



**NTSB** National Transportation Safety Board

Office of Railroad, Pipeline, and Hazardous Materials Investigations  
Office of Research and Engineering

# Supervisory Control and Data Acquisition in Liquid Pipelines

# Study Data Collection

- Accident review
- OPS data review
- Regulation review
- New data
  - Survey
  - Site visits

# Accident Review

- Issues identified in these accidents
  - Critical events not alarmed
  - Significance of alarms not recognized
  - SCADA display not accurate
  - SCADA tool selection
  - Alarm formatting and frequency
  - Controller fatigue
  - Controller training

# OPS Accident Data Review

- Examined data from 2002-2004
- SCADA/LDS detected leaks more quickly than other methods
- These leaks caused release of 4,000,000 gallons of product (59% of all product spilled)

# OPS Regulation

- SCADA not mentioned in the regulations
- Regulations do address some aspects of SCADA
  - OPS training & SCADA guide
- Advisory bulletins on SCADA systems

# SCADA Survey

- 67-item survey
- Survey sent to 91 control centers that control 169 pipelines
- Response rate was 87%
- Showed that 92% of companies use SCADA to control pipeline

# Varieties of SCADA Systems

- Accol 5.12
- Cimplicity Plant Edition V6
- DATAP
- Evolution Scada Veri 4.1
- FactoryLink 7.0
- FactorySuite 2000
- Fisher ROC
- FoxSCADA Rev 5.6.1.4
- Honeywell
- Honeywell Tdc-3000
- Hydril
- Intellution Fix Ver. 6.15, 6.1(2)
- Intouch 7.11
- Iris 76000
- Lookout
- Mini-Mast
- Modicon Plc/Plds
- MOSCAD Version 6.0
- Oasys 5.0, 5.2(8), 5.2.2(4), 6.0, 6.2(2)
- Open Vector- 3.62, 4.11 (2), 4.1.1, 4.2
- PlantScape
- PROCYS
- Process Window 2.35
- RealFlex 1.22, 4.2e1
- Rockwell RSView 32
- RS Logix V
- S/3 SCADA 4.11 [5.1]
- Series VII
- SetCom
- Telvent 5.2, 6.0.6.3
- TSS SCADA
- UCOS Version 3436.3
- US Data FactoryLink Ver3.02a
- Vector 3.6-2
- Wonderware (Intouch) 5.1b, 7.0, 7.1, 7.11, 7.2, 8.0(2), 2000
- X-MidSHIPS Version 4.1

# Functions of SCADA System

92 %	Remote valve operations
87 %	Operating data acquisition
85 %	Trends
65 %	Basic volume balance
61 %	Product level tracking
59 %	Leak detection/computational pipeline monitoring systems
50 %	Batch tracking

# Control Center Site Visits

- 12 liquid pipeline control centers
- Variety of SCADA systems in use, commodity, and size of pipeline
- Visit was 1-2 days
- Interviewed a total of 69 persons
- Average experience 4.7 years
  - Controllers 7 years
  - SCADA manager 4 years

# SCADA Personnel Interviewed

- Controllers (senior and junior)
- Shift supervisor
- SCADA manager
- SCADA technician
- Training manager
- Safety officer

# Information Collected in Interviews

- Company background (history)
- Screen and alarm design
- SCADA system review
- Workstation design
- Personnel
- Controller training
- Work shift scheduling

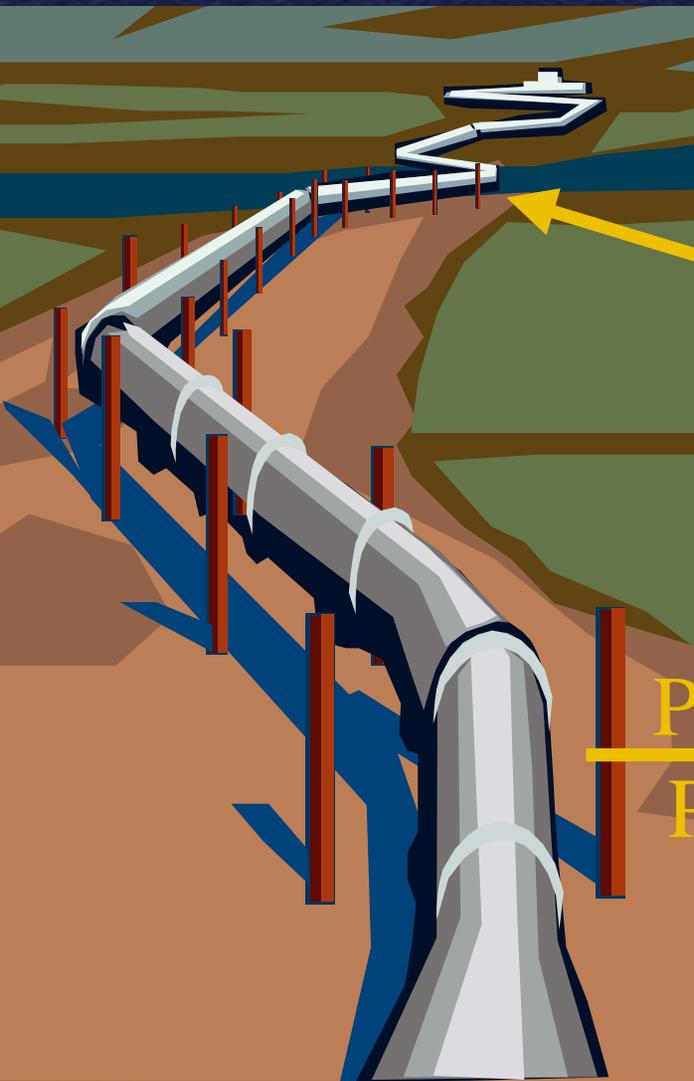
# Safety Issues

- SCADA issues
  - Graphic design
  - Alarm management
  - Leak detection
- Controller issues
  - Fatigue
  - Training

# SCADA Related Issues

- Graphic design
- Alarm management
- Leak detection

# SCADA Systems Basic



Control Commands  
Valves, Pumps

Pipeline DATA  
Pressure, Flow



# SCADA Systems Large Center



# SCADA System Small Center



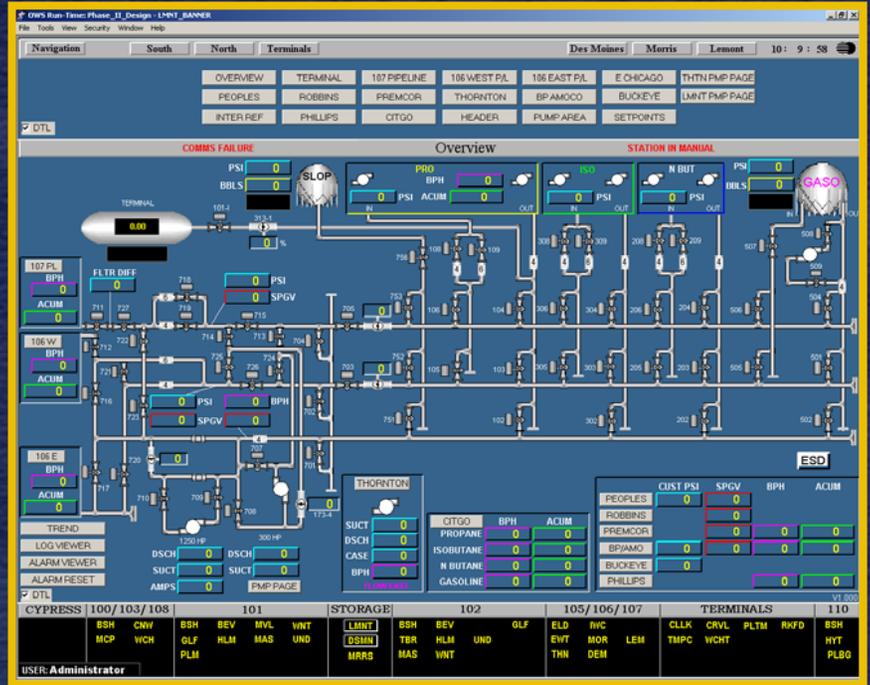
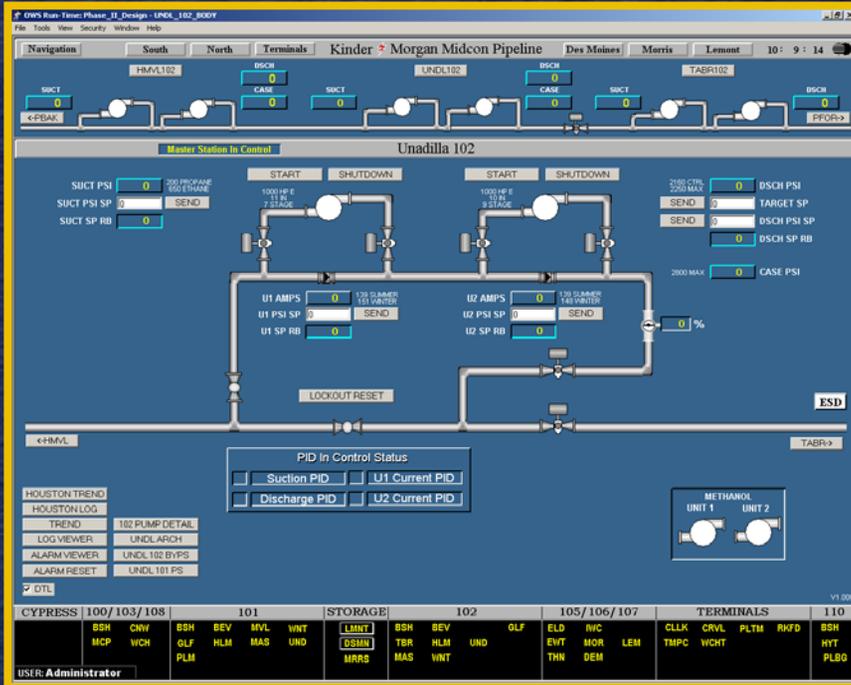
# SCADA Related Issues

- **Graphic Design**
- Alarm Management
- Leak Detection

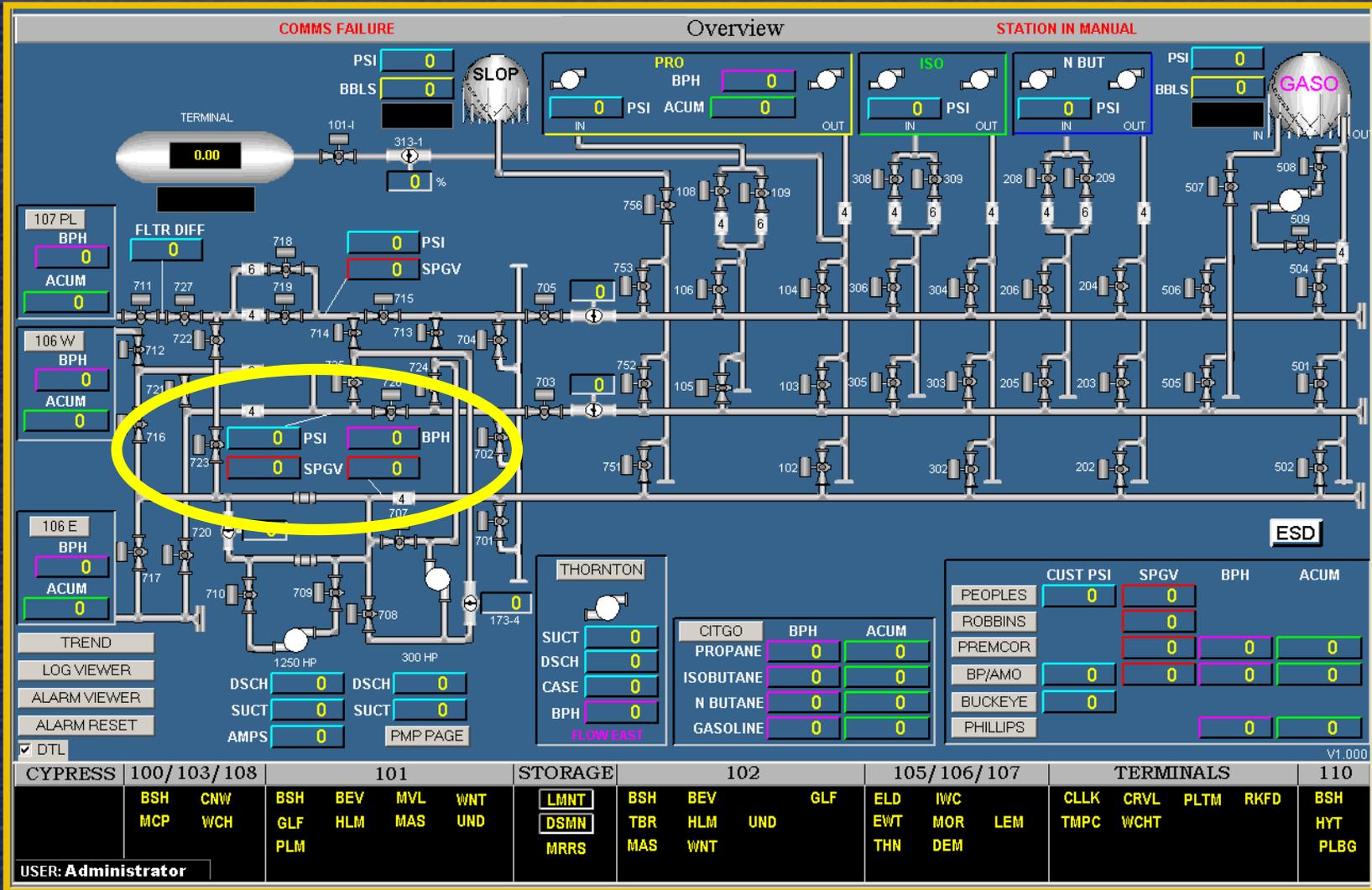
# Graphics Issues

- Screen clutter
- Color usage
- Number of colors
- Color-blind friendly screens

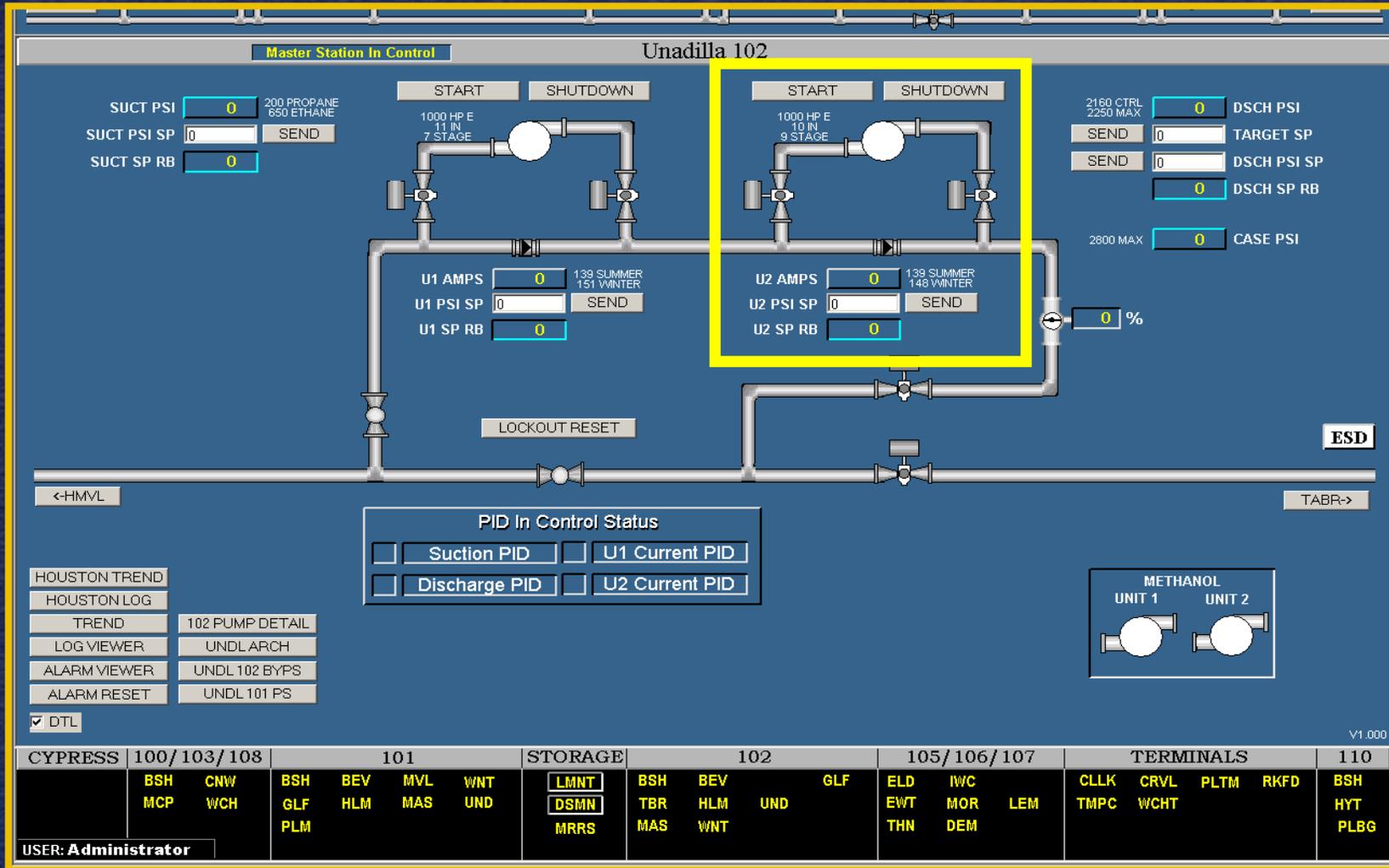
# Screen Clutter



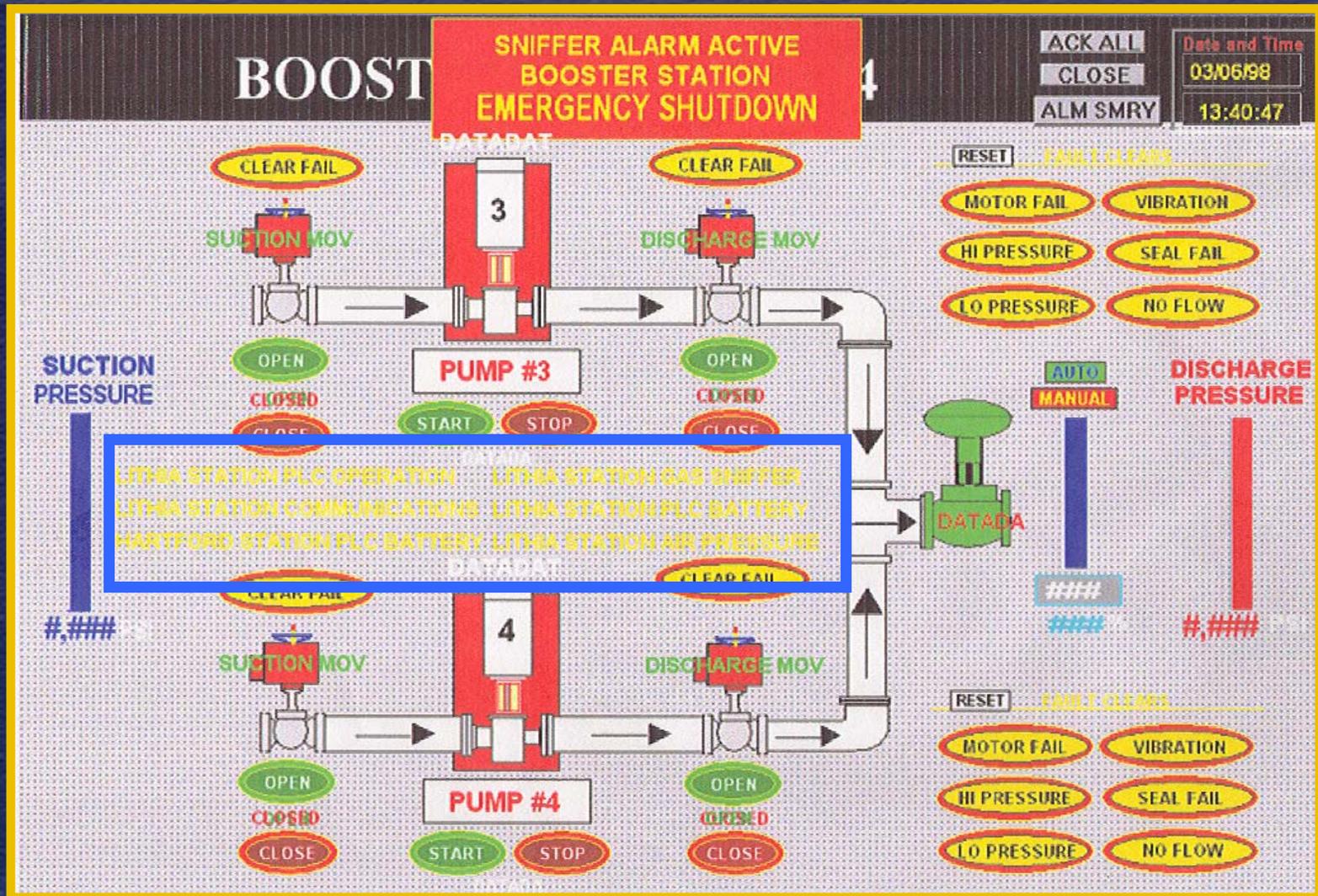
# Cluttered Screen



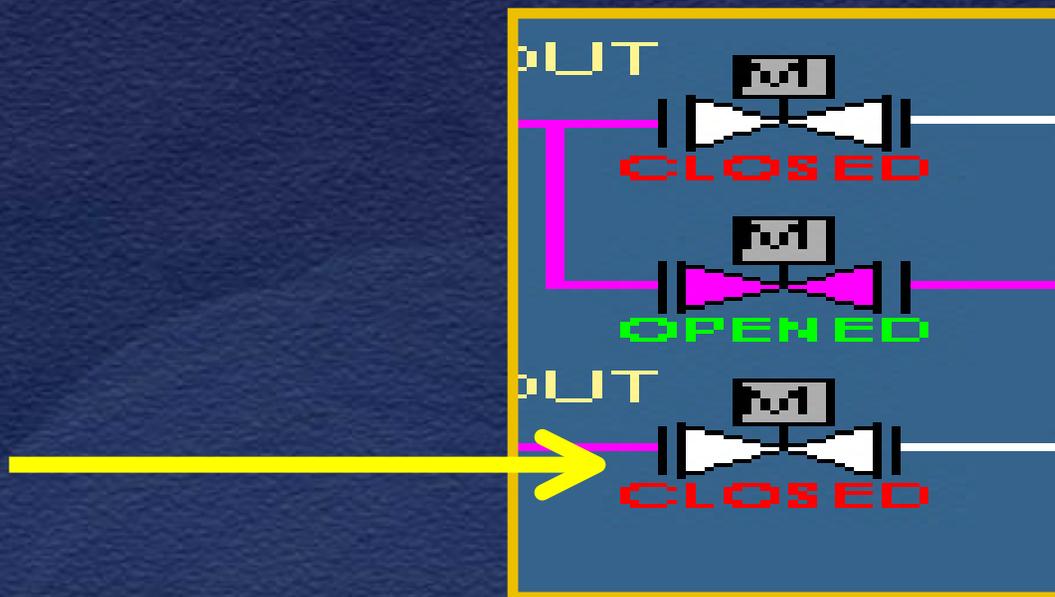
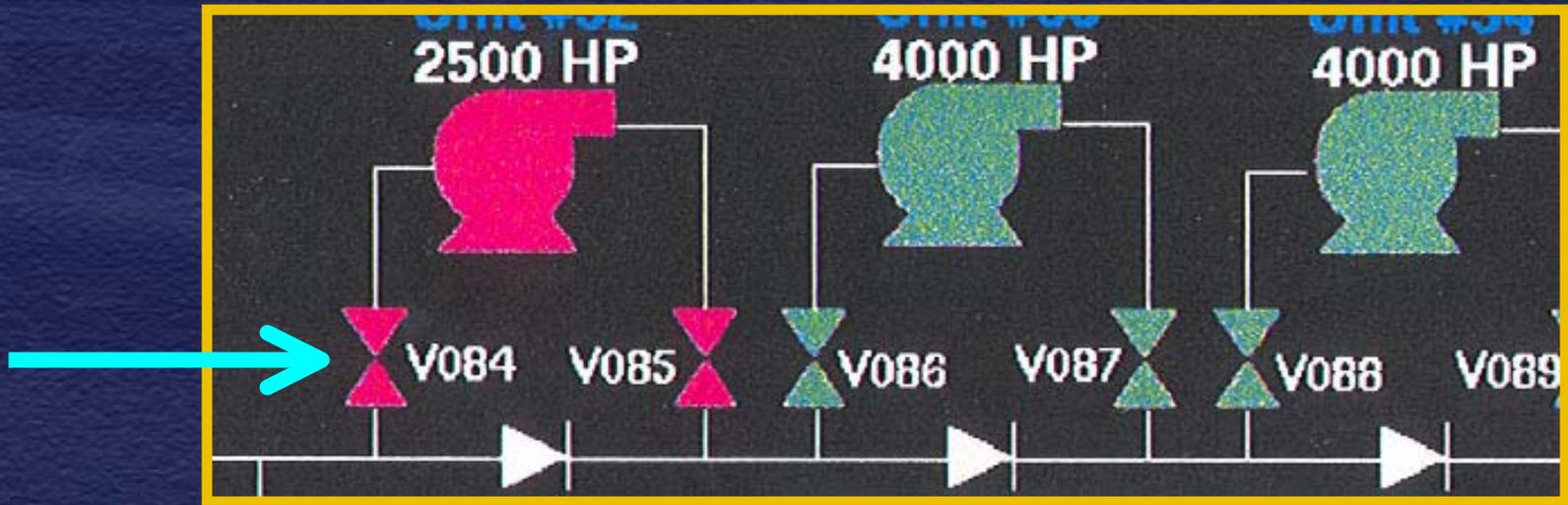
# Uncluttered Screen



# Color Usage



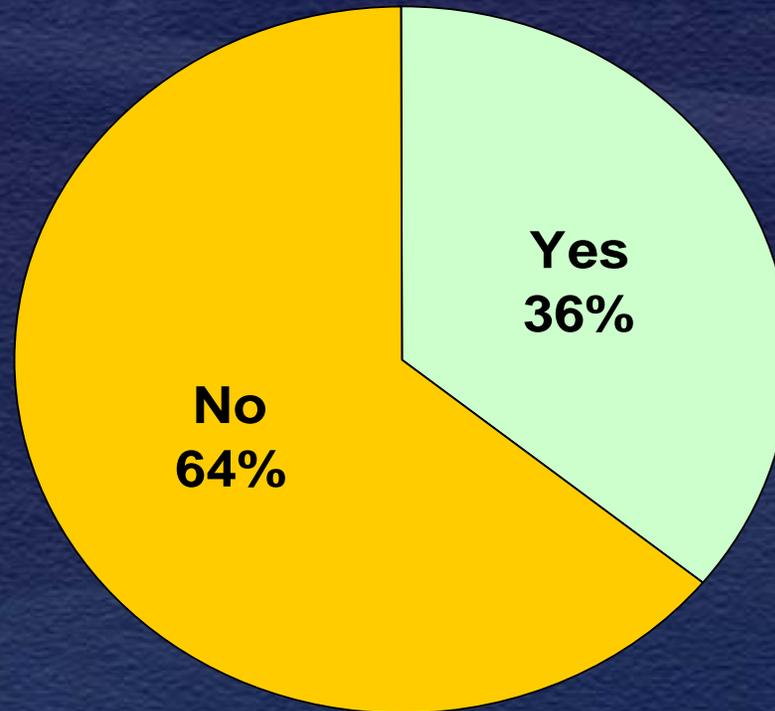
# Color-Blind Accommodations



# Previous Accident: Graphics

- Brenham, Texas
  - Using tabular piping display
  - Graphical display would have improved detection
  - Recommendation for graphical standards
    - P-92-22, Open–Acceptable Action
    - API developing recommended practice

# External Review of SCADA Displays



**Most companies do not review screens**

# Graphics Design Summary

- Accidents show the need to present data clearly
- Companies do not use standards to develop screens
- API currently working on a recommended practice
- OPS support of the recommended practice will improve graphics in the pipeline industry

# SCADA Issues

- Graphic Design
- Alarm Management**
- Leak Detection

# Controllers on Alarms

- Alarm system the most important SCADA safety feature
- Too many alarms and nuisance alarms, sometimes more than 100 alarms in an hour

# SCADA Alarm Screen

Date/Time	Group	Alarm Description
11/03/03 17:12:15	KENO_COLM_14	Columbus_W_NEW: BatchID/Valve Error - Meter 1 - Grade: Change to state CONFIG ER
11/03/03 17:12:15	KENO_COLM_14	Columbus_E_NEW: BatchID/Valve Error - Meter 5 - Grade: Change to state CONFIG ER
10/21/03 14:43:29	SCADA_TEST	Martin_TK_1213: Fire - Office: Value=ALARM - abnormal state.
11/04/03 09:38:38	WABASH_12	Robinson_Wabash: Control Valve Percent Open - Valve 338: Value=83 PCT - analog d
11/04/03 09:38:31	WDRM_CLMT_10	Robinson_Wabash: Meter 2 Head A: Change to state INACTIVE.
11/04/03 09:38:31	WDRM_PATK_22	Wood River - Patoka: CPM - ALARM - 24hr (-0.69%).
11/04/03 09:19:27	BEAU_CRLS_24-26	Dyersburg: Dyersburg: Communication timeout - 180 seconds. Status - no reply.
11/04/03 09:07:57	SPWD_12	West_Delta_79A: Discharge Pressure: Value=127 PSI - analog LOW-LOW.
11/04/03 08:53:12	ESPART_ALL	East_Sparta: Valve Control Disabled: Change to state ALARM.
11/04/03 08:52:34	SPWD_12	WD_Receiving: Control Valve Failure - Plains: Change to state ALARM.
11/04/03 08:47:51	BELL_4	Bellevue: Manifold Relief System High Nitrogen: Change to state ALARM.
11/04/03 08:39:08	SAMA_DETR_16	Samaria: Tank 709 Safe Fill: Change to state LOW.
11/04/03 08:28:08	SPWD_12	WD_Receiving: Meter 3 Temperature Transmitter Failure: Change to state ALARM.
11/04/03 08:21:02	WDRM_CLMT_10	Catlin: Shutdown Unit 1: Change to state ALARM.
11/04/03 07:57:10	WDRM_CLMT_10	Catlin: Lockout Unit 1: Change to state ALARM.
11/04/03 06:29:59	MRTV_LIMA_22	Lima_Gas_Oil: Lima Gas Oil: Communication timeout - 180 seconds. Status - no rep.
11/04/03 06:00:15	RIO_8	Lima_RIO: Phase Failure: Change to state ALARM.
11/04/03 05:56:20	RIO_8	Lima_RIO: Meter 3 Flow Rate: Value=267.205 BPH - analog LOW.
11/04/03 05:51:21	RIO_8	Robinson_RIO: Meter 7 Flow Rate: Value=0 BPH - analog LOW.
11/04/03 05:45:05	MRTV_LIMA_22	Bryant: Lockout Unit 3: Change to state ALARM.
11/04/03 05:44:47	MRTV_LIMA_22	Elwood: Lockout Unit 1: Change to state ALARM.
11/04/03 04:58:25	OWEN_CBRG_24	Owensboro: Meter 14 Flow Rate: Value=2083 BPH - analog LOW.
11/04/03 04:44:28	HETH_DAYT_6	Columbus_Meters: Seal Failure - Manifold Valve IM6: Change to state ALARM.
11/04/03 00:36:02	MRTV_LIMA_22	Roachdale: Unit 2 Percent Speed: Value=0 PCT - analog LOW.
11/03/03 19:58:36	KENO_COLM_14	Kenova: Pig Departure: Change to state ALARM.
11/03/03 19:45:50	KENO_COLM_14	Kenova: Illegal Valve Change: Change to state ALARM.
11/03/03 17:23:52	ESMD-TLSB_PROD	Youngstown: Manifold Relief System Low Nitrogen: Change to state ALARM.
11/03/03 17:11:45	HETH_DAYT_6	Columbus_E_NEW: No Flow Path Exists: Change to state ALARM.
11/03/03 17:11:41	HETH_DAYT_6	Columbus_W_NEW: Shutdown Booster 1: Change to state ALARM.

Select to Acknowledge

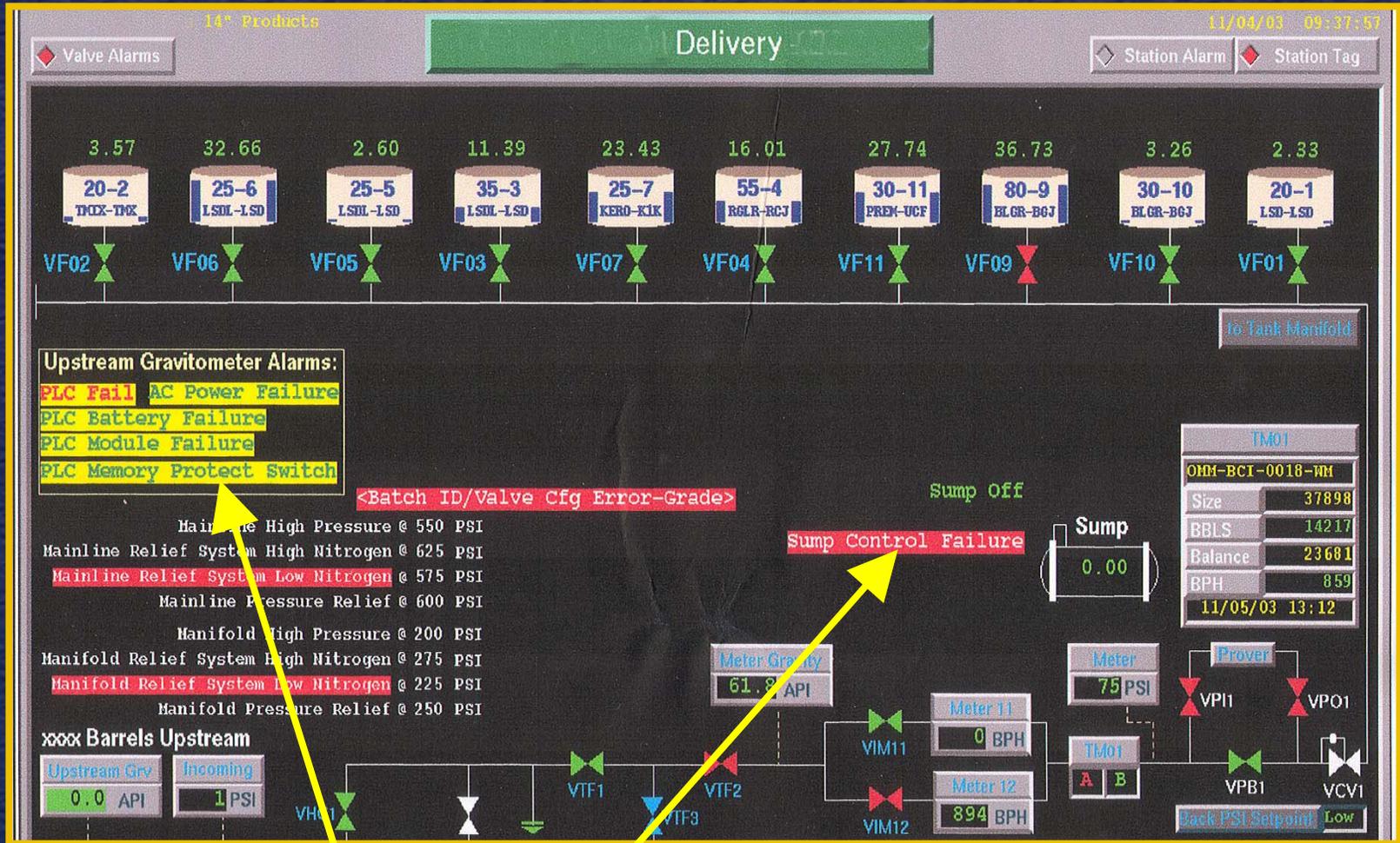
Select for Related Display

Area Filter

Page Acknowledge



# Station Screen Alarms



Alarms



# Event Log and Alarm Frequency

## Event History - Patoka - Owensboro 20" Crude: 01/27/2000 06:00 thru 14:27

Date	Station	Description	Message
6:02:15	Owensboro	Incoming Gravity	Value=33.78 API - analog LOW
6:02:32	Owensboro	Manifold Valve B10	Issued command OPEN by siefker at FPLXOS5
6:02:41	Owensboro	Meter 5	PMC-093-1933-OWT: Automatic track completed: pumped 125030.0 BBLS
6:02:49	Owensboro	Manifold Valve B10	Discrete command TRANSIT - success
6:03:23	Owensboro	Manifold Valve B10	Discrete command OPEN - success
6:03:33	Owensboro	Manifold Valve B7	Issued command CLOSE by siefker at FPLXOS5
6:03:40	Owensboro	Meter 5	PMC-093-1933-OWT: Automatic track completed: pumped 125200.0 BBLS
6:03:41	Owensboro	Meter 5	Issued command TICKET START siefker by siefker at FPLXOS5
6:03:49	Owensboro	Sampler Pot 1	Uncommanded change to state INACTIVE
6:03:49	Owensboro	Sampler Pot 2	Uncommanded change to state ACTIVE
6:04:48	Owensboro	Incoming Gravity	Value=33 API - analog deviation return to normal
6:05:48	Owensboro	Incoming Gravity	Modified analog.OWENGRIGRV.hilow.lolim from "34.000000" to "28.900000" b
6:05:51	Owensboro	Meter 5 Total Flow Rate	Value=567.602 BPH - analog dev-low
6:05:51	Owensboro	Meter 5 Total Flow Rate	Value=567.602 BPH - analog LOW
6:05:52	Owensboro	Incoming Gravity	Modified analog.OWENGRIGRV.hilow.hilim from "42.000000" to "36.900002" b
6:05:55	Owensboro	Incoming Gravity	Value=32.88 API - analog NORMAL
6:05:56	Owensboro	Meter 5 Total Flow Rate	Value=10281.2 BPH - analog deviation return to normal
6:05:56	Owensboro	Meter 5 Total Flow Rate	Value=10281.2 BPH - analog NORMAL
6:06:13	Patoka, PAO	Patoka, Owensboro	Modified status.PDTBATPOWEN.agg_time_high from "04906006" to "0490745

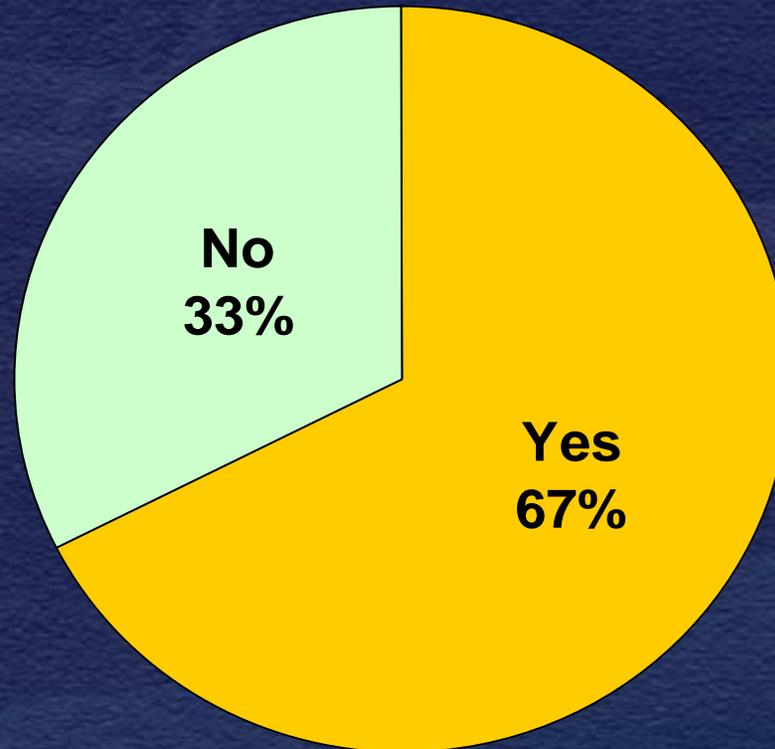


**4 minutes  
18 alarms**

# Previous Alarm Accidents

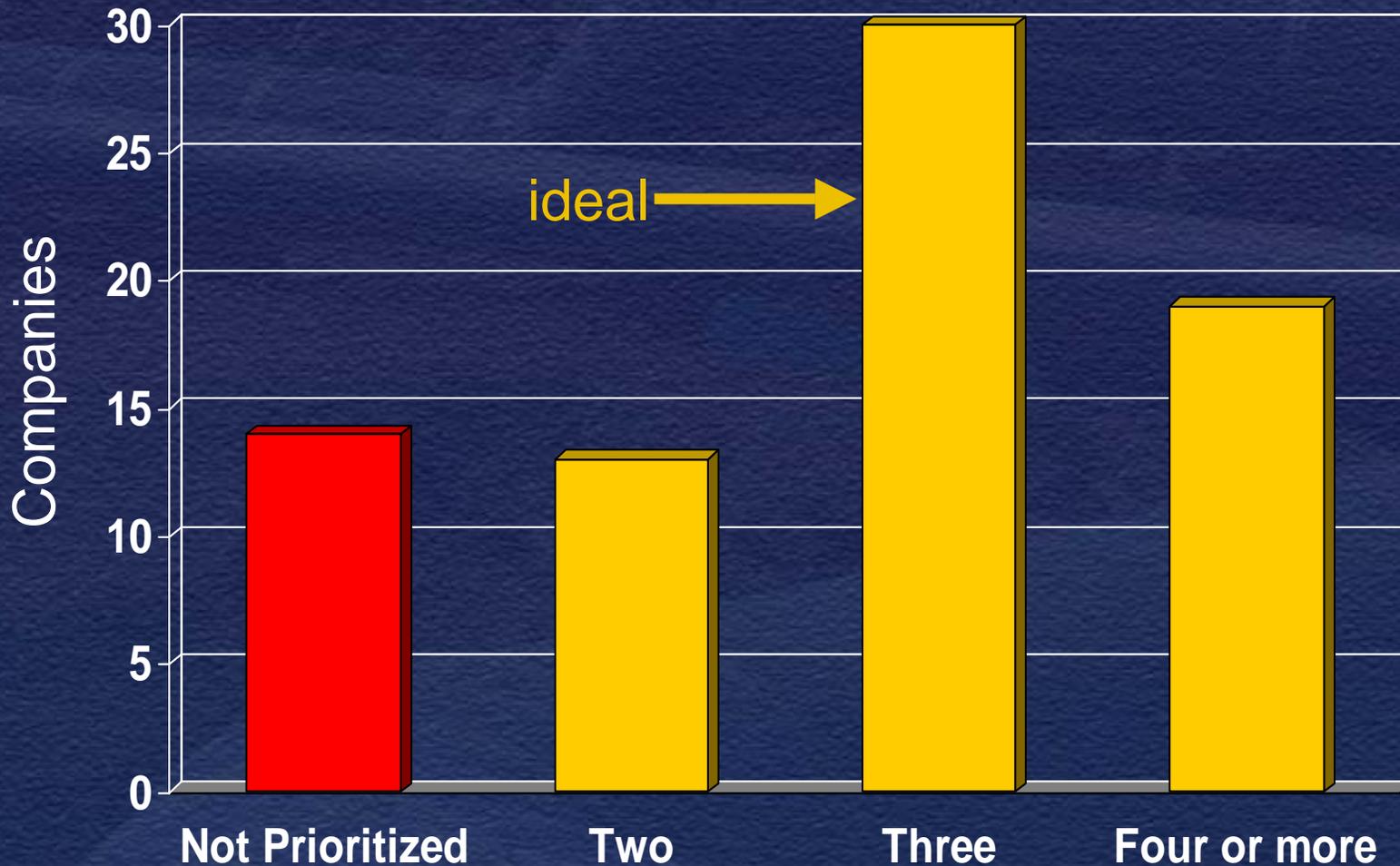
- Gramercy
  - P-98-22
  - Board recommended an audit of alarms
  - Company reported an alarm decrease from 200 to 60 leak alarms per day

# Companies Conduct Alarm Audits



**1 of 3 companies do not audit alarms**

# Number of Alarm Priorities



# Alarms Summary

- Alarms are the most important safety feature of SCADA systems
- Controllers believe they are receiving too many alarms
- Alarm audits can reduce the number of alarms
- Alarm priorities can improve the salience of important alarms.

# SCADA Related Issues

- Graphic Design
- Alarm Management
- Leak Detection**

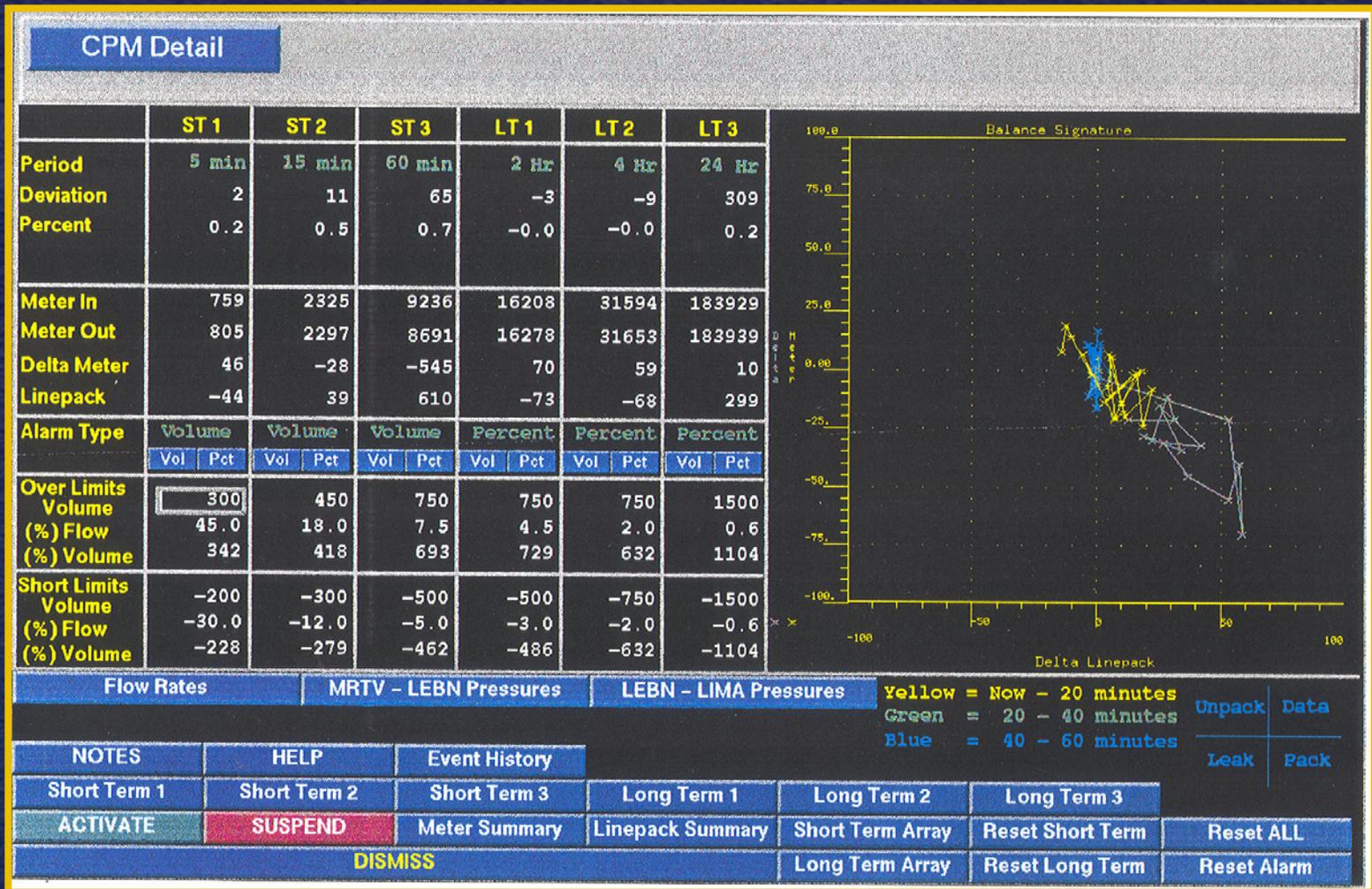
# CPM Systems

- Computational pipeline monitoring is a computerized decision aid to help controllers identify leaks
  - Many methods of CPM
    - Line balance
    - Volume balance
    - Model based
    - Statistical
- 
- Simple
- Complex

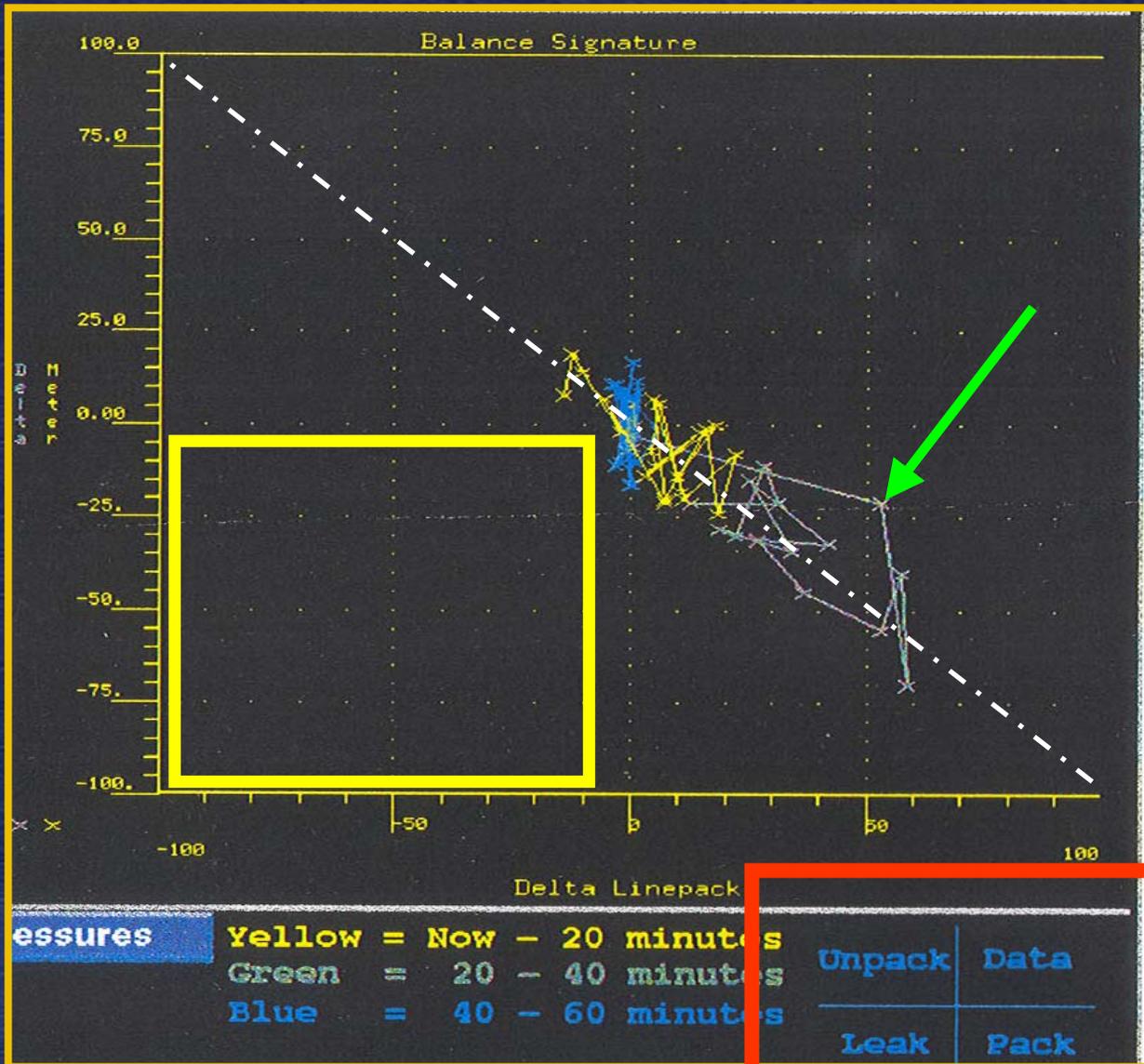
# CPM Detection Times

- CPM systems detected leaks in
  - Cohasset (3 minutes)
  - Gramercy (3 minutes)
  - Winchester (1 minute)
  - Bellingham (13 minutes)

# CPM Screen



# CPM Graphics



# CPM System Screen



# CPM Summary

- CPM systems are effective in indicating leaks
- CPM systems not on 40 percent of companies systems

# Controller Issues

- Fatigue
- Training

# Controller Schedules

- All companies visited monitored the pipeline 24 hours
- 11 of 12 companies visited used a 12-hour shift
- No hours of service in pipeline regulations

# Schedule Limits in Similar Jobs

- Air traffic control
  - 40 hours/wk, max: 10 hours
  - 30-minute lunch break
  - 2 hours on sector before break
- Nuclear power
  - 48 hours/wk, max: 16 hours,
  - Mandatory breaks for shifts > 10 hrs
- Rail dispatch
  - Max 9 hrs (multiple shifts)

# Controller Fatigue

- 8 of 18 controllers least liked their schedules
- 10 controllers noted concerns about getting enough sleep, working nights, or switching shifts
- Controllers like their schedules because of the time off

# Fatigue Effects

- Degraded judgment/decision-making
- Reduced vigilance
- Reduced short-term memory
- Lack of concentration
- Visual/mental fixation

# Previous Board Recommendations

- Issue bulletin on 12-hour shift scheduling
  - Fork Shoals accident (1996)
  - P-98-30
  - Currently Open—Acceptable Action
- Issue hours of service rules
  - Fatigue Safety Report
  - P-99-12
  - Currently Open—Acceptable Action

# PHMSA response

- Advisory Bulletin, *Pipeline Safety: Countermeasures to Prevent Human Fatigue in the Control Room*
  - Shift rotation practices
  - 12-hour shifts
  - 10 hours of rest between shifts
  - Guidelines for scheduling controllers

# Fatigue Issue Summary

- No hours of service regulations
- Controller fatigue
- PHMSA bulletin on fatigue
- Bulletin not mandatory
- No fatigue data collected in OPS accident database

# Controller Related Issues

- Fatigue
- Training

# Previous Accidents and Training

- Inadequate controller training in 7 of the 10 accidents
- Four companies chose to purchase or enhance simulators to improve training

# Electricity SCADA Training

- 2003 power outage in the Northeast
- North American Electrical Reliability Council findings:
  - Controllers not adequately prepared
  - Controllers trained on the job

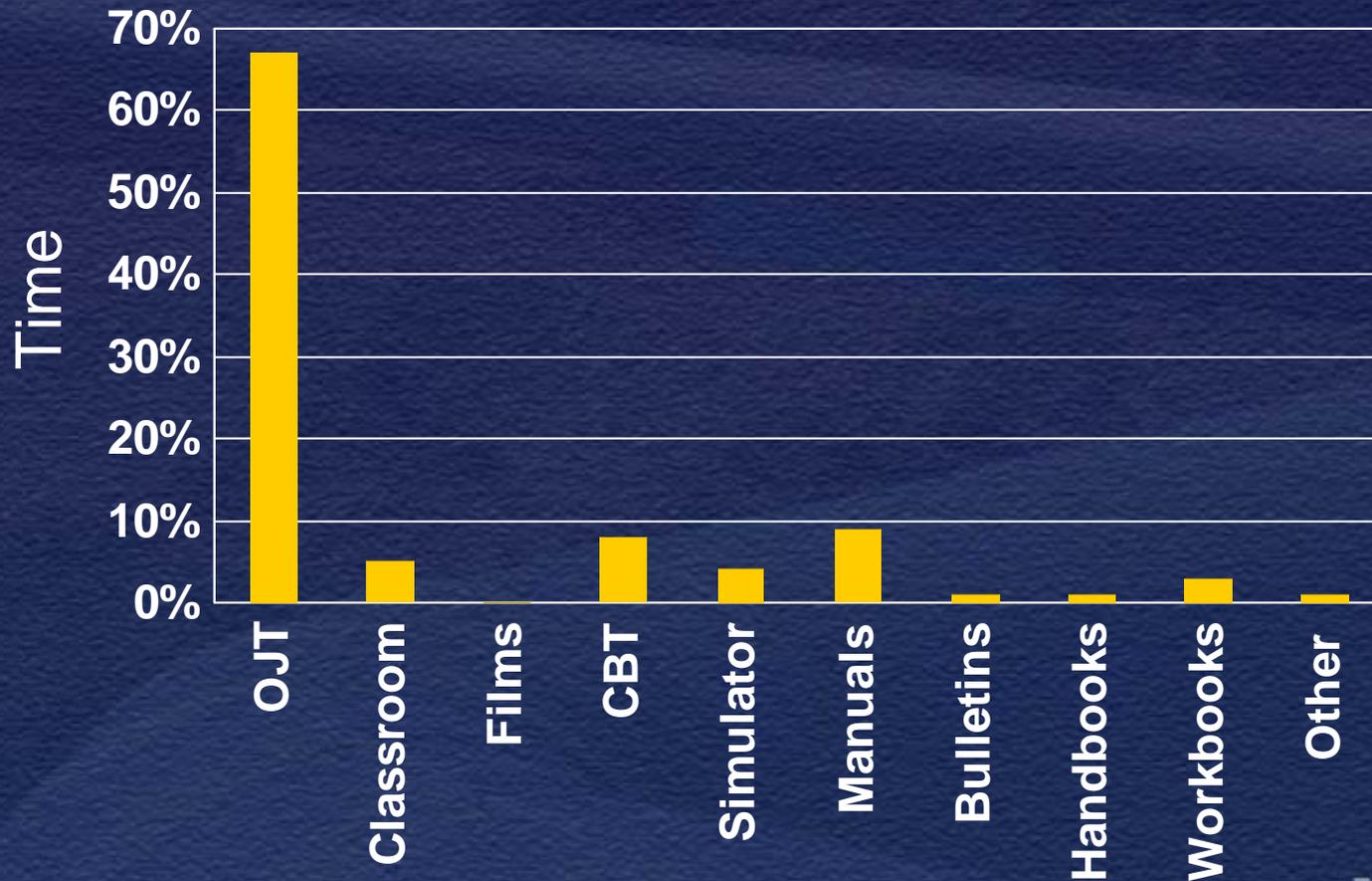
# Power Outage Recommendations

- Improved training for abnormal operations
- Simulations of abnormal operation either on computer or as tabletop drills

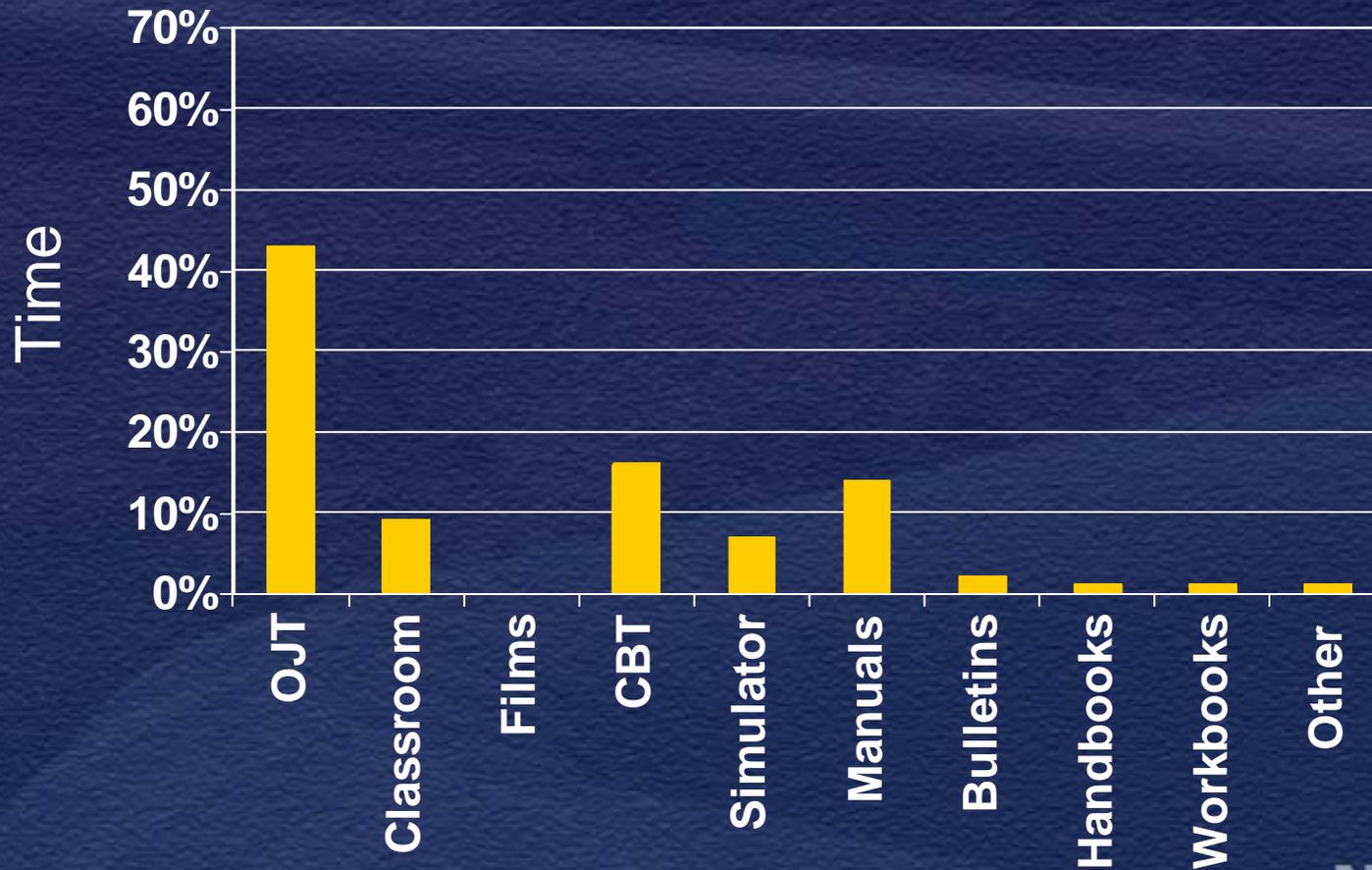
# Typical Controller Training

- Average training for controllers
  - 6 month average
  - 3 months to several years
  - Six companies had simulators
    - Three companies were using them
    - 6 of 18 controllers had simulator training

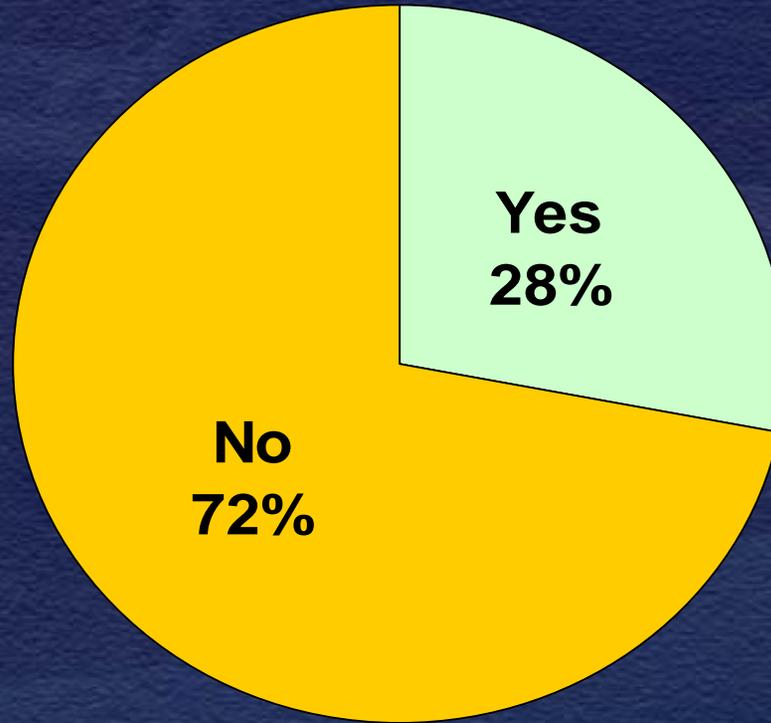
# Majority of Training On-the-Job



# Refresher Training On-the-Job



# Simulator Training



**1 of 4 companies have simulators**

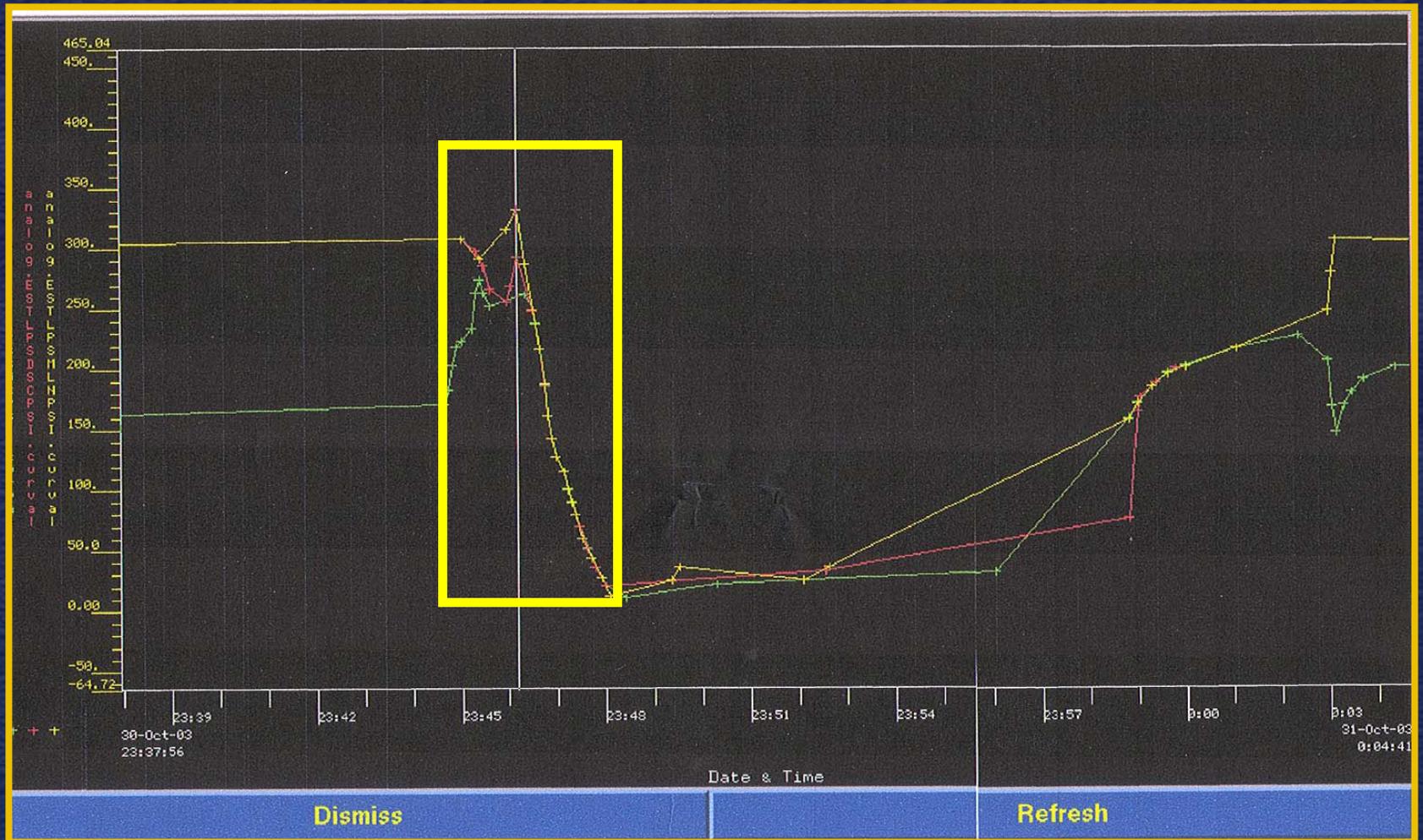
# SCADA Simulator



# SCADA Training Simulator



# SCADA Trend Screen



# Training Issue Summary

- SCADA-related accidents include training issues
- Most training is on the job
- Most companies do not have simulators
- Simulation of abnormal events would better prepare controllers for these rare events



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