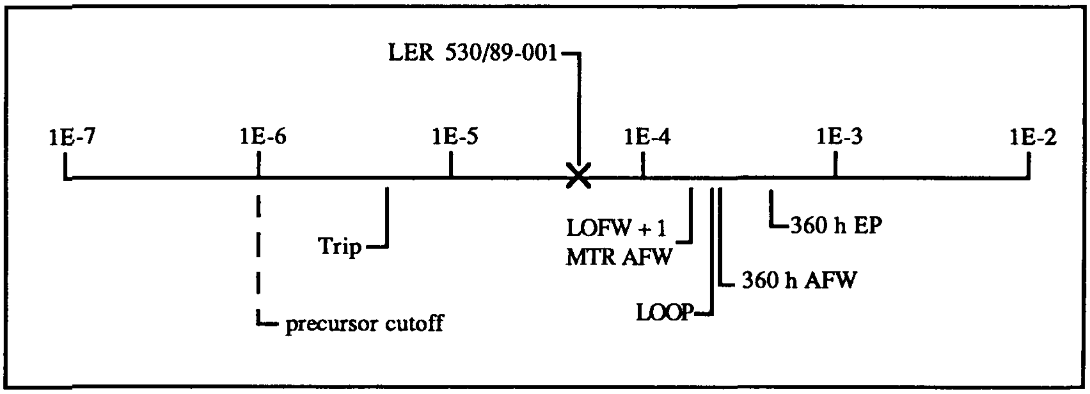
ACCIDENT SEQUENCE PRECURSOR PROGRAM EVENT ANALYSIS

LER No: 530/89-001 R3
Event Description: ADVs and nonsafety-related buses unavailable following trip
Date of Event: March 3, 1989
Plant: Palo Verde 3

Summary

A reactor trip with unavailability of the nonsafety buses and of the ADVs, and with main steam line isolation and safety injection, occurred at Palo Verde 3 on March 3, 1989. Following a loss of load, the steam bypass control system malfunctioned, resulting in MSIV closure and a requirement for ADV operability. When these valves failed to operate from the control room, operators attempted to operate the ADVs locally. This action was hampered by a lack of emergency lighting. Throughout the event, core cooling was provided through the use of the auxiliary feedwater (AFW) system. The conditional core damage probability estimated for the event is 4.9 x 10^{-5}. The relative significance of this event compared with other potential events at Palo Verde is shown below.



Event Description

While at 98% power at 0105 MST on March 3, 1989, Unit 3 experienced a load rejection and subsequent reactor power runback due to an offsite fault and improper actuation of a subsynchronous oscillation protective relay. The fault also resulted in the loss of bus S06. The turbine-generator continued to power house loads, and excess reactor power was dumped to the condenser using the steam bypass control system (SBCS).

The SBCS controller malfunctioned, causing four of the eight SBCS valves to cycle from fully open to fully closed. As a result of the excessive turbine bypass flow during the valve cycling, RCS and SG pressure dropped. The reactor tripped due to low steam generator pressure, which also initiated main steam line isolation. A safety injection signal and containment isolation signal were also generated on low pressurizer pressure. Consistent with procedures, two reactor coolant pumps were tripped. A fast transfer of nonsafety buses S01 and S02 was prevented because of lack of synchronization, and power on S01 and S02 was lost. As a result, power to the two remaining reactor coolant pumps was lost, along with other nonsafety-related loads, including the circulating water pumps and instrument air compressors. Following the trip, the plant was on natural circulation with the main steam isolation valves (MSIVs) closed and the turbine bypass system unavailable due to MSIV isolation.

The atmospheric dump valves (ADVs) did not actuate from either the control room or the remote shutdown panel. The valves failed to operate because an internal piston ring did not seat properly and allowed excessive internal valve leakage, which prevented the valves from opening. Operators were dispatched to the two ADV valve rooms in an attempt to operate the valves manually. In both ADV rooms, manual operation of the ADVs was hampered by a lack of lighting (normal lighting is stripped by an SI signal and battery-backed lighting was degraded and ineffective). In the north room (SG 1), operators used flashlights to read posted valve operating instructions and trace instrument air lines. One of the two ADVs in the room was opened manually (operation of only one ADV is required). In the south ADV room, recovery was additionally hampered by frequent safety valve discharges through an adjacent relief header. One valve (ADV 185) was opened ~3% before its handwheel began to freewheel. An attempt was made to open the other valve using a 2-ft wrench. The operator was unaware that the valve opened in opposite direction from the first valve — the valve was subsequently damaged and rendered inoperable. ADV 185 manual operation was subsequently restored.

Nuclear cooling water was lost following reactor/turbine trip. Seal injection was provided to the RCP seals by the running charging pumps. The operators isolated RCP seal bleedoff and secured the charging pumps to prevent overfilling the pressurizer (this also secured seal injection). Some time after bleedoff flow was secured, it was restored. Seal injection was restored ~1.5 h later, and leakage (≤6 gpm) across the seal of one RCP was observed.

Several components (SG blowdown sample isolation valves, auxiliary building HVAC dampers) either did not respond to actuation signals or indicated no response due to limit switch problems.

The unit remained on natural circulation cooldown for ~1.5 h. During that time, MSSV 579 on SG 1 repeatedly lifted. At 0222, an MSIV bypass valve was manually opened, and the SBCS valves were used to control cooldown. Buses S01 and S02 were re-energized at 0232-0243, and the main steam isolation, safety injection, and containment isolation signals were reset. Forced cooldown was re-established at 0449.

At 0424, the nonessential AFW pump was started to allow securing of the essential AFW pump. The downcomer isolation valve for SG1 associated with this pump was found to be failed closed, and the nonessential pump was subsequently secured and the essential AFW pump used for core cooling.

Additional Event-Related Information

Buses 3E-NAN-S01 and 3E-NAN-S02 are the two 13.8-kV nonsafety-related buses for Palo Verde Unit 3. Numerous 4.16-kV and 480-V buses are fed from these two buses. There are two safety-related 4.16-kV buses, 3E-PBA-S03 and 3E-PBB-S04, each with an associated diesel generator. The safety-related buses are normally aligned (per FSAR Fig. 8.3-2) via buses 3E-NAN-S03 and 3E-NAN-S04 to 13.8-kV intermediate buses in the switchyard, which are in turn fed from startup transformers. On trip, buses S01 and S02 normally fast transfer to buses 3E-NAN-S03 and -S04, respectively. No information concerning specific nonsafety loads is provided in the FSAR.

No PORV or remote manually operated valve on the pressurizer is provided for bleed and feed cooling at Palo Verde. Instead, a set of single-failure proof ADVs are utilized to facilitate depressurization to the initiation pressure for the RHR system. One ADV is sufficient for depressurization. Instrument air, the primary source of power to the ADVs, is not powered from the safety-related buses, and nitrogen backup is provided. An alternate form of depressurization using the auxiliary pressurizer spray is also available.

Since no feed and bleed capability exists, a viable source of feedwater must be provided for secondary-side cooling. In the event of a loss of power on the nonsafety buses, only AFW is capable of providing secondary-side cooling. The AFW system in Palo Verde consists of two seismically qualified pumps — one motor- and one turbine-driven, plus an additional nonseismically qualified motor-driven pump that must be manually started and loaded onto one of the diesel-backed buses.

RCP seal cooling is provided by the nuclear cooling water system. This system is not safety related and is unavailable if the nonsafety-related buses are unavailable. Cooling to the RCPs is also terminated on containment isolation. Seal injection is provided by the

CVCS. The charging pumps are diesel-backed, and valves in the seal injection flow path fail open on loss of air. Seal injection is therefore maintained on loss of the nonsafety-related buses. If both seal cooling and seal injection are lost, procedures require isolation of seal return to prevent seal failure.

ASP Modeling Assumptions and Approach

The event has been modeled as a reactor trip with systems impacted as described above. At the time of trip, both nonsafety 13.8-kV buses were unavailable, and the MSIVs were closed. Because of this, both the main feed and condensate systems were initially unavailable as alternate sources of steam generator cooling, and the turbine bypass system was unavailable for steam generator depressurization. The ADVs were also unavailable from the control room. While the ADV unavailability could have impacted other potential initiators, the observed trip is considered to dominate the risk estimate and was the only initiator modeled.

The following assumptions were made in the analysis of the event.

1. Secondary-side depressurization is assumed failed but recoverable locally. Once one ADV is recovered, it can be used to depressurize a steam generator, allowing the use of the condensate system for SG cooling once nonvital power is restored. Alternately, following RCS depressurization and temperature reduction, the RHR system can be placed in operation to provide core cooling. This alternate possibility is not addressed in the ASP models (or in any typical PRA model).

2. AFW flow to the steam generators, combined with use of the secondary safety valves, is assumed to provide adequate core cooling, consistent with the ASP models and other PWR PRA models. Condensate supplies appear adequate to maintain the plant in hot shutdown for ~23 h without replenishment. Unavailability of the one downcomer isolation valve for the nonessential AFW pump has been assumed to not substantially impact the event (the pump could still feed one generator).

3. The small seal leakage observed during the event has been assumed not to be indicative of a substantial increase in the likelihood of seal failure; such failures have not been addressed in the analysis.

The core damage probability for the event was estimated considering two possible states for the nonvital buses: recovered and not recovered in the short term (~30 min). During the actual event, the nonvital buses were not recovered for ~1.5 h, but power was available to the safety-related buses from nonvital buses S03 and S04, and the core was effectively cooled using the AFW system. If the AFW system had failed, core cooling could have been provided once one dump valve was open by recovering power to nonvital bus S01 or S02 from buses S03 or S04 and using the condensate pumps to supply water to the steam generator. If power could not have been recovered early in the event, then core cooling using steam generator depressurization and condensate system cooling would not be effective in preventing core damage.

Conditional probability estimates for the two nonvital bus states were combined using the likelihood of not recovering one of the two non-afety buses in the short term had this been required (this nonrecovery was assumed to be 0.34) to estimate an overall conditional probability for the event:

p(event|observed failures) = p(event | observed failures and nonsafety bus not recovered) × p(nonsafety bus not recovered in short term) + p(event | observed failures and nonsafety bus recovered) × [1 - p(nonsafety bus not recovered in short term)]

For the case in which power to the nonvital buses was unavailable, the following branches in the event tree model were modified to reflect observed plant conditions:

MFW	Unavailable because of loss of power on nonsafety-related buses; no recovery possible until power to buses restored.
SS.DEPRESS	Inoperable from the control room; recoverable locally.
COND/MFW	Unavailable because of loss of power on nonsafety-related buses; no recovery possible until bus power restored.

For the case in which one nonvital bus was potentially recovered, the condensate system was assumed available as an alternate source of SG cooling. The likelihood of not recovering the condensate system for SG cooling was lumped with the likelihood of not recovering one ADV for this calculation.

Analysis Results

The conditional probability of core damage, given a nonsafety-related 13.8-kV bus is not recovered is estimated to be 1.0×10^{-4}. Given that the nonsafety bus is recovered, the conditional probability estimate is 2.2×10^{-5}. These two estimates, combined with the previous estimate for nonrecovery of one 13.8-kV bus, results in an overall estimate of 4.9×10^{-5}.

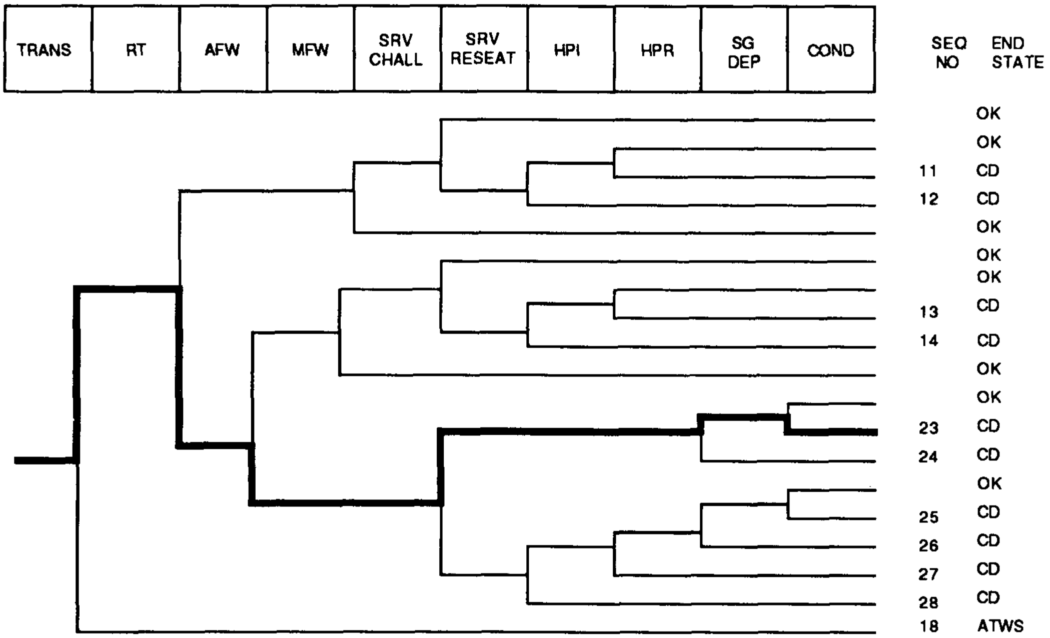
The two dominant core damage sequences postulated for this event involve failure of secondary-side cooling (auxiliary feedwater and main feedwater) and failure to depressurize a steam generator or use the condensate system as an alternate cooling source. The dominant core damage sequence is highlighted on the following event tree. Branches that constitute the two dominant core damage sequences include:

Name	Probability (bus not powered)	Probability (bus powered)	Comment
Transient	1.0	1.0	Reactor trip with unavailable non-safety buses.
AFW	9.9×10^{-5}	9.9×10^{-5}	Observed operable during event.
MFW	1.0	0.34	Unavailable as long as nonsafety buses were not powered. Recoverable once power restored to one nonsafety bus.
SS.DEPRESS	0.34	0.34	Unavailable from control room and remote shutdown panel, recoverable locally. Likelihood of failing to recover assumed to be 0.34.
COND/MFW	1.0	0.34	Unavailable as long as nonsafety buses were not powered. Recoverable once power was restored to one nonsafety bus.

The analysis assumes the likelihood of an RCP seal failure that would require HPI (i.e., beyond the capacity of the charging pumps), but not be large enough to depressurize the RCS, is sufficiently low as to not impact the analysis. If such a seal LOCA had occurred, then ADV or SBCS success (SBCS success requires an open MSIV or MSIV bypass valve) would be required for HPI success. This seal LOCA probability was not estimated.

One observation worth noting is that the need to immediately restore the ADVs to operation was not required, since core cooling was being provided via the AFW system and main steam safety valves. A more controlled restoration of the ADVs could have occurred if power was first restored to the nonsafety buses (which would have restored normal room lighting).

See LER 528/89-005 and PNO-V-89-07 for additional information.



Dominant core damage sequence for LER 530/89-001

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 530/89-001
Event Description: Trip with ADVs and non-safety buses unavailable (calc 1)
Event Date: 03/03/89
Plant: Palo Verde 3

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

TRANS	1.0E+00

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
TRANS	1.0E-04
Total	1.0E-04
ATWS	
TRANS	3.4E-05
Total	3.4E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
23	trans -rt afw MFW -srv.reseat -SS.DEPRESS COND/MFW	CD	6.3E-05	1.7E-01
24	trans -rt afw MFW -srv.reseat SS.DEPRESS	CD	3.3E-05	8.8E-02
25	trans -rt afw MFW srv.reseat -hpi -hpr/-hpi -SS.DEPRESS COND /MFW	CD	2.0E-06	1.7E-01
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
23	trans -rt afw MFW -srv.reseat -SS.DEPRESS COND/MFW	CD	6.3E-05	1.7E-01
24	trans -rt afw MFW -srv.reseat SS.DEPRESS	CD	3.3E-05	8.8E-02
25	trans -rt afw MFW srv.reseat -hpi -hpr/-hpi -SS.DEPRESS COND /MFW	CD	2.0E-06	1.7E-01
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\1989\pwrhseal.cmp
BRANCH MODEL: c:\asp\1989\palover3.sll
PROBABILITY FILE: c:\asp\1989\pwr_bsll.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	1.1E-04	1.0E+00	
loop	1.6E-05	5.3E-01	
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
emerg.power	2.9E-03	8.0E-01	
afw	3.8E-04	2.6E-01	

Event Identifier: 530/89-001

afw/emerg.power	5.0E-02	3.4E-01	
MFW	2.0E-01 > 1.0E+00	3.4E-01 > 1.0E+00	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	2.0E-01 > Unavailable		
srv.chall	4.0E-02	1.0E+00	
srv.reseat	3.0E-02	1.0E+00	
seal.loca	4.6E-02	1.0E+00	
ep.rec(sl)	5.7E-01	1.0E+00	
ep.rec	1.6E-01	1.0E+00	
hpi	1.0E-03	8.4E-01	
hpr/-hpi	1.5E-04	1.0E+00	
SS.DEPRESS	3.6E-02 > 1.0E+00	1.0E+00 > 3.4E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	3.6E-02 > Failed		
COND/MFW	1.0E+00 > 1.0E+00	3.4E-01 > 1.0E+00	1.0E-02
Branch Model: 1.OF.1+opr			
Train 1 Cond Prob:	1.0E+00 > Unavailable		

* branch model file
** forced

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Event Identifier: 530/89-001

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 530/89-001
Event Description: Trip with ADVs and non-safety buses unavailable (calc 2)
Event Date: 03/03/89
Plant: Palo Verde 3

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

TRANS	1.0E+00

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
TRANS	2.2E-05
Total	2.2E-05
ATWS	
TRANS	3.4E-05
Total	3.4E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
24	trans -rt afw MFW -srv.reseat SS.DEPRESS	CD	1.1E-05	3.0E-02
23	trans -rt afw MFW -srv.reseat -SS.DEPRESS cond/mfw	CD	7.4E-06	2.0E-02
11	trans -rt -afw srv.chall srv.reseat -hpi hpr/-hpi	CD	1.4E-06	1.0E+00
12	trans -rt -afw srv.chall srv.reseat hpi	CD	1.0E-06	8.4E-01
26	trans -rt afw MFW srv.reseat -hpi -hpr/-hpi SS.DEPRESS	CD	3.4E-07	3.0E-02
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
11	trans -rt -afw srv.chall srv.reseat -hpi hpr/-hpi	CD	1.4E-06	1.0E+00
12	trans -rt -afw srv.chall srv.reseat hpi	CD	1.0E-06	8.4E-01
23	trans -rt afw MFW -srv.reseat -SS.DEPRESS cond/mfw	CD	7.4E-06	2.0E-02
24	trans -rt afw MFW -srv.reseat SS.DEPRESS	CD	1.1E-05	3.0E-02
26	trans -rt afw MFW srv.reseat -hpi -hpr/-hpi SS.DEPRESS	CD	3.4E-07	3.0E-02
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\1989\pwrhseal.cmp
BRANCH MODEL: c:\asp\1989\palover3.sll
PROBABILITY FILE: c:\asp\1989\pwr_bsll.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	1.1E-04	1.0E+00	
loop	1.6E-05	5.3E-01	
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	

Event Identifier: 530/89-001

emerg.power	2.9E-03	8.0E-01	
afw	3.8E-04	2.6E-01	
afw/emerg.power	5.0E-02	3.4E-01	
MFW	2.0E-01 > 1.0E+00	3.4E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	2.0E-01 > Unavailable		
srv.chall	4.0E-02	1.0E+00	
srv.reseat	3.0E-02	1.0E+00	
seal.loca	4.6E-02	1.0E+00	
ep.rec(sl)	5.7E-01	1.0E+00	
ep.rec	1.6E-01	1.0E+00	
hpi	1.0E-03	8.4E-01	
hpr/-hpi	1.5E-04	1.0E+00	
SS.DEPRESS	3.6E-02 > 1.0E+00	1.0E+00 > 3.4E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	3.6E-02 > Failed		
cond/mfw	1.0E+00	3.4E-01	1.0E-02

* branch model file
** forced

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Event Identifier: 530/89-001