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Seabrook Station

CALDON NUCLEAR

MEASUREMENT UNCERTAINTY RECAPTURE

FPLE/CALDON® - NRC MEETING

December 16, 2005

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PR542

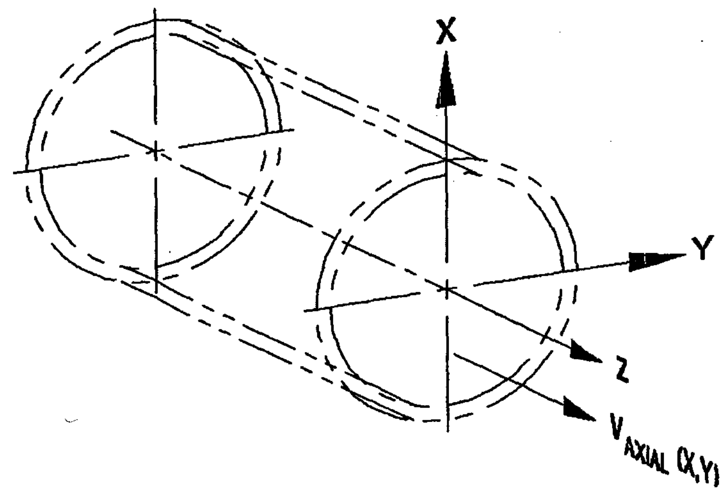
Enclosure 1

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



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

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LEFM Principles

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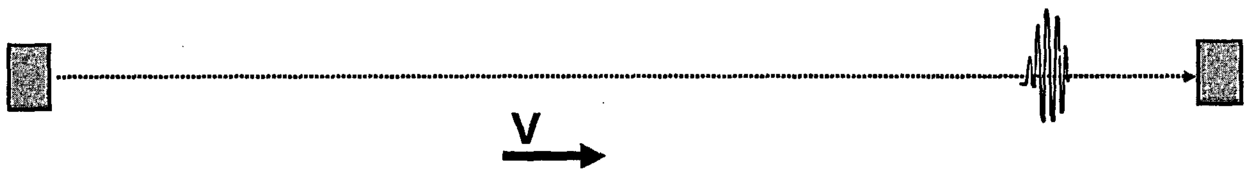
What the elapsed times of transiting pulses measure



C = sound velocity of fluid at rest

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

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

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

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

$V = (½)\ \Delta t\ (L_{path}/\ t_{up}t_{down})$

$L_{path}\ V = (½)\ \Delta t\ (L_{path}{}^2/\ t_{up}t_{down})$

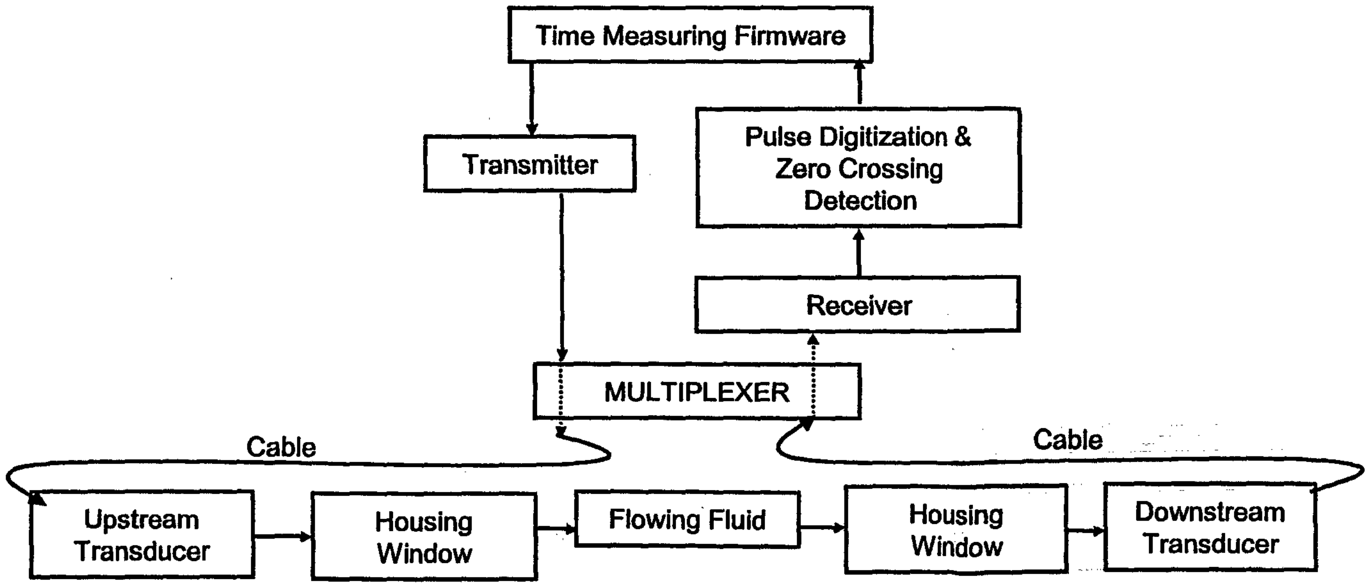
$C = L/[t_{up}/2 + t_{down}/2]$

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

LEFM Principles

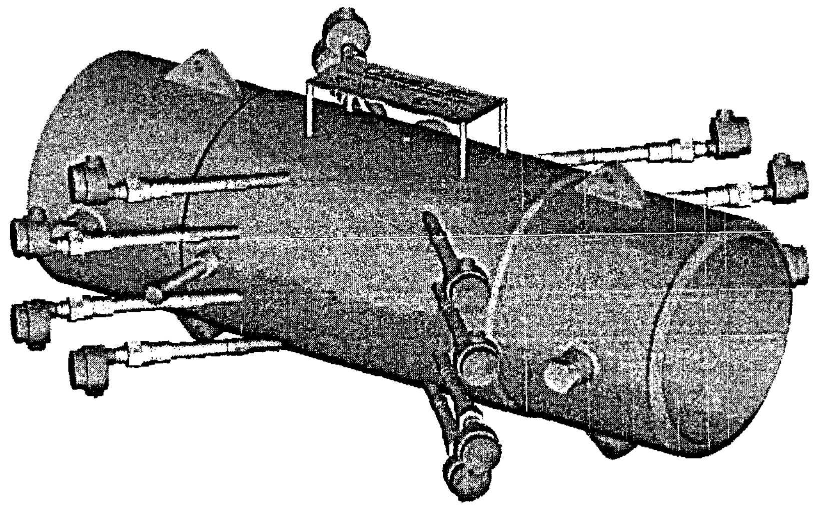
- The UFM measures the transit times of ultrasonic pulses traveling in each direction along each acoustic path and uses these data to determine the average fluid velocity and the average sound velocity along each chord. But the time measured includes more than the transit time through the fluid.

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



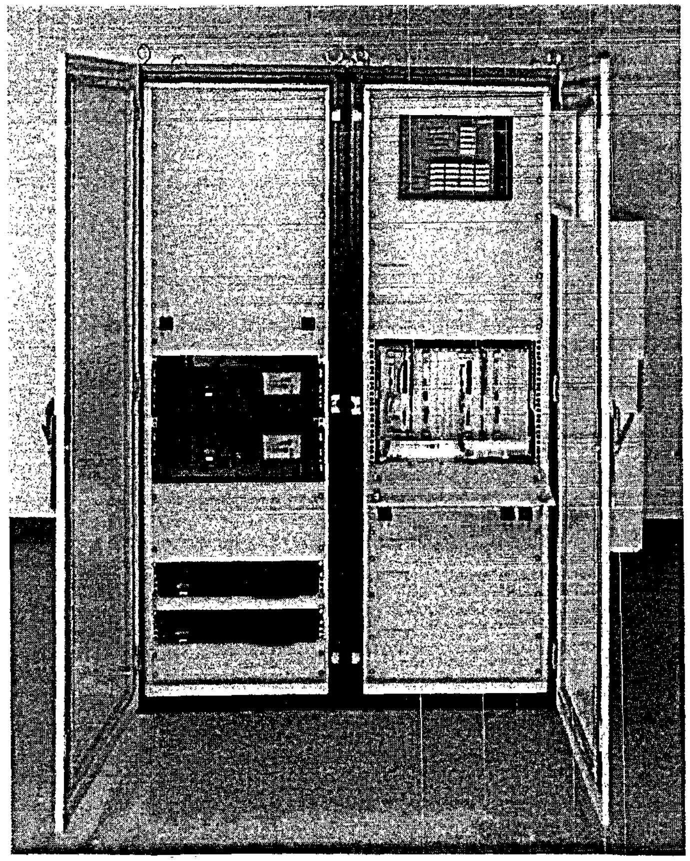
LEFM Principles

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



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

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LEFM Principles

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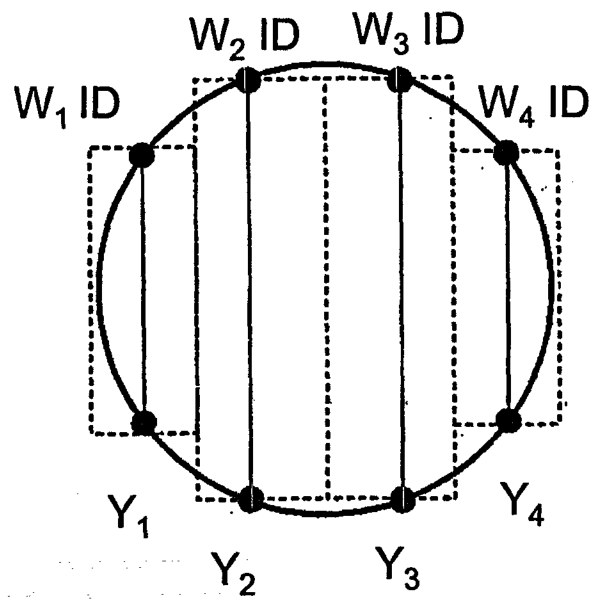
- Chordal LEFMs determine volumetric flow by numerically integrating the axial velocity at 4 pre-selected chordal locations
- The LEFM measures the integral of $V_{axial}(x)\,dx$ at each location.
- The volumetric flow is determined by summing the flow contribution of the four segments. Each contribution 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.



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LEFM Principles

- The chordal LEFM Mass Flow Algorithm:

$$W_f = \rho^{*} \; PF^{*} F_{a3} (T) \; ^{*}(ID/2) \sum_{i=1}^{4} \frac{w_i L_{ffi}^{\;2} (\Delta ti)}{\tan(\varphi i)(ti + \Delta ti/2 - \tau i)^2}$$

$$\rho = f\,(T, p)$$

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

$$C_{mean} = F_{a1}\,(T) \sum_{i=1}^{4} [w_i \; L_{ffi}]/[t_i + (\Delta t_i/2) - \tau_i]$$

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

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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

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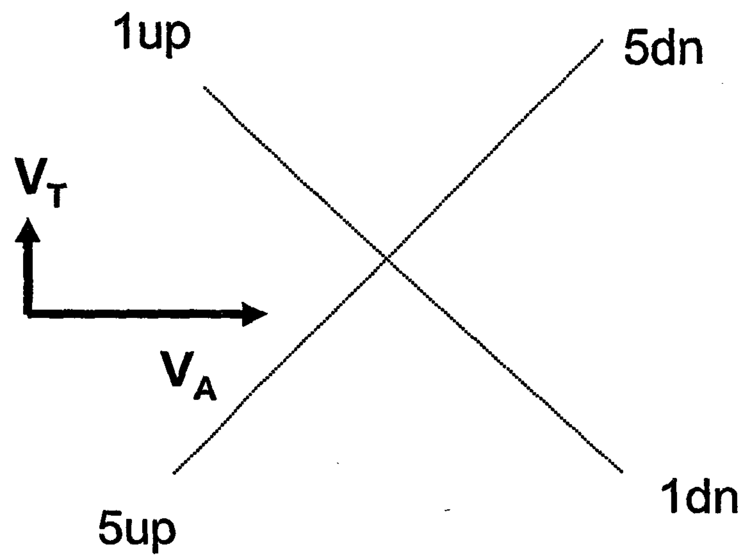
LEFM Principles

- 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.



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LEFM Principles

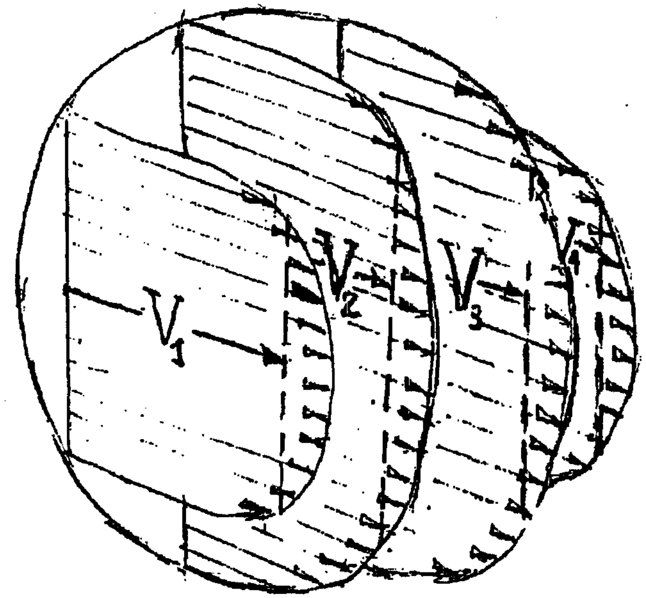
- Chordal LEFMs measure the axial velocity profile, characterizing it by its Flatness, the ratio of the outer path average velocity to the inner path average velocity

  - 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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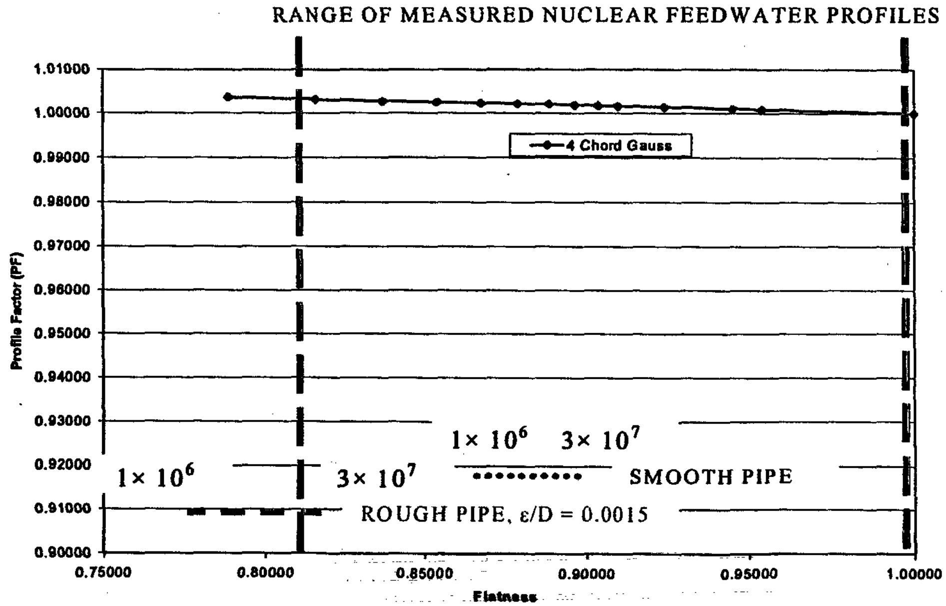
LEFM Principles

- 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



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

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LEFM Principles

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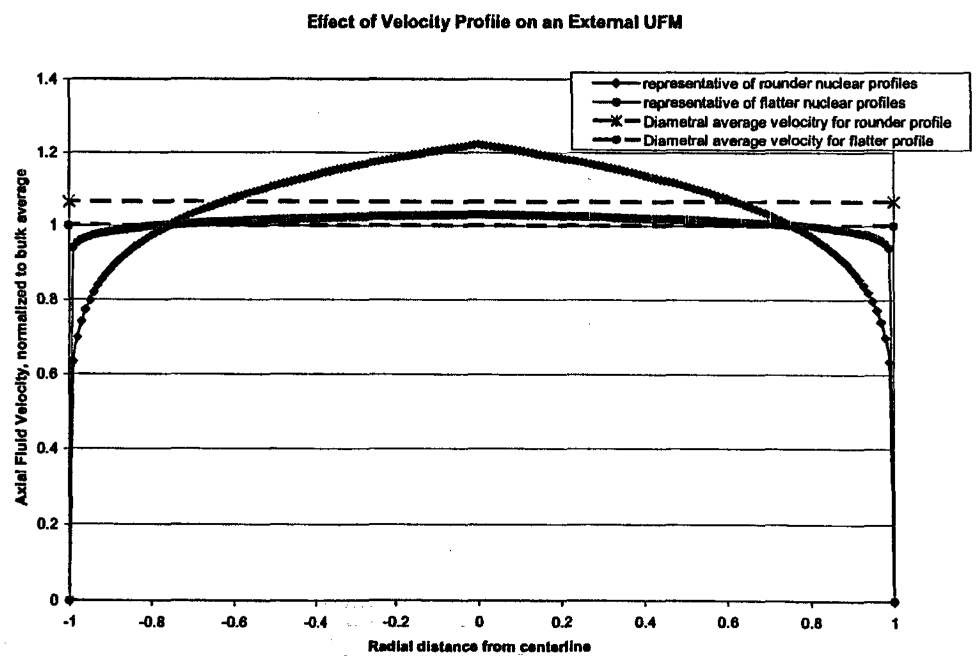
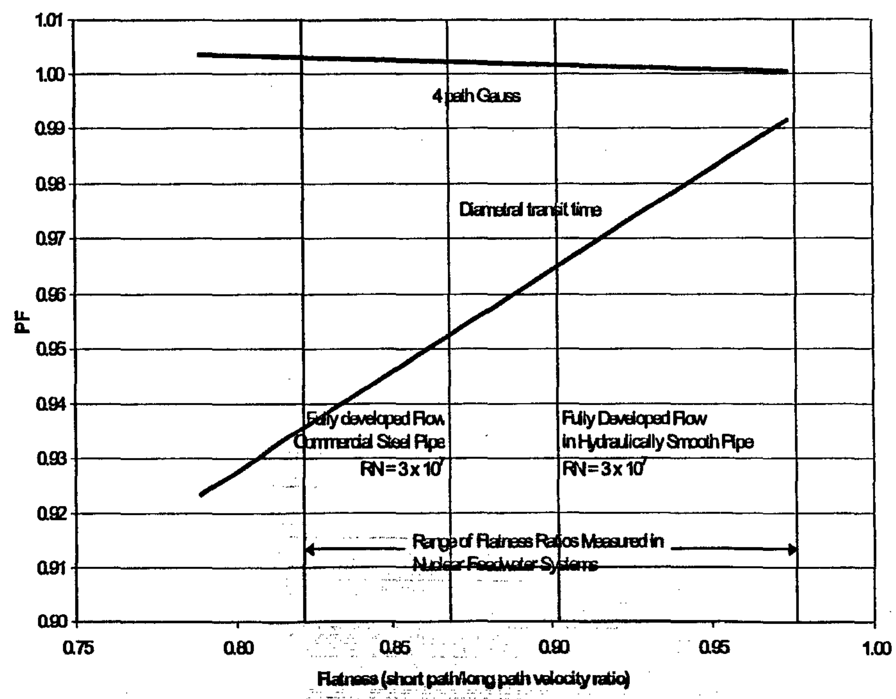
- In contrast, an external UFM is constrained to measure a velocity along a diametral path
- An externally mounted transit time meter measures the diametral average axial velocity
- The relationship between diametral average axial velocity and cross-sectional average axial velocity is sensitive to profile shape



LEFM Principles

- The relative sensitivities of chordal and external UFMs to axial velocity profile are shown in the graph on the right

Calibration Coefficient (PF) versus Profile Flatness;
4 path chordal and external transit time flowmeters,



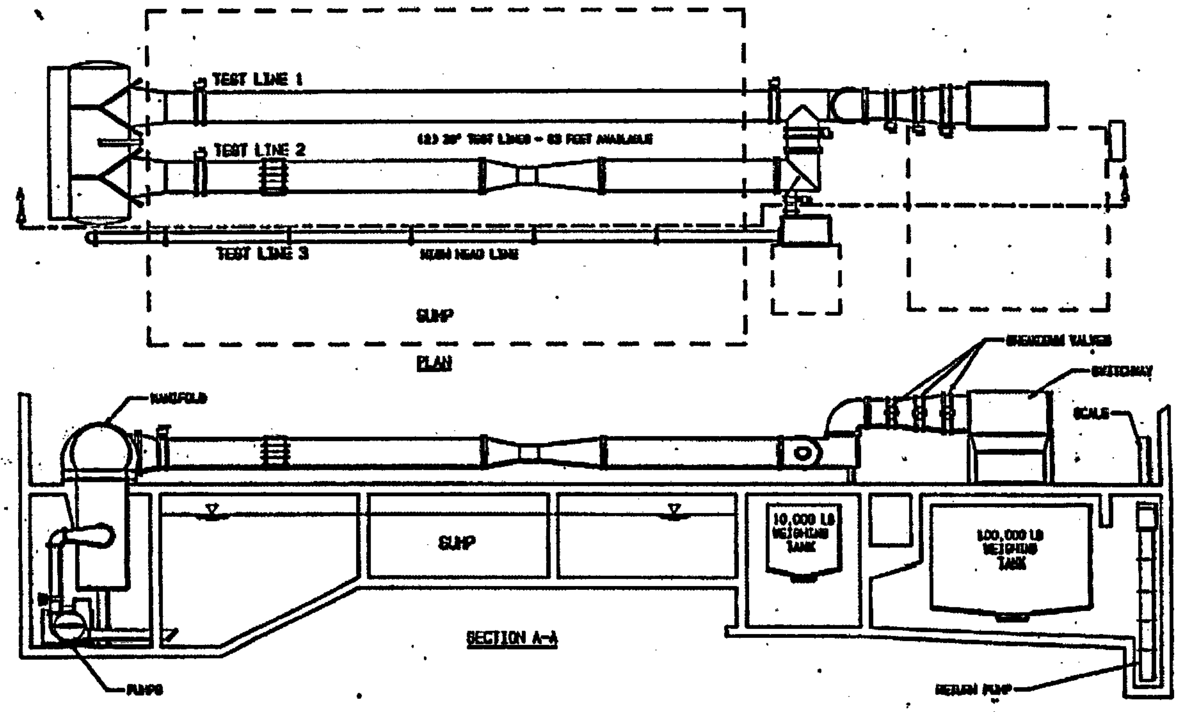
1. Laboratory Testing

- 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

1. Laboratory Testing

- The Alden Research Lab Facility

FIGURE 1



BUILDING #1
FLOW MEASUREMENT FACILITIES

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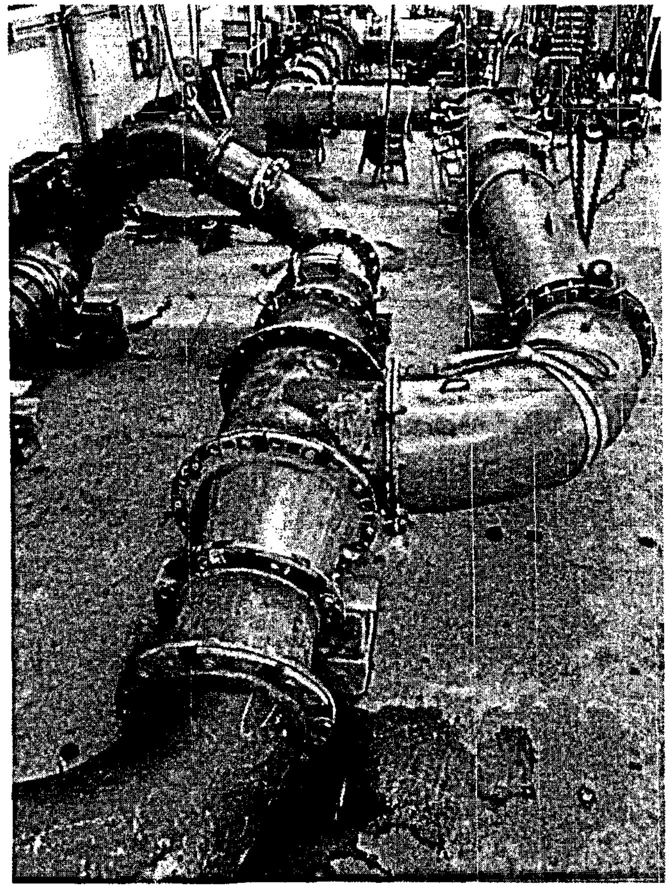
1. Laboratory Testing

- Full scale model testing of the Beaver Valley 2 flow element

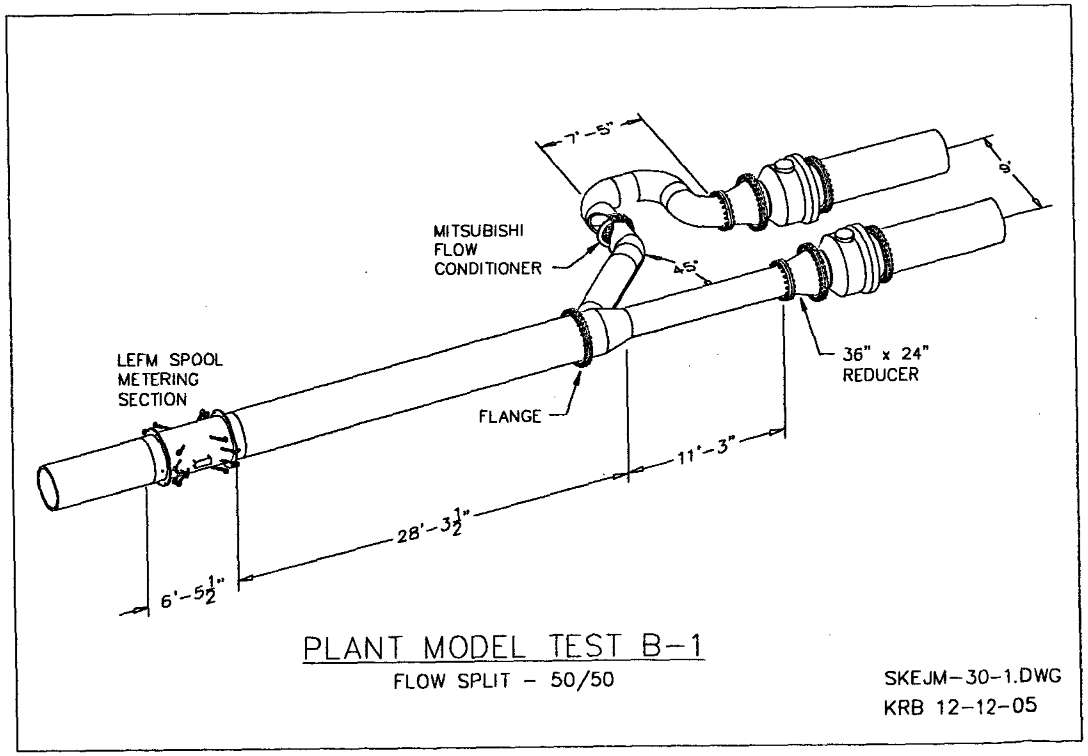


1.1 Laboratory Testing

- 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

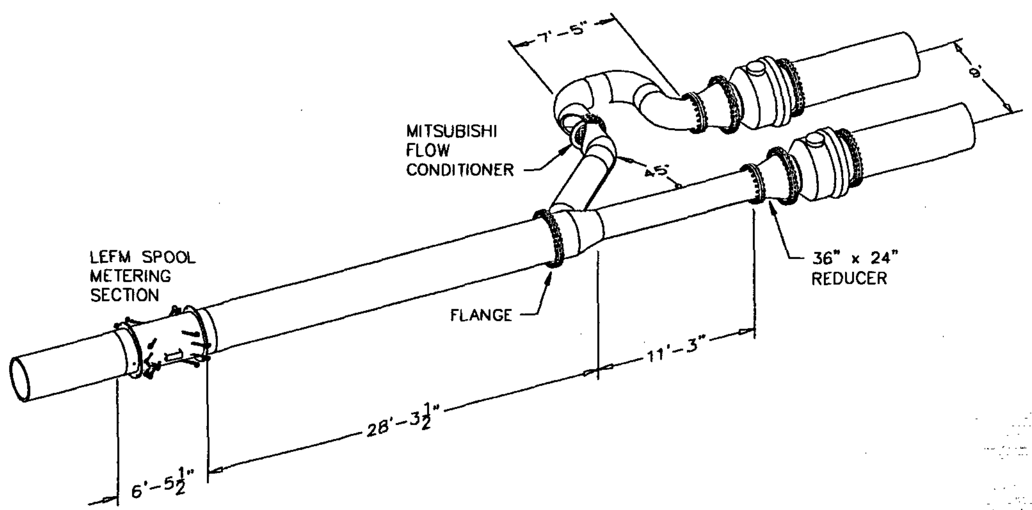
1.1 Laboratory Testing
A description of the test configurations

- Test B-1 Reference configuration
  - 50-50 Flow split
  - 25 weigh tank runs; 5 flow rates over a ~4:1 range of flows



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

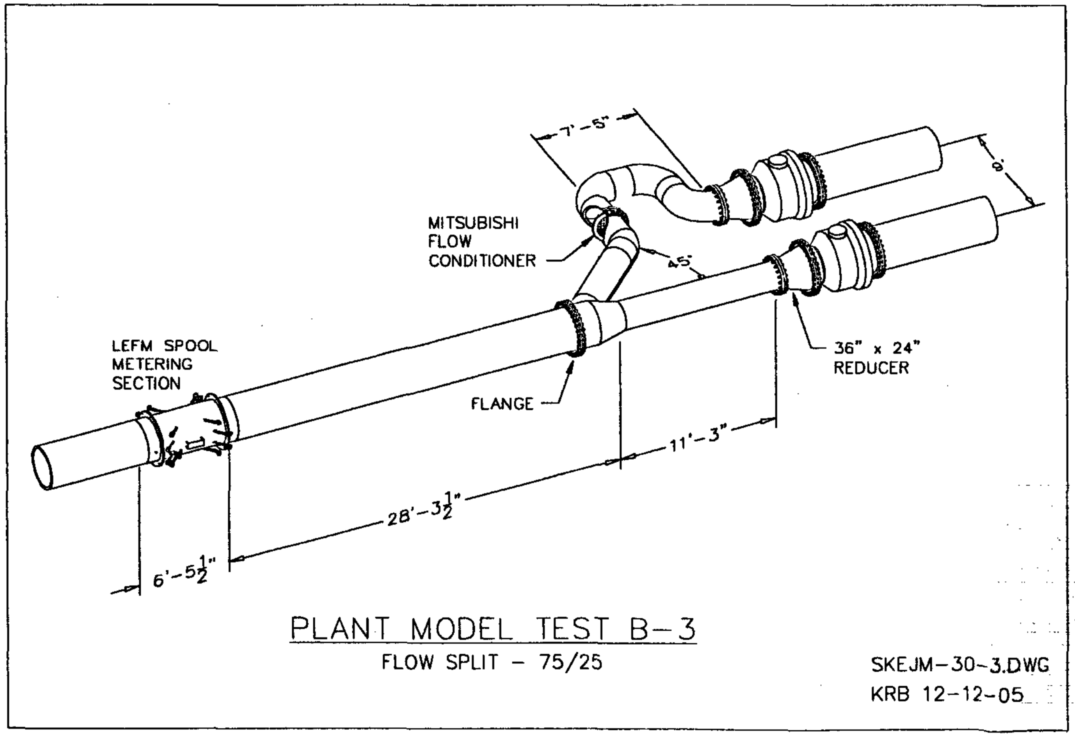


PLANT MODEL TEST B-2
FLOW SPLIT - 25/75

SKEJM-30-2.DWG
KRB 12-12-05

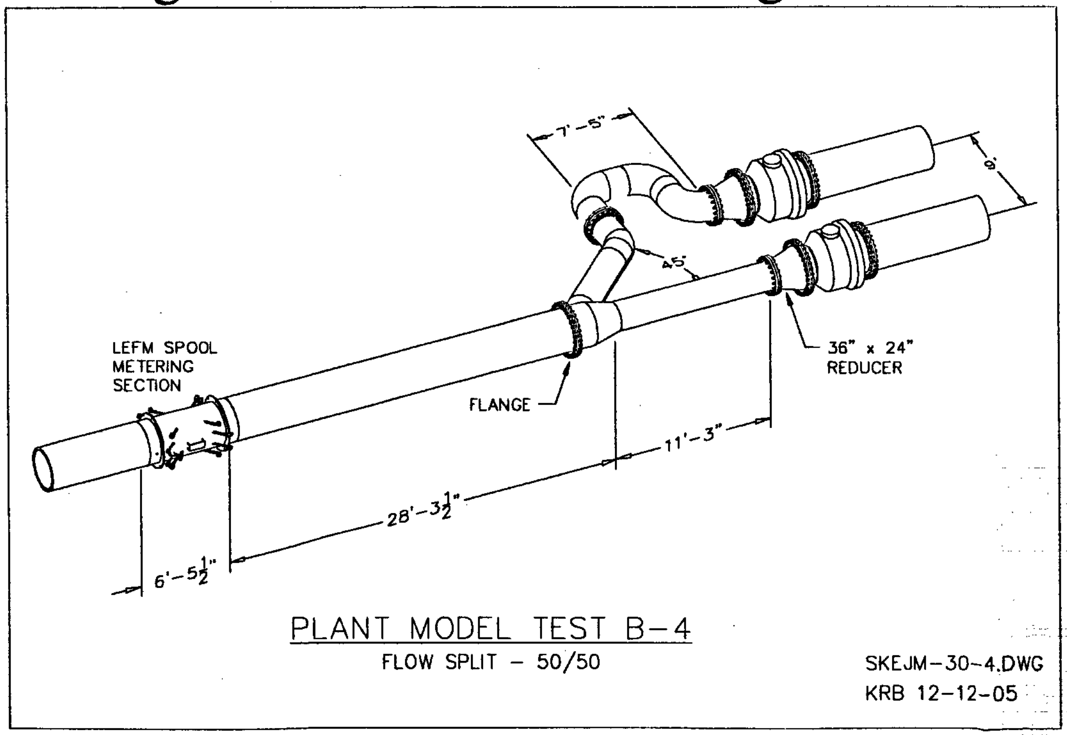
1.1 Laboratory Testing
A description of the test configurations

- Test B-3 Maximum branch flow
  - 75-25 Flow split
  - 15 weigh tank runs; 3 flows over a ~2.5:1 range of flows



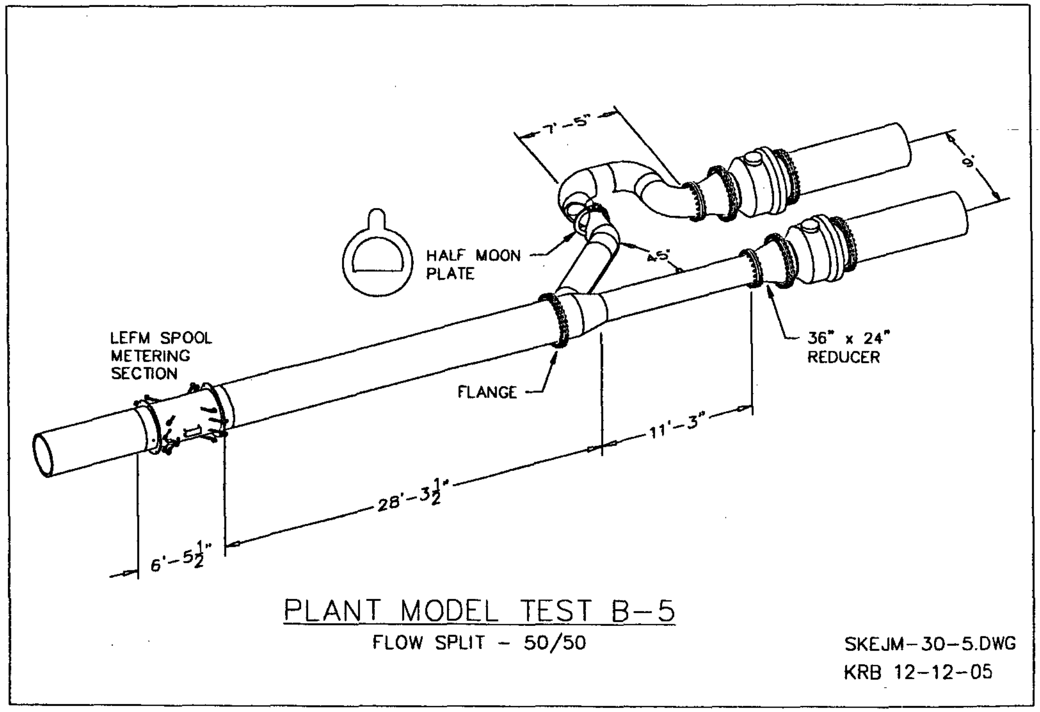
1.1 Laboratory Testing
A description of the test configurations

- 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



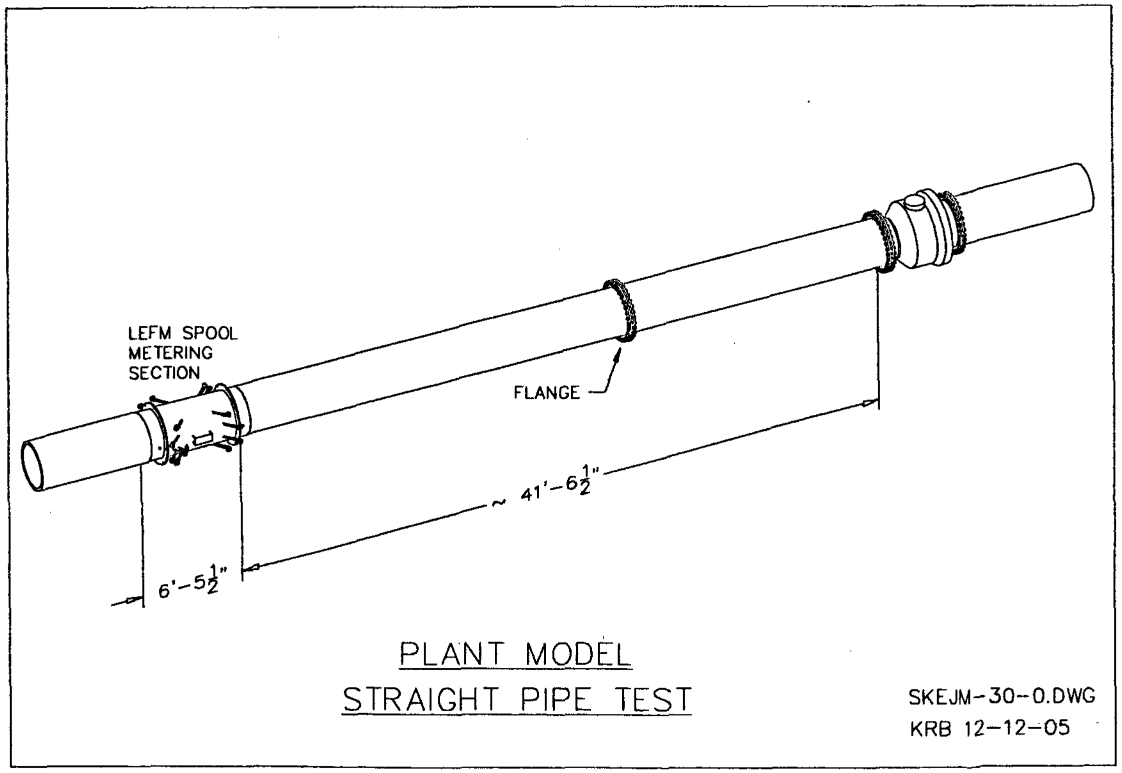
1.1 Laboratory Testing
A description of the test configurations

- 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



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



1.2 Laboratory Testing
Description of supporting analyses

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

- 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.

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)*

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

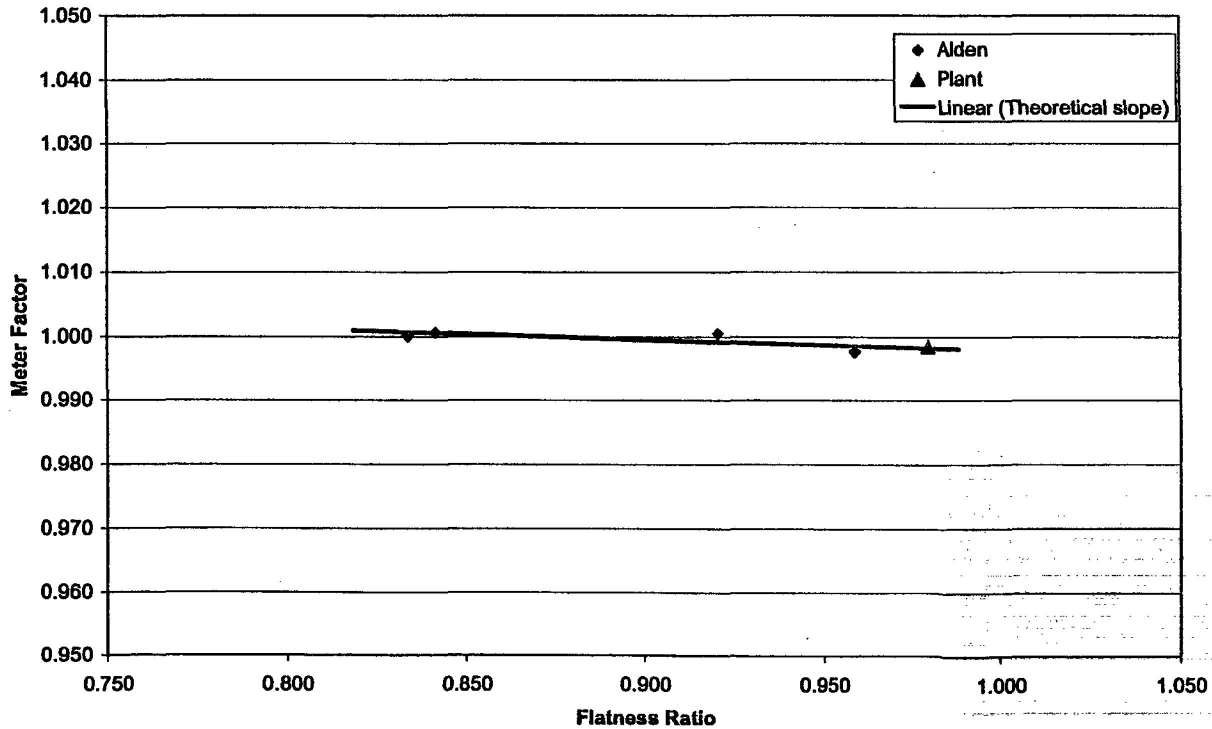
1.3 Laboratory Testing
Summary of data from each lab test

- 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

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



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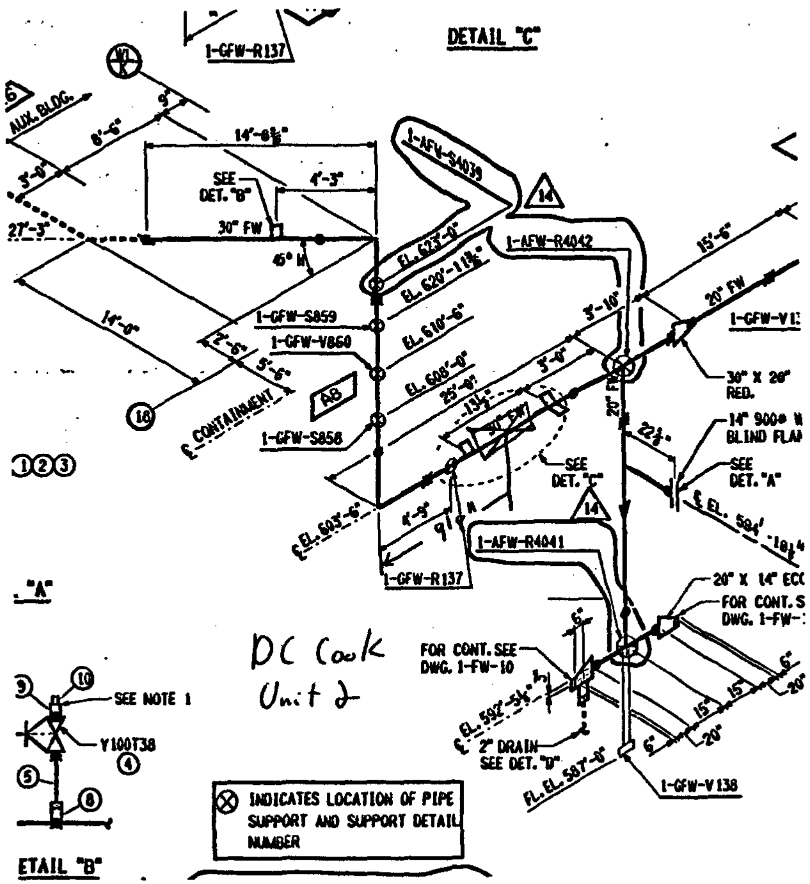
1.3 Laboratory Testing
A summary of data from each lab test

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



1.4 Laboratory Testing
Noise Issues

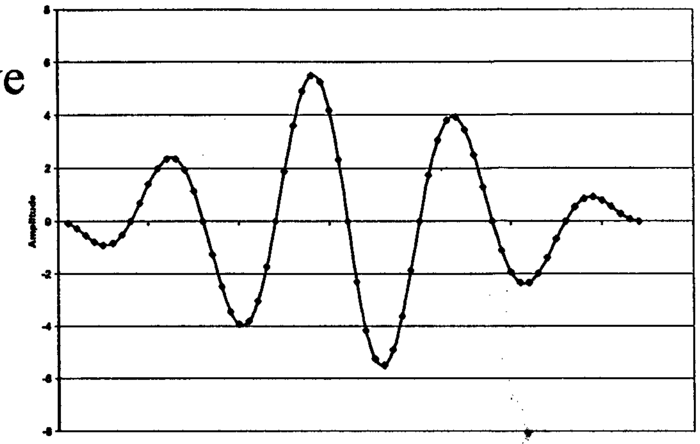
- CIB 110 *(Reference Tab 4 of INFO 18)*, was issued on September 2003 analyzing the effects of hydraulic noise and vibrations on chordal LEFMs
  - LEFM Receiver pass band (700 kHz to 3 MHz) is above mechanical vibration frequencies of piping systems
  - Pressure pulsations can cause sound velocity variations but effects on LEFM less than 0.05%, bounded by uncertainty allowance for turbulent velocity variations

- 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 <u>must be controlled if the instrument is to remain within its design basis</u>

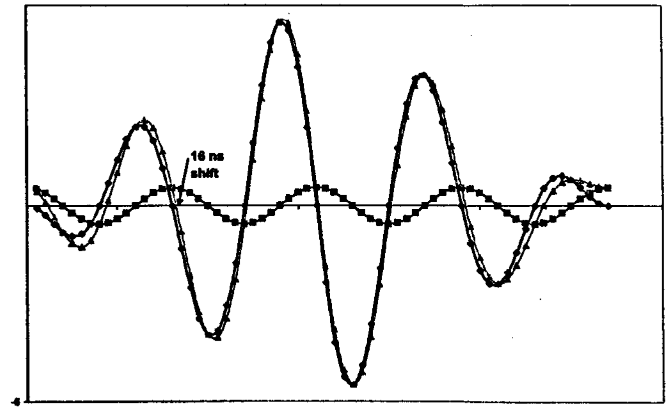
1.4 Laboratory Testing
Noise Issues

- 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

  Max Δt error = (1/SNRC)x(Transducer Period)/π
- 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



SNRC ~6, 1.6 MHz Transducers



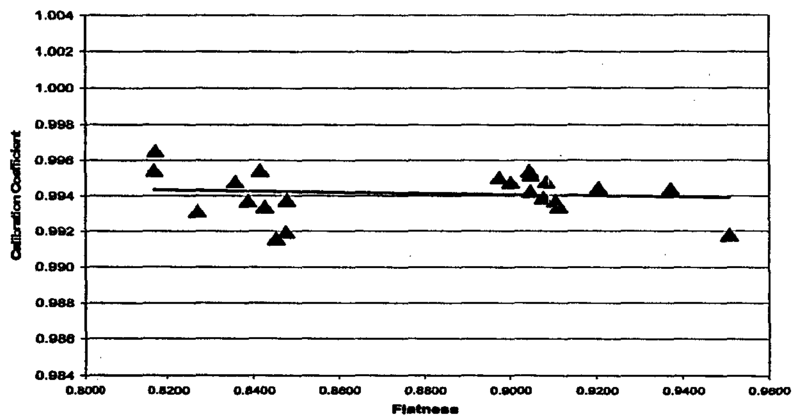
1.4 Laboratory Testing
Noise Issues

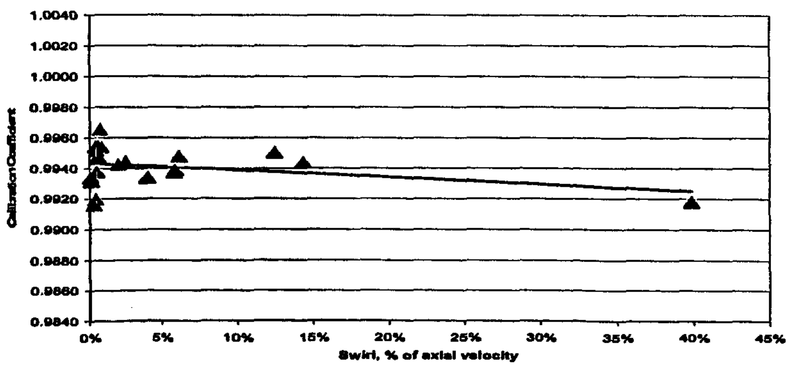
- Coherent noise as well as other potential sources of time measurement errors must be monitored in the lab tests as well as in the plant to ensure that
  a) This source of uncertainty in the Profile Factor determination is appropriately bounded
  b) Time measurement errors in the plant flow determination 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

1.5.1 Laboratory Testing

Application of Lab Test Results to Plant; Swirl

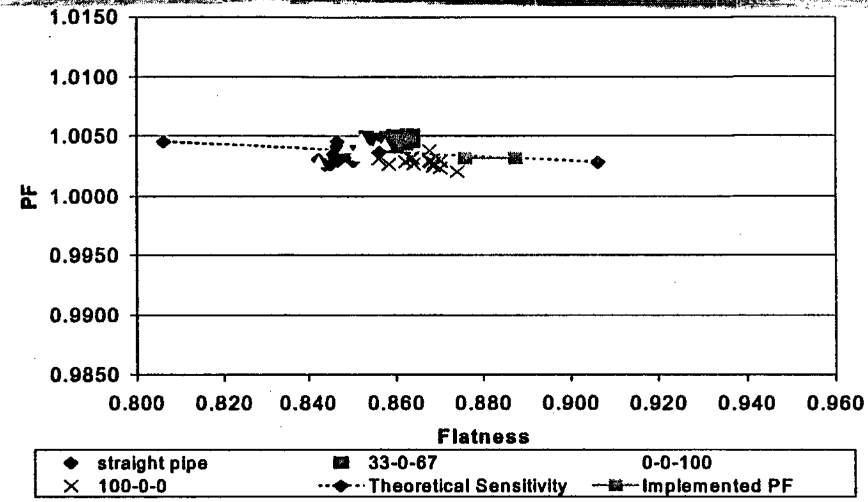
- On one occasion, the calibration of an LEFM CheckPlus was questioned after installation. The calibration tests had failed to model non planar upstream features. Consequently the swirl in the plant was greater than that in the model. A new calibration test was performed using a 16 inch prototype CheckPlus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

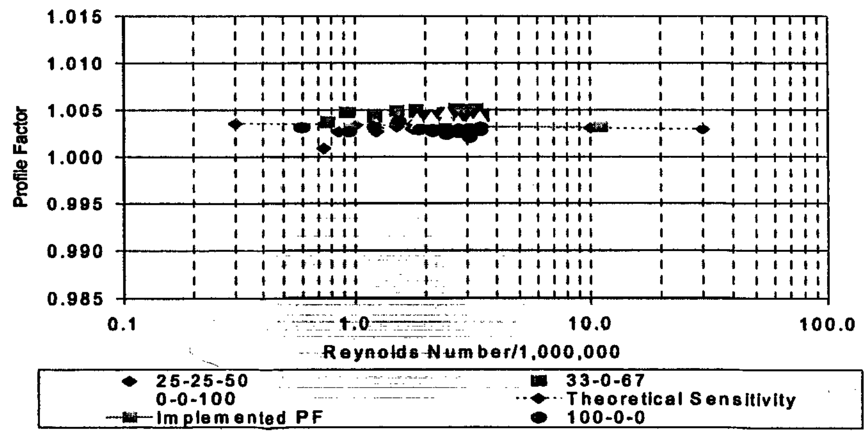




1.5.2 Laboratory Testing
Application of Lab Test Results to Plant

- 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





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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

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)

- 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

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- 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

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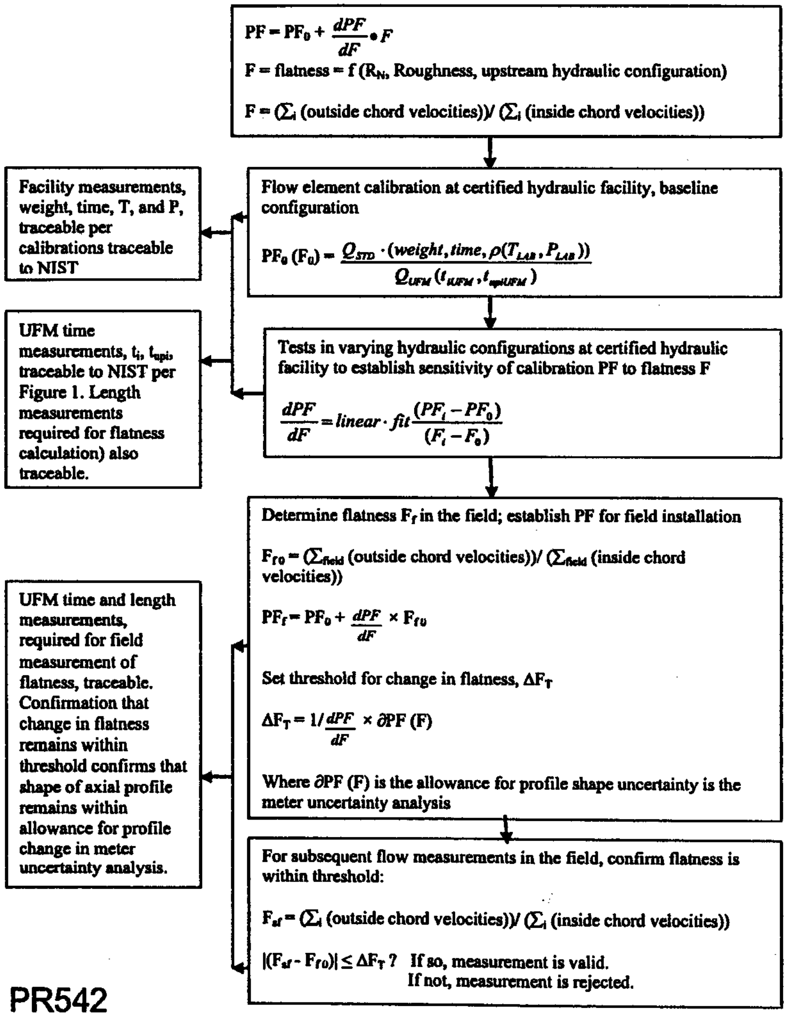

The diagram opposite, extracted from the paper, illustrates the traceability of the calibration data (profile factor) as applied in the plant – TP76

(Reference Tab 7 of INFO 19)

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2. Plant Installation
2.1 Specification for the UFM

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- 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

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Seabrook Nuclear Power Station

Specification S-X-1-E-0128
Rev. 00
Ultrasonic Feedwater Flow Metering System

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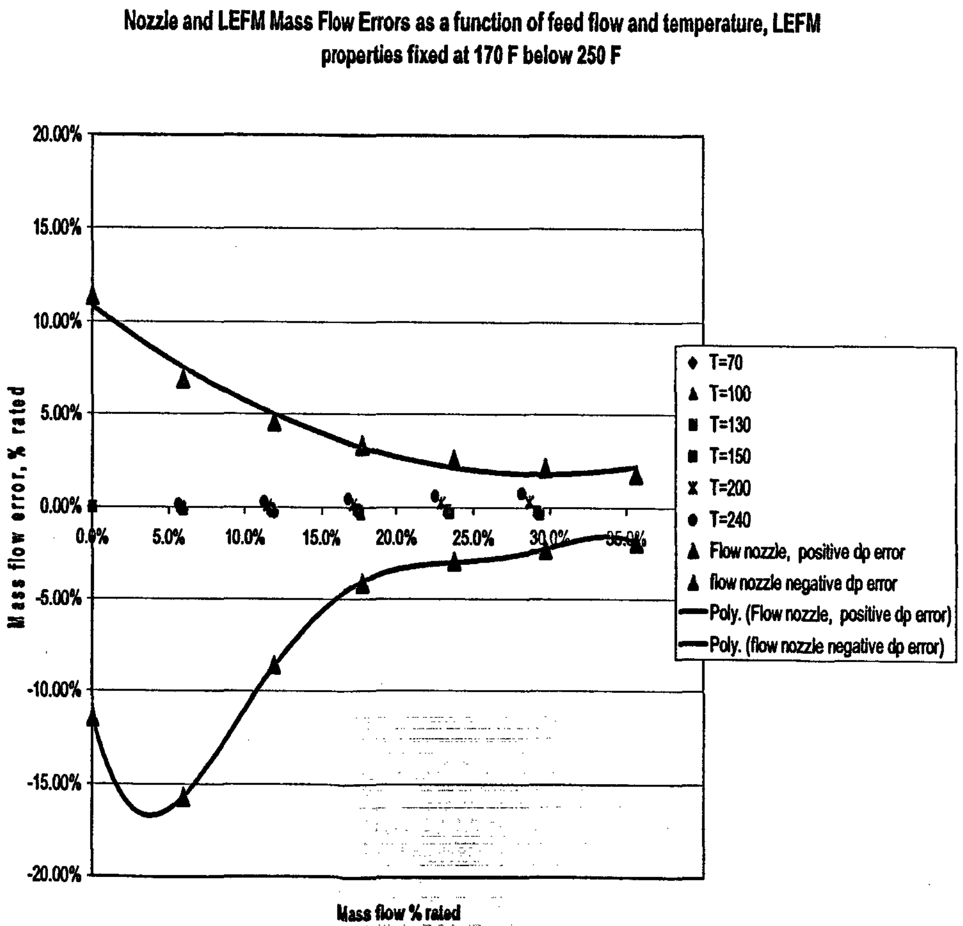
2. Plant Installation

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



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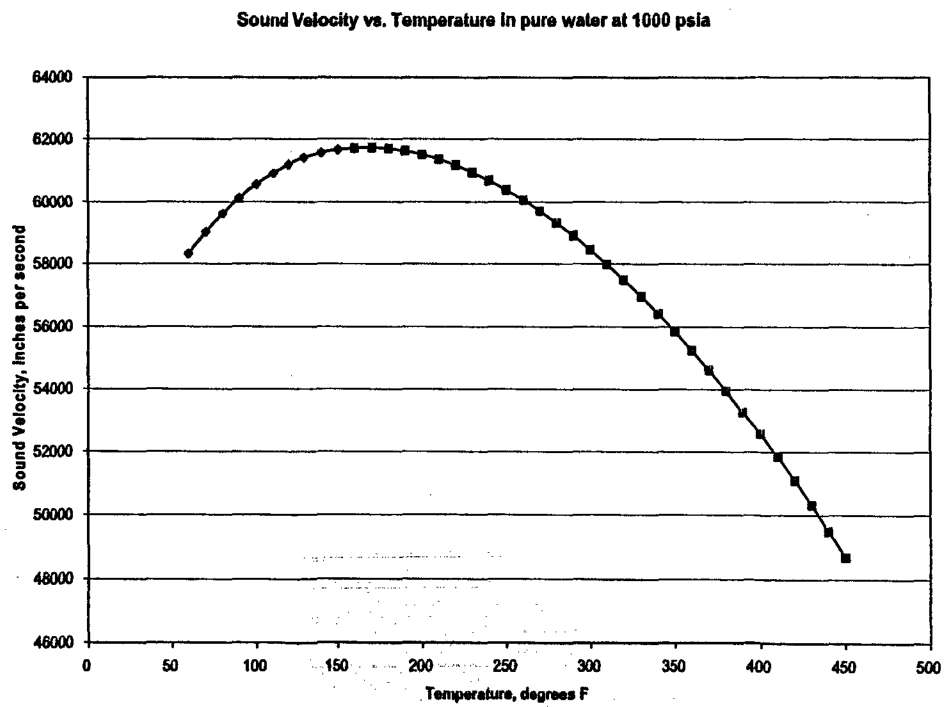
2. Plant Installation

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



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

2. Plant Installation

2.3 Description of Feedwater System

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

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

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
  - 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

2.3.3 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

Conclusion: No plausible bypass paths

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
- 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

2.6 Comparison and Evaluation of Lab 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

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

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

2. Plant Installation

2.6 Comparison and Evaluation of Lab 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.

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 ±0.1%

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

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.

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 ±0.1% accounted for modeling uncertainty covers this effect for LEFM CheckPlus Systems

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.
  - 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

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

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

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

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)*

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.

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 ~ ±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.

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

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°).

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

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

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

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

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 UFMs and venturies provide additional feedwater flow indication
- Evaluating additional "best-estimate" methods, including River Bend method

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

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

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

FPL Energy
Seabrook Station

Conclusions; Action Items

CALDON NUCLEAR

- Open Discussion