breakers. The resulting short circuit caused a loss of the non-safety-related RK system control board alarm annunciator functions, and PC COLSS. In addition, the main generator exciter control system transferred from automatic to manual operation.

At about 0500, CEAC #2 became inoperable for all CPCs. At about 0708, the CMC COLSS ceased performing calculations and the licensee initiated action to verify TS compliance with DNBR, LPD, ASI, and AZTILT information. At about 0749, the operators began borating the RCS to reduce power, in accordance with TS Loss of COLSS action requirements.

At about 0814, the remaining PC alarm monitoring functions failed and, in accordance with emergency procedures, an ALERT was declared at 0819. As required by the Emergency Plan upon declaration of an ALERT, the licensee staffed and placed into service the TSC and EOF. The licensee continued to reduce power, while conducting hand calculations of the reactor core performance, until reaching approximately 70%.

The licensee notified the NRC of the ALERT via ENS at about 0830. Discussions between the licensee and the NRC were frequent throughout the event and the recovery.

Throughout the afternoon and evening of May 4, the licensee continued activities to return CEAC #2 and the CMC and PC COLSS systems to service. In addition, the licensee continued to troubleshoot the plant annunciator systems supplying control board alarms (RK system) and plant computer alarm inputs (RJ system).

Due to the indeterminate status and unreliability of the plant alarm annunciator system, the licensee determined that certain actions were prudent, including:

1. Maintaining the plant in a stable, steady state condition at about 70% reactor power;

2. Delaying all unnecessary activities on all units which could potentially initiate a Unit 3 transient;

3. Troubleshooting and repairing the plant alarm system;

4. Devising a method to test and validate the operability and function of the alarm systems following repair; and

5. Augmenting the operating crew with additional staff (two reactor operators and four AOs) to provide enhanced monitoring and oversight of control room indications and plant conditions. (Crew augmentation was completed at about 0700 on May 4, 1992, and remained in effect until the ALERT was secured.)

The licensee's troubleshooting efforts on the plant alarm system resulted in replacing 77 control board lamp driver logic cards, 9 computer multiple input relay cards, 1 power supply transformer, and 1 RK system chime power supply.

The licensee then began processes to test and validate the functionality and operability of the alarm system. These efforts involved three activities:

1. Confidence Test: testing the operability of a statistically significant random sample of alarm functions to establish a 95% confidence level that 95% of the alarm functions were operating satisfactorily;

2. Field Test: selecting a sample of process parameter alarm functions (62 were tested) and, by manipulation of the field device, testing for proper operation of the appropriate control board and computer alarms; and

3. Normal Alarm Verification: documenting, logging, and verifying by field observation the validity of alarms received during normal, stable plant operation.

Concurrent with these three activities, the licensee management began to chart their course of action once the plant annunciator and alarm system testing and validation programs were completed satisfactorily. The licensee decided to shut down Unit 3 when these activities were completed sufficiently to provide confidence in the functionality of the plant alarm system and after securing the ALERT. Realizing that some alarm functions would still be indeterminate at that time, the licensee conducted simulator training for two operating crews, using the reactor shutdown and reactor trip procedures, under loss of the plant annunciator and PMS

conditions. This training verified that the crews could safely perform those activities under the postulated plant conditions.

The license established that, to terminate the ALERT and exit the Emergency Plan, the confidence and field testing programs should be completed satisfactorily, with discrepancies reviewed and accepted by the PRB. Upon completion of these conditions and obtaining assurance regarding the functionality and reliability of the plant annunciator and alarm systems, the EOD was authorized to terminate the ALERT. The ALERT was terminated on May 7 at 2321.

The plant shutdown was commenced at 2340 by one of the crews trained on the simulator, and completed on May 8 at 0420 with a manual reactor trip from 20% power. The shutdown was conducted without incident.

B. Detailed Sequence and Chronology

DATE/TIME		EVENTS
5/3	1639	CPC Channel A declared inoperable, due to several auto restarts of CPC A during the previous 24 hours.
5/3	2300	Electrical foreman briefs senior electrician on WO 521473.
5/4	unknown	Asst SS signs WO 521473 as releasing organization.
		Senior electrician and electrical foreman discuss testing methods for installed and spare breakers.
		Senior electrician and Asst SS agree on testing method, and an AO is assigned for communications during lifting of leads on the breaker alarm circuits. Permission to test spare breakers is given at this time.
		Electrical foreman and senior electrician discuss working on active breakers.
		Electrical foreman assigns an additional electrician to the task. The senior electrician briefs the new electrician on the WO scope.
		A tailboard brief regarding the WO is held in the control room with the Asst SS, a reactor operator, the AO, and the electricians.
		The electricians hold an additional tailboard at the work area to discuss details of lifting the leads.
5/4	0436	Electrician performing maintenance in load center NGNL18 allows 24 vdc lead to contact 480 vac bus.

The resulting contact causes a loss of annunciators on five of seven main control board windows and alarm chimes.

STATUS OF PLANT SYSTEMS AFTER ELECTRICAL FAULT:

* PC COLSS is inoperable.
* CMC COLSS is operable.
* PDIL auctioneered alarm circuit is inoperable.
* CEAC #2 is inoperable (operators enter LCO 3.1.3.6, Action a.1 and LCO 3.3.1, Action 6.a).
* SESS/SEAS are verified to be functioning normally.
* Main generator voltage regulator shifts to dc control mode.

Assistant Shift Supervisor orders stoppage of work activity.

Loose lead is re-terminated for equipment and personnel safety.

Control Room operating crew notes the following annunciator window status:

*B01 - all windows lit and inoperable
*B02 and B03 - operable
*B04 - all windows dark and inoperable
*B05A - all windows lit and inoperable
*B05B - all windows light, then went dark and inoperable
*B06 - all windows light brightly, then went dark and inoperable
*B07 - all windows lit, then went dark and inoperable

5/4 0440 SS notifies AO to ensure work has halted in Panel NGNL18. I&C is contacted to evaluate the problem.

Control Room operators verify PC operational by noting that alarms are still appearing on CRT. Operators begin periodically testing PC operation by cycling hand switches to bring in and clear alarms.

5/4 0445 Electricians inform SS that loss of control of 24 vdc lead caused introduction of 480 vac into annunciator system. SS reviews EPIP-02 to determine if classification of an event is warranted.

5/4 0450 SS briefs Operations Supervisor, and they conclude that an ALERT is not justified, based on the availability of the PC.

5/4	0500	Operators reprogram CPC addressable constants to disregard signals from inoperable CEAC #2.
5/4	0507	Unit 3 STA responds to Control Room loss of annunciator problem. Unit 3 STA and reactor operator decide to print CMC-COLSS to obtain control room log points.
5/4	0530	SS updates Operations Supervisor on plant status, and notes that the PC is still functional. Attempts to contact the Plant Manager are unsuccessful. GCC notified of limitations due to main generator voltage regulator shift to DC.
5/4	0602	Operations Supervisor arrives in control room.
5/4	0610	VP Nuclear Production briefed by SS on event status.
5/4	0639	Operations Manager arrives in control room.
5/4	0643	System engineer arrives in control room.
5/4	0645	Shift manning augmentation begins (full augmentation completed by 0715).
5/4	0648	VP Nuclear Production arrives in control room.
5/4	0655	Operations Manager briefs Plant Manager by telephone. Unit 3 STA notifies STA Supervisor of plant conditions and initiates a CRDR.
5/4	0701	Plant Manager arrives in control room.
5/4	0708	CMC COLSS is declared inoperable, due to ceasing to perform calculations (operators enter LCO 3.2.4.c).
5/4	0710	Licensee discussions are held regarding notification. Plant Manager directs Operations Manager to inform NRC residents.
5/4	0715	Operations Manager notifies senior NRC resident of loss of annunciators and current plant status. Process computer analyst determine PMS executive load was at about 16% instead of the usual 58% to 60%.
5/4	0732	NRC inspector arrives in Control Room.
5/4	0748	Senior NRC resident inspector arrives in Control Room.
5/4	0749	Operators commence boration to reduce unit power, in compliance with LCO 3.2.4, Action 2.a.

5/4	0808	Operators shift from LCO 3.2.4, Action 2.a to LCO 3.2.4, Action 2.b, and continue with power decrease to restore DNBR to within limits of Table 3.2-2.
5/4	0814	Control Room determines that remaining functions of PC have failed and computer analysts are given permission to cold reboot the PC. No verifiable data from PC exists.
5/4	0819	ALERT declared.
5/4	0830	Licensee completes 1-hour notifications to NRC for ALERT classification.
5/4	0846	Licensee activates EOF.
5/4	0849	Control Room completes power reduction to 76%. Operators exit LCO 3.2.4.
5/4	0850	State EOC briefs Governor's office on initial conditions.
5/4	0854	Licensee activates TSC.
5/4	0930	Plant troubleshooting begins to determine PMS status.
5/4	0955	Operators enter LCO 3.2.3, Action a, for AZTILT.
5/4	0959	HPN communications link established.
5/4	1014	Control Room reduces power to 70%, due to changing values of AZTILT and ASI.
5/4	1021	Operators exit LCO 3.2.3, Action a.
5/4	1253	PRB approves action plan to deal with event.
5/4	1308	Region V NRC inspectors are dispatched to PVNGS.
5/4	1430	Night orders are issued alerting the operators to alternate indications to be used in place of annunciators when executing EOPs.
5/4	1447	CMC COLSS is verified functioning properly, and declared operable.
5/4	1450	PC COLSS is verified functioning properly, and declared operable.
5/4	1506	AZTILT is restored in each CPC channel.

5/4	1730	STSC verifies CEAC display for CEA position is functional.
5/4	1857	CEAC #2 declared operable. Operators remove CEAC #2 flags from all four CPCs.
5/4	1958	PC COLSS unschedules itself when toggle switch T21 SW1 is reopened during troubleshooting. PC COLSS is declared inoperable. CMC COLSS remains operable.
5/4	2003	PC COLSS is rescheduled, all calculations restarted, and values verified to be consistent with CMC COLSS. PC COLSS is declared operable.
5/4	2030	Licensee reviews reliability of plant systems, JCOs, and the possible consequences of thunderstorms in NE Maricopa County.
5/4	2031	PC COLSS unschedules itself when toggle switch T21 SW1 is reopened during troubleshooting. PC COLSS is declared inoperable.
5/4	2035	PC COLSS is rescheduled, all calculations restarted, and values verified to be consistent with CMC COLSS. PC COLSS is declared operable.
5/4	2050	Troubleshooting of toggle switch T21 SW1 causes PC COLSS to unschedule. Repeat test gives same results.
5/4	2156	Control Room notes 43 of 59 field input isolation switches to both the relay card and the multiple input logic cards have been tested. Seven of 170 relay cards tested have failed, and have been replaced.
5/4	2309	Control Room notes 59 of 59 switches tested. Of the seven failed relay cards, three are on Switch 3, Rail T28, at the point of 480 vac entry. The remaining 4 failed relay cards are on 4 other switches.
5/5	0010	Licensee determines that the "right-hand" inverter in Cabinet 3JRNC02C requires replacement.
5/5	0059	Thunderstorms increasing in plant vicinity.
5/5	0108	Licensee commences replacement of inverter in Cabinet 3JRNC02C.
5/5	0205	National Weather Service reports severe thunderstorms approaching the site from the southwest.
5/5	0236	Inverter repairs are completed. Troubleshooting of RK and PMS continues.

5/5	0250	While restoring RKN-C02 isolation switches, computer alarm CRT shows only partial listing of expected alarms. Testing is stopped.
5/5	0312	Control Room notes 4 of 59 input relay switches restored without problems. The inputs and outputs of each switch are being checked when the switch is closed. Operators are verifying annunciator windows.
5/5	0342	Emergency Coordinator and EOD state that they would like the on-duty STA to be relieved due to the number of continuous hours that he has been in the control room.
5/5	0345	When Switch 152 on Rail T32 is closed, most PC CRT alarms disappear from the screen and alarm reporting stops. The alarm reappears on the CRT when the alarm is individually restored. Control Room notes 33 of 59 switches restored.
5/5	0450	Control Room notes that a PC reboot may be necessary to get an adequate check when isolation switches are brought back.
5/5	0527	PC is rebooted. PC & CMC COLSS are inoperable. Prior to closing additional switches, an alarm summary is run to establish a benchmark of alarm status.
5/5	0535	Operators determine that DNBR is not within the acceptable region of TS Figure 3.2-2. Operators enter LCO 3.2.4, Action 2.a, to restore DNBR.
5/4	0546	PC COLSS functional verification completed. PC COLSS declared operable. Operators exit LCO 3.2.4, Action 2.a.
5/5	0553	CMC COLSS functional verification completed. CMC COLSS is declared operable.
5/5	0628	Licensee resumes closure of isolation switches.
5/5	0742	NRC Region V inspectors briefed by EOD.
5/5	1000	Licensee determines that a hardware interface exists between the RK system and the turbine auto-start system. EC requests that rework facility have boards quarantined.
5/5	1030	Licensee work in progress to validate all existing alarm conditions, verify all computer alarms, and demonstrate interface between RJ & RK system. PRB

proposes retest plan to demonstrate 95/95% confidence:

Test 57 inputs if 0 failures
Test 85 inputs if 1 failure
Test 112 inputs if 2 failures

5/5 1130 Status of Testing:
B04 complete, with 11 of 16 logic cards failed
B05A, B, C complete, with 13 total failures

5/5 1215 PRB approves confidence test plan.

5/5 1326 CPC Channel A declared operable. Operators exit LCO 3.3.1, Actions 2 and 7.

5/5 1437 Operators in requalification simulator training perform a scenario for a reactor shut down without annunciators from 70% power. Separate scenarios for a loss of feedwater pump and a reactor trip are also performed by the requalification crew.

5/5 1500 Status of Testing:
B04: 11 logic cards failed
B05: 13 logic cards failed
B06A: 14 logic cards failed
B06B: 11 logic cards failed
B07A: in progress

5/5 1610 Beta Corporation (PMS manufacturer) representatives arrive at site.

5/5 1700 B07 Testing Status:
B07A: 7 logic cards failed
B07B: 4 logic cards failed
B07C: 10 logic cards failed

5/5 2033 Auto restart signal received on Channel D of CPC DNBR and LPD trips. Operators verify proper RK and PMS systems alarms and indications.

5/5 2146 PRB determines requirements for exiting ALERT.

5/5 2325 Authorization given to check for grounds on cabinets.

5/5 2352 Ground detection cards are reinstalled on cabinets in Bay #2 and Bay #6. Beta representative believes that a ground exists on the return line. The short does not appear to be significant.

5/6 0043 Auto restart signal again received on CPC Channel D.

5/6 0104 Operators declare CPC Channel D inoperable.

Parameters 3 and 4 placed in bypass. Operators enter LCO 3.3.1, Action 2.

Troubleshooting of alarm points completed. All observed problems have been resolved except for several computer problems not related to RJ/RK systems. I&C commences testing of randomly selected alarm points.

Troubleshooting of CPC Channel D completed. Problem is not related to the event. (Retaining bracket for the power monitor card was found improperly installed, allowing more than normal movement of the card. The auto restart signal was repeated by moving the board. The board was reseated and the bracket reinstalled properly.)

5/6 0135 Licensee commences retesting of the 7 replaced relay cards.

5/6 0230 Operations is generating a list of approximately 100 instruments to test from the field component through the RK system. Engineering is generating a random testing list for the RK system.

5/6 0303 Retest of the 7 replaced relay cards completed.

5/6 0314 Revised Night Orders are issued for use of indications instead of annunciators.

5/6 0320 One relay card of the seven replaced on May 4 fails and requires replacement. This is later determined to be an "infancy" failure not related to the event.

5/6 0329 Control Room notes an annunciator dimly lit (3JRKNUA0004B, window #4C, MSR High Level first out window). Window is not considered valid since a valid signal would have resulted in a turbine trip.

5/6 0800 Licensee commences testing of RK system field input devices (for the 96-point list involving non-impact board manipulations and field manipulations) to verify proper RK annunciation.

5/6 0805 Licensee commences random testing of RK annunciators via isolation switch operation.

5/6 0930 Control Room notes 28 of the 30 annunciator tests complete.

5/6 1100 Testing of RK system field input devices completed.

Licensee determines that relay cards, MI relay cards, and logic cards provided isolation from the 480 vac short to the field devices.

5/6	1353	While troubleshooting the RK chime function associated with boards 3, 4, 5, 6, and 7, a ground is discovered when lifting the 24 vdc lead to the chime chassis. The ground is verified and the chassis is removed for repair.
5/6	1411	Retest completed for CPC Channel D. Operators declare CPC Channel D operable and exit LCO 3.3.1, Action 2.
5/6	1500	With 75 random test points completed, one failure noted. Licensee increases population of sample from 57 to 91.
5/6	1805	Oncoming crew is required to perform abbreviated simulator scenario for shutdown without annunciators, and abbreviated loss of main feedwater and reactor trip scenarios. This crew will perform the reactor shutdown to Mode 3.
5/6	1945	Licensee receives temporary waiver of compliance for TS Surveillance 4.3.1.1.
5/6	2122	Main generator regulation is placed into the ac mode per normal operations.
5/6	2320	Unit 3 plant annunciator system (RK) and plant computer annunciator (RJ) have been determined to be functional. The approved testing and troubleshooting plan has been completed.
5/6	2321	ALERT emergency classification terminated.
5/6	2336	Licensee completes emergency event termination message to site personnel.
5/6	2340	Control Room commences power reduction from 70% to 20% power.
5/7	0420	Control Room initiates manual reactor trip from 20% reactor power.
5/7	0432	Control Room classifies reactor trip as an "uncomplicated reactor trip."

III. Licensee Control of Maintenance

In order to determine the effect the maintenance control process had on this event, the team investigated the background for the work which initiated the event. After the background was understood, the team identified and evaluated the procedures used by the licensee which address maintenance work during plant power operation. The team observed that the licensee's program and procedures for controlling maintenance activities applied equally to both safety related and

non-safety related maintenance. The team evaluated the effectiveness of the licensee's maintenance procedures, and examined the licensee's adherence to these procedures as they related to the event.

A. Background for Work in Load Center 3E-NGN-L18

Load Center 3E-NGN-L18 (L18) is a non-safety-related lighting distribution load center located in the turbine building. I-T-E Gould had manufactured load center L18, using Westinghouse Type SPCB-600 circuit breakers. These Westinghouse circuit breakers are manually-operated, molded-case circuit breakers, with overcurrent trips. L18 contains six active and four spare SPCB-600 circuit breakers. Secondary contacts on the active circuit breakers are wired in series to provide a control room bell (annunciator) alarm whenever any individual active circuit breaker is tripped open.

The licensee had attempted to order a spare Type SPCB-600 circuit breaker from Westinghouse, using Purchase Requisition 9476181. Westinghouse had noted that this type of circuit breaker was obsolete, and had recommended a replacement circuit breaker. EER 89-NG-033, dated September 25, 1989, had requested an engineering evaluation of the Westinghouse-recommended circuit breaker substitute.

On March 30, 1991, the licensee had determined that EER 89-NG-033 was lost. The licensee had subsequently initiated EER 91-NG-002, which again requested an engineering evaluation of the Westinghouse-recommended substitute.

On June 13, 1991, Unit 2 personnel had obtained a spare Type SPCB-600 circuit breaker from a warehouse, as a contingency item for correction of a ground problem identified in WO 00499498. Unit 2 personnel had determined that the spare circuit breaker had a "b" contact for the bell alarm circuit. The system wiring diagram required this contact to be an "a" contact. (The term "b" contact identifies an open auxiliary breaker contact when the main breaker is closed; an "a" contact is a closed auxiliary contact when the main breaker is closed.) The spare circuit breaker had been subsequently determined to be unnecessary for correction of the ground problem.

On September 25, 1991, Engineering had completed evaluation of EER 91-NG-02. Engineering personnel had determined that purchase of a substitute for the obsolete Type SPCB-600 circuit breaker was unnecessary, due to the number of existing spares.

In addition, Engineering had resolved the problem of the incorrect contact arrangement found on the spare circuit breaker under WO 00499498. Apparently, I-T-E Gould had converted bell alarm contacts from a "b" configuration to an "a" configuration to support the annunciator system wiring diagram during construction of L18. Engineering had noted, however, that the Westinghouse nameplates still indicated the "b" configuration.

Engineering had initiated WR 804370 to request correction of all the original Westinghouse nameplates in L18. In addition, Engineering had determined that the four installed spare Type SPCB-600 circuit breakers in L18 had unknown bell alarm contact configuration. Engineering had specified that the bell alarm contact configuration for these spare circuit breakers should be verified by a continuity check.

The licensee's work control process had directed WR 804370 to Unit 3 planning personnel for action. On October 24, 1991, planning personnel had issued WO 00521473 to accomplish the requested work. (By the licensee's definition, a work request (WR) is the document used to identify a problem or request work; a work order (WO) is the document used to authorize the work.) In addition to the work requested in WR 804370, the planner had added instructions to perform the same continuity checks, verifying bell alarm contact configuration, for the active circuit breakers.

On May 4, 1992, graveyard shift, Unit 3 electrical personnel began performing WO 00521473. The electricians decided that the bell alarm contact continuity check, as specified, was not sufficient to verify bell alarm contact configuration for the active circuit breakers. The electricians decided to verify the contact configuration by disconnecting a lead from the bell alarm circuit for each active circuit breaker, and verifying that the Control Room received the appropriate alarm. After obtaining SS permission, the electricians began this check. When disconnecting the lead from the second circuit breaker, the electrician lost positive control of the lifted lead, and the lead momentarily contacted a nearby 480 vac bus.

B. Maintenance Procedure Effectiveness and Adherence

1. Work Order Concurrence

Palo Verde Procedures 30DP-9WP02, Revision 4, "Work Order Development," and 30AC-9ZZ01, Revision 15, "Work Control Process," specified the required WO concurrences and approvals. Neither procedure required WO concurrence from the person or organization requesting the work. In the case of WO 00521473, the engineering personnel who had initiated WR 804370 were unaware that WO 00521473 had required continuity checks for the active L18 circuit breakers.

The team discussed WO 00521473 with the engineering personnel who had initiated WR 804370. The engineering organization stated that startup testing had proven the correct configuration of the bell alarm circuit for the L18 active circuit breakers. Therefore, they considered that the continuity checks of the active breaker bell alarm circuits, as added by the planner, were unnecessary. The team noted that the only technical concurrence universally required for WOs by Procedures 30DP-9WP02 and 30AC-9ZZ01 was peer review by a second planner.

2. Planner Review of Previous Work

The planner who had prepared WO 0521473 told the team that he had been unwilling to relabel the L18 bell alarm contacts, as requested by WR 804370, without a specific circuit check. The planner told the team he had added circuit checks of the active circuit breakers based upon his experience that wiring problems, not identified by startup testing, had previously been found in non-safety circuits.

Procedure 30DP-9W02, Section 3.1.2, required that the planner, "review applicable archived WOs....(and) Maintenance Test Procedures (MT) for information or documentation that may assist in developing the WO."

Procedure 30AC-9ZZ01, Section 3.1.3, stated, in part, "The planner reviews applicable archived work documents for information or documentation that may assist in developing the Work Order."

The team reviewed archived L18 maintenance history records, and determined that Maintenance Test Procedure 32MT-9ZZ28, Revision 0, "Maintenance of Westinghouse Low Voltage Circuit Breakers Type SPCB 600," had been completed in L18 in April 1991. Procedure 32MT-9ZZ28 verified proper bell alarm contact configuration for all L18 active circuit breakers.

3. Method of Accomplishing Circuit Checks

WO 00521473 required electrical maintenance personnel to, "Verify type bell alarm switch contact utilized in circuit breaker .... A continuity check can be made across leads ... landed on points ... of terminal....."

The electrician assigned to perform this work had decided to verify the bell alarm contact configuration (type "a" or type "b" contact) by disconnecting one lead from the bell alarm circuit to each active circuit breaker and having Control Room personnel verify correct bell alarm response. The electrician told the team that he had considered this check to be the only positive method of verifying proper alarm operation. He stated that, after reviewing EER 91-NG-002 and Unit 2 WO 00499498, he had misunderstood the Unit 2 circuit breaker in question (identified in WO 00499498 as having incorrect contact configuration) to be an active plant circuit breaker instead of a spare breaker. Based on this mistake, he had concluded that WO 00521473 was being performed in Unit 3 to identify potential plant wiring problems on active breakers.

Procedure 30DP-9MP01, Revision 4, "Conduct of Maintenance," Section 3.1.1, identified "skill-of-the-craft" work skills that did not usually require step-by-step instructions. Included in "skill-of-the-craft" work skills was electrical troubleshooting Unit 3 supervisory electrical personnel considered the task of

verifying alarm bell contact configuration to be equivalent to a troubleshooting task. Based on this information, the licensee concluded that the electrician's decision to disconnect leads was within the procedure requirements.

4. Personnel and Equipment Safety

Numerous licensee maintenance control procedures applied to the actions taken under WO 00521473. The following paragraphs define and discuss some of the requirements concerning plant and personnel safety.

WO 00521473 required that the work be accomplished in accordance with the PVNGS Accident Prevention Manual. Section 29.8 of this manual defined the requirements for work on energized systems or equipment. Section 29.8 required:

* A tailboard conference to be conducted on safety issues;

* The work area to be made as safe as practicable by installation of protective equipment to protect the worker and tools;

* Personnel protective equipment to be worn as dictated by job requirements; and

* Barrier tape to be installed around the work area as dictated by job requirements.

a. Tailboard

Section 1.4 of the Accident Prevention Manual stated that each job supervisor/foreman was responsible to conduct a tailboard covering safety requirements. The requirements included explaining the plan to everyone and making sure the plan was understood, thinking about what could go wrong and checking safety hazards, and considering alternate methods, including the elimination or control of hazards. The Unit 3 electrical work group supervisor had held a safety tailboard with one electrician, but had assigned this electrician to relay the tailboard information to the second electrician. The second electrician was the individual performing the work at the time of the event.

b. Work Site Safety

The electricians had decided that the only safety equipment required for disconnecting the bell alarm leads in L18 was special screwdrivers.

As noted above, Section 29.8 of the Accident Prevention Manual required that the work area be made as safe as practicable by the installation of protective equipment to

protect the worker and tools from accidental contact with energized equipment.

Procedure 30DP-9MP01, Section 3.5.16, required that, "Necessary precautions shall be taken whenever work is done, such that the work activity ... will not accidentally damage or remove equipment from service, thus compromising essential plant safety functions." Section 3.5.17 required that, "Personnel shall be aware of the potential effects maintenance work may have on associated plant functions and personnel."

The team asked the electricians why they had not installed any protective barriers between the work area and the close-by energized 480 vac buses. The electricians told the team that they had considered the installation of protective barriers to be difficult due to the switchboard arrangement, and that they had considered the protective barrier to be unnecessary.

The team asked the electrical work group supervisor why he had not specified any protective barriers in the work area. The supervisor told the team that he had not sighted the work area and had relied upon the skill of the electricians to determine the electrical safety equipment necessary.

The team asked the Unit 3 electrical maintenance supervisor if the decision on the extent of electrical safety equipment required for work in energized equipment was normally left to the discretion of the workers. The supervisor told the team that often the extent of electrical safety equipment to be used on a job was left to the skill of the electricians, but that safety equipment had been discussed by the supervisor and electricians during the required tailboard.

The team also noted a general lack of details in the electrical section of the Accident Prevention Manual. Specifically, the team was concerned that the existing definition of management involvement in electrical safety decisions, combined with the lack of guidance on when electrical safety equipment was required, might allow poor electrical safety decisions to be made at the working level. The licensee's safety organization acknowledged the team's concerns, and reported that they had reached similar conclusions and were in the process of revising the manual. The licensee agreed to consider the team's concerns in the revised manual.

C. Conclusions

Based on the discussions contained in Section III.B.3, above, the team reached the following conclusions.

1. Work Order Concurrence

Engineering personnel who initiated WR 804370 told the team they considered the circuit checks added by the planner to be unnecessary. Performance of these added checks ultimately initiated the event. Therefore, the team concluded that the licensee's work control process, by failing to route WO 00521473 to the engineering personnel requesting the work, missed an opportunity to have precluded this event.

2. Planner Review of Previous Work

The team concluded that the planner had not reviewed the archived work documents as required by Procedures 30DP-9W02 and 30AC-9ZZ01. The team considered this failure to be a contributing cause to this event, since the configuration checks of the active circuit breakers added by the WO had been completed less than 6 months prior to WO initiation. Licensee management personnel stated that they would not have expected the planner to perform an exhaustive, time-consuming review of archived work documents in preparation for such a simple continuity verification task. The team expressed concern to licensee management regarding the communication of management expectations which were not consistent with procedure requirements.

3. Method of Accomplishing Circuit Checks

The team concluded that the electrician's decision to disconnect leads, in lieu of performing the WO-specified continuity check, had been within the bounds of the licensee's administrative control procedures. However, the team also concluded that this decision had been flawed, based on the electrician's misreading of WO 00499498.

4. Personnel and Equipment Safety

The team concluded that the electricians had not taken action to adequately protect equipment as required by the PVNGS Accident Prevention Manual and Procedure 30DP-9MP01. The team concluded that installation of a protective barrier between the terminals being disconnected and the close-by buses would have prevented the event. The team considered this failure to be the primary contributing cause of the event.

The team also noted that the electrical supervisor was required by the Accident Prevention Manual to hold a safety tailboard with his crew. Instead of briefing both electricians, however, the supervisor had held the safety tailboard with the senior electrician, and had asked that the information be relayed to the electrician who performed the work. The team concluded that this was a questionable work practice.

The team reviewed the Accident Prevention Manual electrical safety instructions. Based on this review, the team concluded that the manual did not adequately detail management control and did not contain specific guidance on when safety equipment was required.

D. Summary and Analysis of Root Cause

In review of the four conclusions discussed above, the team noted that each of the actions taken had been approved by a supervisor. Supervisory personnel, in essence, had experienced four separate opportunities to have prevented the event. The team concluded that the lack of intrusive supervisory involvement in the initiation and performance of routine, balance-of-plant electrical work in Unit 3 was the underlying root cause of the event.

IV. Implementation of the Emergency Plan

The team reviewed the licensee's actions related to event classification, NRC notification, staffing of emergency response centers, information updates, and emergency response coordination.

A. Classification

At 0436 on May 4, 1992, the licensee lost the function of the plant annunciator system. At 0814 the licensee's plant computer became unreliable. EPIP-02 requires that an ALERT classification be made if both the plant computer and plant annunciators are lost for greater than 5 minutes. The event was classified as an ALERT in accordance with EPIP-02, Appendix B, Tab 3 at 0819 on May 4. NRC guidance given in NUREG-0654 lists no specific criteria for an NUE based on loss of annunciators. The NUREG-0654 guidance for an ALERT classification includes "Most or all alarms (annunciators) lost." The event appears to have been properly classified in accordance with EPIP-02 and NRC guidance.

The licensee has a TBD for the EALs that provides a basis for the EAL classification criteria. On February 12, 1992, the licensee developed a TBD for their EALs which includes the loss of all annunciators as an example of an NUE. The EPIP was not consistant with this TBD. This inconsistency was resolved by the licensee prior to the end of the inspection to revise the TBD to the criteria of the EAL. The EAL was consistent with NRC guidance.

The team noted that the licensee had no pre-established criteria for exiting the ALERT. As a result, these criteria had to be decided during the event, through licensee management discussion and consensus.

B. Notification

Licensee logs indicated that all notifications were completed within 15 minutes. 10 CFR 50.72 requires that the licensee notify the NRC by using the ENS within one hour of an event classification. The

event was classified at 0819. The NRC was notified by the licensee via the ENS at 0830. A review of the notification form indicated that the information was complete. The team, however, found that the licensee's processes for notification of necessary APS organizations and individuals were in need of improvement. This finding is discussed elsewhere in this report.

C. Staffing

Licensee records indicated that all Emergency Response Centers were staffed within the 1-hour time required by the Emergency Plan. The licensee developed and implemented a shift rotational schedule to ensure that personnel assigned to an emergency response staff position would remain rested. The schedule ensured that each staff member was relieved by a qualified replacement every 12 hours.

During the event, the inspectors observed shift turnovers on several occasions. Based on observations, interviews with licensee staff, and log entries, the inspector concluded that the shift turnovers were adequate.

D. Information Updates

Based on observations by the onsite NRC inspectors during the event, it appeared that information flow was adequate, with no major breakdowns in the transfer of information. Interviews with licensee management indicated that one area needing improvement was in the area of hardcopy information transfer.

E. Emergency Response Coordination

During the event the NRC inspectors noted that the emergency response facilities appeared to coordinate well together. Interviews with licensee management substantiated this conclusion. Licensee logs and post-event comment sheets noted no problems in facility coordination.

The NRC inspectors noted that, on the second day of the event, the engineering corrective action effort appeared to partially revert to the non-emergency review, approval, and implementation path. This resulted in the Emergency Coordinator in the TSC not always approving and directing the plant recovery effort as called for in the emergency plan. It also resulted in dual information pathways, which caused minor confusion because the information was not always identical. Engineering activities in the TSC were also noted as an NRC concern in the recent evaluated emergency exercise.

F. Licensee Post-Alert Comments

Subsequent to the event the licensee obtained observation comment sheets from the event participants. Examples of significant comments are listed below:

o PRB personnel need to be scheduled so that an adequate number of individuals are available for each shift.

o The TSC needs more room for engineering drawing use.

- EOD briefings were timely and informative.
- Consider adding additional engineering personnel in the TSC to address current issues and postulated events.
- The TEC position in the TSC needs to be reviewed to ensure adequate management perspective and training.
- TSC operations were hindered due to the amount of routine (non-event-related) paperwork generated by personnel housed in the facility on a daily basis.

G. Conclusions

Overall, except as noted above, performance in the Emergency Planning area went well in an extended event. Coordination and communication between the various emergency response organizations went well. Classification and notification went as planned and in accordance with NRC requirements. The team observed that more clearly defined criteria for exiting emergency procedures may be appropriate.

V. Plant Performance Evaluation/Equipment Evaluation

A. Plant Protection System

After reviewing plant data related to this event, the licensee concluded that plant safety limits had not been exceeded and no plant protection system actuation had occurred.

B. Instrumentation and Control Systems Response

1. Annunciation System Description

The Unit 3 annunciation system consists of 2 cabinets. Each cabinet has 4 bays. Cabinet 1 has Bays 1 through 4; Cabinet 2 has Bays 5 through 8. Cabinet 1 drives lamp boxes (annunciator window assemblies) 2A, 2B, 3A, 4B, 6A, 6B, 7A, 7B, and 7C. Cabinet 2 drives lamp boxes 1A, 1B, 1C, 4A, 4C, 5A, 5B, and 5C. The numerical value of the lamp box designation corresponds to the control board number in the Control Room.

Each control board has four push button switches, used for flasher reset, lamp reset, test, and alarm reset. The flasher reset, lamp reset, and test switches are unique to each of the annunciator boards. The alarm reset on the operator console is common to all annunciator boards. There are three groupings of the alarm resets: Boards 1 and 2, Boards 3, 4, and 5, and Boards 6 and 7. The annunciator system provides a chime circuit for each grouping of boards.

The annunciation system supplies a 24 vdc interrogating voltage to sense the state, open or closed, of the field contact through the terminal rail. Each terminal rail has from two to

four isolation switches which connect the positive 24 vdc to the field contacts. Unit 3 has about 2100 annunciator points. Forty-seven field contacts are normally-open contacts, which are closed to alarm. Forty-three of these normally-open contacts are from non-safety-related equipment, and the other four are from safety-related equipment. The remaining field contacts are normally-closed contacts, which are open to alarm. Approximately 620 of these normally-closed contacts are from safety-related equipment. All safety-related field contact inputs to the annunciation system are optically isolated by the EIS.

The signal from the field contact is connected to the relay card and the multiple input card. The output of the relay card is through a solid state reed relay contact. The contact of the reed relay gets the 48 vdc interrogating voltage from the PMS computer. There is 500 volt coil-to-contact isolation between the annunciation system and the PC. From the multiple input card, the field signal goes into the multiple input logic card which drives the annunciator window assembly (the lamp box). Each annunciator window has four General Electric Type 1819 lamps.

The annunciator system has two sources of power: the non-Class 1E station battery 125 vdc and the non-Class 1E 120 vac instrument bus. The annunciator system has a filtering circuit located at the input of the inverter to shunt any noise from the loads of the inverter. A transformer on the inverter assembly controls a switching relay on the transfer of dc to ac.

The inverter takes an input of 125 vdc and produces a 250 Hz square waveform, which is rectified into 24 vdc and regulated 12 vdc. The returns of all 24 vdc and all 12 vdc power supplies are tied together. This tie point is the signal common for the annunciation system. The annunciator is an ungrounded system. The bus bar in the annunciator cabinet is the grounding bar for grounding the cabinet frame and also for connection to the ground detector circuit.

The filtered and regulated 12 vdc source supplies power to multiple input cards, multiple input logic cards, and the clock card. The 24 vdc source supplies power to the relay cards, the horn circuits, the annunciator window, the push-button relays, and the interrogation of field contacts.

2. <u>Circuit Protection in the Annunciation System</u>

The EIS provides optical isolation for the safety-related inputs to the annunciator system. The qualification test report demonstrated the optical isolator card capable of providing isolation for a voltage of 1500 vac by the use of a high pot test. A voltage of 1500 vac was applied to the output to input, input to ground, output to ground, input power to

ground, and input power to output. The AIT reviewed vendor document J108-262-3, "Nuclear Qualification of Beta Products Electronic Isolation System (EIS)," and concluded that the optical isolator card appeared to be able to withstand the surge voltage from both the input and output sides.

The input circuit of the multiple input card provides additional optical isolation between field input and the multiple input logic card, the annunciator window driver. The output of the relay card also provides 500 volt coil-to-contact isolation between the annunciation system and the PC.

The other protection circuit is the annunciator ground detection circuit. The ground detector is a balanced bridge circuit which detects any leakage between the supply side of the field wiring system and chassis (earth) ground. The setting on the ground detection circuit is 20.0 kilo-ohms. When the leakage resistance lowers to the detection level, an LED will light both on the ground detector card and remotely on the annunciation window in the control room.

3. Annunciation System Response

On May 4, 1992, a plant electrician was lifting a lead in a 480 vac load center to test an annunciator window. The electrician lost control of the 24 vdc field lead from Cabinet 2 and the lead contacted one phase of the 480 vac bus. This caused a surge of 277 vac (392 vac peak) through the lead into the plant annunciator system, Cabinet 2.

Most of the annunciation lamps on Boards 4, 6, and 7 were burnt out. Cabinet 1 (Bays 1 to 4) actuated lamps on Boards 6 and 7. Cabinet 1 actuated lamp box 4B and Cabinet 2 (Bays 5 to 8) actuated lamps boxes 4A and 4C. No lamp was burnt out on Boards 2 and 3. All windows on Boards 1 and 5 were lighted and locked in solid. The licensee replaced lamps in Boards 1, 4, 5, 6, and 7, but kept no account of the total number of lamps being replaced. The combination of burnt-out lamps indicated that a voltage surge in Cabinet 2 had affected those circuits associated with Cabinet 1.

The chime circuit, for Boards 3, 4, and 5, located in Bay 6, had a burned 2-watt resistor. The burned resistor was 47 ohms, rated at 2 watts, but some vendor documents indicated that a 2-watt, 470-ohm resistor was required. Apparently, an undersized resistor had been installed on the chime circuit board. The transistor in the same chime circuit was mounted on the chassis with one of two mounting screws missing. This allowed the collector of the transistor to come into close proximity with the chassis. This provided a ground path for the surge current to exit. The transistor and the chassis had burn marks, indicating that they were part of the fault path. The annunciator ground detection circuit was not able to detect

this ground prior to the event. The ground path manifested itself with the high voltage application.

The licensee replaced 77 multiple input logic cards. On May 9, the team examined the failed components at the I&C rework facility. The technician at the facility had repaired, at this time, 71 multiple input logic cards. Approximately 90% of the repaired cards had output lamp driver transistors failed shorted, which, in turn, had energized the annunciator window lamps. In one case, the failed multiple input logic card had a failed inverter, which was at the input of the output switching transistor. Similarly, a RFFM (R--return to normal indicating sequences; FF--multiple flash rates; M--lock-in of all alarms until manually reset) card, a modified logic card, had three vaporized traces: the 24 vdc, the 12 vdc, and the test circuit. Four SSFM logic cards with functions similar to the multiple input logic cards failed in a similar fashion, with the output transistor damaged.

In all these cases, the 480 vac surge had touched the positive 24 vdc side of the field contact, gone through the negative 24 vdc side of the lamp box power supply, burned out the annunciator lamps, and damaged the output switching transistor of the multiple input logic cards. The voltage surge in one field contact power supply had gone through the common tie point of all power supplies and damaged additional components powered by the other supplies in the system. It appeared there was no isolation among the circuits within the annunciation system.

Seven relay cards failed. The relay card had a series diode in three parallel branches, consisting of a reed relay coil, a 50 volt capacitor, and an inductive voltage suppression diode. At the I&C rework facility on May 9, the team observed that the majority of the failed relay boards had failed series diodes, shorted capacitors, burnt-open conducting traces, and marks indicating overheating on the circuit board. It appeared that the fault current had surged through the input of the relay card, damaged the series diode, and shorted the capacitor.

The licensee reported blown input fuses in the two 24 vdc power supplies to the field contact where the surge voltage occurred. A failed switching transformer T1 and a blown input fuse also occurred in the upstream inverter assembly. The transformer controlled the relay which switched the inverter power source from 125 vdc to 120 vac. This was the extent of observable damage in the power source of the annunciator system.

At the shift turnover, the operators recognized the generator excitation control, the Generex system, had transferred from the normal automatic control (ac) to direct control (dc). The licensee found no alarms or any other evidence indicating that the ac regulator had failed. The licensee did not have the time of the transfer documented.

During subsequent power reduction maneuvering, the operator observed the volt/hertz trip timing light flashing. The operator manually lowered the generator excitation field. The operators informed the team that they had a maximum of 60 seconds to correct the excitation caused by distribution grid disturbance or power change before a turbine trip occurred. The time available to the operator to correct the generator excitation would depend on the magnitude of the excitation deviation. The available time to the operator could range from less than 2 seconds to a maximum of 400 seconds before a turbine trip occurred. The licensee was not able to determine from the available records the time available to the operator at the time when the volt/hertz trip timing alarm occurred.

The licensee indicated that there were approximately 600 solid state field contacts in the EIS for the annunciator. The licensee tested all but four of these solid state contacts and found no damage. The four solid state contacts which were not tested would have required cycling safety related equipment which could not be cycled during the existing plant conditions. There were no other solid state field contacts connected to the annunciator system.

The licensee did not observe any damage in the optical isolation cards in the EIS nor in the multiple input cards. The multiple input cards had a 3.9 kilo-ohm input resistor, which was of higher input impedance than that of the relay cards and less susceptible to fault current than the relay cards. The optical isolator on the multiple input cards also isolated the remaining components from the voltage surge.

The licensee also indicated that all the local annunciation alarm panels worked as required during the event and that no actuation of the sequence-of-events recorder trigger had occurred.

4. Adequacy of System

After reviewing the damage caused by the 480 vac voltage surge through the annunciator system, the team made the following observations:

a. Many connections existed between Cabinets 1 and 2. There were field contact input wires that went through Cabinet 1, used the Cabinet 1 terminal blocks as junction points, and terminated at Cabinet 2. The alarm reset was one of these connections. The licensee estimated the existence of approximately 100 such cross-connections. The annunciation system had no internal divisions; the fault could propagate through the whole system and affect the functions of the system as a whole. There was no isolation among the circuits within the annunciation system.

b. The existing ground detection circuit detected the leakage between the field wiring system and chassis (earth) ground. It detected any ground occurring on the supply

side of the 24 vdc. The ground detection system was not designed to detect grounds within the annunciation system.

c. The Generex system relied on the annunciation system for indication of the transfer from the normal automatic control to direct control. With the loss of the annunciation system, the licensee did not know when the transfer had occurred.

d. The optical isolation circuitry in the annunciation system had performed as designed.

C. Plant Computer Systems

1. Description

There were four different types of computers that failed during the event of May 4, 1992, or failed shortly before or after the event. These computers are briefly described below.

a. CPC - There are four Class 1E CPCs (one per channel) in the RPS. Each CPC receives its electrical power from a separate Class 1E power bus. Each receives analog signals from the nuclear instrumentation, RCS temperatures and pressures associated with the respective RPS channel, and selected ("target") CEA reed switch position transmitters. Each also receives digital inputs from the RCP speed sensors and CEA position penalty factors from the CEAC. The CPCs provide trips to the RPS logic, alarms to the alarm system, and indication to Control Room displays.

b. CEAC - There are two Class 1E CEACs. They receive analog signals from each CEA reed switch position transmitter. They provide indication output to the Control Room, digital inputs to the CPCs, and alarms to the alarm system. Each CEAC is powered from a separate Class 1E bus.

c. PPC - There is a single, non-Class 1E PPC. The PPC and a second non-Class 1E computer (the CMC) are paired to make up the PMS. Both the PPC and the CMC are powered by a common non-Class 1E inverter that is powered, in turn, from one of the non-Class 1E batteries supplying alarm system power. The PPC performs several functions under the control of a master program (scheduler). Each major function is described below.

   i. COLSS - The COLSS is a subroutine that is executed on a pre-set timed basis. With the exception of CEA position, the COLSS receives the same signals as the CPC and CEAC, plus balance-of-plant analog signals. CEA positions are input to COLSS by counting CEA drive pulses. COLSS performs more detailed calculations than the CPC. Unlike the CPC, COLSS is

not required for plant safety since it does not initiate any direct, safety-related function. TSs define the LCO required to ensure that reactor core conditions during operation are no more severe than the initial conditions assumed in the safety analyses and in the design of the RPS functions. COLSS serves to monitor core conditions and provides indication and alarm functions to aid the operator in maintaining core conditions within the LCOs.

COLSS algorithms are executed in the PPC and CMC. The calculational capacity and speed of these computers enable numerous separate plant operating parameters to be integrated into three easily monitored parameters: (1) margin to core power limit, (2) azimuthal tilt, and (3) axial shape index.

ii. ATS - The ATS subprogram is designed to assist in the safe and efficient startup of the turbine generator. By design, among other functions, the ATS provides signals to the generator exciter for selection of ac or dc control.

iii. Alarm functions are also provided by the PPC. The PPC surveys approximately 2000 data points in the plant (most of which are not displayed on the annunciator windows) and processes these alarms in several ways. These processes provide for CRT displays of current alarms, printed logs of alarms and their setpoints, a post-trip log, and a sequence of events after a turbine or reactor trip.

iv. Logs of CEA position, deviation and exposure; turbine diagnostics; Xenon Reactivity Balance; selected analog signal trending; and various balance of plant performance measurements are also provided by the PPC.

d. CMC - As previously stated, the CMC is non-Class 1E. It runs COLSS and is the preferred source of COLSS information.

2. <u>Interfaces</u>

One of the major problems in understanding this event was the relatively complex set of interconnections between the various computers and the alarm system. As a general statement, non-Class 1E inputs to the CPC and the non-Class 1E outputs from the CPC are isolated by Class 1E isolation devices. In addition, each computer input and output is isolated to prevent propagating fault currents. As previously stated, the alarm system, PPC, and CMC share non-Class 1E dc sources. Each major interface is briefly described below.

a. CEA - Each CEA position transmitter sends isolated analog signals to both CEACs. Also, target CEA position transmitters send isolated analog signals to each CPC.

b. CPC - Each CPC receives isolated information from target CEA transmitters. Each CPC also receives isolated digital inputs from both CEACs and switch-actuated commands from the respective RPS channel. Each CPC also receives unisolated Class 1E signals from its channelized instrumentation (identified in Section V.C.1.a, above).

c. CEAC - Each CEAC receives isolated analog signals from each CEA transmitter. Each CEAC provides digital inputs to the isolators that connect them to the CPC. If a CEA deviates by more than a specified limit within a rod subgroup, a penalty factor is sent to the CPCs. Each CEAC also provides optically isolated outputs to display the position of each CEA.

d. PPC - The PPC receives isolated analog signals from each RPS channel and counts CEA drive pulses, to enable it to duplicate the CPC calculations in greater detail. It also receives isolated inputs from both of the CEACs, relay-isolated inputs from the alarm system, and manual inputs from control switches and a keyboard in the Control Room. The PPC provides relay-isolated outputs to the alarm system and isolated digital outputs to the COLSS display. Outputs are also provided to alarm CRTs, typers and trend recorders.

e. CMC - The CMC receives isolated analog signals from the RPS to enable COLSS calculations, and it provides optically isolated outputs to the COLSS display. The CMC is the preferred source of COLSS information. It also receives inputs from control switches and a keyboard in the Control Room. A common reset switch, with isolated contacts, is provided for the PPC and the CMC.

3. <u>Failures</u>

Several computer failures (or apparent failures) were experienced either before, during, or after the event. Each failure is discussed below.

a. CPC A - CPC A failed three times (between 1559 and 1630 on May 3) before the event. It was bypassed at 1639 on May 3 and returned to service at 1326 on May 5. The failures (auto restart) were caused by a loose connection on a connector in CPC A.

b. PPC COLSS - The PPC COLSS function failed on several occasions during the event. Each time, the failure was associated with the loss of alarm sensing current supplied from Rail T21 Switch 1. The signals associated with T21S1

involve the undervoltage sensors for the CEA and indicate a reactor trip. The PPC scheduler stops the COLSS function of the PPC upon a reactor trip. Therefore, the loss of COLSS was according to PPC design. The COLSS was restored by resetting the computer PIU power and rebooting the computer, and restarting the scheduler when T21S1 was manipulated.

c. CEAC #2 - CEAC #2 alarmed at the start of the event at 0436 on May 4. The failure that occurred was not a hard failure. The calculated CEA withdrawal speed exceeded allowable limits. Also, the particular CEA was already fully withdrawn. After data verification, CEAC #2 was declared operable at 1857 the same day. Licensee personnel believed that electrical noise was the most likely cause for the false CEA position data.

d. PPC - The entire PPC suffered a gradual degradation after the event and was declared inoperable at 0814 on May 4. Although the licensee had not completed the review of this failure, several plant conditions are known to have a significant impact on the PPC and CMC. These conditions are identified below.

   i. Switching transients in the alarm system have the potential for generating high frequency noise and creating false data. The alarm system and the PPC have the same power source. Between 0436 and 0814 the alarm system was powered up and powered down twice. The various power supplies within the alarm system were then sequenced on one at a time. Some of these power supply restorations still supplied faulted loads.

   ii. For a considerable period of time, all three units have had "contention" problems with requests from the PPC and CMC for analog data from the PIU. Software modifications have been designed and installed in Units 1 and 2 that prevent these computers from stopping when they do not receive a timely reply from a PIU and there is a contention between the PPC and the CMC for the data. These modifications have not been installed in Unit 3, but are scheduled for the next refueling outage.

   iii. Instrumentation grounding problems existed in the alarm system before the event.

e. CMC - The CMC failed at 0708 on May 4. The probable causes for this failure are the same as those described in V.C.3.d, above. An additional failure was reported in the Control Room log at 0527 on May 5. However, this was not a real failure but an administrative judgment, made after the PPC and CMC were rebooted from their common switch in the Control Room. The inoperable condition was cleared by

successfully completing Surveillance Procedure 72ST-3RX03 and verifying that the resulting calculations of core conditions, such as DNBR and Local Heat Rate, agreed with the COLSS results.

f. CPC D - CPC D auto restarted several times, starting at 2038 on May 5, and was declared inoperable on May 6. The cause was attributed to an improperly positioned seismic support that prevented proper insertion of a printed circuit card (a situation unrelated to the event). The support was repositioned under WO 554429 and the CPC was declared operable at 1410 on May 6. CPCs in Units 1 and 2 were inspected and found to be satisfactory.

g. CPC C - The unit log for May 7, at 0913, stated that CRDR-3-2-0165 was signed for CPC C and D failures involving the seismic restraint. The CRDR stated that all of the other CPCs in Unit 3 were inspected under WO 554429, and CPC C was found to have the same problem CPC D had. WO 822874 was prepared to repair CPC C.

4. <u>Conclusions</u>

a. Although CRDR-3-2-0165 recommended that Units 1 and 2 be checked for the same problem discovered in CPC C and CPC D, the multiple failures experienced with the CPCs in the period before, during, and after the event suggested inadequate maintenance of the CPCs at all three units.

b. PPC COLSS responded as designed to commands from the scheduler. However, because the PPC alarm functions are redundant to the alarm system and PPC COLSS is redundant to CMC COLSS, alarm system control of the PPC scheduler may be a poor practice in that it reduces the level of redundancy. Also, the Control Room data sheets require inputs from PPC COLSS that are not available from CMC COLSS for calculating the 12-hour rolling average of reactor power.

c. Discussions with the licensee indicated that they believed the false CEA position data that resulted in the stall of CEAC #2 to have been most likely caused by noise. The team agreed; however, this implied that either the optical isolator between the CEAC and the alarm system was inadequate or significant ground loops existed in the non-Class 1E alarm and computer systems.

d. The licensee had not finished reviewing the causes for the failure of the PPC and CMC. However, the licensee's preliminary evaluation was that the stall of both computers was caused by contentions for PIU data and the large volume of data that the PIUs were required to handle. The team noted that electrical noise could have contributed to these communications problems.

e. The team also concluded that the FSAR did not adequately represent the design of the non-Class 1E systems which are used to ensure that the plant stayed within the assumptions of the design. Examples are presented below.

   i. FSAR Chapter 8.3 did not provide a load list for equipment connected to the various non-Class 1E busses.

   ii. FSAR Chapter 7.7 did not adequately describe the plant annunciator. No clear description was given of how the alarm function is divided between alarm indication and the PPC, or of how power supplies are shared by alarms and computers.

   iii. FSAR Chapter 7.2 did not address the capability of the various isolation devices to isolate data rate noise.

   iv. FSAR Chapter 8.3 did not describe the grounding systems that are provided.

The licensee agreed to evaulate revising the FSAR to incorporate the above information.

VI. Human Performance Evaluation

A. Training

1. Operators

A review of portions of the operator training program indicated that operators had not received training on loss of all annunciators during either initial or continuing training. Prior to this event, the simulator could not model a loss of all annunciators. Loss of all annunciators had not been included in training due to the perceived low probability of such an event.

The crews had been trained in loss of PMS and CMC. This training had provided guidance applicable to this event and had recommended avoiding all unnecessary power changes and maintenance activities during a loss of PMS. Steady state operation at or near original conditions, as much as possible, had been emphasized.

Operators had been trained to monitor control boards as a primary means of determining plant status. PMS was used as a tool to provide integrated information about plant status, since it provided an indication of degrading plant or equipment conditions. This PMS information included additional data not available on control boards as well as audible alarm functions.

Operators also had received training in the areas of predicting plant response to plant changes and recognizing how collection and evaluation of uncertain data can impact the diagnostic

process. The operators used PMS to interpret the cause of panel annunciator alarms, by identifying which of multiple parameters was responsible for the alarm.

The operators had been trained to use the EOP flow charts, which used control board indications rather than PMS or annunciators to initially assess the status of safety functions during response to an emergency.

In response to this event, simulator scenarios were conducted for the crew in requalification training. These scenarios consisted of performing a plant shutdown with loss of annunciators and PMS. Additionally, the crew performed a reactor trip and a loss of main feed pump (also without annunciators and PMS). These sessions were held to observe operator capabilities in responding to these events. Prior to actual shutdown, the crew that was to perform the shutdown also participated in a scenario for shutdown without annunciators and PMS. The scenario was run without any malfunctions.

2. Maintenance

Training of electrical workers had included mandatory training on generic topics including grounding, electrical safety work practices, effective work practices, and operations experience reports, including discussions on related industry events. Workers then had completed training on selected special topics such as "Low Voltage Circuit Breaker" and "Connectors and HV Terminations." Task qualification for working independently had been accomplished using job performance measures. Records of task qualifications had been updated and provided to the plants twice a month and had been used for work assignment.

Continuing training on industry events had been held quarterly. Electrical safety work practice training had been part of initial training (but had not been included in continuing training).

B. Working Conditions

1. Time of Day

The event occurred during the time of day that historically has the highest number of human errors. The licensee had increased the number of preventive maintenance and surveillance test procedures during the night shift to increase operator activity and keep the staff alert. The licensee observed that routine activities are scheduled for backshift work; however, critical maintenance may also be worked if necessary.

The promotion of routine preventive maintenance and surveillance testing during backshift hours appears appropriate. However, during these hours, when the probability of human error is normally at its highest, the scheduling of less routine activities may be questioned. The team observed

that risk may be an appropriate criteria to be used to assess the advisability of non-routine backshift work activity.

2. Physical Conditions of the Work Location

The work area was lit by a fluorescent light above and slightly in front of the cabinet. The amount of light provided was adequate for performance of the task; however, additional lighting was needed to adequately see into the area behind the breaker where the 480 vac bus bar was located.

The load center cabinet was the topmost in a stack of three, and required the use of a step-ladder to access the inside. Inside the cabinet, two breakers, approximately 4 inches apart, were located in the lower half of the cabinet. The termination strip was located in back of and slightly above the breakers, with a wiring bundle running parallel to the strip (between the top of the breaker and the bottom of the strip). The wire was routed from between the breakers, behind the wiring bundle, and was attached with a closed lug to the termination strip. The termination wire was not physically restrained, which allowed approximately 12 inches of slack wire once the termination was removed.

The configuration of equipment within the cabinet made manual restraint of the wire difficult. Any effort to manually restrain the wire could have presented a potential safety hazard for personnel, in that it would have required the use of both hands in the cabinet.

The electrician stated that he thought the wire was restrained close to the termination point by a tie-wrap to other wires, and therefore did not note the 12 inches of slack. The team inspected other breakers and terminal boards in load center L18, and noted other areas where insulated wires were touching 480 vac bus work and were not restrained by tie-wraps near their termination points. The licensee stated that installation procedures specified restraining wires near their termination points, when possible, and that procedures also specified maintaining clearance between wires and bus work. The licensee issued work requests to correct these conditions in load center L18 and other similar I-T-E built load centers.

C. Work Practices, Preparation, and Performance

The sequence of events leading to the development of the work order for the task which led to this event is covered in Section III of this report. Once the work order had been assigned for the night shift to complete, normal work preparations had been completed.

After reviewing the work order and being briefed by the maintenance supervisor, the senior electrician had reviewed the work to be performed with the Asst SS. The work had been divided into two parts, with the Asst SS authorizing work only on the first part.

The first part, consisting of checking spare breakers, had been completed by the senior electrician, working alone, without any incident.

The second part of the work was on energized equipment; therefore, a second electrician had been assigned, as required by licensee practices for working on energized equipment. The senior electrician had briefed the junior electrician on the work already performed and on the scope of work remaining.

The second portion of the work did not require lifting of leads; however, the Asst SS and the electrician had discussed and agreed upon doing so. The electrician had been instructed by the Asst SS to use appropriate termination and re-termination documentation. During the briefing, the senior electrician had requested an AO to act as a communicator with the Control Room, since lifting the lead would result in Control Room indications that would need to be verified. In addition to discussing documentation and communication, the briefing also had covered safety. Personnel and equipment safety had been discussed in general terms, and the electricians had been given final responsibility for determining needed safety precautions.

At the work site, the electricians used certain work practices appropriate for working around energized equipment. This included using only one hand to perform work inside the cabinet. The tools selected for this task allowed the electrician to lock onto the screw. The electrician believed that he would also be able to keep the wire lug on the screw. Using this method, the task was performed on one breaker without incident. While performing the same task on a second breaker, the electrician was not able to keep the wire lug on the end of the screw, and the termination wire fell, brushing against the energized bus bar.

D. Event Response

1. Adherence to Procedures

This event was identified by the operators as a loss of PMS with a total loss of annunciators. Although no procedure specifically covered a total loss of control board annunciators, procedural guidance was given for the loss of PMS. This guidance directed the operator to maintain the plant in a steady state configuration. Response to this event was consistent with recommendations given in the procedure.

During the event, an alternate method of determining compliance with the license power limit was determined and used, due to the loss of PMS. Although both SROs agreed and verbally approved the alternate method, they did not formally document the temporary procedure change. The facility intended to resolve this discrepancy by making a permanent change to the procedure to include this guidance.

The shutdown was performed in accordance with normal plant and reactor shutdown procedures.

2. Operational Approach to Event

a. Operator Monitoring and Response Without Annunciators and Plant Monitoring System (PMS)

Interviews with operators indicted that they recognized the relationships that exist between the annunciators and the PMS. Operators stated that loss of annunciators did not limit their ability to monitor the plant to ensure safe operation. Operator response to emergency situations required use of EOP flow charts, which relied on control board indications rather than annunciators.

The operators stated that annunciators were a convenience, but not a necessity, for them to carry out their duties. Loss of annunciators forced them to change their thinking patterns to prioritize the additional monitoring that might be needed, including on-going monitoring of control boards and more frequent reviews of information from the PMS, to ensure continued satisfactory operation.

Loss of PMS was more limiting for the operators, since the computer would no longer be available for identifying which of several inputs was responsible for causing an annunciator to alarm. The operators did have a document (Window Sort) listing the inputs to various alarms, which allowed them to interpret the indications to differentiate one alarm input from another. Several operators cited this operator aid as an integral approach to handling various situations involving loss of PMS. Discussions revealed, however, that many operators were unaware that the aid had been moved from the Control Room approximately 3 months earlier as part of a document reduction effort.

b. Staffing

During normal operations, shift staffing consisted of an SS, an Asst SS/Control Room Supervisor, 3 reactor operators responsible for control board monitoring and operations, an STA, and 4 AOs responsible for in-plant monitoring of operation.

During this event, normal shift staffing was augmented with 1 reactor operator from each of the unaffected units, as well as with AOs from the shift in requalification training.

Normal shift length for Control Room staff was 12 hours, from 7 to 7. Normal shift rotation for the STA was round-the-clock. During this event, operators worked longer

than normal shifts; however, the overtime was authorized in accordance with site procedures and TSs.

c. Communication and Teamwork

An AO had been assigned to the electrical workers performing the test that initiated the event. This allowed the Control Room to communicate immediately with the work crew. Subsequent to the event, the operators indicated that they had been kept informed of overall status by periodic general announcements by the SS and Asst SS. Periodic shift meetings were used to keep the operators informed of and involved in the development of response strategies. Requesting staff from the other units on site, as well as recalling unit staff from training, demonstrated an appropriate use of available resources.

3. Stress

The operators stated that the initial stress they experienced was the result of the contradiction between the observed annunciator indications, which were typical of a reactor trip, and the control board indications, which indicated that plant conditions had not changed. After determining that the initial problem involved the annunciator system, the operators' anxiety shifted to the need for increased plant status monitoring activities. The operators were concerned about ensuring that all appropriate indications were being looked at to make a thorough assessment of plant status. The increased AO staffing in the plant and the additional reactor operators in the Control Room helped to reduce this stress.

The operators stated that prior to the declaration of the Alert, the presence of unusually large numbers of licensee management and NRC personnel in the control room increased their level of stress. The level of control room stress was reduced, when the Alert was declared and these additional observers left the control room for their emergency stations.

E. Management

During interviews with the VP Nuclear Production, Plant Manager, and Operations Manager, each expressed the same operational philosophy with regard to operator actions and procedural adherence. Each stated that they expected the operators to use their assessment of plant status rather than any management direction to determine the appropriate response to a degrading plant condition. Each also stated that adherence to procedures was expected. Interviews with the operators disclosed that they were aware of management expectations, and that their performance during this event was consistent with their responsibilities as they understood them. Operator responses during this event were also consistent with those required or recommended by procedure.

A review of management activities in response to the event indicated that the need for additional staffing was recognized and acted upon early in the event. Management authorized cancellation of AO training so the AOs could be used to perform in-plant monitoring. Additional operator support was also provided by using operators from the other units on site.

There were no procedures dealing with the loss of both PMS and annunciators even though reactor operators had discussed the possibility of losing both annunciators and PMS among themselves. This, as well as recent industry events, suggest that additional procedural guidance to address loss of annunciators and PMS would have been prudent.

Licensee management and the loss of PMS procedure provided the operators with guidance to avoid unnecessary power level changes. However, licensee management did not fully consider the actions which would be needed in responding to other possible degrading plant conditions that would require power level changes without the plant computer or annunciators.

Each of the managers interviewed also expressed an awareness of the effects of stress on workers responding to the event. Shift rotations were established for the TSC staff to ensure coverage but minimize fatigue. Direct conversations with the SS were used to assess the level of stress in the Control Room.

Management activities in response to this event were appropriate and appear to have been effectively carried out.

VII. Radiological Consequences

No radiological consequences resulted from this event.

VIII. Security Consequences

No security consequences resulted from this event.

IX. Licensee Corrective Actions

A. Immediate Corrective Actions

1. Sequence and Description

At 0436 on May 4, when control board annunciators were initially lost, the operators' immediate reaction was to verify plant status by means of control board indication. Within 30 seconds, the crew ascertained that the reactor, turbine, and generator, were at a steady power level. Initially, the operators concluded that the loss of annunciators did not seem to have affected any significant plant parameter.

The SS held an immediate crew briefing, to ensure that operator focus was properly directed. Observing that the plant was steady at 100%, he ordered his operators to maintain constant visual surveillance of control board indications. The operators placed no reliance on the rapidly scrolling PC CRTs. Although justifiably concerned by the increased difficulty of monitoring adverse trends without annunciators, the operators were confident of their ability to detect trends using control board indicators.

The CRS called the field electrician, who reported that a wire had been shorted. The CRS told the electrician to stop work and restore the system being worked on. At 0450, the CRS called the Unit 3 Operations Supervisor and delivered a 10-minute briefing on the event.

The on-duty STA arrived in the Control Room at 0507. Although he did not receive an immediate briefing, he reviewed all the control boards and concluded that the plant was stable.

The reactor operator responsible for turbine controls performed a number of self-conceived diagnostic tests to determine the condition of the BO-5 annunciators, and to verify PMS operation after it quit scrolling. He replaced an annunciator bulb and it lit, indicating that the entire panel had burnt-out bulbs. He then replaced all bulbs in the panel. He attempted to verify PMS operation by periodically creating a minor alarm condition (e.g., starting a sump pump, placing a standby pump momentarily in "pull-to-lock," and verifying alarms). He continued this throughout his shift.

At about 0530, the Operations Manager called the Control Room from a car phone, and was briefed on the event. At 0555, the Operations Manager briefed the Maintenance Manager, but was unsuccessful in contacting the Plant Manager. At 0610 the VP Nuclear Production arrived in the Control Room because he had not received his morning report. The licensee later concluded that delays in management notification showed the need for improvement in timely communication, and issued a letter on the subject.

At about 0700, the primary reactor operator received an alarm indicating CMC COLSS was inoperable. Based on Surveillance Procedure 72ST9ROX03, he determined that the plant could not comply with the TS for DNBR. The SS agreed, and decided to decrease reactor power to comply with the TS.

During the reactor power decrease, an augmenting reactor operator discovered the actuation of the volts/hertz trip timing circuit. The SS directed appropriate immediate action to avoid a turbine trip (and subsequent reactor trip).

By maintaining power at about 70%, the operators met TS requirements and provided additional margin for DNBR. In addition, this power level made the plant less vulnerable to small transients.

The loss of PMS procedure was designed to deal with the loss of a few alarm variables, rather than a total loss of control board annunciators. To verify the existence of an alarm, the procedure directed operators to take measurements on the terminal boards (rails) in the system cabinets. Although the annunciator rail list was referenced in the loss of PMS procedure (72OI9RJ04), it had been removed from the Control Room during a "manual-reduction program" several months prior to the event. Control Room operators had not been informed of this change. The rail list was returned to the Control Room after the event.

2. Conclusions

The operators' immediate action to maintain a steady power level after loss of plant annunciators was an appropriate, conservative response, and was in keeping with the guidance provided in the loss of PMS procedure. Shift supervision immediately took control of the situation.

Subsequent operator calculation of reactor parameters (such as DNBR, AZTILT, and ASI) and control of reactor power during the event appeared appropriate.

Operators and licensee management made frequent attempts to determine PMS operability. These efforts were hampered, however, by a lack of training on verifying PMS operability and a lack of criteria for classifying PMS degradation. The operators expressed interest in developing PMS operability criteria.

Licensee management made appropriate decisions to augment the operating crew with additional reactor operators and AOs.

Operators maintained excellent awareness of equipment status and monitoring of plant trends during the period of annunciator unavailability. The downpower to 70% and subsequent plant shutdown were both controlled well.

Licensee management notification and communication with the other two units was not as timely as desired by licensee management. The team concluded that the licensee's internal notification procedures, responsibilities, and timeliness criteria needed clarification.

B. Troubleshooting Plans and Actions

1. Initial Troubleshooting Activities

The licensee's troubleshooting activities were initially focused on efforts to determine which lamp driver/logic cards, multi-input logic cards, and computer driver relay cards had been faulted and to replace the faulted cards. This activity was required before any meaningful verification of alarm channel functionality could be accomplished.

2. Plant Alarm System Testing Activities

The licensee devised a strategy for testing the plant alarm system to establish a sufficient level of confidence in the functionality of the system to provide confidence in its ability to support plant maneuvering transients.

This testing took the form of two strategies. First, a confidence testing strategy was devised to provide 95% assurance that 95% of the alarm channels were functional. Second, a field testing strategy was developed to verify the functionality of a representative sample of field input devices through the appropriate plant alarm system channels. In each strategy, receipt of the proper alarm(s) on the main control board annunciator panels and correlation with the PMS alarm printer output were the acceptance criteria.

In addition, the licensee began logging alarms received on the plant alarm system, verifying consistency between the main control board annunciators and the PC output, and verifying the actual condition of the process variable in the field for each received alarm. This process was intended to provide additional information on acceptable alarm loops in support of the field testing strategy.

The confidence test involved selecting a random sample of the total population of alarm channels to provide 95% assurance that 95% of the total channel population was functional and operating acceptably. The licensee's statistical analysis randomly selected 57 alarm channels from each of the two plant alarm system cabinets, based upon the total number of channel inputs available in each cabinet. The total number of channels actually used in each cabinet was about one-half the total input channels available, with the result that the 57 points randomly selected were more than adequate to support the 95% criteria. The licensee established a statistically based method for increasing the sample size should any failures occur during the testing. The confidence test program was completed on 116 points without a failed alarm channel being identified.

The field testing was accomplished by selecting 62 devices and actually manipulating the field relay contacts and/or providing an alarm condition to the plant alarm system interrogation and

processing logic. This was supplemented by logging actual alarms received in the Control Room, verifying the condition of the process variable in the field to establish alarm validity, and verifying consistency of the control board alarm with the plant computer output. The field testing plan was completed without identifying an inoperative alarm channel loop. Some non-safety-related process variable sensors were identified as inoperable, and WOs were prepared for their repair. The alarm loops, however, were satisfactory.

C. Retest Plan Action

The licensee used a PRA approach to testing to achieve a 95% confidence of 95% reliability for the retested components. Additionally, points associated with failed components were to be tested per normal I&C retest methods.

There was a concern that field contacts may have been damaged, because they shared the same power supply as the "culprit" contact of Annunciator 1B, Window 15D. Therefore, all mechanical contacts tied to a damaged annunciator cabinet relay card were tested (since the fault current that damaged the relay card would have passed through the contact).

The licensee's overall strategy combined field testing with selected component analysis to verify that each of the following components would perform its design function:

	Total	Tested
Plant Alarm Field Points		
Non-safety-related	1533	228
From Safety-related	600	78
Optical Isolation Cards (Safety-related)	600	600
Multi-Input (MI) Cards (Total Points)	2133	464
Logic Window Driver		100%
Relay Cards Points (Computer Inputs)		100%
Plant Computer Points		100%
Annunciator Lamp Boxes		100%
Chime Drivers		100%
12 Volt and 24 Volt Power Supplies		100%

The licensee's troubleshooting and retest plans were appropriately directed, conducted by trained personnel, and properly documented.

D. Actions to Return the Plant Alarm System to Operable Status

1. Testing Program

The licensee's course of action to verify the operability of the plant alarm system is summarized below:

- Testing of Field Devices: The licensee's program for testing of field contacts involved full alarm loop verification of about 315 points. The licensee verified actual alarms received in the Control Room over about a 3-day period, and field tested a sample of 62 inputs (selected based on PRA).

- Logic Card Testing: The licensee functionally tested the logic card lamp driver capabilities shortly after the event, and identified 77 failed cards. These cards were replaced with spares, or repaired and replaced, and all cards were tested satisfactorily following replacement. The licensee also tested these cards each shift by routine testing of the Control Room annunciator boards.

- Multiple Input Logic (MI) Card Testing: The alarm system contained about 500 of these cards. Each card had the capability of accepting four field process variable inputs, and drove a lamp driver logic card. The total number of input variable points was about 1900, of which the licensee's testing program had exercised about 800 points with no failures identified. The licensee's engineering organization had performed analyses which concluded that the cards should not be damaged as a result of the event. Testing substantiated these analyses.

- Relay Card Testing: The relay cards provide input to the plant computer interface system. The licensee's testing program provided that 100% of these cards would be functionally tested. Nine card failures were identified; eight were failures of a tantalytic input capacitor and the remaining failure was an infancy failure of a newly replaced card.

- Chime Driver Testing: The licensee's troubleshooting activities identified a ground path for current flow in the chime driver circuitry. The fault was repaired and the circuitry retested satisfactorily.

- Power Supply Testing: As a result of the event one inverter failed. The licensee replaced the failed inverter and tested it satisfactorily. The licensee also tested satisfactorily all 24 vdc and 12 vdc power supplies in the system.

- Safety-Related Electric Isolation System Testing: About 620 safety-related field inputs are processed into the non-safety-related plant annunciator system by optical isolation cards. The licensee analyzed the isolation system and concluded that the safety-related portion of the isolator card would not have been damaged as a result of the event. In order to ensure that the non-safety-related side of the optical isolation circuits had not sustained any damage, the licensee tested all

cards on the non-safety-related side of circuits (except four input points that would have required cycling certain safety-related equipment which could not be safely cycled given the state of plant conditions and system lineups). No failures were identified.

2. Conclusions

The licensee concluded that, as a result of their analyses and test results, the plant alarm system was operable and fully capable of supporting returning the unit to service. The NRC reviewed the licensee's test programs, analyses, and results, and concurred with the licensee's position.

X. Exit Interview

The AIT met with licensee management at the conclusion of the inspection on May 14, 1992. The scope and findings of the AIT were summarized. The licensee acknowledged the team's observations and findings.

APPENDIX A

PERSONS CONTACTED

R. Adney, Plant Manager, Unit 3
C. Anderson, Assistant Shift Supervisor, Unit 3, Initial Event & Shutdown Crew
L. Aguilar, Electrical Maintenance Supervisor, Unit 3
R. Baker, Controls Engineer, Nuclear Engineering
T. Barsuk, Emergency Planning Supervisor (Acting)
H. Beiling, Emergency Planning Supervisor
P. Brandes, Corporate Assessment Group
A. Briese, STA Initial Event Crew
E. Cesena, Nuclear Instructor
M. Clyde, Operations Manager, Unit 3
S. Coates, Reactor Operator, Unit 3, Initial Event & Shutdown Crew
D. Coe, NRC Senior Resident Inspector
W. Conway, Executive Vice President
D. Ensign, Shift Supervisor, Unit 2/Training Coordinator
L. Esau, Supervisor, Operations Computer Service
R. Flood, Plant Manager, Unit 2
D. Fuller, Nuclear Safety
[illegible] Garrett, ~~Work Control/~~Shift Supervisor, Unit 3
S. Guthrie, Director Quality Assurance/Quality Control
K. Hamlin, Director Nuclear Safety
D. Hakey, Technician, I&C Rework Facility
A. Hartwig, Plant Alarm System Engineer
D. Hettick, HPES, Evaluator
J. Hughes, Reactor Operator, Unit 3, Initial Event & Shutdown Crew
J. Johnston, Technician, I&C Rework Facility
D. Kanitz, Engineering Compliance
J. Levine, Vice President, Nuclear Production
L. Lighthill, Maintenance Training Supervisor
M. Mc Ghee, Reactor Operator, Unit 1, Event Extra Staff
C. Merendo, Reactor Operator
J. Minnicks, Maintenance Manager, Unit 3
R. Nunnez, Training Manager
P. Ohlson, Electrician
M. O'Leary, Reactor Operator, Second Crew
G. Overbeck, Site Director, Technical Support
L. Perea, Technical Assistant to Director of Site Technical Support
A. Peroutka, Training Supervisor
R. Prabhakar, Manager Independent Safety and Quality Engineering
T. Radke, Operations Advisor, Unit 3
F. Ringwald, NRC Resident Inspector
K. Roberson, Senior Compliance Engineer
W. Rowe, Health and Safety Engineer
J. Rowland, ANPP Procurement Engineering
W. Rudolph, Training Supervisor
S. Ryan, Shift Supervisor, Unit 3
M. Salazar, Electrical Maintenance Manager, Unit 3
J. Schmadeke, Work Control Manager, Unit 3
J. Scott, Assistant Plant Manager, Unit 3

G. Shamker, Manager Station Operating Experience Department
T. Shiver, Assistant Plant Manager, Unit 2
D. Shaffer, Senior Mechanical Planner, Unit 3
W. Simko, Unit 2 Maintenance Manager (Emergency Maintenance Coordinator)
R. Simmons, STA
B. Simpson, Vice President, Nuclear Engineering
J. Sloan, NRC Resident Inspector
W. Sullivan, Reactor Operator, Second Crew
D. Swan, Shift Supervisor, Unit 3, Initial Event & Shutdown Crew
L. Tran, NRC Resident Inspector
J. Turner, Reactor Operator, Unit 3
J. Valerio, Supervisor, Nuclear Software Operations Computer Support
C. Vo, Electrical System Engineer
J. Wadella, Engineer III, NEA
D. Ward, Senior Process Computer Analyst
M. Wazir, Electrical Engineer, Site Nuclear Engineering
C. Weber, Operations Evaluator, Unit 3
R. Wellborn, Electrical System Engineer
T. Whitlock, Electrician

APPENDIX B

AUGMENTED INSPECTION TEAM CHARTER
PALO VERDE UNIT 3 LOSS OF CONTROL ROOM ANNUNCIATOR SYSTEMS ON MAY 4, 1992

The Augmented Inspection Team (AIT) is to perform an inspection to determine the causes, conditions, and circumstances relevant to a May 4, 1992, event at Palo Verde, Unit 3, which has potential significant generic implications and involves questions pertaining to licensee operational and managerial performance. In particular, the inspection should accomplish the following:

1. Develop a complete description of the event, develop a detailed sequence of events that occurred during the loss of Control Room annunciator event, and identify all equipment failures and human errors that occurred during the event and during event recovery.

2. Determine the specific circumstances and events which led up to the shorting of the 24 vdc and 480 vac power systems and attendant loss of Control Room annunciator and plant monitoring computer systems on May 4, 1992. This ~~includes assessing~~ the adequacy of system design and circuit protection equipment. Interview licensee and contractor personnel as appropriate.

3. Verify and evaluate the licensee's immediate actions following this event, including ability to restore plant systems in a timely manner. Operations and management effectiveness are to be evaluated.

4. Evaluate the effectiveness of licensee management in corrective actions subsequent to the event.

5. Identify and evaluate the procedures used by the licensee which address maintenance work during plant power operation. Provide specific emphasis on the types of activities which contributed to this event. Determine the effectiveness of, and adherence to, these procedures as they relate to the current event.

6. Evaluate the human factors aspects associated with this event, including:

   a. The circumstances surrounding the review, approval, and coordination of the maintenance activities which initiated this event.

   b. Personnel training and briefings associated with those work activities.

   c. Adequacy of and adherence to emergency operating, abnormal, and administrative procedures.

   d. Reliance of operators on plant monitoring system including annunciators.

e. Team work, command, control and communication within the Control Room during the event.

f. Performance shaping factors such as familiarity and stress.

7. Within the time constraints of the AIT, evaluate the effectiveness of the licensee's root cause investigation of this event, including:

   a. Thoroughness and adequacy of the licensee's evaluation of the extent of potential damage to plant components directly and indirectly associated with this event.

   b. Adequacy of the licensee's determination of any equipment design or interface problems (e.g., indication, annunciation, computer performance, and interaction).

   c. Adequacy of the technical basis for licensee conclusions that all affected plant components are fully capable of return to service to perform their design functions.

8. Assess the adequacy of the licensee's instrumentation and control systems, operator staffing level, operator training, procedures, and equipment design to perform a safe and controlled shutdown of the reactor (and to the extent possible, the adequacy to deal with a reactor trip) following a complete loss of annunciator and computer capability, as occurred during the Palo Verde Unit 3 event.

9. Assess the adequacy of the licensee's response to the event (including classification, notification, manning, information updates, and coordination).

10. Provide a Preliminary Notification upon initiation of the inspection and an update at the conclusion of the inspection.

11. Prepare a special inspection report documenting the results of the above activities within 30 days of the start of the inspection.