



FPL Energy
Seabrook Station

*Completed
5/5/06*

*Strap-ons are used for power recovery - 740 applications
get claimed w 1% uncertainty*



Ref 2

*Follow up on this
sometime*

MEASUREMENT UNCERTAINTY RECAPTURE FPLE/CALDON® - NRC MEETING

December 16, 2005

Steve Hale
Herb Estrada
Ernie Hauser

A-822

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Proposed Agenda



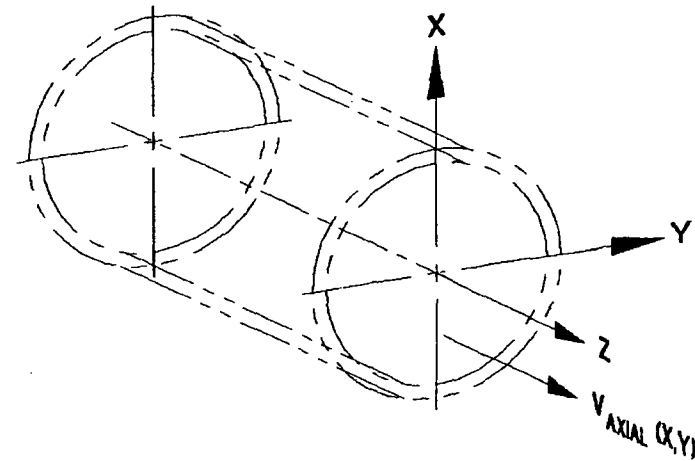
Introductory Remarks – NRC, FPL Energy, Caldon
Principles of Operation; the LEFM CheckPlus™ System
Discussion, Topical Areas of Concern
(will follow the outline of the attachment to the meeting notice)
 Laboratory Testing – Caldon*
 Plant Installation - Caldon, FPL Energy
 UFM Operation – FPL Energy, Caldon
Conclusions; Action Items



LEFM Principles



The volumetric flow in a pipe is given by the integral of the axial velocity over the cross sectional area of the pipe



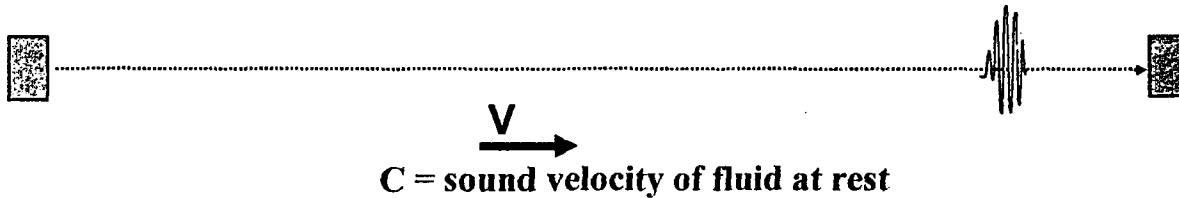
$$Q = \int_{\text{axial}}^{\text{pipe area}} V(x, y) dx dy$$



LEFM Principles



What the elapsed times of transiting pulses measure



$$t_{\text{down}} = L_{\text{path}} / (C + V)$$

$$t_{\text{up}} = L_{\text{path}} / (C - V)$$

$$\Delta t = t_{\text{up}} - t_{\text{down}} = 2 L_{\text{path}} V / (C^2 - V^2)$$

$$t_{\text{up}} t_{\text{down}} = L_{\text{path}}^2 / (C^2 - V^2)$$

$$V = (1/2) \Delta t (L_{\text{path}} / t_{\text{up}} t_{\text{down}})$$

$$L_{\text{path}} V = (1/2) \Delta t (L_{\text{path}}^2 / t_{\text{up}} t_{\text{down}})$$

$$C = L / [t_{\text{up}}/2 + t_{\text{down}}/2]$$

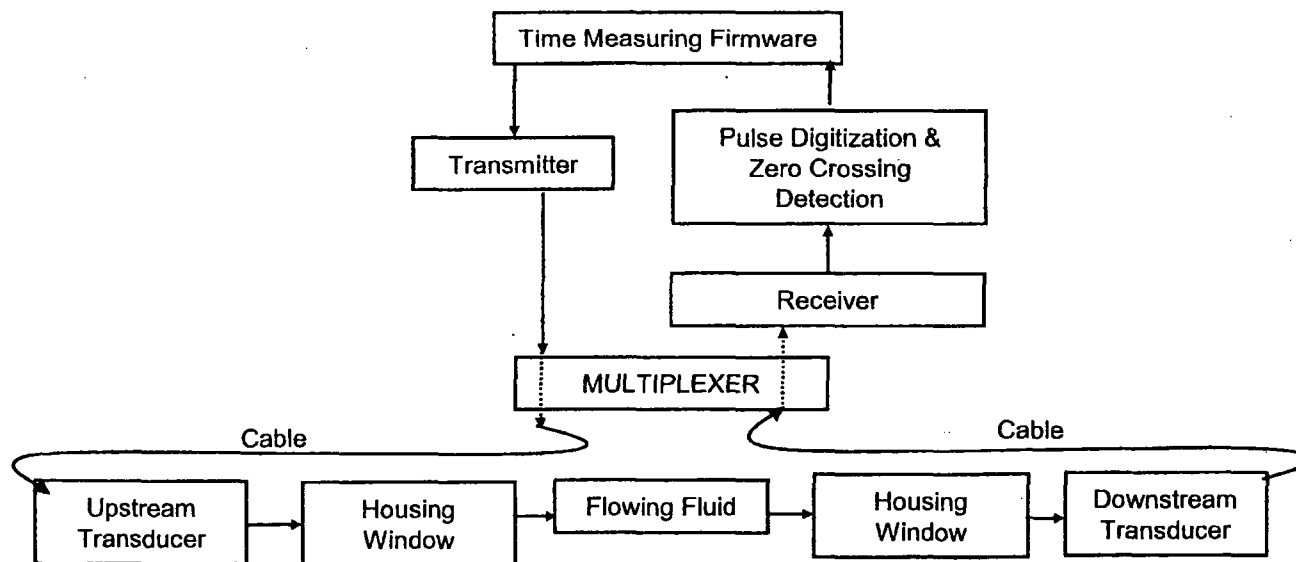
For further study, TP-44 (*Reference Tab 4 of INFO-19*)



LEFM Principles

The UFM measures the transit times of ultrasonic pulses traveling in each direction along each acoustic path and uses these data to determine the average fluid velocity and the average sound velocity along each chord. But the time measured includes more than the transit time through the fluid.

$$t_{\text{measured}} = t_{\text{elec}} + t_{\text{transducers}} + t_{\text{cable}} + t_{\text{fluid}} + t_{\text{detection}}$$





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*Discuss how variations
are addressed:*

LEFM Principles

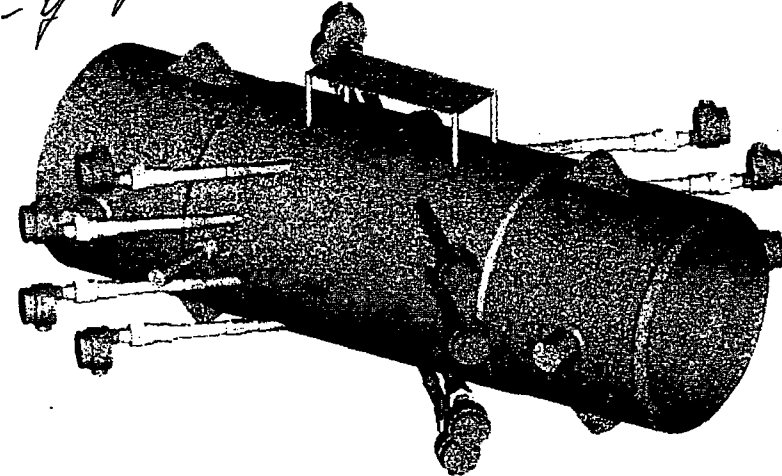
*test-to-plant
during operation
transducer rep*



An 8-path chordal LEFM—
the LEFM CheckPlus used for
MUR uprates

*What about
out-of-plane behavior.*

In the 8 path configuration,
transverse velocity components
exactly cancel ?



The 4 path LEFM Check can be
affected by transverse velocity
but its sensitivity is low (~ 0.2%)
in most hydraulic locations

Discuss



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LEFM Principles



Ultrasonic pulses are generated and detected in an electronics unit, which also processes the transit time measurements and performs the mass flow and temperature calculations



Seabrook Electronics Unit shown



LEFM Principles



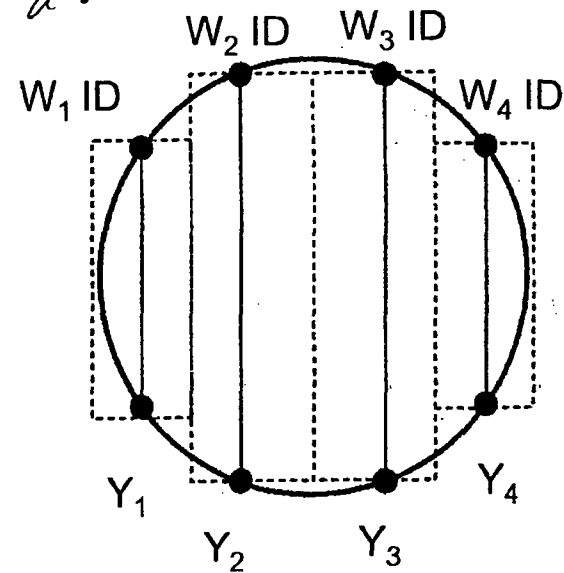
Chordal LEFMs determine volumetric flow by numerically integrating the axial velocity at 4 pre-selected chordal locations

The LEFM measures the integral of $V_{axial}(x) dx$ at each location.

The volumetric flow is determined by summing the flow contribution of the four segments. Each contribution is calculated as the product of the width of the segment, ($w_i * ID$), and the Vdx integral for that segment.

The low sensitivity of the result to axial velocity profile has been determined by analysis and by 100s of hydraulic tests in a wide range of configurations.

Append. Provide Data



*See KR 486
Tab 2*



LEFM Principles



The chordal LEFM Mass Flow Algorithm:

TR 44 on Web Site provides derivation. Glenn Miller was given a copy of info - Section IV

$$W_f = \rho * PF * F_{a3} (T) * (ID/2) \sum_{i=1}^4 \frac{w_i L_{ff}^2 (\Delta t_i)}{\tan(\phi_i)(t_i + \Delta t_i / 2 - \tau_i)^2}$$

$\rho = f(T, p)$ — *I'm not sure \underline{w} assigns an uncertainty to steam tables. Check this.*

$T = f_T(C_{mean}, p)$

$$C_{mean} = F_{al} (T) \sum_{i=1}^4 [w_i L_{ff}] / [t_i + (\Delta t_i / 2) - \tau_i]$$

Uncertainties

Property functions and pressure measurement, Dimensions, Hydraulics (axial profile), Time Measurements



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LEFM Principles

Representative Mass Flow Uncertainties for LEFM CheckPlus



TOTAL POWER UNCERTAINTY DETERMINATION

Parameter ⁽¹⁾		ER-157P Uncertainty	Seabrook Station Uncertainty
1.	Hydraulics: Profile factor	0.25%	0.20%
2.	Geometry: Spool dimensions, alignment, thermal expansion	0.09%	0.10%
3.	Time Measurements: Transit times and non fluid time delay	0.045%	0.07% ⁽⁶⁾
4.	Feedwater Density: ⁽²⁾ LEFM temperature determination, pressure input, and correlation ⁽⁵⁾	0.07%	0.07%
5.	Subtotal: Mass flow uncertainty (Root sum square of items 1, 2, 3, and 4 above)	0.28%	0.24%
6.	Feedwater Enthalpy: ⁽³⁾ LEFM temperature determination, pressure input, and correlation ⁽⁵⁾	0.08%	0.08%
7.	Steam Enthalpy: Pressure input and moisture uncertainty	0.07%	0.08%
8.	Other Gains and Losses	0.07%	0.03%
9.	Total Power Determination Uncertainty	0.33% ⁽⁴⁾	0.30%

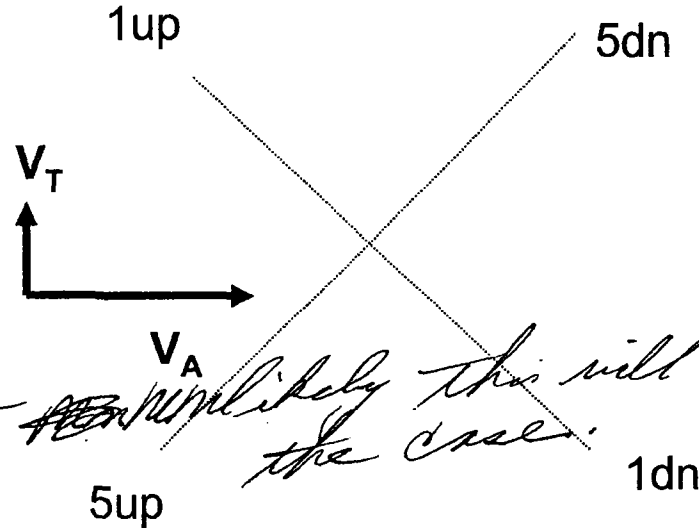
*Notes for Table are included in handout



LEFM Principles



In an 8 path meter, transverse velocity vectors projections are essentially equal and opposite on paired acoustic paths



In a 4 path meter transverse projections due to swirl cancel if the swirl is centered. Projections of "Goertler" vortices (from a single bend) also tend to cancel when summed.

Probably this will be the case.

*ER ADP app 7 -
addresser orienting instr
to flow path (bends etc)
see 1979 Rpt by W. that
is included*



LEFM Principles



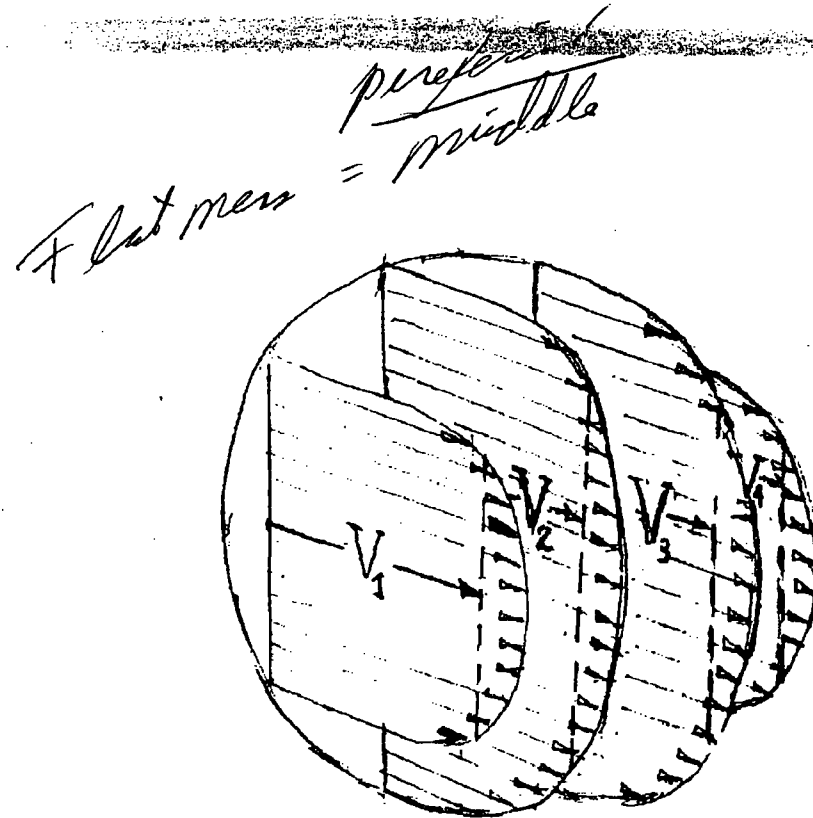
Chordal LEFMs measure the axial velocity profile, characterizing it by its Flatness, the ratio of the outer path average velocity to the inner path average velocity

For a 4 Path LEFM

$$F = \frac{(V1 + V4)}{(V2 + V3)}$$

For an 8 path LEFM

$$F = \frac{(V1+V4+V5+V8)}{(V2+V3+V6+V7)}$$





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LEFM Principles



Axial profiles in nuclear feedwater systems can vary widely

Inertial effects dominate

Wall roughness can be an important factor

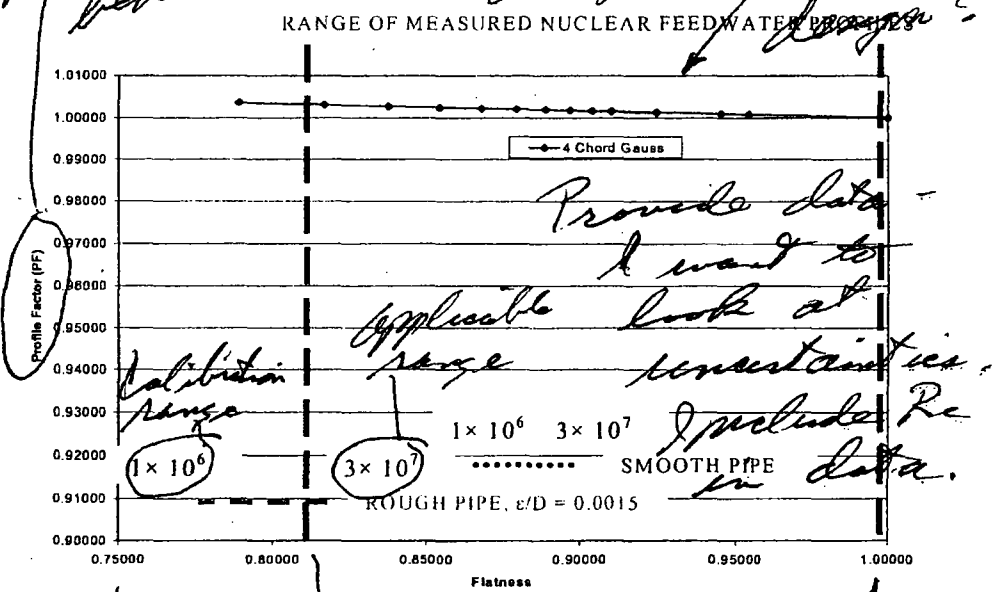
Reynolds Number is a relatively small and inconclusive factor

BUT

When the chordal paths are located in accordance with the rules of Gaussian quadrature numerical integration, the calibration of a 4 path chordal meter is not very sensitive to axial profile. The graph plots the Profile Factor against flatness, over the range of profiles seen in nuclear feedwater systems

Is this the correction factor for flow rate? Discuss. Indicated vs actual flow rate?

depend on this and discuss behavior. What about long-term change? Which design?



Provide data - I want to applicable look at

Re ≈ 10^4

0.83 (rough pipe)

- 1.001 (in Read Pattern) Re big

showing dish profile down stream of perturbation)



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LEFM Principles



Sensitivity to swirl and other factors

Because transverse velocities cancel in an 8 path chordal LEFM, swirl and other vortices do not affect calibration significantly, except as they affect axial profile

Provide data

Experience has shown that the 4 path system integrates moderately asymmetric axial profiles within ~0.1%

#



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LEFM Principles

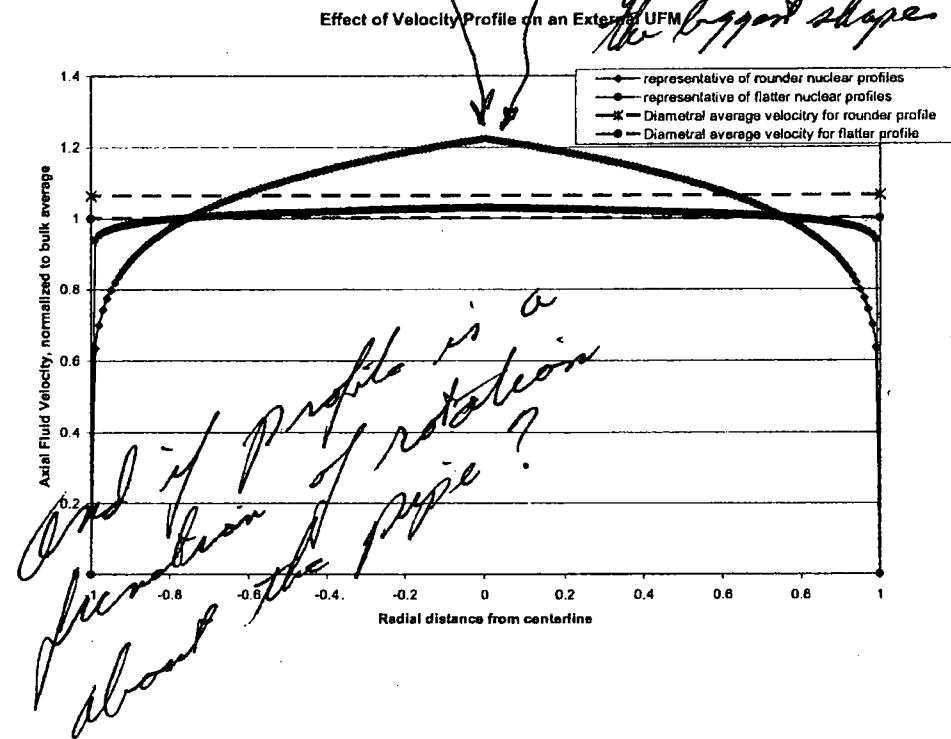
In contrast, an external UFM is constrained to measure a velocity along a diametral path

An externally mounted transit time meter measures the diametral average axial velocity

The relationship between diametral average axial velocity and cross-sectional average axial velocity is sensitive to profile shape

How was this determined? The uncertainty doesn't make sense.

Surquahanna about the biggest slope.





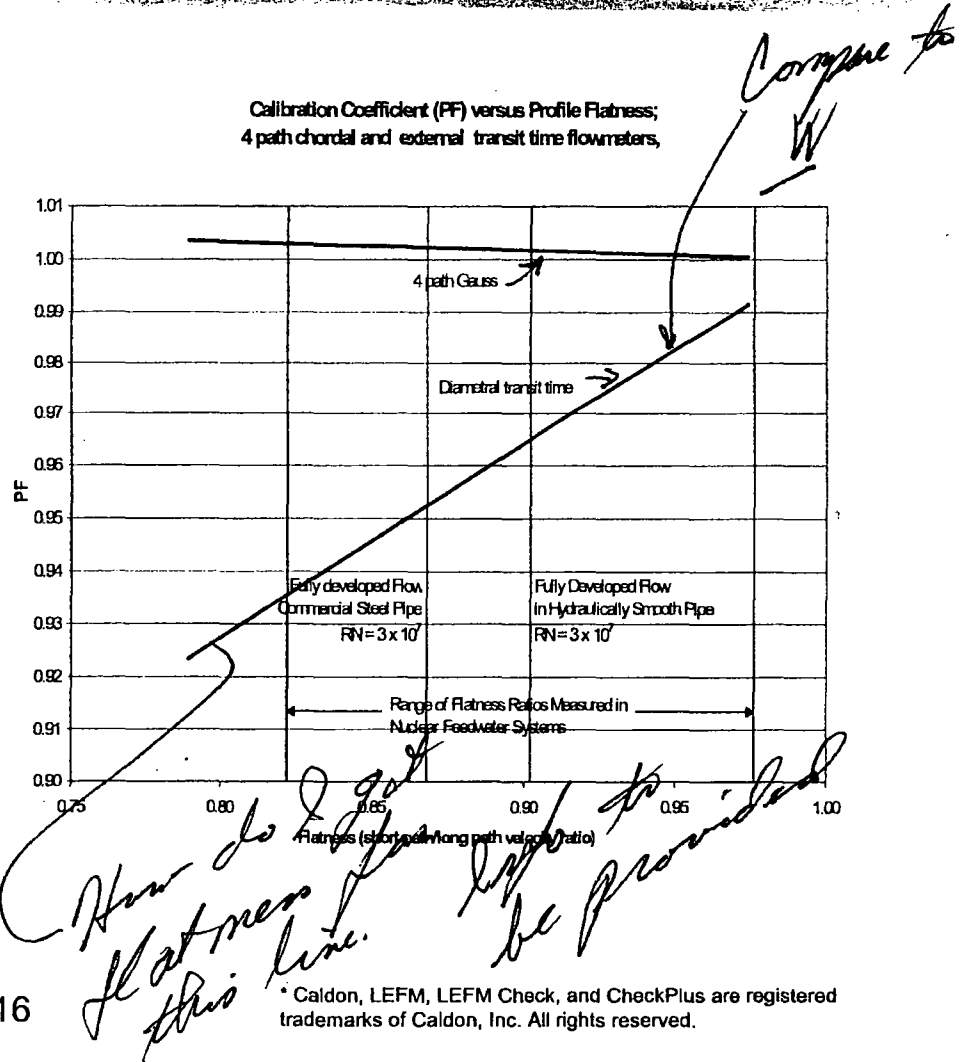
LEFM Principles



The relative sensitivities of chordal and external UFM's to axial velocity profile are shown in the graph on the right

*External 9 Permanent
Flows 2 Single cycle*

Over 70 units in pipes





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1. Laboratory Testing

The tests calibrate the flow element for a spectrum of hydraulic conditions; they establish the Profile Factor, PF, as a function of Flatness and also form the basis for the uncertainty in the Profile Factor

Test Plan ALD-1081 Rev. 1 (*Reference Tab 5 of INFO 18*)

Purpose,

ARL and Caldon Responsibilities,

Prerequisites,

Tests, and

Documentation

Scheduled for January 16-20, 2006



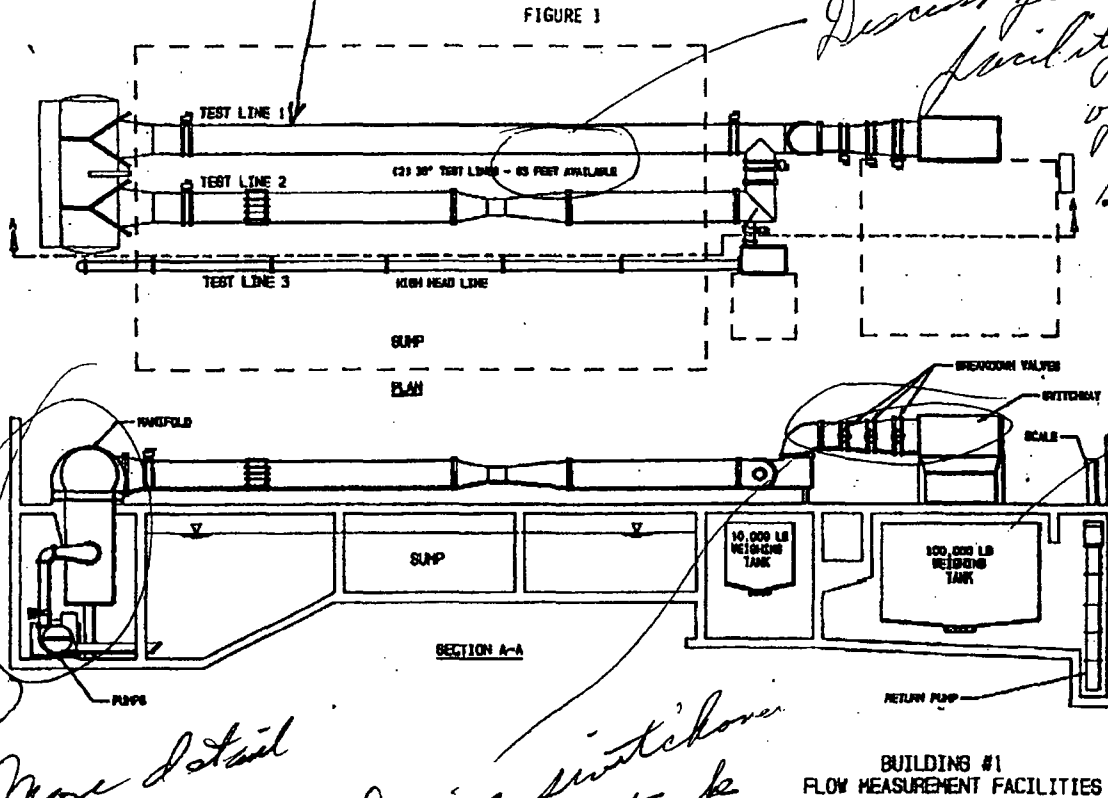
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*What are materials?
pipe materials? Effect
of test to plant?*

1. Laboratory Testing

The Alden Research Lab Facility



Discuss flow profile in facility as a function of distance. Include swirl, measurements, calcs (later CFD, more sophisticated if done)

What do data look like as $f(t)$? Provide representative data. Summarize uncertainty.

Provide More detail

Discuss switchover to weigh tanks

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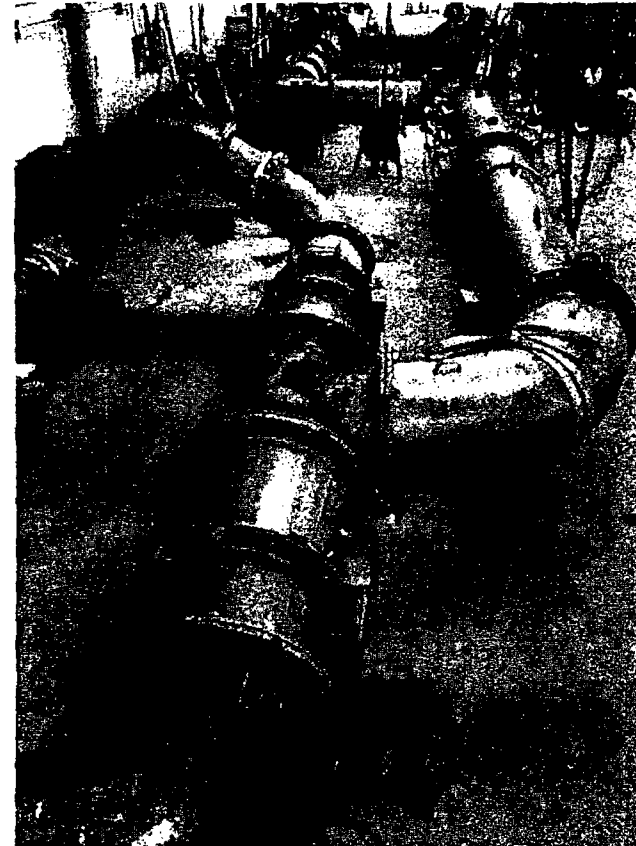
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1. Laboratory Testing



Full scale model testing of the
Beaver Valley 2 flow element

*Discuss effect of
noise, pipe vibration.
Any noise from pumps
at test location?*





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1.1 Laboratory Testing

The Main Feedwater system at Seabrook (*PID-1-FW-B20687*)
Feedwater pumps to the four feeds to the steam generators
P&ID and Isometric Drawings are included in the handout



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1.1 Laboratory Testing

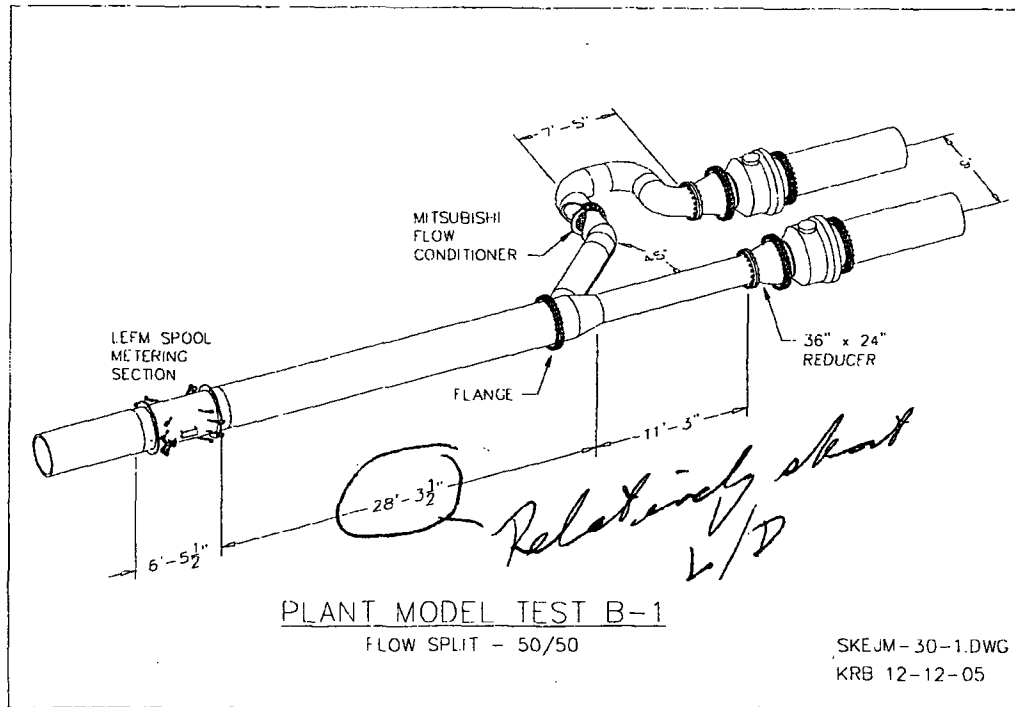
A description of the test configurations



Test B-1 Reference configuration

50-50 Flow split

25 weigh tank runs; 5 flow rates over a ~4:1 range of flows



Look at plant config



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Laboratory Testing

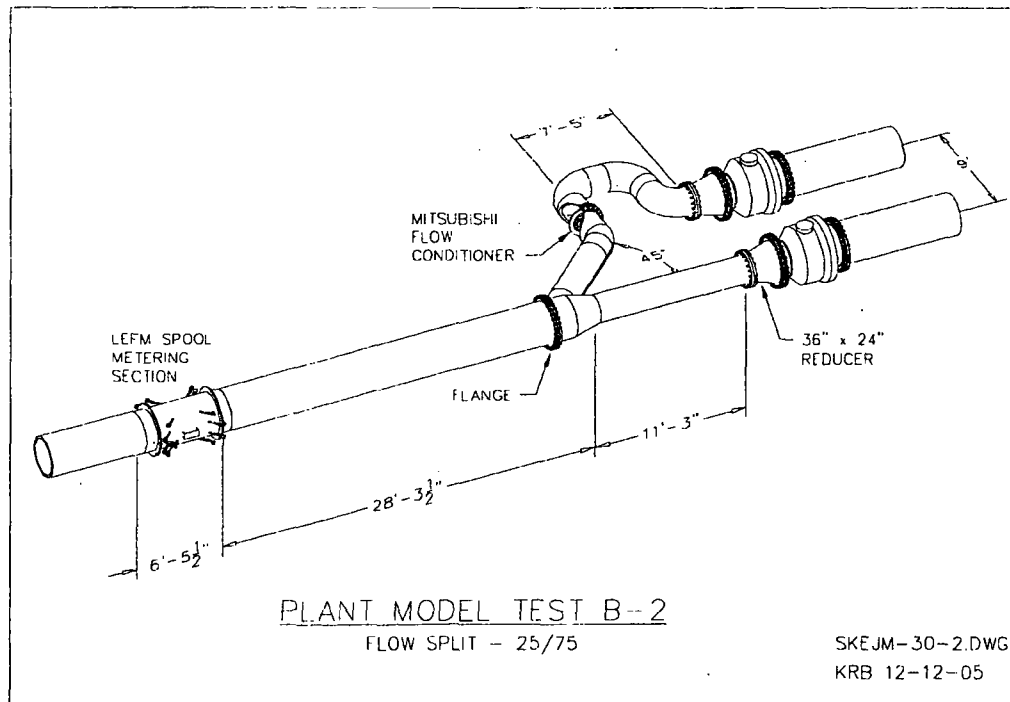
A description of the test configurations



Test B-2 Minimum branch flow

25-75 Flow split

15 weigh tank runs; 3 flow rates over a ~2.5:1 range of flows





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1.1 Laboratory Testing

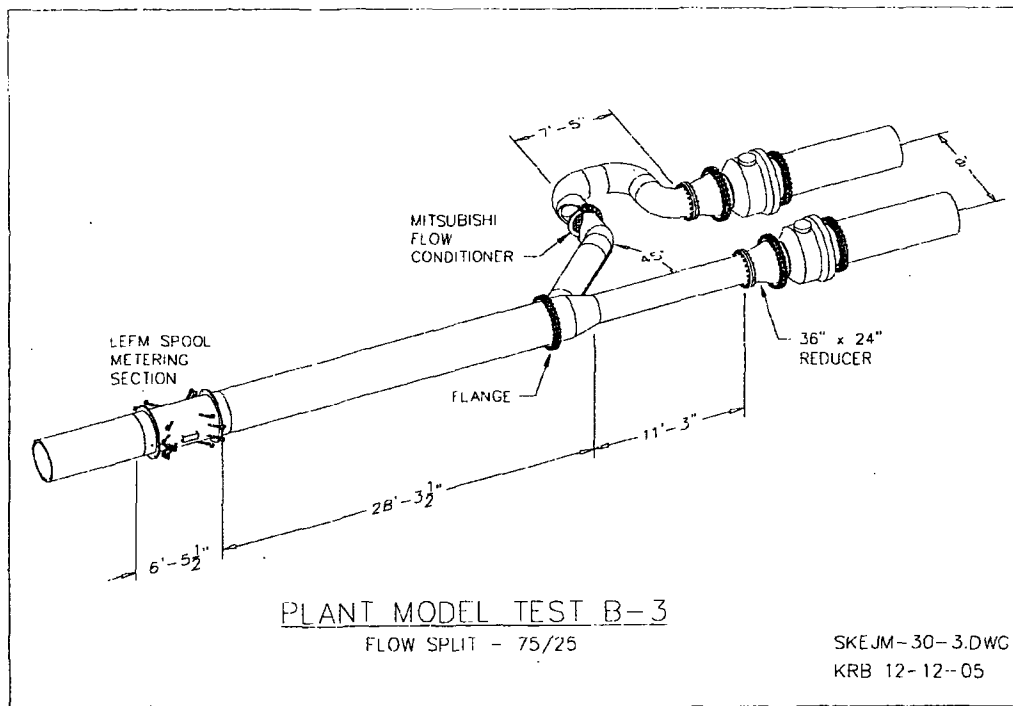
A description of the test configurations



Test B-3 Maximum branch flow

75-25 Flow split

15 weigh tank runs; 3 flows over a ~2.5:1 range of flows





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1.1 Laboratory Testing

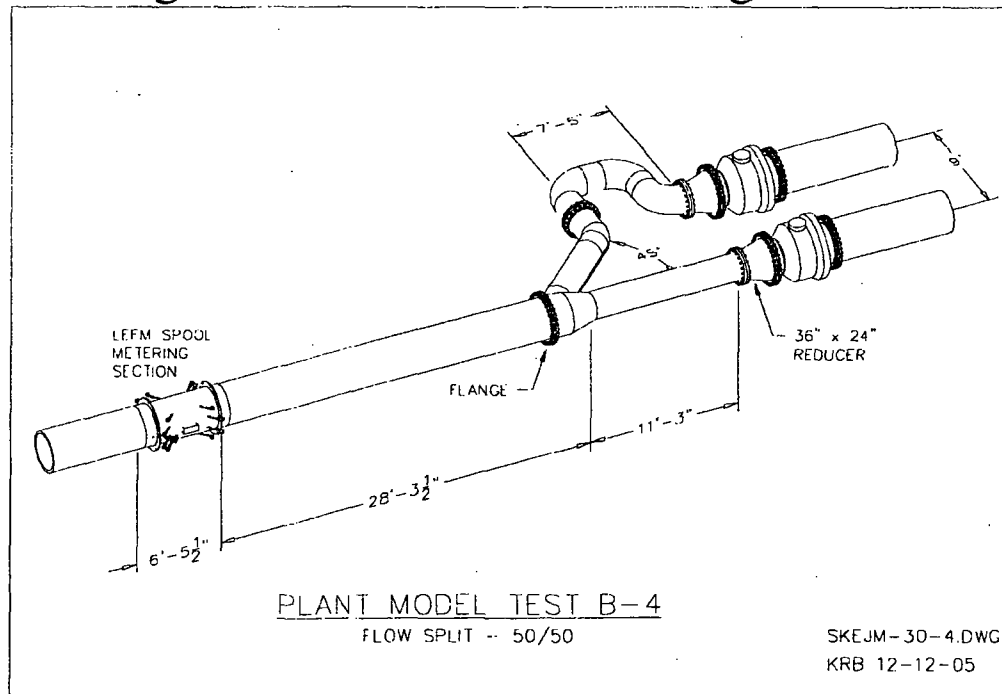
A description of the test configurations



Test B-4, Upstream Profile Sensitivity
Remove Flow Conditioner upstream of Branch

50-50 Flow split

25 weigh tank runs over a ~4:1 range of flows





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1.1 Laboratory Testing

A description of the test configurations

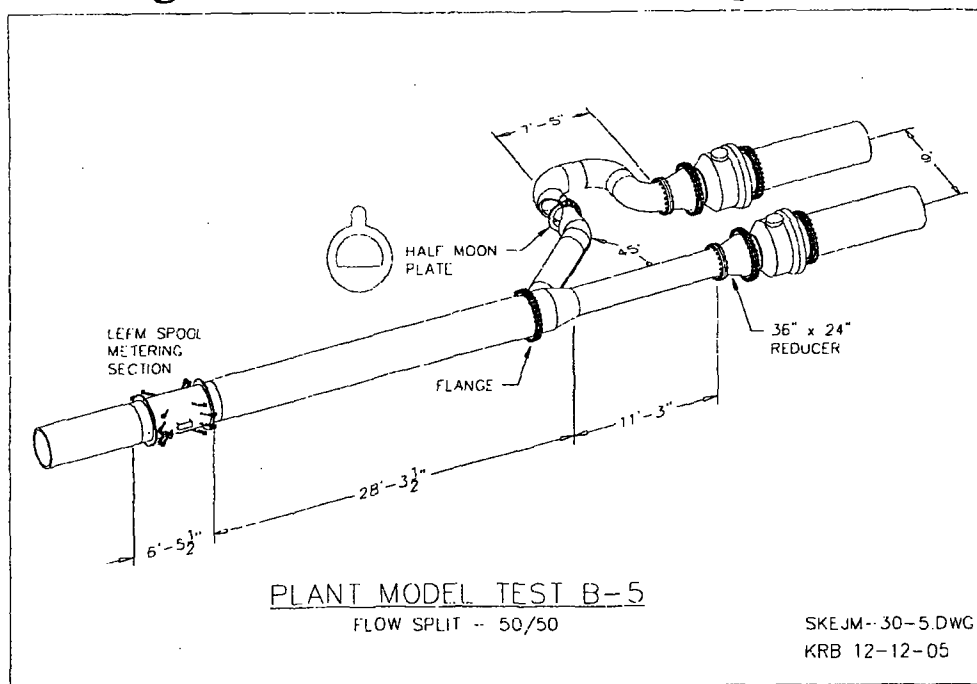


Test B-5 Maximum Swirl Test

Half moon plate upstream of 45 degree bend in branch

50-50 Flow split

25 weigh tank runs over a ~4:1 range of flows



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1.1 Laboratory Testing

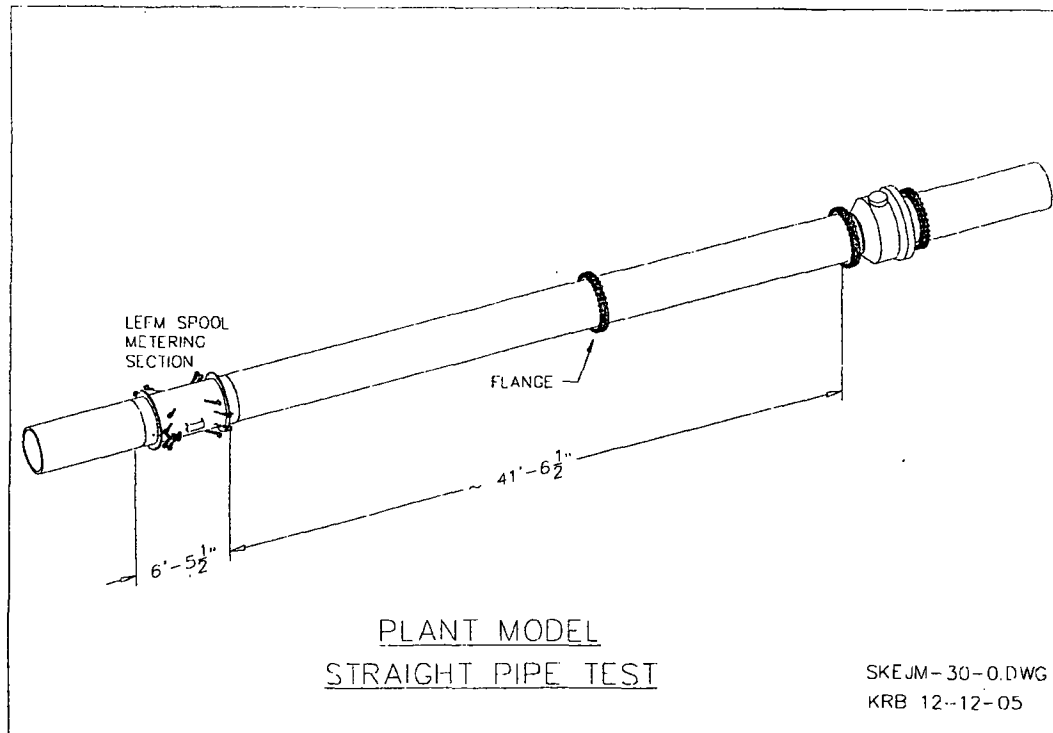
A description of the test configurations



Test A-1 Straight pipe—

A benchmark and low flatness datum

25 weigh tank runs over a ~4:1 range of flows



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1.2 Laboratory Testing

Description of supporting analyses



The Preliminary Uncertainty Analysis for Seabrook,
ER-482, Rev 1 (*Reference Tab 6 of INFO 18*)

Refs?

EFP-61, Commissioning Procedure for the LEFM electronics used in the calibration tests (*Reference Tab 7 of INFO 18*)

A test procedure that establishes the signal quality, coherent noise level, non fluid time delays, etc. for the lab equipment, thereby establishing the time measurement uncertainties for the calibration test.



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1.2 Laboratory Testing

Description of supporting analyses



A profile factor calculation and uncertainty assessment will be issued for the Seabrook flow element following the calibration tests. Examples of previous reports are referenced below.

ER -287 Rev. 1, the PF Calculation and Accuracy Assessment for D C Cook 1 (Reference Tab 9 of INFO 18)

FCDP-118, Field Commissioning Data Package which includes the data for EFP-61 for the Cook 1 flow element (Reference Tab 8 of INFO 18)



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1.2 Laboratory Testing

Description of supporting analyses



A new revision to the Seabrook Uncertainty analysis, incorporating the results of the calibration tests will be issued after these tests are complete. An example is referenced below.

ER-275 Rev 2 (Reference Tab 1 of INFO 18) The final uncertainty analysis for D.C. Cook 1, incorporating the results of the calibration tests and the plant commissioning



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1.3 Laboratory Testing

Summary of data from each lab test



The calibration reports and dates for all calibration tests performed for LEFM Check and CheckPlus flow elements (*Reference Tab 1 of INFO 19*)- (Q-1.3.1)

No data are excluded from any calibration test (Q-1.3.2)

ER 486 Rev. 1 (*Reference Tab 2 of INFO 18*) is a compilation of calibration data for 44 LEFM Check and CheckPlus flow elements

For staff & ACRS only: include by side comparison of UFM process.

See Tab 9 of ENUG 30 May 2005

I want a complete rundown of problems encountered during operation that affected indicated flow rate. No other failures

Only problem was noise associated to transducer degradation at Van Dellen (again)

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1.3 Laboratory Testing

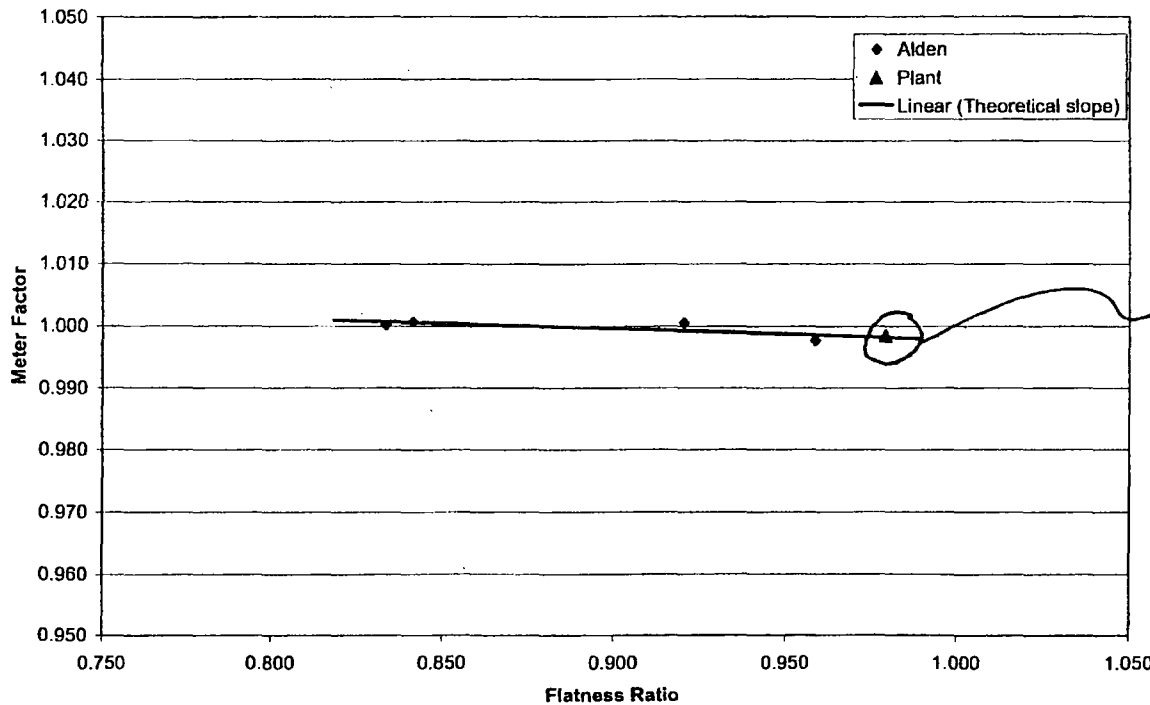
Summary of data from each lab test



A sample of the data in ER-486: D.C. Cook Unit 2

Extrapolation to plant conditions based on Flatness is shown

DC Cook Unit 2



Again - I want the data.

*How was this point determined?
Set by meter factor that was in the meter.*



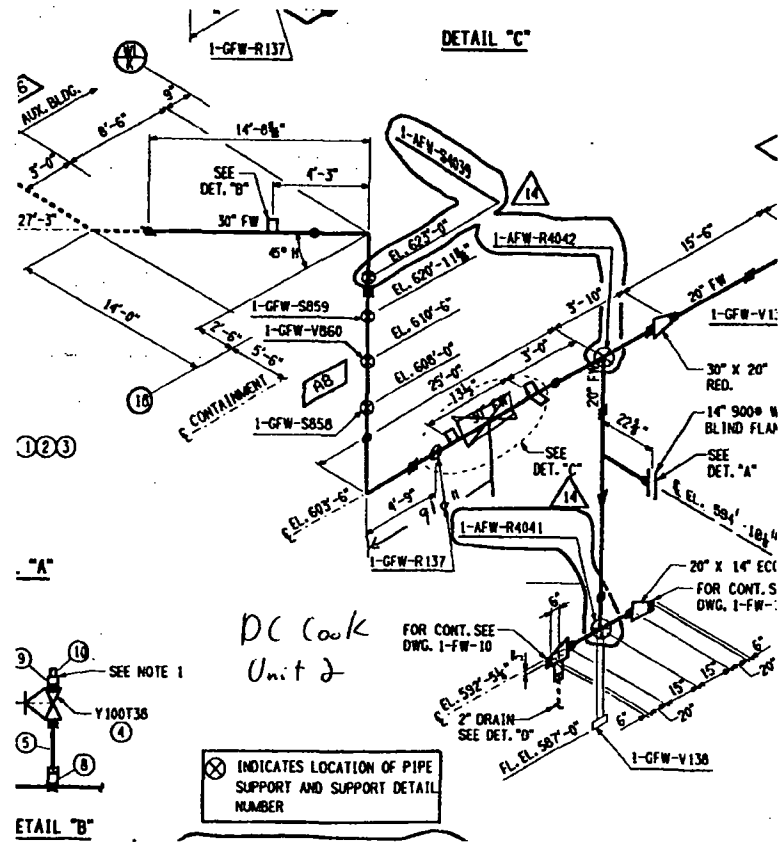
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1.3 Laboratory Testing

A summary of data from each lab test



An ISO from ER-486: D.C. Cook Unit 2





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Meet this

1.4 Laboratory Testing Noise Issues



CIB 110 (*Reference Tab 4 of INFO 18*), was issued on September 2003
analyzing the effects of hydraulic noise and vibrations on chordal LEFMs

LEFM Receiver pass band (700 kHz to 3 MHz) is above mechanical
vibration frequencies of piping systems

Pressure pulsations can cause sound velocity variations but effects on LEFM
less than 0.05%, bounded by uncertainty allowance for turbulent velocity
variations

How do we know?

Coherent and random noise from acoustic or electronic sources can cause errors
in the measurement of transit time differences— Δt 's

Measurement errors due to random noise can be reduced to negligible
magnitudes by multiple samples

Measurement errors due to coherent noise can be significant and must be
controlled if the instrument is to remain within its design basis

Discuss



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1.4 Laboratory Testing Noise Issues



LEFMs measure time from the initiation of pulse transmission to the zero crossing of the first positive half cycle of the received signal—the transit time including non fluid delays

The graphs show the effect of coherent noise—a shift in the time at which the first zero crossing of the received signal occurs

SNRC = the ratio of the received signal to the coherent noise that is present

$$\text{Max } \Delta t \text{ error} = (1/\text{SNRC}) \times (\text{Transducer Period}) / \pi$$

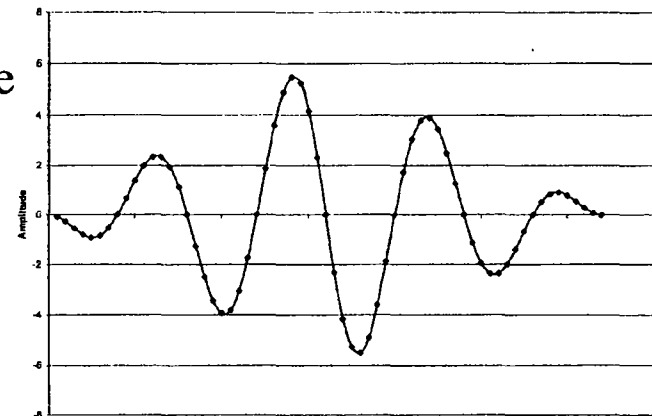
Issues for coherent noise

The amplitude of the received signal must be monitored to ensure that SNRC remains within acceptable limits

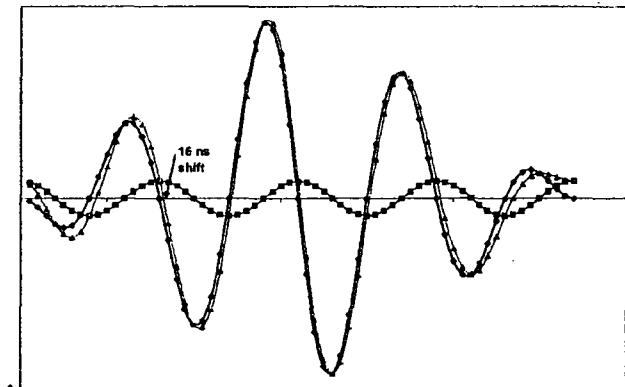
The signal to aggregate noise ratio is also monitored

*Worst case is x2
Normal is x 1.34*

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Time
SNRC -6, 1.6 MHz Transducers



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1.4 Laboratory Testing Noise Issues



Coherent noise as well as other potential sources of time measurement errors must be monitored in the lab tests as well as in the plant to ensure that

This source of uncertainty in the Profile Factor determination is appropriately bounded

Time measurement errors in the plant flow determination remain within their budget

Temperature changes, either spatially or temporarily, do not introduce errors in a transit time UFM

They can degrade the statistics of the transit time measurements thereby requiring larger measurement samples to achieve desired accuracy

Think about this



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1.5.1 Laboratory Testing Application of Lab Test Results to Plant; Swirl



On one occasion, the calibration of an LEFM CheckPlus was questioned after installation. The calibration tests had failed to model non planar upstream features. Consequently the swirl in the plant was greater than that in the model. A new calibration test was performed using a 16 inch prototype CheckPlus flow element ("Sputnik"). Model geometry was varied extensively, producing the data at the right.

Discuss Sputnik. What's it look like? What do the profiles look like and how does CheckPlus respond?

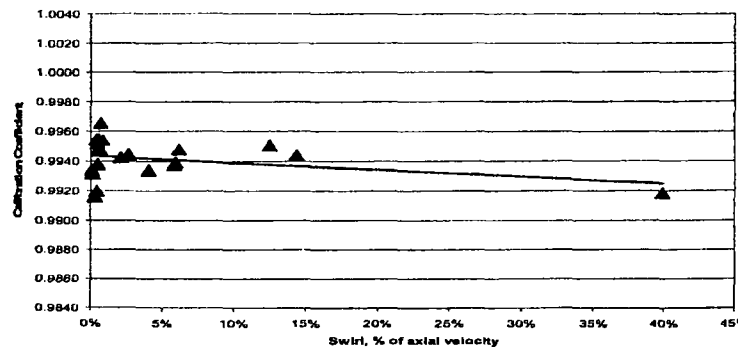
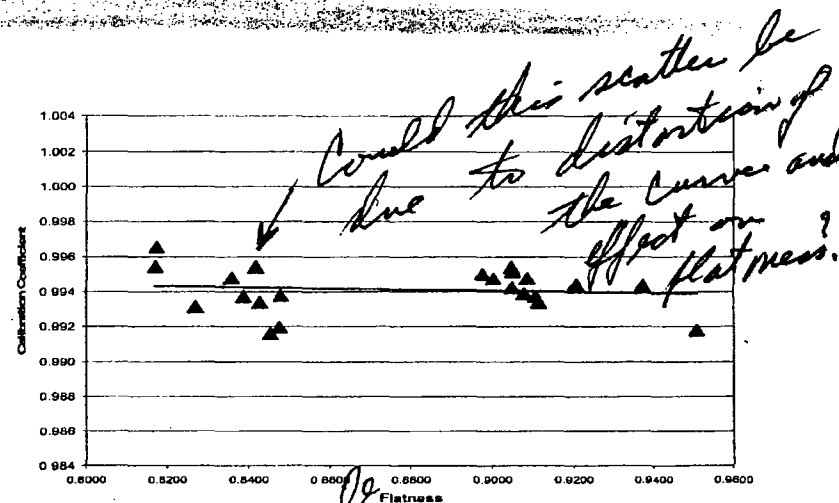
The sensitivity of the chordal meter to increasing swirl (the lower curve) is entirely due to the increased flatness produced by the swirl.

An adjustment of 0.06% to the plant LEFM Profile factor.

ER-293, (Reference) Tab 3 of INFO 18)

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M and - (Sputnik) dot.



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4 different meters for Millstone 3.



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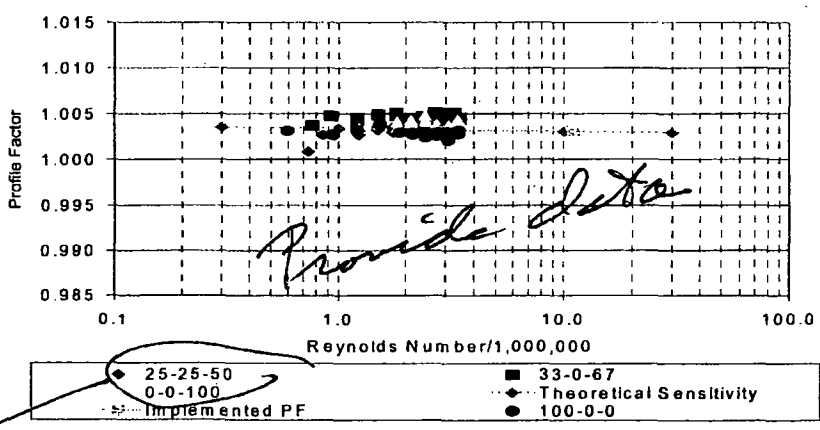
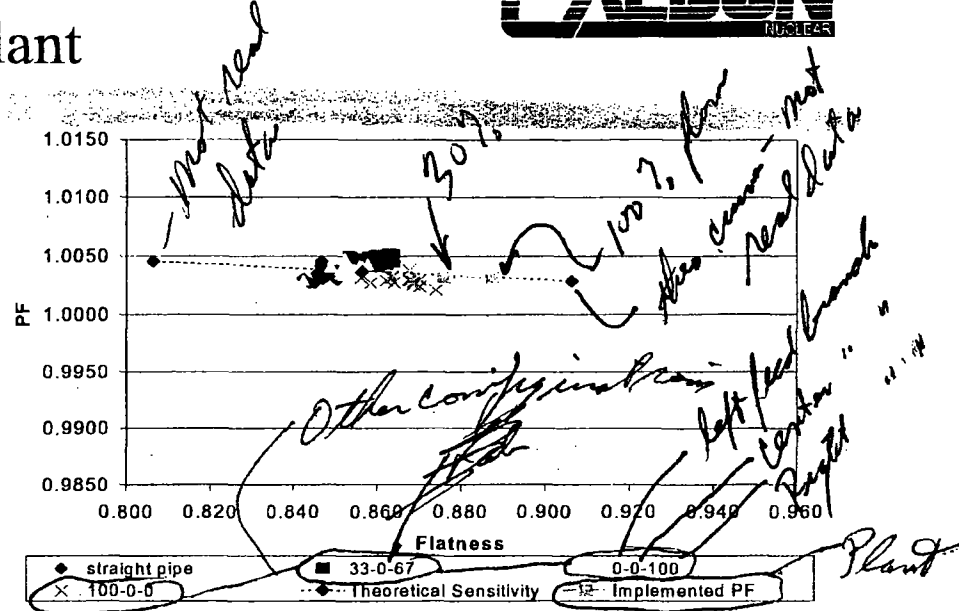
1.5.2 Laboratory Testing Application of Lab Test Results to Plant



Interpolation/extrapolation of lab test results to plant conditions is performed on the basis of Flatness (see ER-486)

Flatness captures plant-lab differences due to inertial effects, wall roughness AND Reynolds Number

In the examples shown (Loop B LEFM at Millstone 3) flatness and RN yield identical results
In-plant commissioning tests are covered later in the presentation



Explain meaning of values



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1.6 Data Analysis Summary

Uncertainty Analysis of the Calibration Data



The 130 weigh tank runs for the 6 hydraulic configurations in which the Seabrook flow element will be tested will be analyzed to determine its profile factor vs. flatness characteristic. These data, along with the signal noise and non fluid transit delay data of EFP-61 will also be used to establish the uncertainty in the profile factor.

The elements of the uncertainty in profile factor include:

Facility uncertainty

Observational (turbulence, etc.) uncertainty

Time measurement uncertainty

Modeling and (Flatness) curve fit uncertainty (extrapolation/interpolation to plant conditions)

The results of the analysis of the Seabrook data will be published in a flow element specific report

A typical analysis of calibration data has been cited on an earlier slide (1.6.1)

ER -287, the PF Calculation and Accuracy Assessment for D C Cook 1

How measured?



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1.6 Data Analysis Summary

Uncertainty Analysis of the Calibration Data



ER-287 Rev. 1 also describes the application of the calibration data to the plant installation (Q-1.6.2)

Look at this

The final revision of the uncertainty analysis for D.C. Cook 1, (ER-275 Rev 2, cited previously) is an example of the analysis of overall flow, feedwater temperature, and thermal power determination uncertainties, incorporating the results of the calibration tests, as well as the commissioning data of the LEFM in the plant

The methodology for establishing instrument uncertainties follows ASME PTC19.1 and is described in detail on Caldon Topical Reports ER-80P and ER-157P



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1.6.3 Traceability of Laboratory Testing and Plant Installation to NIST



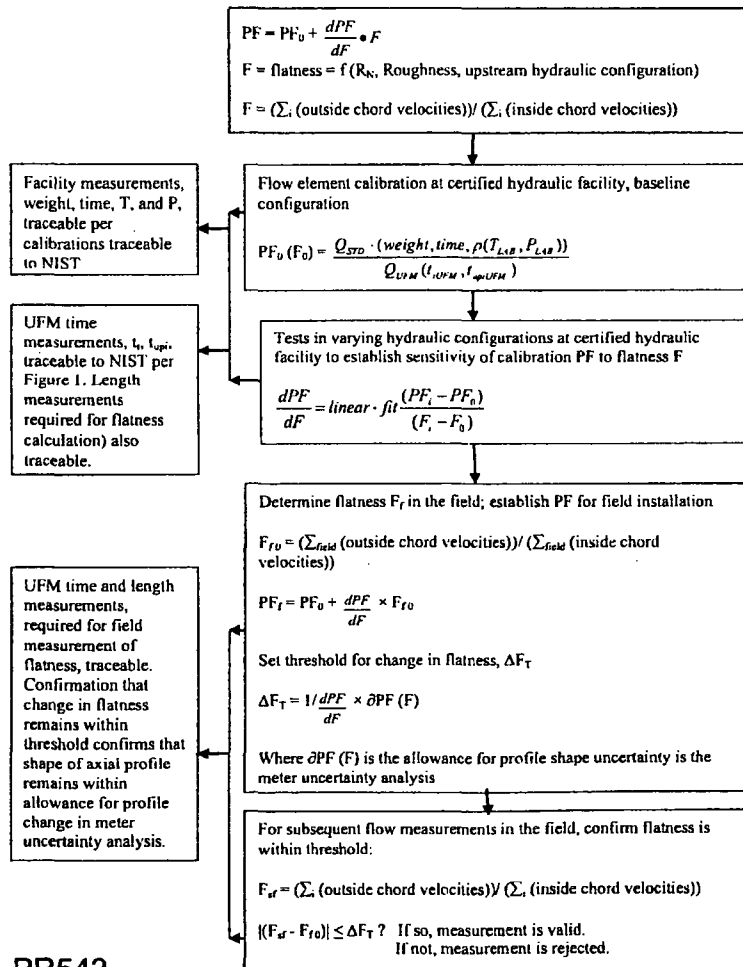
The Traceability of LEFM Check and CheckPlus measurements has been the subject of an ANS technical paper

*Traceability of Thermal Power Measurements, Part 1,
Chordal Ultrasonic Flow Measurements D. Augenstein, et al.,
- (Reference Tab 7 of INFO 19)*

4th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technology. September, 2004



1.6.3 Traceability of Laboratory Testing and Plant Installation to NIST



The diagram opposite, extracted from the paper, illustrates the traceability of the calibration data (profile factor) as applied in the plant – TP76
(Reference Tab 7 of INFO 19)



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2. Plant Installation

2.1 Specification for the UFM



The FPL Energy purchase specification is the governing document (*Reference Tab 10 of INFO 18*)

The preliminary uncertainty analysis for Seabrook, ER-482, previously cited, forms the performance specification for the LEFM

FPL Energy Seabrook Nuclear Power Station
Specification 5-K-1-E-0133
Rev. 00
Ultrasor™ Feedwater Flow Metering System

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2. Plant Installation

2.1 Specification for the UFM



LEFM Uncertainties versus Flow Rate

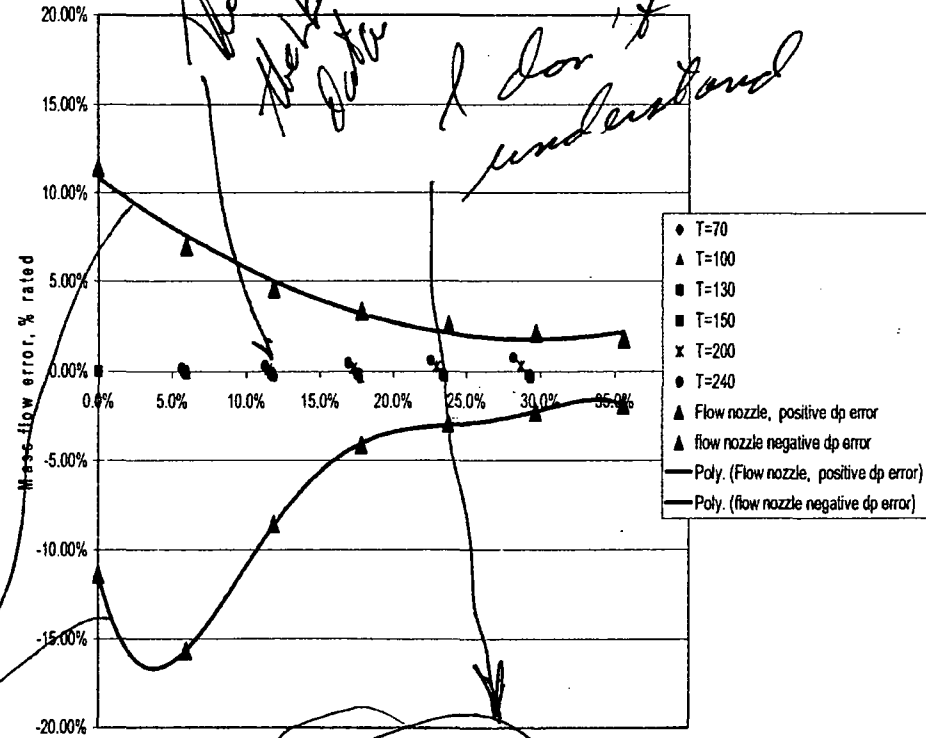
Volumetric Flow:
Most error contributors affect the measurement as a % of reading.

Exception: Δt errors which affect the measurement as a % of rated flow

Mass flow:
Follows volumetric flow, density error due to temperature is a small % of reading

Bound for dP cell

Nozzle and LEFM Mass Flow Errors as a function of feed flow and temperature, LEFM
Properties fixed at 170 F below 250 F





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2. Plant Installation

2.1 Specification for the UFM



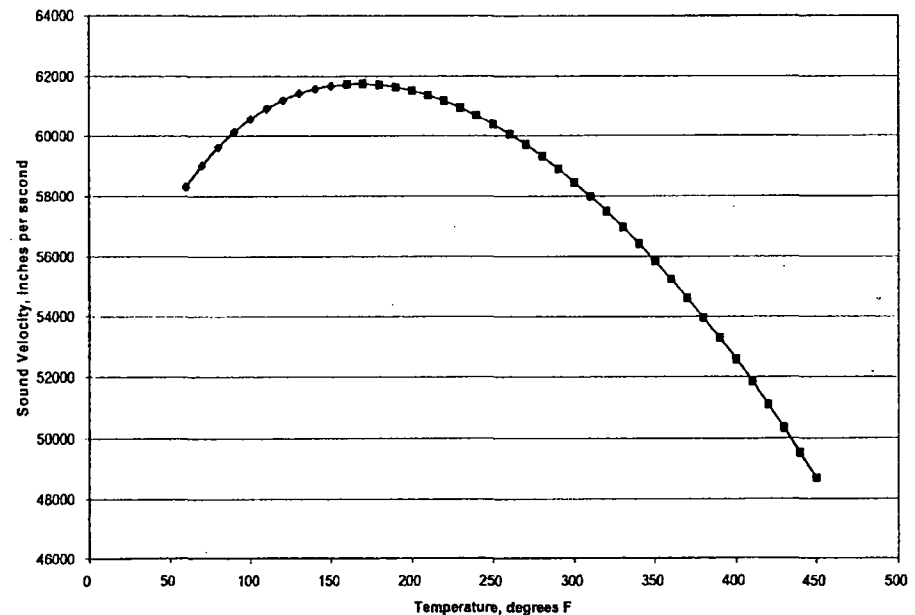
LEFM Uncertainties versus Flow Rate

Temperature derived from sound velocity can only be used above temperatures ~ 250° F.

Between this temperature and 150°F the RTD provides the mass flow computation and temperature output

Temperature errors range from ±1.5 degrees at 200 F to ±0.6 degrees at 430 primarily because of the changing slope of the temperature-sound velocity curve

Sound Velocity vs. Temperature in pure water at 1000 psia





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2. Plant Installation

2.2 Flow conditioners



As discussed in the calibration test slides, flow conditioners are used in calibration testing to “homogenize” upstream hydraulic effects

LEFM Check or CheckPlus flow elements are typically not installed downstream of flow conditioners in nuclear feedwater systems

Tests of chordal LEFMs in petroleum applications show that flow conditioners should be installed about 15 diameters upstream of the flow element if a lab calibration is to be transferred to the field

Experience in petroleum applications shows that tube type flow straighteners preserve distortions in axial profile that would otherwise dissipate



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2. Plant Installation

2.3 Description of Feedwater System



2.3.1 P&ID and Isometric Drawings are included in the handout



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2. Plant Installation

2.3 Description of Feedwater System



2.3.2 Hardware that can affect the profile

The model includes

The lateral

Bend upstream of the lateral branch

Reducer upstream of lateral straight

The model does not include

The long straights, planar bends and non planar bends from the outlet water boxes of the HP feedwater heaters

These effects are bounded by the test with the flow straightener upstream of the branch elbow removed and by the test with the “half moon” plate installed upstream of the branch.

How do you know these are bounds?



2. Plant Installation

2.3 Description of Feedwater System



2.3.2 Hardware that will not affect the profile

1 ½ inch vent and drain connections are located ~ 5 diameters upstream of the LEFM. The interfaces between the connections and the ID of the upstream pipe are flush. The lines are capped. Experience with similar connections show that they will not affect the axial profile seen by the LEFM - *Describe experience*

The tubes of the feedwater heaters act to eliminate the impact, on the profile, of hydraulic features upstream of the heaters

The 25-75 and 75-25 flow split tests bound the effects of operations with a heater bypassed



2. Plant Installation

2.3 Description of Feedwater System



2.3.3 Potential bypass flow paths

A sample connection immediately downstream of the LEFM is used intermittently to sample the chemistry of the feedwater. It is a ¼ inch connection and, if in service, would result in a negligible but conservative flow error.

1 inch chemistry injection connections in each of the individual steam generator feeds (4 total) are used only to inject chemicals during steam generator wet lay-up

4 inch emergency feedwater connections to each steam generator (4 total) can inject feed only if the emergency feedwater pumps are in operation, not a normal full power condition

EFW testing?

Conclusion: No plausible bypass paths



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2. Plant Installation

2.4 Rationale for LEFM Location



FPL Energy Criteria

Located inside (OE with existing system)
Facilitate maintenance
Consistent with the guidelines

Caldon Criteria

Capability to model
Access for installation and maintenance



2. Plant Installation

2.5 Pre-operational Test Configurations



The parametric approach to calibration tests for LEFM CheckPlus flow elements obviates the need for varying feedwater system configuration

A change in configuration may change the axial profile

Axial profile is monitored to ensure that it remains within allowable variation (± 0.05 change in Flatness) established at Commissioning

Experience shows that changes in flatness exceeding ± 0.05 are extremely unusual

The key is Flatness. Need to understand how this correlates to flow rate + flow during operation.

Data supporting these conclusions can be found in Caldon Engineering Report ER-262 (Reference Tab 5 of INFO 19)

Spatial and temporal variations in feedwater temperature do not affect LEFM performance.



2. Plant Installation

FPL Energy 2.6 Comparison and Evaluation of Lab Seabrook Station Test Configurations with Plant Installations



2.6.1 Assessment of changes in profile between the laboratory test and the plant installation

ER-486 provides calibration data for a comprehensive sample of installations, showing the Flatness measured in plant for each. For several of the installations variations in Flatness in plant are also shown

ER-262 contains a comprehensive listing of measured variations in Flatness for 16 installations. Appendices describe the circumstances of two significant variations (Flatness changes of 0.04 to 0.05)

Caldon certifies the LEFM performance for all practical upstream hydraulic configurations including variations in lineup, wall roughness, and feedwater temperature/viscosity

Need these



2. Plant Installation

FPL Energy 2.6 Comparison and Evaluation of Lab
Seabrook Station Test Configurations with Plant Installations



2.6.2 Changes in profile are detected by changes in Flatness which is automatically measured and alarmed if a change exceeds ± 0.05 .

*or less
in some cases;*

There are no restrictions on the LEFM in terms of total flow rate or the flow rate in either branch of the lateral upstream of the LEFM

Never more.

*is 1/2 of the uncertainty
associated with that
variable (i.e.
0.1% vs 0.05%)*



2. Plant Installation

FPL Energy 2.6 Comparison and Evaluation of Lab Seabrook Station Test Configurations with Plant Installations



2.6.3 This question has been addressed in previous slides.

Comment: While Caldon has used computational fluid dynamics for parametric analyses of flow effects (e.g., the distortion of the flow field produced by the transducer apertures in small flow elements) we have found that the CFD methodology is generally not accurate or traceable enough to use to establish profile factors.



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2. Plant Installation

2.6 Comparison and Evaluation of Lab Test Configurations with Plant Installations



- 2.6.4 The calibration process establishes the sensitivity of the profile factor to profile flatness. The uncertainty in applying this relationship to the plant conditions, as established by the flatness measured during commissioning is typically in the order of $\pm 0.1\%$



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Seabrook Station

2. Plant Installation

2.6 Comparison and Evaluation of Lab Test Configurations with Plant Installations



2.6.5 The effect of noise in the plant

Coherent acoustic and electronic noise can cause errors in the measurement of Δt 's

To ensure that the errors due to noise remain within the bounds budgeted in the site specific uncertainty analysis:

During commissioning, the magnitudes of the received signals, coherent noise, and random noise are measured in each direction for each acoustic path, to ensure that potential errors from these sources are within the uncertainty budget

The magnitude of the received signals is continuously monitored during subsequent operation of the LEFM. If the signal strength on any acoustic path falls below the level at which the signal/coherent noise ratio is acceptable (from the standpoint of the budgeted uncertainty) that signal is rejected. Continuous rejections cause a path to be declared "out of service" and the meter will enter the "maintenance mode" with increased uncertainty (and therefore a lower allowable thermal power).

In addition, a diverse back up, the ratio of signal strength to the aggregate noise (coherent plus random) is also used as a measure of signal acceptability



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2. Plant Installation

2.6 Comparison and Evaluation of Lab Test Configurations with Plant Installations



2.6.6 Effect of pipe roughness changes

An increase in pipe roughness will tend to decrease the flatness of the axial profile (because it makes the profile more rounded). The change in profile factor should be characterized by the parametric calibration tests. Typically, an increase in roughness will change the calibration by less than 0.1%, within the uncertainty budget for such effects.



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2. Plant Installation

2.6 Comparison and Evaluation of Lab Test Configurations with Plant Installations



2.6.7 An examination of the evaluation results

ER-262 and ER-486 provide a comprehensive database comparison between profiles encountered in lab calibration and encountered in the plant

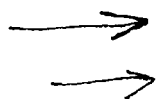
Important observations are:

Plant profiles cannot be precisely predicted in the laboratory

Profiles are subject to change over time and in fact, change in 100% of the cases

Therefore, an allowance must be maintained to account for meter factor change commensurate with profile changes observed. The $\pm 0.1\%$ accounted for modeling uncertainty covers this effect for LEFM CheckPlus Systems

Expand on these



Why can't the meter correct for these?



2. Plant Installation

2.7 Duration of Data Collection



During Lab Calibration

For each run, filling the weigh tank takes between 40 seconds and 3 minutes to complete depending on flow rate

The LEFM performs flow calculations with a frequency of about 50 Hz

Thus the number of flow samples N per weigh tank run ranges between 2000 and 9000. / 8000?

The standard deviation of each flow sample due to turbulence is ~ 2%.

The standard deviation of the average flow reading for a weigh tank run is reduced by the large number of flow samples. However the reduction is not as great as $1/(N)^{1/2}$ because the periods of some of the turbulent frequencies are only 1 order shorter than the weigh tank fill time

The uncertainties due to these statistics are accounted as the observational uncertainty contributor to the profile factor uncertainty

*Contrast
to W*

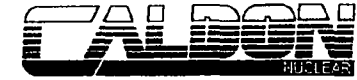
Interesting



FPL Energy
Seabrook Station

2. Plant Installation

2.7 Duration of Data Collection



In the plant

A sample period greater than 2 minutes will generally reduce uncertainties due to turbulence to ~ 0.1%

However, a longer averaging period may be necessary to reduce observational uncertainties due to limit cycling of the feedwater regulating valves

A longer averaging period—in the 5 minute range—may also be required to ensure that the measurement is representative of thermal equilibrium between the reactor/steam generators and the power conversion system

Seabrook will use an LEFM rolling average of 30 seconds to be consistent with the 4 minute, 1 hour, and 8 hour rolling averages currently used at the plant



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2. Plant Installation

2.8 Evaluation of UFM Operational Characteristics



EFP-61 is performed to commission the LEFM in-plant

Signal Quality is confirmed (e.g., coherent and random signal noise ratios, reciprocity of upstream and downstream received signals)

Non fluid time delay inputs are confirmed by in-plant measurements for each acoustic path

Settings for individual path alarms are established

Upstream and downstream gains (signal magnitude)

Upstream and downstream signal/(aggregate) noise ratios
(diverse backup to the gain alarms)

Individual path reciprocity requirements are established

Allowable variations in transit times and Δt 's are established, for use in signal processing filters



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2. Plant Installation

2.8 Evaluation of UFM Operational Characteristics



Flatness is measured for each 4 path acoustic plane and for the 8 path system as a whole

The appropriate profile factor for operation in the 8 path (CheckPlus) mode is established

The range of acceptable changes to Flatness is established to obtain the settings for the high and low flatness (profile change) alarms

The profile factors for each acoustic plane are established for use when one plane is out of service

(with reduced system accuracy in the “maintenance mode”)

Settings for other system level alarms are established

Allowable variation in individual path sound velocity versus average sound velocity from all paths



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2. Plant Installation

2.9 Vendor Validation and Certification



The final revision of the uncertainty analysis engineering report incorporates the results of the commissioning process

ER-275 (for D.C.Cook) has been provided as an example

(Reference Tab 1 of INFO-18)

The Caldon letter forwarding the final revision of the uncertainty analysis also forwards a certificate of compliance for the UFM installation

An example is shown *(Reference Tab 9 of INFO-19)*



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3. UFM Operation

3.1 Description of the UFM's error analysis methodology



Table 6-1 of ER-80P lists the bounding, validation, and verification procedures for each elemental uncertainty of the uncertainty analysis of Appendix E of that document. The table also applies to the uncertainty analysis of Appendix A of ER-157P (for CheckPlus Systems). Table 6-1 demonstrates that all error contributors that can plausibly change in the short term in the field are alarmed.

Note: The table indicates that item 5c, signal to coherent noise ratio, is not alarmed. The LEFM *does* provide alarm protection for this variable in the form of a high gain (low signal strength) alarm.



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3. UFM Operation

3.1 Description of the UFM's error analysis methodology



3.1.1, 3.1.2

Changes in profile are recognized by changes in the measured flatness. An allowance for changes in flatness is included in the error budget. The allowance takes the form of a profile factor uncertainty $\sim \pm 0.1\%$. If a measured change in flatness exceeds that which would cause a change in calibration exceeding 0.1% (flatness change ~ 0.05), the condition is alarmed, the meter is considered “failed”, and its output is not used.

The discussion in 3.1.2 appears to imply that errors in the LEFM are detected by comparing its indication with other plant indications. The LEFM does not rely on other plant indications for the detection of errors. Nevertheless, licensees are encouraged to perform calculations to determine a “best estimate” of the feedwater flow, as a diverse check. Caldon Information Bulletin CIB-121, Appendix A, (*Reference Tab 11 of INFO-18*), describes a rigorous process for forming a best estimate.



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3. UFM Operation

3.1 Description of the UFM's error analysis methodology



3.1.3 Operational limits on the use of the UFM

There are no operational limits on the use of the LEFM

3.1.4, 3.1.5 Effect of operating at operational limits,

Cross Checking

These topics are not applicable to LEFM Check and CheckPlus Systems



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3. UFM Operation

3.1 Description of the UFM's error analysis methodology



3.1.6 Effect of differing temperatures in the two feeds to the main feed header

Temperatures of the two feeds may differ by 1° or 2°F during normal operation and may differ by as much as 30° or 40°F if one of the two heaters is out of service, isolated and bypassed. Experience with similar situations in other installations shows the following:

Whether the lateral mixes the fluid or not, the LEFM will measure the bulk average feedwater temperature within its design basis accuracy (± 0.6 degrees) because the sound velocity is numerically integrated over the pipe cross section (unlike RTDs which are point measurements).

If significant streaming (varying spatial temperature gradients) is present, it may be necessary to increase the set point for the system alarm on path sound velocity differences.

Streaming can also increase variations in transit time, which may require broadening the statistical filter setting on this variable. (This measure was necessary to obtain an accurate reactor outlet temperature measurement in the presence of a coolant temperature gradient of about 20°).



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3. UFM Operation

3.2 Control Room Procedures



Operations personnel reviewed LAR and procedures to identify required changes

Procedures revised to reflect MUR power level

Maintenance Department - I&C notified of system alarms

Allowed Outage Time (AOT), and Action Statement requirements are provided in LAR 05-04 Attachment 1, Section 2.4 (page 2-10)

Will be incorporated as a Limiting Condition for Operation (LCO) in the Technical Requirements Manual

Although Caldon Topical Report provides an uncertainty for loss of one plane of LEFM Checkplus™, power will be reduced to pre-MUR levels when required by TRM Action Statements



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3. UFM Operation

3.2 Control Room Procedures



Technical Requirements Manual

- Power to be reduced to pre-MUR power level prior to exceeding 48-hours
- Power change of 10% during AOT, limits power level to pre-MUR level
- Loss of the main plant computer system will require reduction in power to pre-MUR level prior to the next daily calorimetric calibration



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3. UFM Operation

3.3 Personnel Training



One of significant lessons learned with industry over power events was over reliance on vendor expertise

Took an aggressive approach to training

General description of training provided in LAR 05-04, Attachment 1, Section 2.4 (Page 2-8)

Training courses at Caldon to train the trainers

- Engineering and Maintenance personnel

Specific training for operators as part of the licensed operator training classes prior to the refueling outage



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3. UFM Operation

3.4 Operational Experience with Currently Installed UFM's



Flow rates in the individual steam generator leads are currently measured by two path chordal ultrasonic flow elements designed and built by another vendor

When the vendor no longer supported these nuclear installations, Seabrook contracted with Caldon to provide signal processing electronics (an LEFM 8300) so that the instruments could be used as a check on the venturis

FPL Energy Experience

No operational experience with the Caldon LEFM CheckPlus™

Older devices installed since original plant startup

- Maintenance, Engineering, and Operations personnel very familiar with maintenance and operation of the system
- Primary maintenance issues have been weather exposure and obsolescence



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3. UFM Operation

3.5 Time dependent plant conditions that might affect UFM performance



ER-262, previously cited, describes changes in velocity profiles that have been measured in nuclear feedwater systems. One case, documented in Appendix A of that report, describes a significant change in axial profile and swirl brought about by a marked decrease in wall roughness as evidenced by a flattening of the axial profile and increased swirl. The change in roughness is believed to have occurred as a result of several days of operation in the “cold recirculation” mode, at high pH. As described in the reference, the effect of the change in flatness on the LEFM calibration was less than 0.1%. The error was conservative

Corrosion products do not preferentially deposit on the ID of the LEFM flow element (as they do in the throat of a flow nozzle). The interior diameter of the flow element is monitored by periodic measurement of the wall thickness, under the ISI program. A conservative allowance for wall thickness change (± 15 mils) is included in the ER-157P uncertainty analysis



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3. UFM Operation

3.6 Available comparisons of UFM indications with other parameters



Topic does not appear to apply to Seabrook since UFM is not yet installed.

As noted previously, comparisons with other plant parameters are not necessary to validate LEFM operation.

Nevertheless Caldon encourages users to form a “best estimate” of feedwater flow using diverse other indications. The best estimate methodology is described in Appendix A of CIB-121 Rev. 0, referenced earlier.

FPL Energy

Monitoring primary and secondary parameters

Existing UFM and venturies provide additional feedwater flow indication

Evaluating additional “best-estimate” methods, including River Bend method



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3. UFM Operation

3.7 Participation in Caldon Nuclear Users' Group (CNUG)



Agendas and attendees for the annual meetings of CNUG are provided
(*Reference Tab 8 of INFO 19*)

FPL Energy decision to purchase in 2005

Obtained previous CNUG meeting minutes

Reviewed and applied applicable information for previous CNUG meeting
minutes into design change

Registered in the VIP Room on Caldon Website

Will attend Users Group meeting in 2006



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Seabrook Station

3. UFM Operation

3.8 Responding to information

obtained from Users' Group and from CIBs



Users Group meetings are typically documented under self-assessments

Condition Report System used to evaluate

- Issues identified
- Applicable Technical Bulletins
- Applicable operating experience

Future applicable Caldon Customer Information Bulletins (CIBs) will be processed through the Condition Reporting System



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3. UFM Operation 3.9 Past instances



Past instances where UFM flow rate indications would have resulted in plant operation above the licensed power limit

There has never been an instance where the use of an LEFM Check or Check Plus system has led to operation above a plant's licensed power level

How do we know?



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Seabrook Station

Conclusions; Action Items



Open Discussion