NRC FORM 658
(9-1999)

U.S. NUCLEAR REGULATORY COMMISSION

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Do not include proprietary materials.

DATE OF MEETING
02/16/2000

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Docket Number(s)	**PROJECT NO. 669**
Plant/Facility Name	**EPRI**
TAC Number(s) (if available)	**M93653**
Reference Meeting Notice	**1/24/00**
Purpose of Meeting (copy from meeting notice)	**TO DISCUSS STATUS OF STAFF'S REVIEW OF EPRI TOPICAL REPORT, TR-104965, "ON-LINE MONITORING OF INSTRUMENT CHANNEL PERFORMANCE"**

NAME OF PERSON WHO ISSUED MEETING NOTICE	TITLE
L. N. OLSHAN	**PROJECT MANAGER**

OFFICE
NRR

DIVISION
DLPM

BRANCH
PD II-1

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Docket File/Central File
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DF03

On-Line Monitoring TR-104965

EPRI-Utility OLM Working Group

EPRI-NRC Meeting
White Flint, MD
February 16-17, 2000

DALE CARNEGIE® TRAINING

Wednesday Feb. 16 2000

10:00 AM Introductions *ALL*

10:15 AM Purpose & Overview

10:30 AM Plant Implementation of On-Line Monitoring *Hooten*

11:00 AM Description & Use of MSET *Gross*

12:30 LUNCH

1:30 PM Plant Applications of MSET

2:00 PM NRC Research in Instr. Calib *Hashemian*

3:00 PM Q&A *All*

4:00 PM Adjourn Day 1

Thursday Feb 17 2000

8:30 AM Purpose of Discussion

9:00AM Review of NRC Status Report

9:30 AM Review of "Stipulations" *Rusaw & Hooten*

12:00 LUNCH

1:30 PM Discussions *All*

3:00PM Actions Items *All*

4:00 PM Adjourn

Introduction

Why are we here?

Day 1: How does MSET work?

How & Where has it been used?

Questions & Discussion

Introduction

- Day 2:
  - Review of Status Report Dec 1999
  - Discussion of "Stipulations" and EPRI's Response
  - Discussions
  - Action Items & Adjourn

Why are we here?

- EPRI Team dedicated to Implement Technology for Improved Reliability
  - Support of Products
  - Tech Transfer & Training
  - Liaison with NRC
  - TR-104965 "Living Document"

TR-104965," On-Line Monitoring of Instrument Channel Performance

- Improved Reliability.
- Ability to Identify Instrument Drift During Plant Operation
- Preventive Action.
- Improve Plant Efficiencies

EPRI Goals

- More comprehensive view on how MSET works and Applications
- Provide EPRI Response to "Stipulations"
- Mutual Agreement

Opportunities

- Instrument Operating Experience
- Application & Lessons-Learned
- Understanding of Instrument Drift

EPRI Follow Up

- Users Group Formation
- Training & Tech Transfer
- Product Improvements

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MSET
Advanced Pattern Recognition System for Ultra-Reliable Online Instrument Surveillance

Kenny Gross

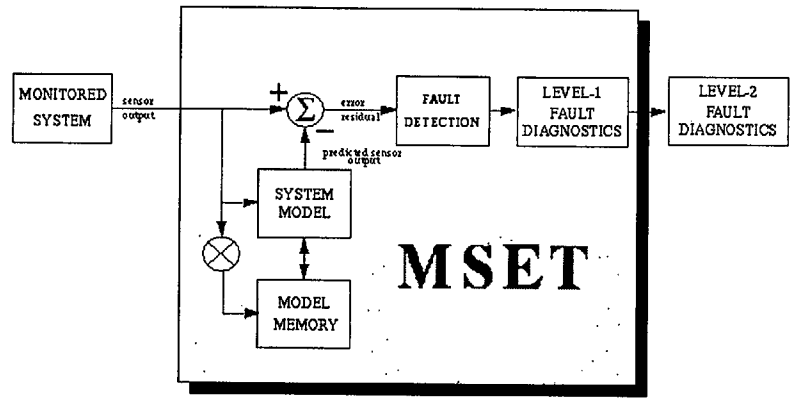
Reactor Analysis Division

Argonne National Laboratory

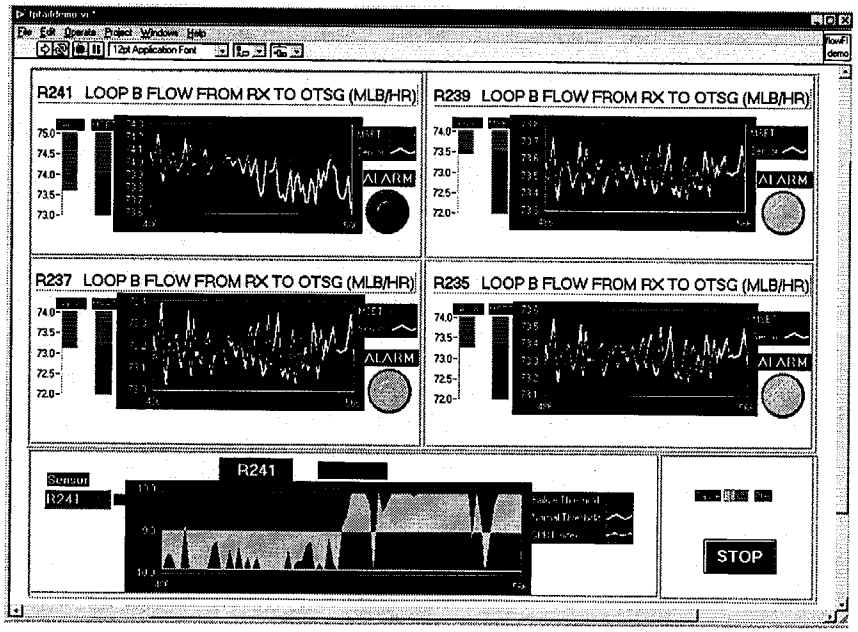
February 16, 2000

ANL's MSET System
Multivariate State Estimation Technique

Argonne National Laboratory has developed an advanced pattern recognition system, MSET, for monitoring signals in nuclear plants for extremely sensitive identification of disturbances in sensors or operating equipment. MSET brings together four powerful pattern recognition methods in one package to produce a system with unique monitoring capabilities that surpass any traditional approaches, including neural networks, in sensitivity, reliability, and computational efficiency.



MSET system compares sensors signals with a system model (above) to detect disturbances in nuclear power plants



MSET screen view (left) shows MSET surveillance of systems at Florida Power's Crystal River-3 nuclear plant

Argonne National Laboratory

MSET Background

Online pattern recognition is essentially an empirical approach to online instrumentation and component surveillance and is most useful to:

(1) Find relationships between seemingly unrelated pieces of data and construct new information from them;

(2) Predict sensor signals based on previous behavior and the current observations from correlated sensors

(3) Detect the incipience or onset of subtle developing faults in sensors or operating components at the earliest possible time.

MSET
Multivariate State Estimation Technique

ANL has developed an advanced pattern recognition system, MSET, for surveillance of sensor configurations in nuclear plants for extremely sensitive identification of the onset of sensor degradation or process anomalies. ANL's system comprises a synergistic integration of powerful pattern recognition and optimization techniques to produce a system with unique surveillance capabilities that surpass any conventional approaches, including neural networks, in sensitivity, reliability, and computational efficiency.

"Virtual Sensor" Capability:

When MSET detects degradation in any sensors under surveillance, it has the capability to automatically mask out the degraded signal and swap in a synthesized signal that is generated from all of the correlated variables in the system.

ANL Patented Tools for Ultrahigh Reliability Surveillance

Sequential Probability Ratio Test (SPRT)

Advanced pattern recognition technique for high sensitivity, high reliability sensor and equipment operability surveillance.

Multivariate State Estimation Technique (MSET)

Online model-based fault detection and identification. MSET predicts what each signal should be on the basis of learned correlations among variables. MSET incorporates the SPRT to provide the earliest mathematically possible annunciation of subtle disturbances in any plant instrumentation.

MSET won a 1998 R&D-100 Award from R&D Journal for one of the best 100 technological innovations in the world for 1998.

MSET System for Incipient Fault Annunciation

- ❖ Built-In, Quantitative Confidence Factors
- ❖ Early Annunciation of Discrepant Signals
  - ANL has proven in refereed journals that MSET provides the earliest mathematically possible annunciation of a subtle disturbance in a noisy process variable
- ❖ Avoidance of False Alarms
- ❖ Enhances System Availability and Economics

MSET

Multivariate State Estimation Technique

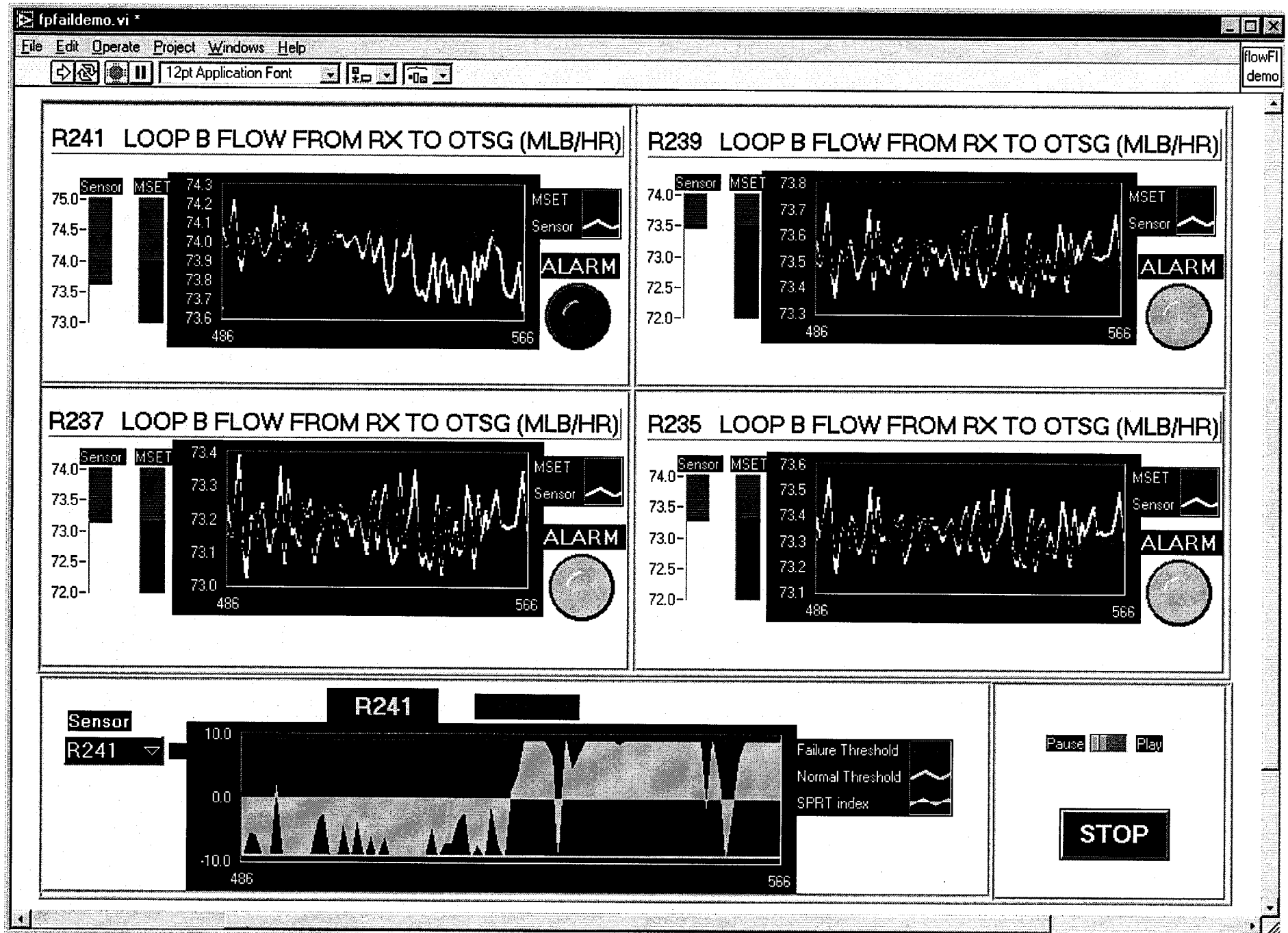
Example Reactor Applications:

(1) MSET detects Venturi flowmeter fowling with a high accuracy. (Generic nuclear industry problem costing $7.3M per year per plant in lost revenues).

(2) MSET detects with high sensitivity the loss-of-time-response failures in Rosemount pressure transmitters. (Generic nuclear industry problem).

(3) MSET provides continuous instrument calibration validation throughout a plant's operating cycle for all plant sensors.

(4) MSET provides incipient fault annunciation in reactor coolant pumps (RCPs). [Most recent RCP success 5/99 with Davis Besse PWR in Ohio].


fpfaildemo.vi *
File Edit Operate Project Windows Help
12pt Application Font
flowFl demo
R241 LOOP B FLOW FROM RX TO OTSG (MLB/HR)
Sensor
MSET
75.0
74.5
74.0
73.5
73.0
74.3
74.2
74.1
74.0
73.9
73.8
73.7
73.6
486
566
MSET
Sensor
ALARM
R239 LOOP B FLOW FROM RX TO OTSG (MLB/HR)
74.0
73.5
73.0
72.5
72.0
73.8
73.7
73.6
73.5
73.4
73.3
486
566
MSET
Sensor
ALARM
R237 LOOP B FLOW FROM RX TO OTSG (MLB/HR)
74.0
73.5
73.0
72.5
72.0
73.4
73.3
73.2
73.1
73.0
486
566
MSET
Sensor
ALARM
R235 LOOP B FLOW FROM RX TO OTSG (MLB/HR)
74.0
73.5
73.0
72.5
72.0
73.6
73.5
73.4
73.3
73.2
73.1
486
566
MSET
Sensor
ALARM
Sensor
R241
R241
10.0
0.0
-10.0
486
566
Failure Threshold
Normal Threshold
SPRT index
Pause
Play
STOP

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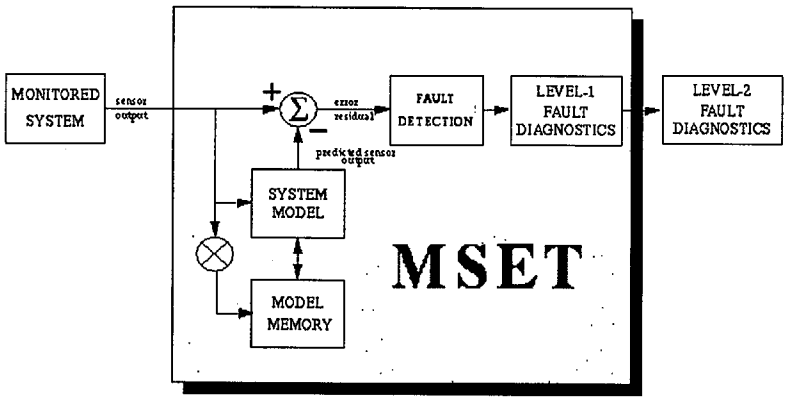
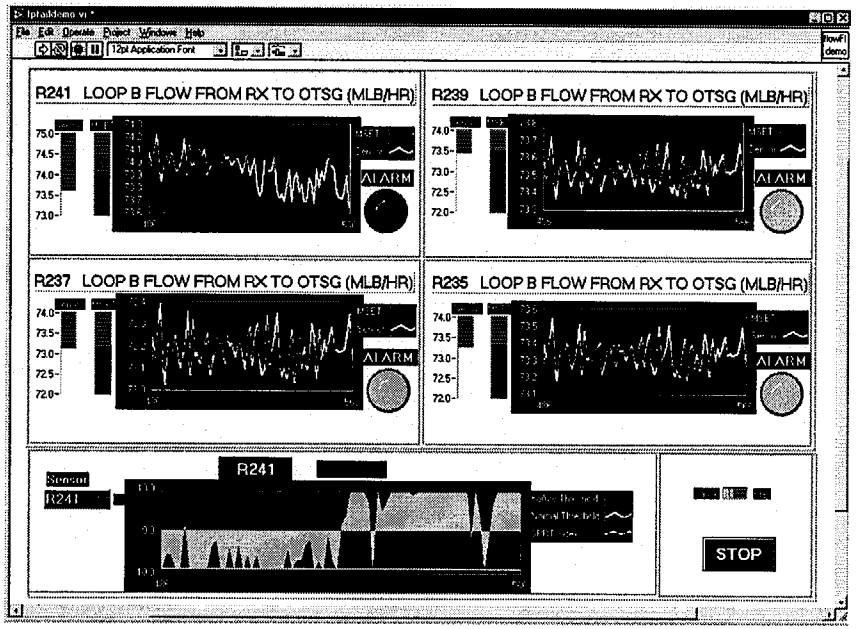
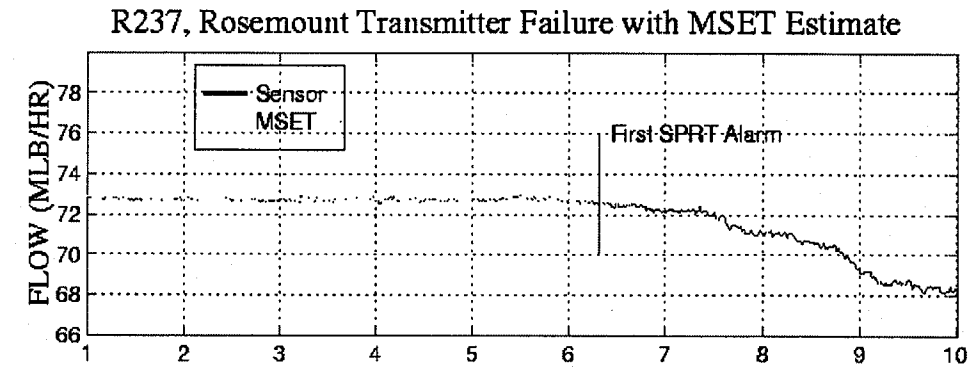


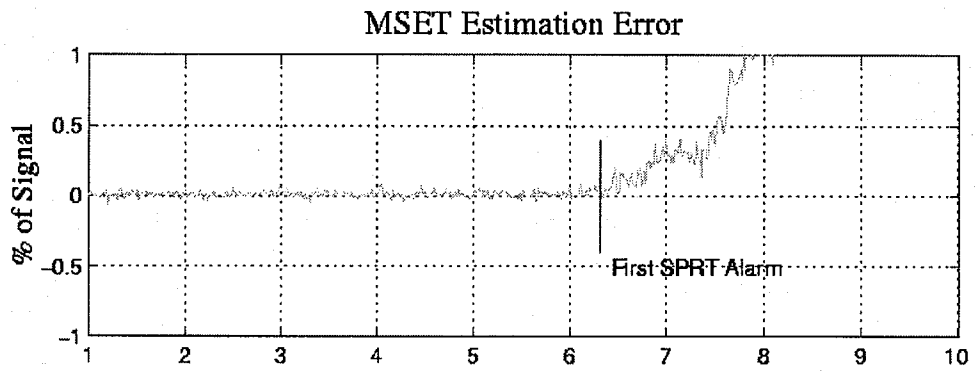
MSET system compares sensors signals with a system model (above) to detect disturbances in nuclear power plants

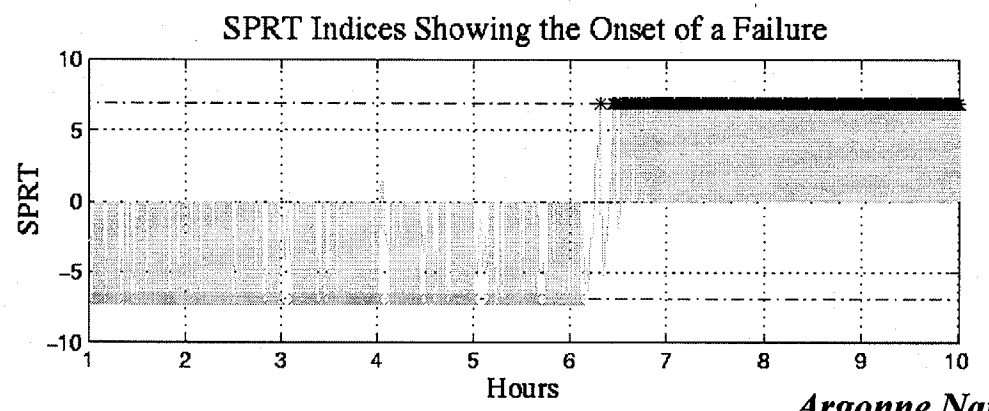


MSET screen view (left) shows MSET surveillance of systems at Florida Power's Crystal River-3 nuclear plant

Argonne National Laboratory


R237, Rosemount Transmitter Failure with MSET Estimate
Sensor
MSET
First SPRT Alarm
FLOW (MLB/HR)
78
76
74
72
70
68
66
1
2
3
4
5
6
7
8
9
10


MSET Estimation Error
% of Signal
1
0.5
0
-0.5
-1
First SPRT Alarm
1
2
3
4
5
6
7
8
9
10


SPRT Indices Showing the Onset of a Failure
SPRT
10
5
0
-5
-10
1
2
3
4
5
6
7
8
9
10
Hours

MSET HANDLES INTERMITTENT FAULTS

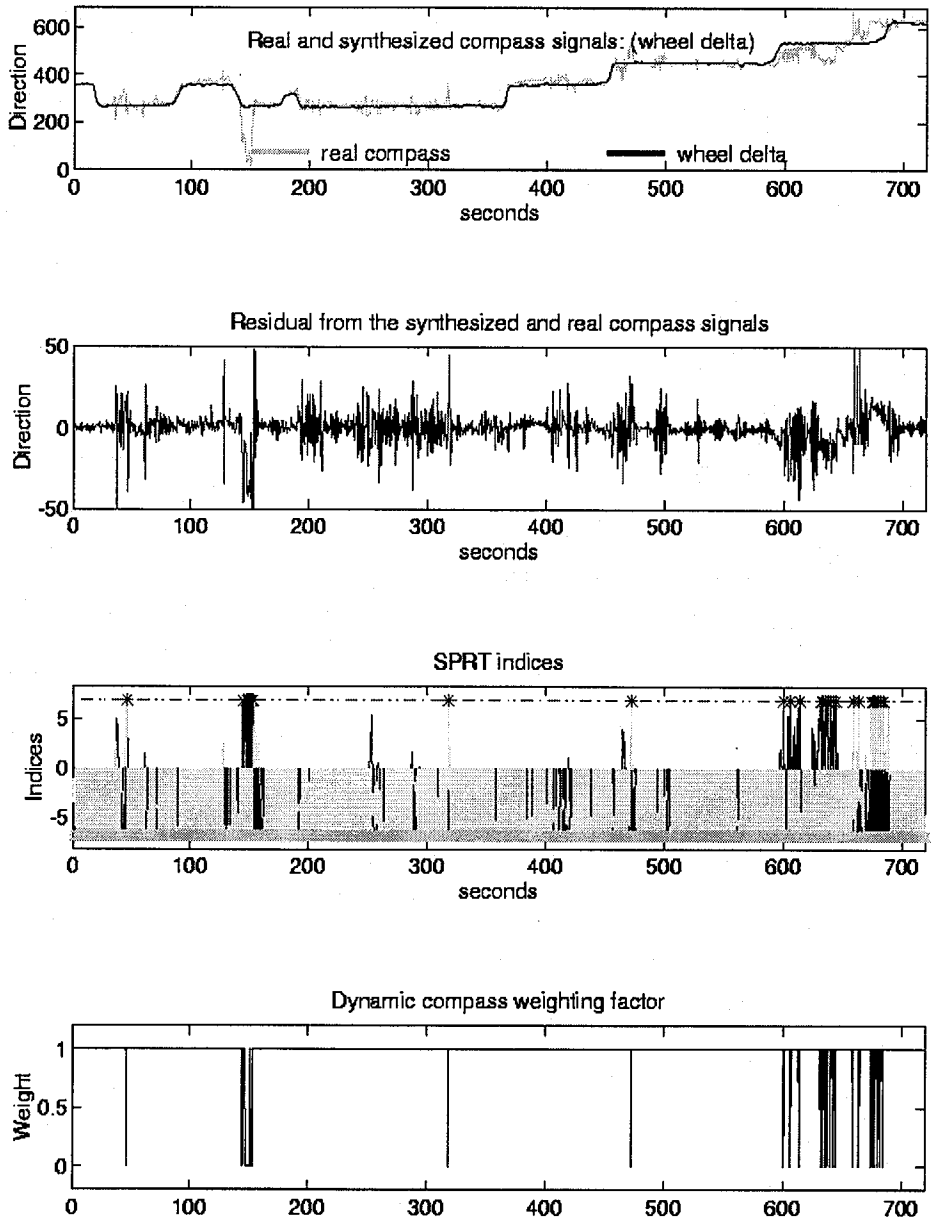
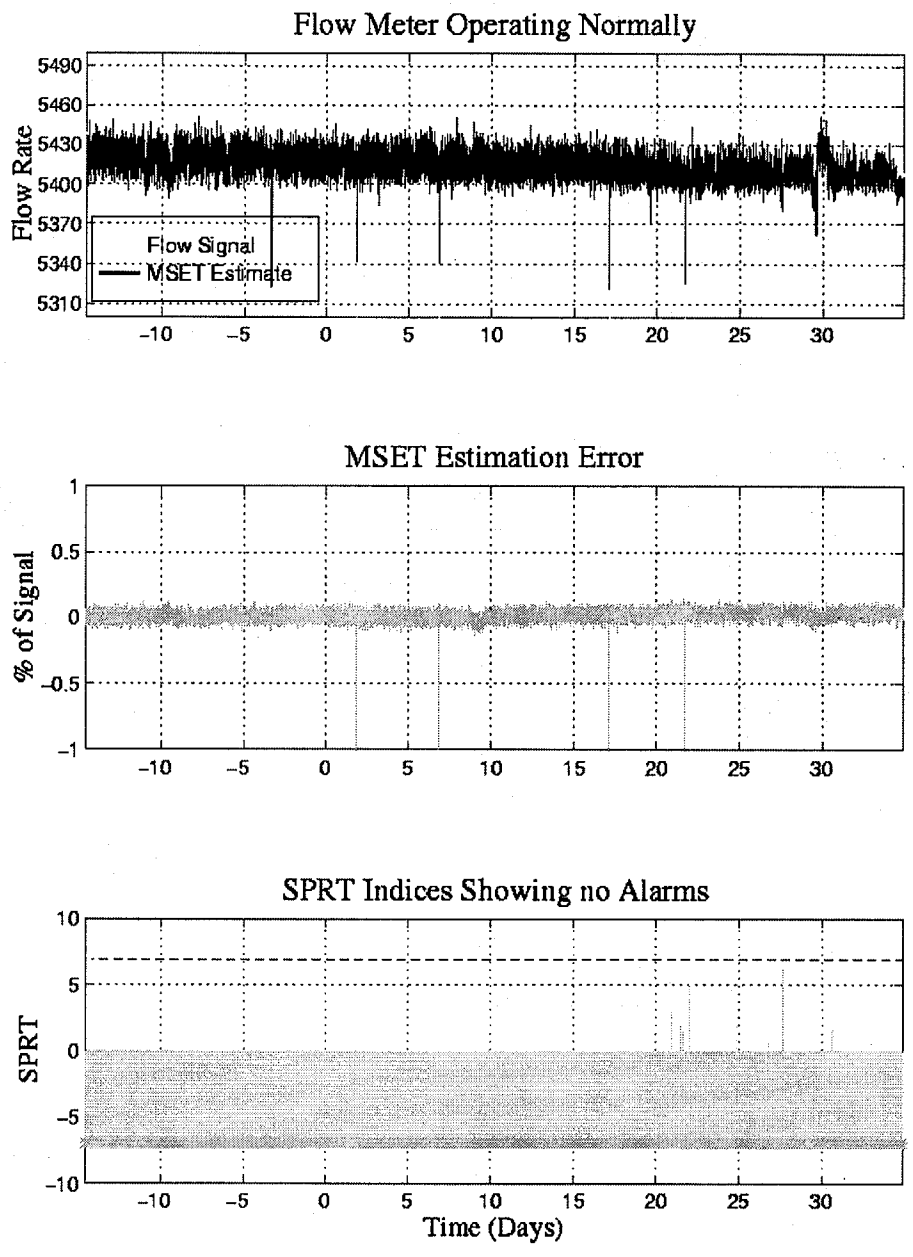
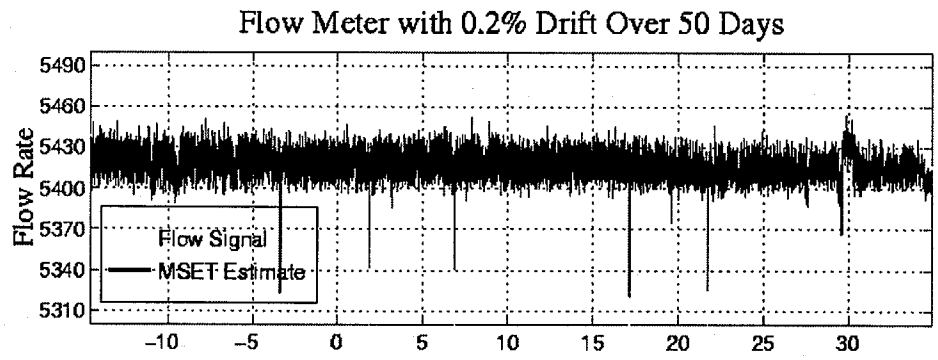


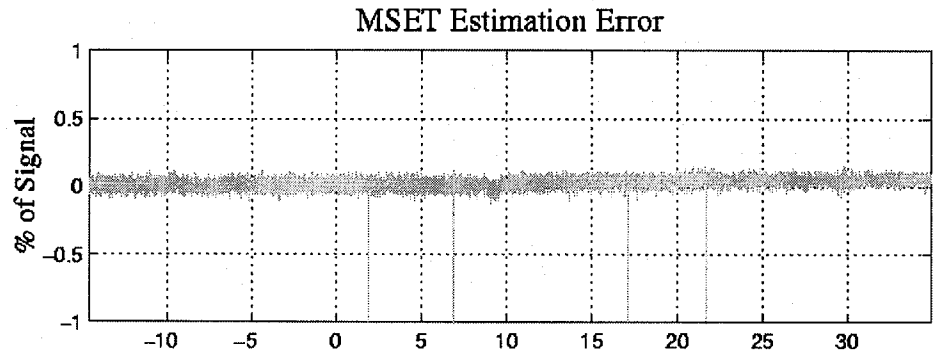
FIGURE 7a, 7b, 7c and 7d

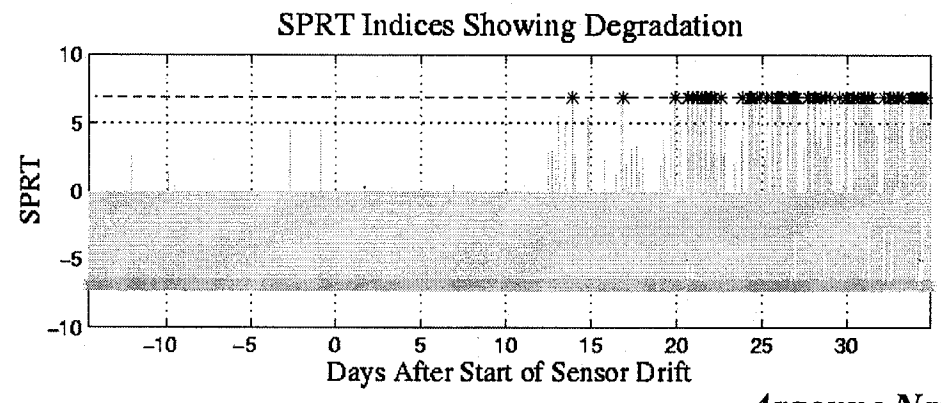
Argonne National Laboratory



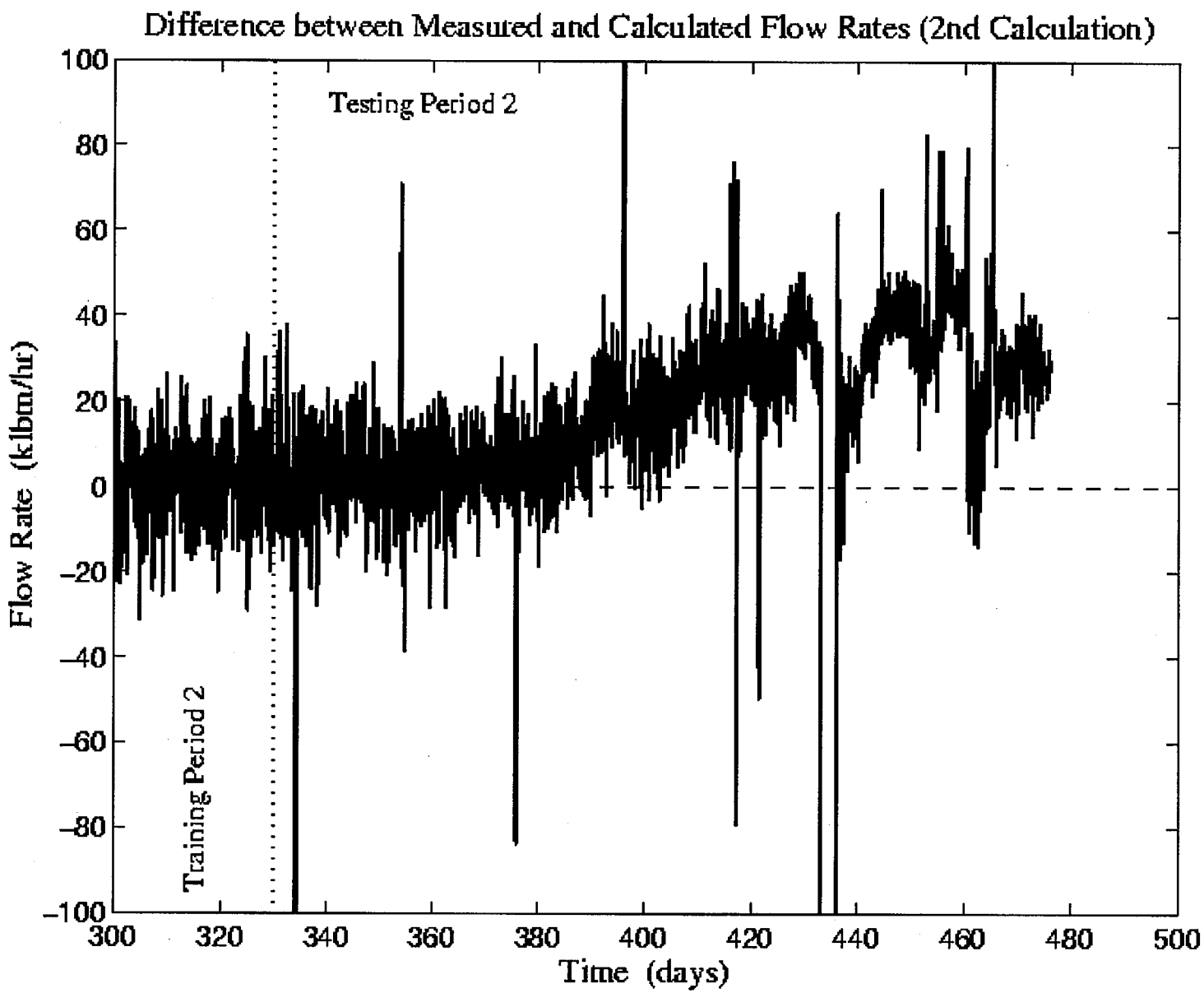
Argonne National Laboratory







Argonne National Laboratory



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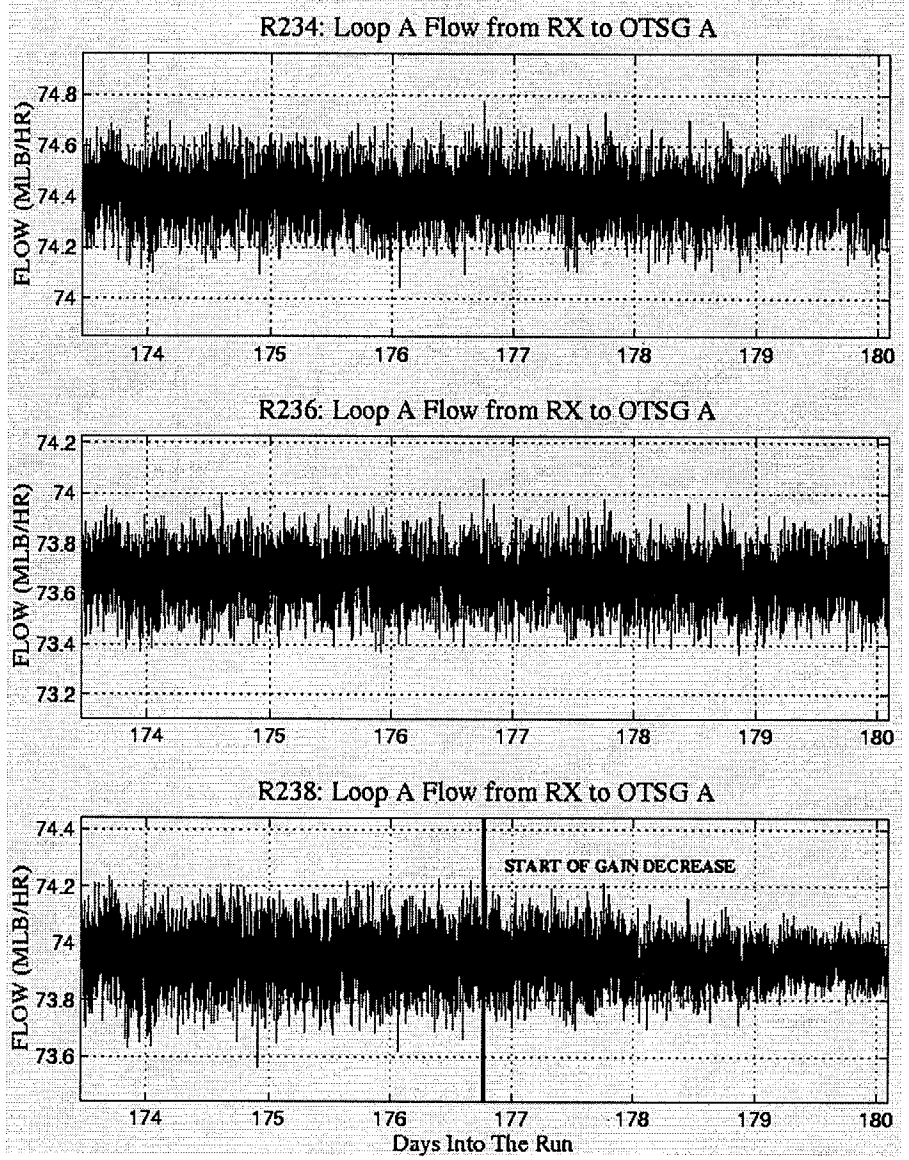
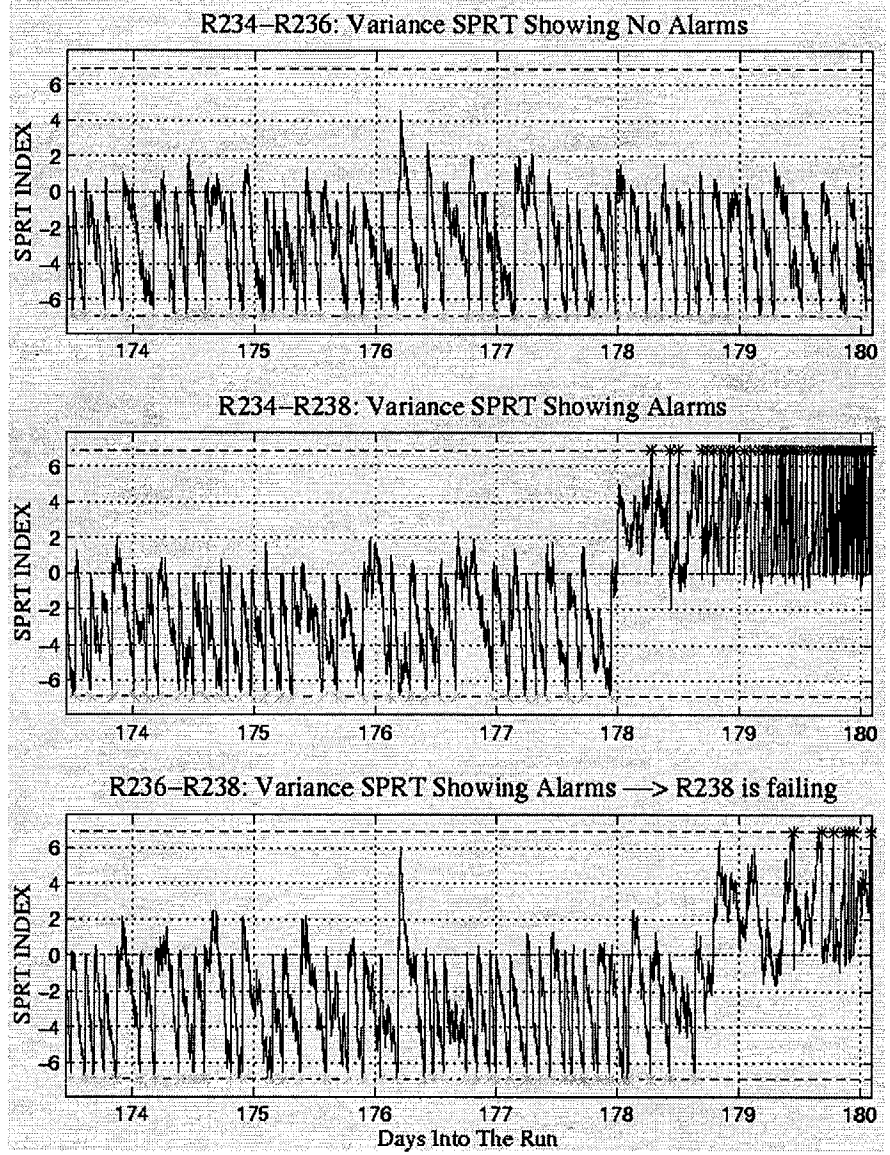
Linearly Decreasing Gain Factor Failure Detection



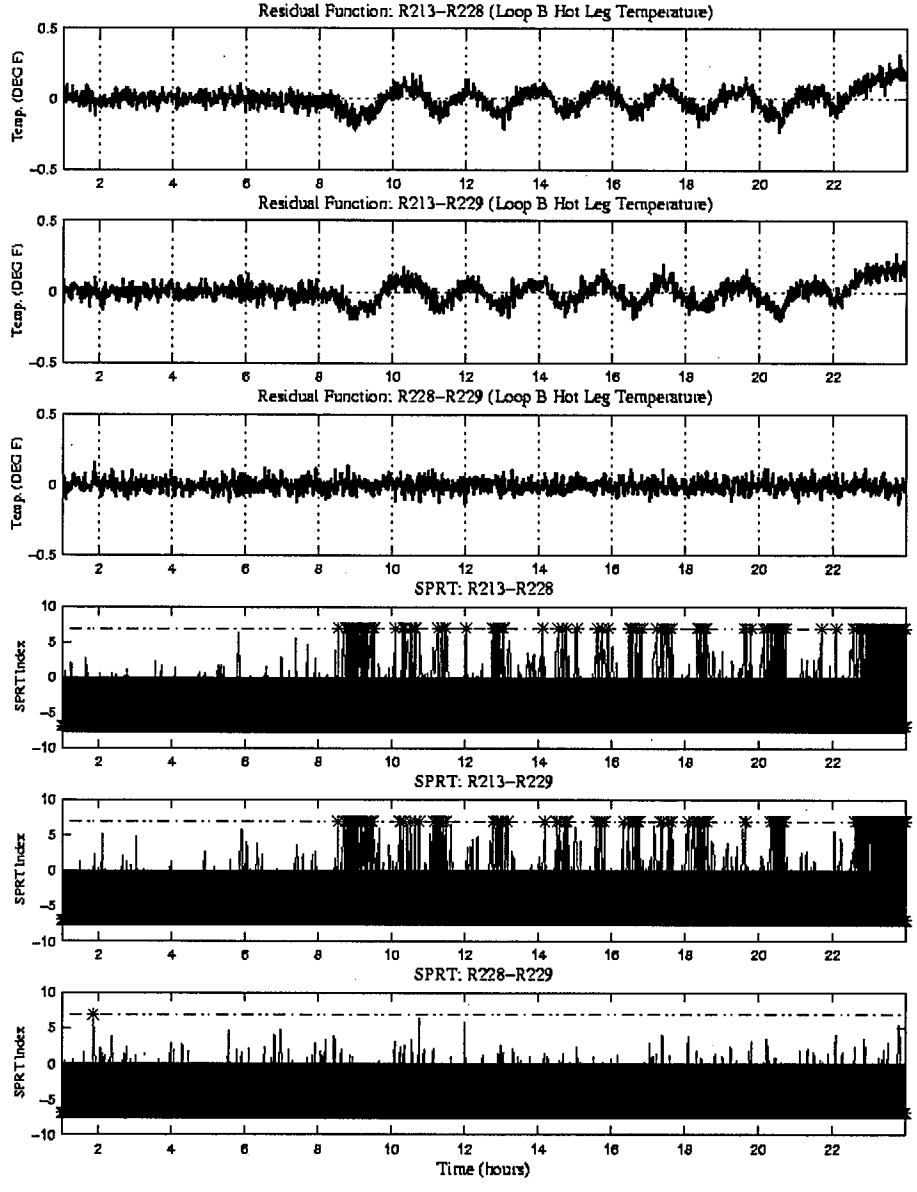
Argonne National Laboratory

Variance SPRT Detects the Gain Factor Failure in R238



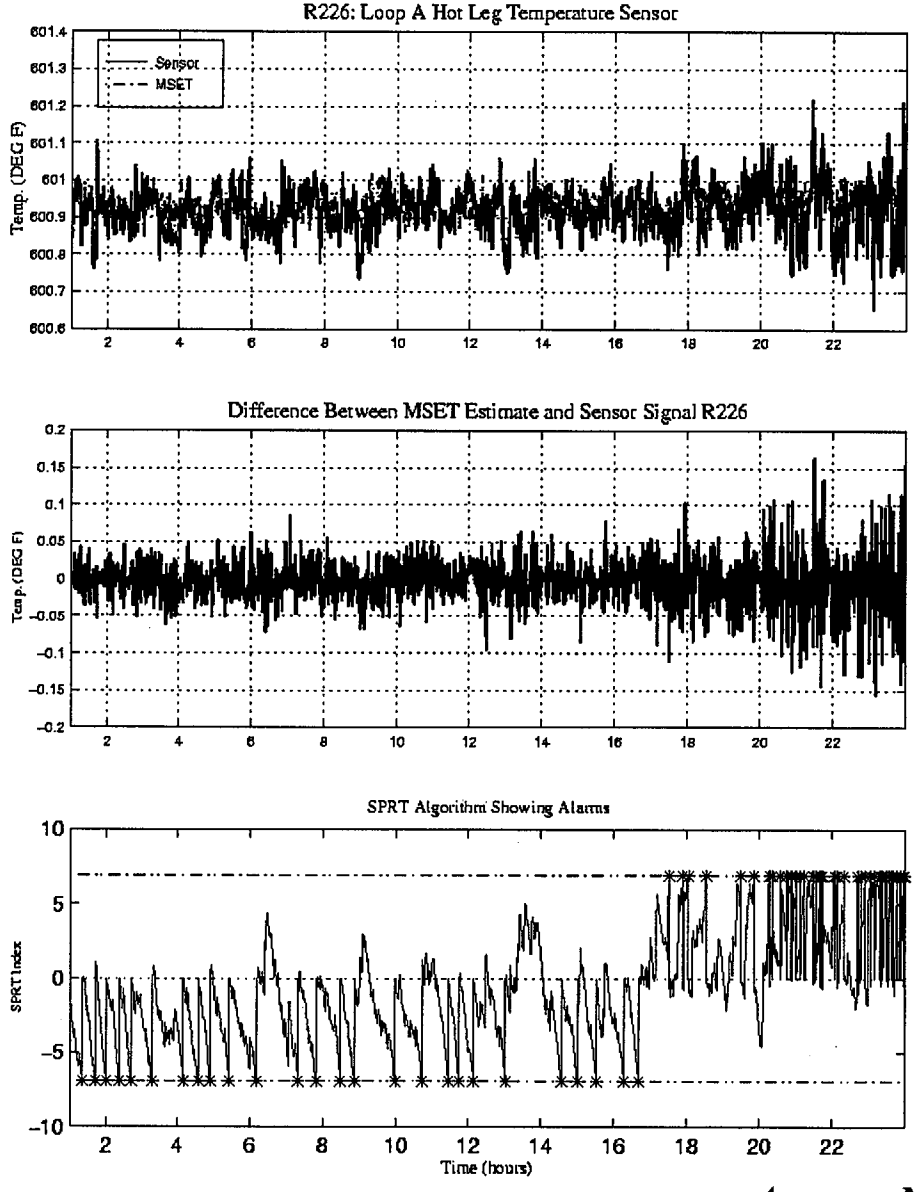
Argonne National Laboratory

SPRT Detects a Sinusoidal Interference in Sensor R213



Argonne National Laboratory

MSET Detects an Increase in Sensor Noise in R226



Argonne National Laboratory

Advantages of MSET for Calibration Reduction in Nuclear Plants

- Training involves a one-step, deterministic computation
- If any plant systems or instrument strings are changed during operating cycle, retraining is trivial
- Robust relative to signal noise, sensor failure modes, and system non-linearity
- Exploits ANL-patented Sequential Probability Ratio Test (SPRT) for ultra-high sensitivity fault detection and avoidance of false alarms
- Amenable to formal propagation-of-uncertainty analysis (unlike Neural Nets)
- Unlike kalman filters, MSET cannot "bootstrap" its way into recognizing slowly degrading signals as normal
- Unlike parity space surveillance, MSET cannot be fooled by common-mode failures
- MSET is the only surveillance scheme with a patented subroutine that automatically accommodates time lags from flow delays between correlated sensors
- Can detect any failure modes including:
  - change of gain failures
  - loss-of-time-response failures (including Rosemont pressure transmitters)
  - degradation that is a small fraction of the noise band (including Venturi flowmeter degradation)

Recent MSET Activities and Contracts

- Beta demonstration contract with Florida Power Corp. installing real-time version of MSET at the Crystal River-3 (CR-3) Plant.
- NASA awarded a $100K grant (1998) and a $500K collaborative grant (1999) to adapt MSET for surveillance of instrumentation on Space Shuttle main launch vehicles.
- Collaborative University/Utility Project (CUUP) with U. of Cincinnati, First Energy (Toledo), and ANL to demonstrate MSET for identifying and correcting anomalous readings by Venturi flowmeters.
- ANL received a DOE Laboratory Directed R&D grant ($150K) in FY 1998 to customize MSET for use with the Safety Parameter Display Systems (SPDSs) for commercial nuclear reactors.
- Private company licensed MSET for energy optimization of co-generation technologies (a nondisclosure agreement signed with the company prevents divulging the name of the company).

Recent MSET Activities and Contracts (Cont'd)

- Startup company, Smart Signal Corp., formed with venture capital to commercialize MSET software to non-utility industries.

- License granted to Illinois Institute of Technology for use in a collaborative IIT/MIT project for commercial aircraft noise abatement, a project jointly funded by AFOSR, NASA, and United Technologies Research Center.

- A formal recommendation was recently made by the Babcock and Wilcox (B&W) Owners Group to adopt MSET technology for inservice inspection functions for B&W-designed nuclear reactors.

- Collaborative contract negotiations between EPRI and ANL to integrate MSET with EPRI's Instrument Calibration Monitoring Program for instrument calibration reduction in nuclear plants (NRC ruling expected Sept. 1999).

Recent MSET Activities and Contracts (Cont'd)

- Real-time version of MSET installed in Lockheed's Integrated Testing and Equipment Laboratory as part of an ANL/Lockheed demonstration project for long-term surveillance of radioactive materials.
- R&D Journal announces MSET won a 1998 R&D-100 Award as one of the top 100 technological inventions in the world.
- ANL received $40k R&D grant (2/99) to work with geneticists at the U.. of Chicago to customize MSET's pattern recognition capabilities for genetic linkage scans.
- Pacific Northwest National Laboratory and ANL signed Inter-Laboratory Agreement (5/99) to integrate MSET with Decision Support for Operations & Maintenance (DSOM) system used in steam plants at military bases.
- General Dynamics contracts with ANL (7/99) to adapt MSET for online Condition Based Maintenance of shipboard weapons and propulsion systems on Navy destroyers.
- TVA VP authorizes MSET to be installed on five TVA fossil plants (7/99).

Recent MSET Activities and Contracts (Cont'd)

- Contract signed (8/99) to customize a version of MSET for online surveillance of centrifugal charging pumps for Tennessee Valley Authority nuclear plants.
- Contract signed (8/99) to adapt MSET for Plant Rad Monitors at Watts Bar nuclear power plant.
- SCE&G VP signed a contract (8/99) with ANL for an MSET demonstration at the V.C. Summer PWR for a variety of instrumentation surveillance applications.
- Beta demonstration contract signed with Lockheed Martin Tactical Aircraft Systems Div for use with USAF Joint Strikeforce Initiative. (8/99)
- Contract signed to adapt MSET for calibration reduction of nuclear plant instrumentation for TVA's Sequoyah plant. (8/99)
- Contract signed to customize MSET for online surveillance of Reactor Coolant Pumps for Browns Ferry nuclear power plant.

SUMMARY AND CONCLUSIONS

- A state-estimation technique based upon methods of artificial intelligence has been developed and applied for ultra-reliable surveillance of plant instrumentation

- MSET has the following attributes
  - data-based
  - operates in real-time on low-cost notebook PCs (C-code modules portable to any architecture)
  - trained to recognize normal behavior
  - is robust relative to signal noise, failure types and system non-linearity's
  - generates synthetic signals for faulted sensor replacement
  - can be applied to any system that has sensors

On-Line Monitoring for Determining When to Calibrate Instrument Channels in Nuclear Power Plants

A Review of NRC's Research

Presented By

H.M. Hashemian

Analysis and Measurement Services Corporation

AMS 9111 Cross Park Drive, Bldg. A-100

Knoxville, Tennessee 37923 USA

Phone: 865-691-1756

Fax: 865-691-9344

Email: hash@ams-corp.com

Presented At

NRC

Rockville, Maryland

February 16, 2000

On-Line Monitoring for Determining When to Calibrate Instrument Channels in Nuclear Power Plants

A Review of the NRC's Research

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[redacted]

History of NRC Research
(1991-1995)

- Phase I (1991-1992)
- Phase II (1992-1995)

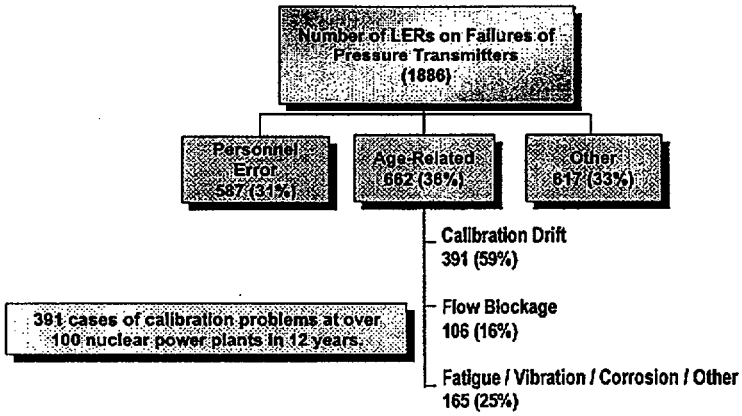
[redacted]

NRC Research Publications

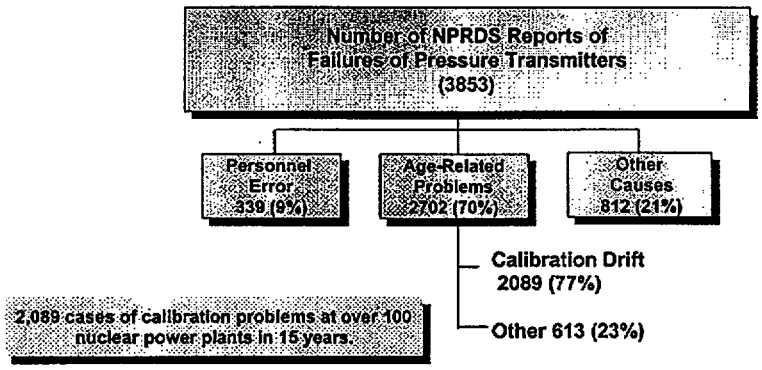
- **NUREG/CR 5903**
  "Validation of Smart Sensor Technologies for Instrument Calibration Reduction in Nuclear Power Plants," January 1993.

- **NUREG/CR 6343**
  "On-Line Testing of Calibration of Process Instrumentation Channels in Nuclear Power Plants," November 1995.

Search of LER Database
(1980-1992)



Search of NPRDS Database
(1974-1989)



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Traditional Calibration vs. On-Line Calibration Monitoring

Traditional Calibration

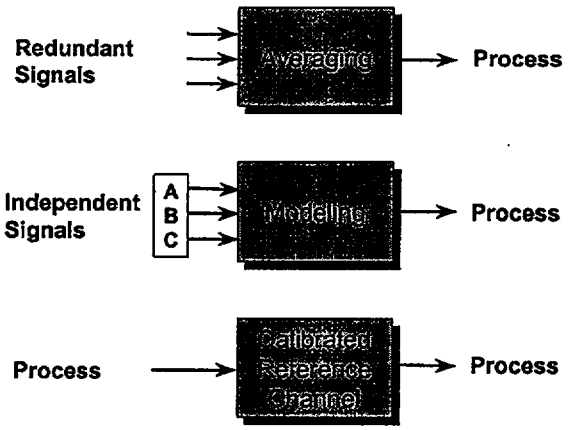
1. Determine if calibration is needed
2. Calibrate if needed

On-Line Monitoring

Same as above except Step1 is determined by on-line monitoring.

[redacted]

Reference for Drift



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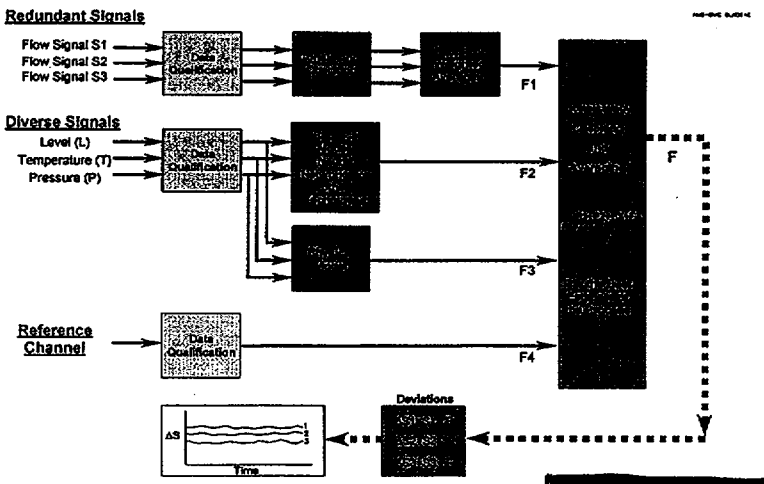
Integrated System



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AMS Approach

Use All Available Techniques

- Single and Weighted Averaging
- Empirical Modeling
- Physical Modeling
- Neural Networks
- MSET (multivariate state estimation technique)
- PEANO (fuzzy classifications and neural networks)
- Calibrated Reference

[redacted]

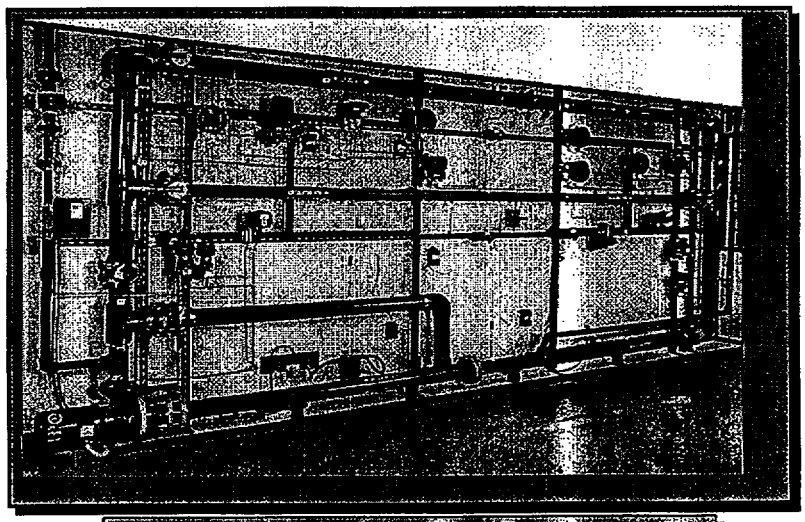
Technology Validation

- Laboratory Validation
- In-plant Validation

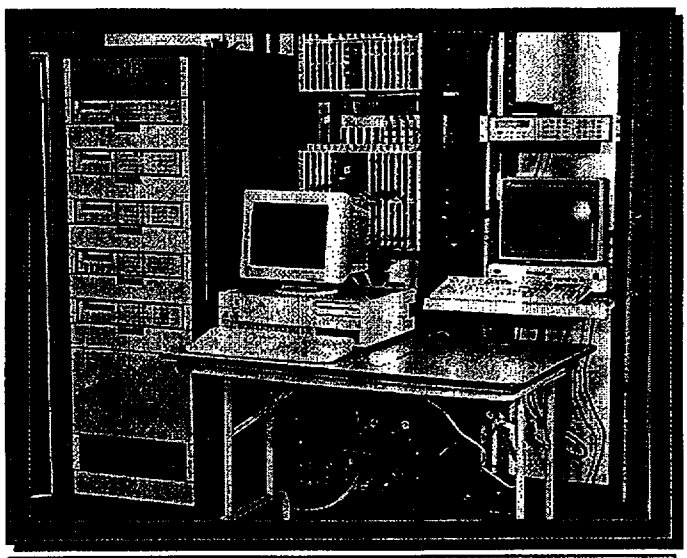
[redacted]

AMS Laboratory Loop for Technology Validation

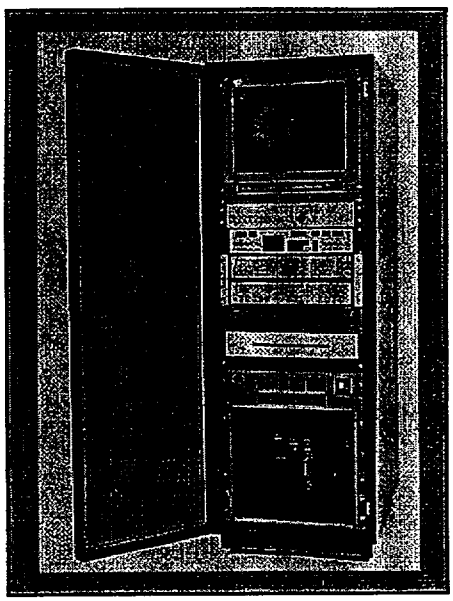
- **500 GPM pump**
- **50,000 BTU heat exchanger**
- **50 sensor signals**
  - RTDs / Thermocouples
  - Flow transmitters
  - Pressure transmitters
  - Smart sensors
- **Nuclear-grade signal processing racks**



Laboratory Test Loop for Research and Development



Test Setup for Development of Calibration Reduction Equipment

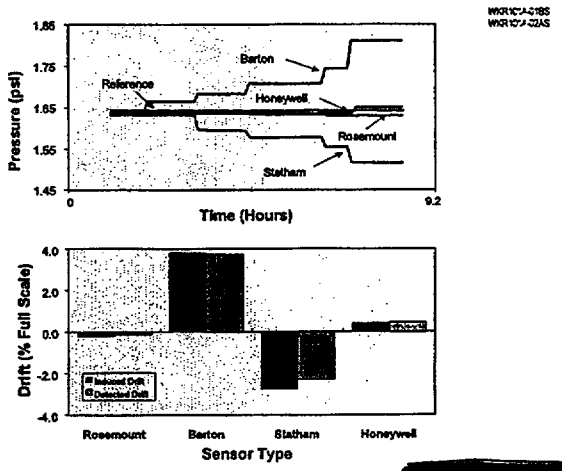


Calibration Reduction System

(Old Model)

[redacted]

Laboratory Validation Results



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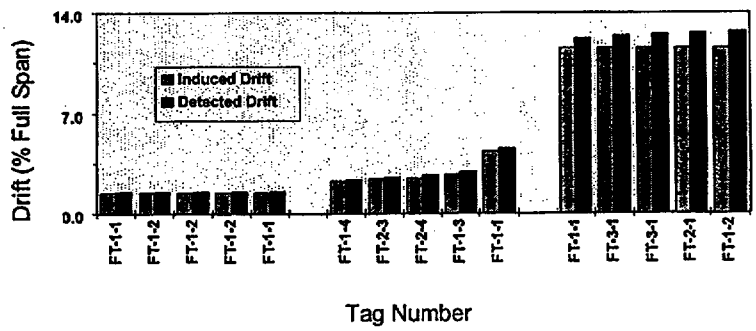
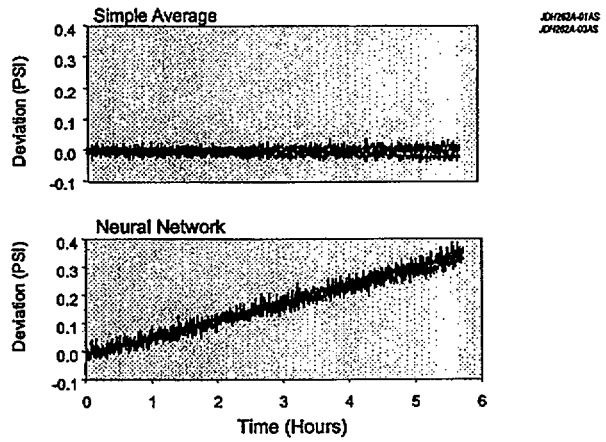
Software Validation Results



[redacted]

Results When All Four Channels Drift



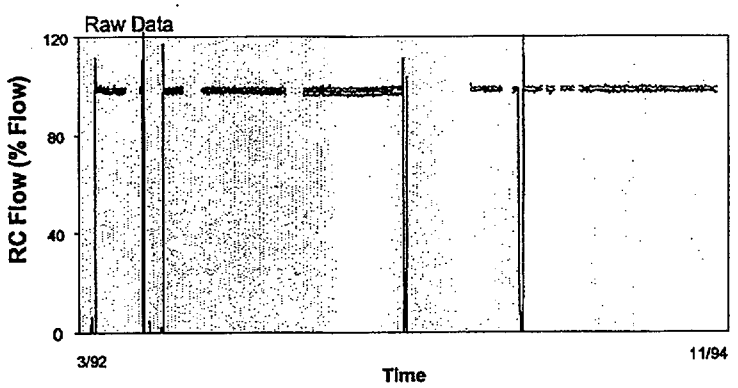
[redacted]

In-Plant Validation at McGuire Unit 2

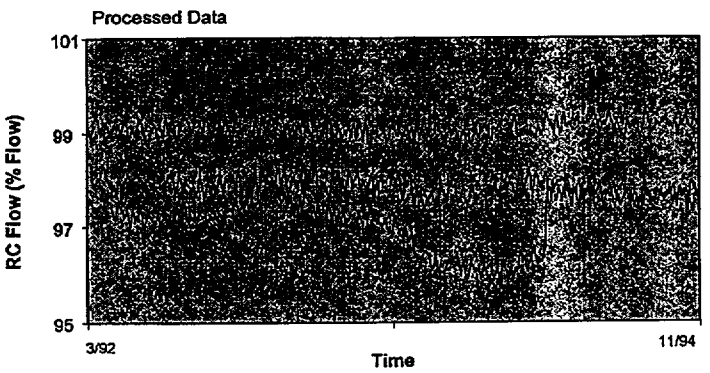
- McGuire is a four-loop Westinghouse PWR
- On-line monitoring was performed for three years; two fuel cycles
- 170 signals were monitored

[redacted]

Raw Data

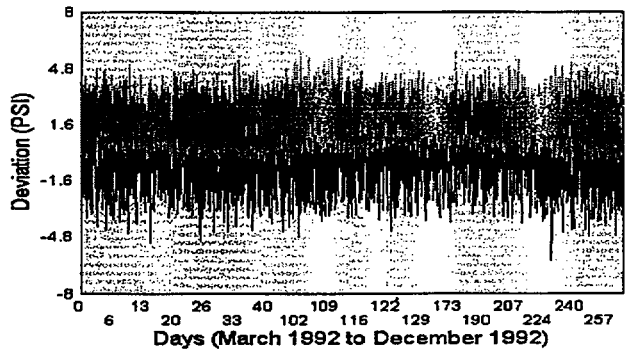


Processed Data



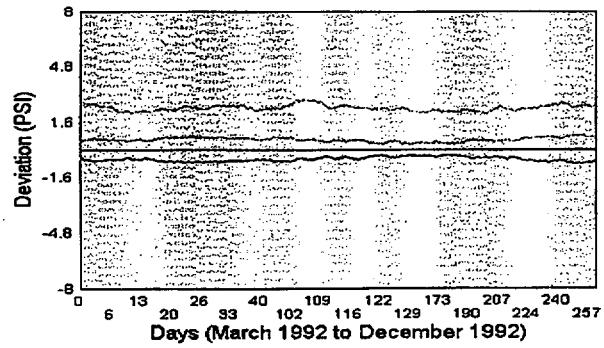
[redacted]

Data With Noise



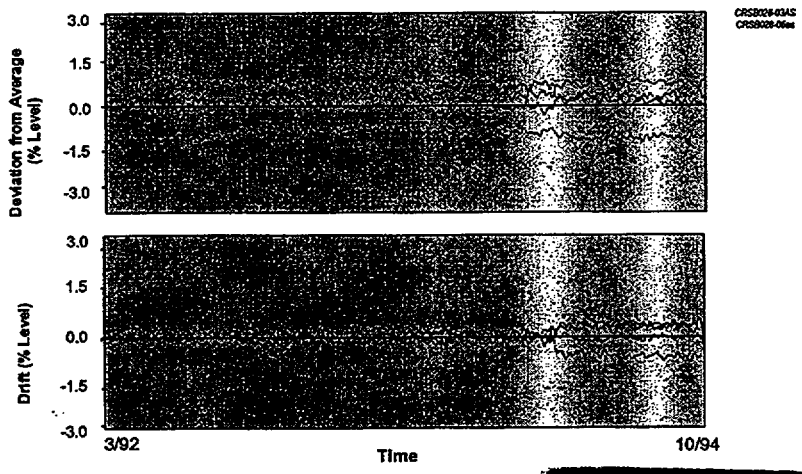
[redacted]

Filtered Data



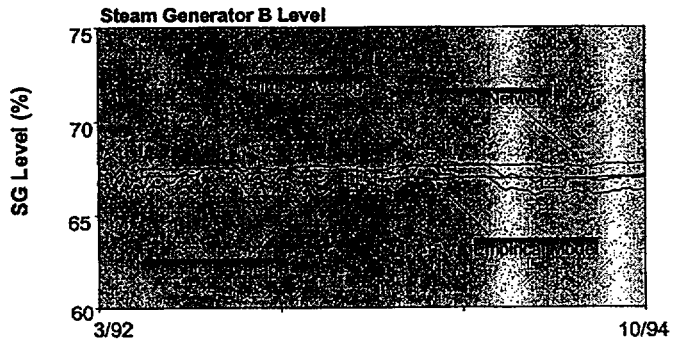
[redacted]

SG D Level Data From McGuire



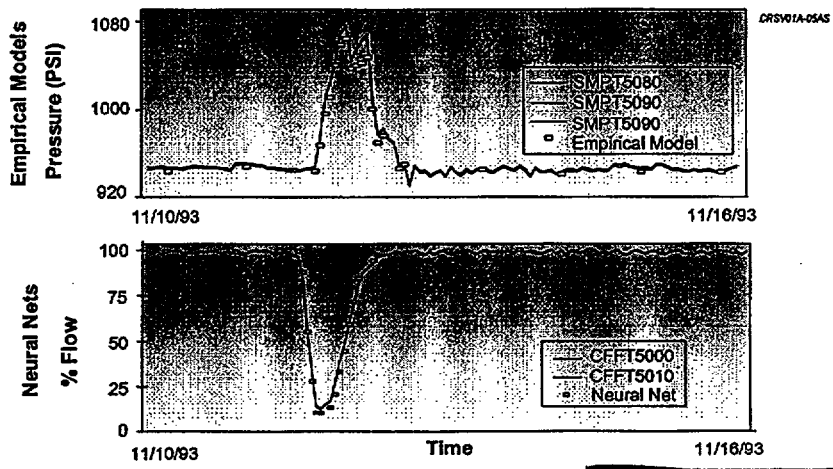
[redacted]

Comparison of Process Estimation Results



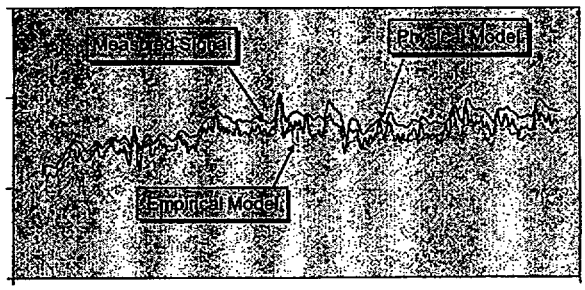
[redacted]

Model Validation Under Transient Conditions



[redacted]

Physical Modeling Results



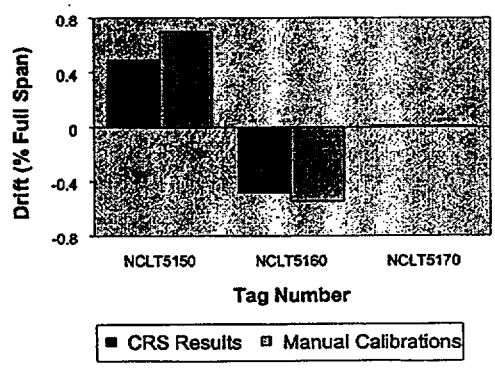
[redacted]

Interpretation of In-Plant Validation Results

- Compare with Manual Calibrations
- Plot within Allowable Drift Band

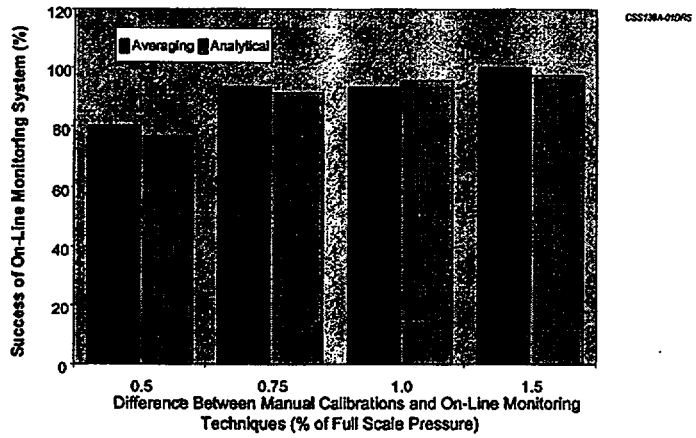
[redacted]

Comparison of On-line Monitoring Results with Manual Calibration Results



[redacted]

Difference Between Manual Calibration and On-Line Monitoring Results for McGuire Instrument Channels



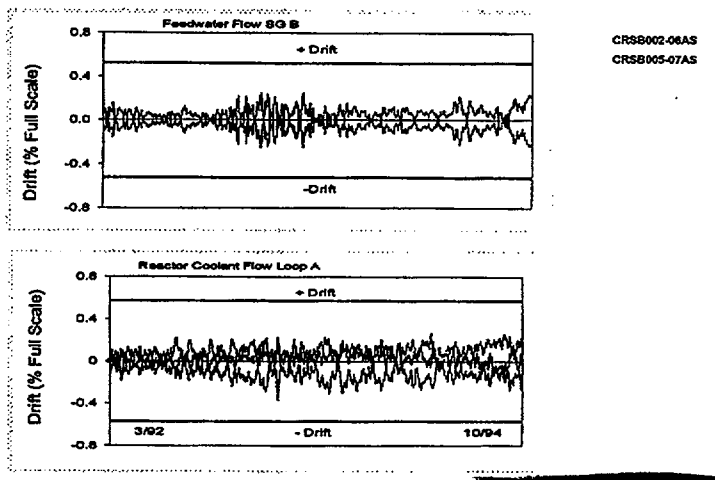
[redacted]

Example of Allowable Drift Bands (% of Span) for McGuire Instrument Channels

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
PZR Level	[illegible]
PZR Pressure	[illegible]
VR Pressure	0.91
CONTMT Pressure	0.94
STM Pressure	1.53
Turbine Impulse	0.59

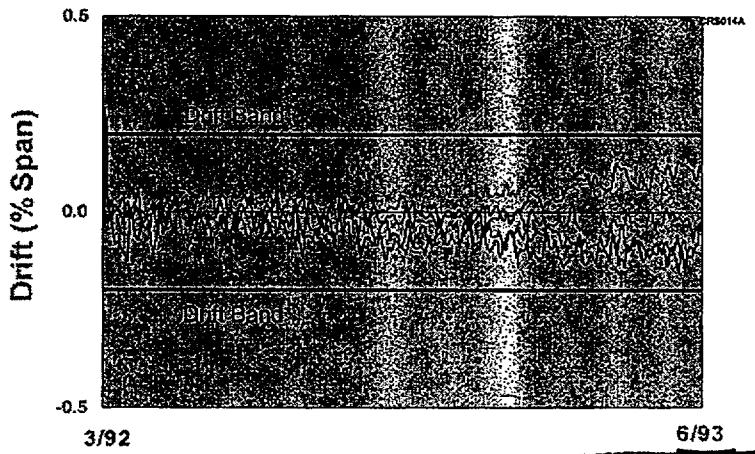
[redacted]

On-Line Monitoring Results for Pressure Transmitters



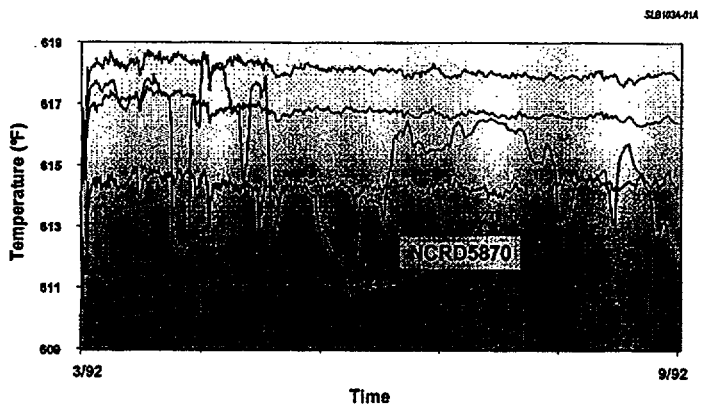
[redacted]

On-Line Monitoring Results for Core Exit Thermocouples



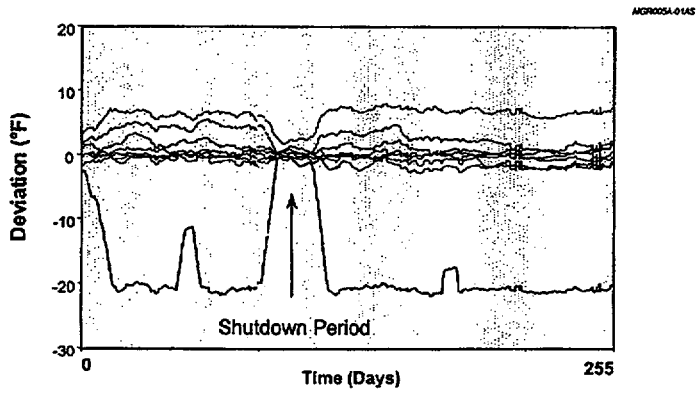
[redacted]

Erratic RTD Detected
(Hot Leg Loop D)



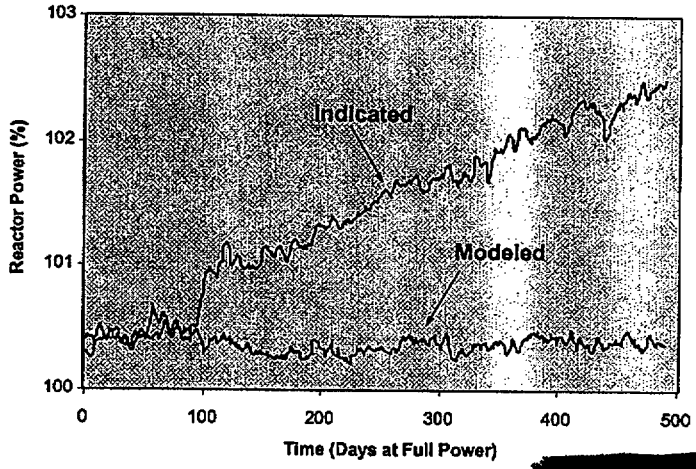
[redacted]

On-Line Monitoring Data Showing a Bad Thermocouple



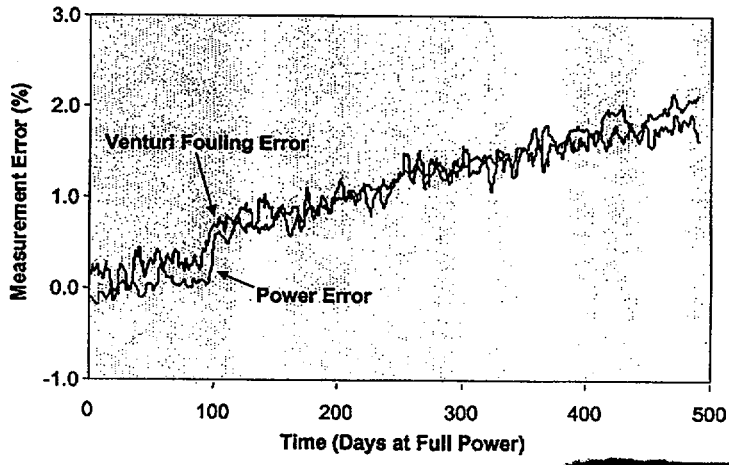
[redacted]

Test Results Showing Venturi Fouling in a PWR Plant



[redacted]

Feed Flow Error from Venturi Fouling and Corresponding Error in Reactor Power



[redacted]

Conclusion

- Sample outputs of isolated plant signals
- Remove noise/spike/discontinuities
- Obtain a best estimate of the process
- Plot deviation/drift data
- Evaluate results and determine which channels must be manually calibrated

[redacted]

End of Presentation

[redacted]