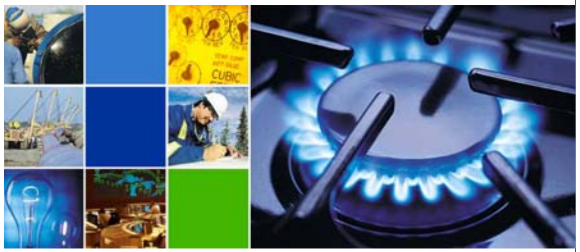

Improved Inspection and Assessment of Pipeline Welds

Advanced Welding and Joining Technical Workshop

David Horsley
Boulder CO
January 25, 2006

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Outline

Background Information
- Problem Statement
- Design Requirements

Review of welding, inspection and assessment technologies
- Current
- New
- Future

Introduction to gaps and challenges
- Weld Design
- Inspection
- Assessment

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Example Problem Statement

Build a pipeline with optimum levels of life cycle cost

- Capital – material and construction
- Maintenance – fit for purpose over long term

CAPITAL

- Materials/Grade
- Construction Efficiency
  - productivity and repair rate
  - Installation loads

•Mat'l availability & cost
•Labor rates
•Project size
•Equipment costs

MAINTENANCE

- Response to loading events

Project Specific Choices!

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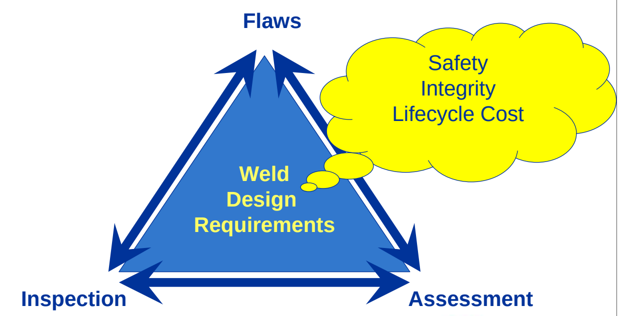
Design Requirements



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Inspection and Assessment is with reference to Weld Flaws. All three should be considered together for a comprehensive design. For example, a particular welding system and bevel is designed to give certain weld properties and to have good weldability and thereby avoid flaws.

Current Technologies – Widespread Implementation

Welding	Inspection	Assessment
•SMAW •FCAW •Mechanized GMAW	•Radiography •Manual UT •Automated UT •Mag Particle •Dye Penetrant	•Workmanship Standards •ECA Standards for Stress Based Design

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These technologies are used worldwide.

New Technologies – Limited / Recent Implementation

Welding	Inspection	Assessment
•Multi-wire Mechanized GMAW •Tandem •Dual Tandem •Advanced Welding Systems •Position-based Parameters •Digital QA/QC Communications	•Automated UT using Phased Arrays •Improved AUT Interface •Phased Arrays for sleeves and branch connections	•ECA Methods (often company specific) for Severe Loading •Strain •Cyclic •ECA Standards for Severe Loading •DNV •(CSA Z662-07)

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Welding:

Advanced systems give much greater control of welding parameters, and provide more information than was previously available.

Inspection:

Phased arrays offer the potential to account for variability not previously tolerated. Modern software provides easy to visualize and interpret information to the operator.

Assessment:

Current codes are not addressing industry needs (eg. API 1104 Appendix A). Companies will often implement their own assessment methodologies to address known deficiencies, particularly with respect to more severe conditions such as strain based loads

Future Technologies

Welding	Inspection	Assessment
•Adaptive/Intelligent GMAW Welding Systems •LAZER Assisted GMAW •Stand Alone LAZER •Friction Stir Welding	•Enhanced Phased Array UT •Improved Visualization and Interpretation Interface •Intelligent Systems	•Improved ECA Predictions •Reliability Based Design and Assessment

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The previous presentation by Nate Ames showed several technologies that will change the way that mechanized GMAW welding systems are/or will be controlled:

-Real-time adaptive control

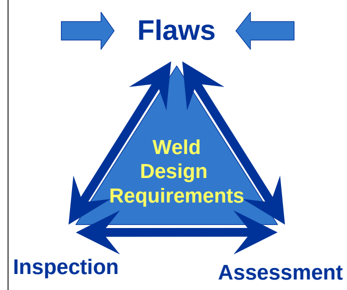
-Single sensor differential thermal anhalysis

-Audible noise

Phased array systems are at infancy stage of development. Technologies borrowed from medical and geophysics/seismic industries will be adapted to pipeline weld inspection. They have the potential to account for, and adapt to, many of the problems we see in current systems (e.g. temperature, acoustic velocities, misalignment, etc.) and give much better POD, resolution and accuracy, and do much of the interpretation currently left to the UT operator.

As our modeling capabilities advance, and we extend our database of experimental tests, we will have much deeper understanding of the influences of the various parameters on the overall integrity of the welds. By developing tools specifically tailored to reliability based methods will be key inputs to the overall RBDA methodology. RBDA will provide a means to appropriately design pipelines to ensure a minimum level of risk is achieved.

Design Considerations



Weld:
- Pipe Properties
- Process, Consumable, Procedure+
- Weld / HAZ Properties

Inspection:
- Probability of Detection
- Accuracy and Precision

Assessment:
- Variability of Loads and Properties
- Accuracy of Prediction
- Safety Factor

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Weld Flaw Considerations

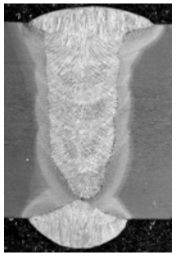
Fitness for service depends on:

- Weld/HAZ Properties
- Pipe Properties
- Loads
- Flaws

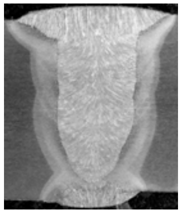
All are Variable:

- Weld/HAZ Strength and Toughness – Procedure, fit-up, o'clock, preheat & inter-pass temp., weld/weld
- Pipe Strength and Toughness – Heat to heat, o'clock, along length, pipe/pipe
- Loads – Installation, service conditions, o'clock, location on ROW
- Flaws – Length, height, depth, o'clock

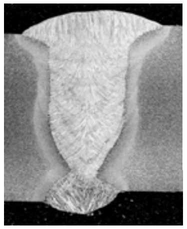
Procedure Variation



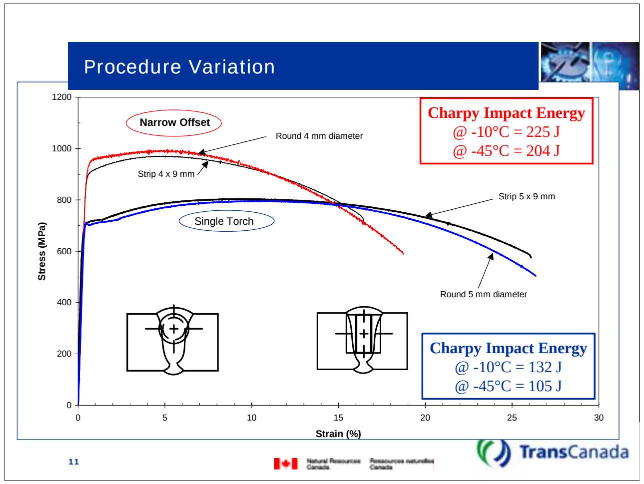
Single Torch Narrow Offset
15.3 mm W.T.



Single Torch
14.3 mm W.T.

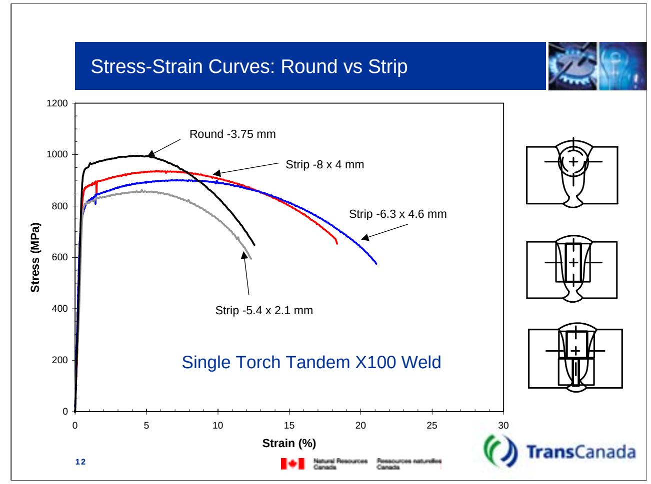


Single Torch Tandem
13.4 mm W.T.



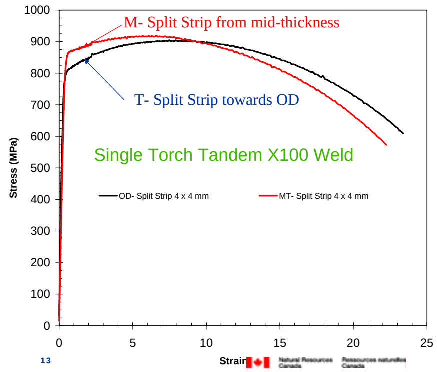
This slide shows that very different properties can be achieved with only slight changes to the width of bevel.

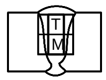
Slight differences are seen due to round as compared to rectangular specimen types.



This slide shows several test results from the same weld, but using different specimen types.

Stress-Strain Curves-Split Strip





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This slide shows differences in properties at different locations in the through-wall direction.

The important message from these curves is that welding parameters, sample location, and specimen type all have effects on the resulting stress strain curve. Because material properties are a key input into flaw assessment, it is extremely important to understand the effect of so-called "essential variables."

Weld Challenges and Gaps

Challenges

- What are the weld and HAZ properties?
- How to measure properties?
- How do these properties vary?
- What causes the variation and how can it be controlled?

GAPS

- Need standard procedures for measuring properties
- Need guidance on quantifying variation for a "given" procedure
- Need to understand "essential variables" with respect to the level of assessment

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Inspection

- Probability of Detection
- Accuracy and Precision
  - Appropriate to Design Requirements

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Automated Ultrasonic Inspection

In the context of Flaw Assessment - Inspection System Must:

- Detect flaws
- Determine height
- Determine length
- Determine position in WT

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Ultrasonic Testing

- Detection depends on reflection of sound waves
- Typically use probes that focus sound on target area
  - Degree of focus depends on design of lens
- Strength of reflected wave depends on many factors
  - Size of reflector (flaw)
  - Shape
  - Orientation
  - Position
- System must accommodate:
  - Wide range of temperatures
  - Variable acoustic properties

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Automated Ultrasonic Inspection

Two "philosophies" for sizing in common use:

1. Full Zone Height Assumption
2. Amplitude Based

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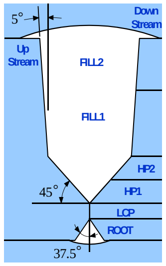
Full Zone Height Assumption:

The weld bevel is divided into numerous zones, and each zone is interrogated by a dedicated ultrasonic probe. If a signal stronger than the calibrated threshold is detected on that probe, the flaw is assumed to be the full height of that particular zone. Adjacent channels are examined to determine if the flaw is located across two or more zones. And again, if a signal is present the flaw is assumed to lie within that entire zone. No attempt is made to size the flaw on the basis of signal strength.

Amplitude based sizing:

The weld bevel is divided into zones (but typically fewer than described above). Signals above threshold strength are interpreted, and an estimate of flaw height is made on the basis of signal strength.

Full Zone Height Assumption



- Weld bevel is divided into many zones
- One UT channel assigned to each zone
- Flaw is assumed to be the full height of the zone if signal is above threshold

- Advantage:
  - Easy interpretation
- Disadvantage
  - Numerous probes required

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Amplitude Based Sizing

- Weld bevel is divided into zones
- One UT channel assigned to each zone
- Signal is manually interpreted to estimate flaw height based on strength of signal

- Advantage:
  - Fewer probes required
- Disadvantage:
  - Operator dependent
  - Size uncertainty
  - Requires time for interpretation

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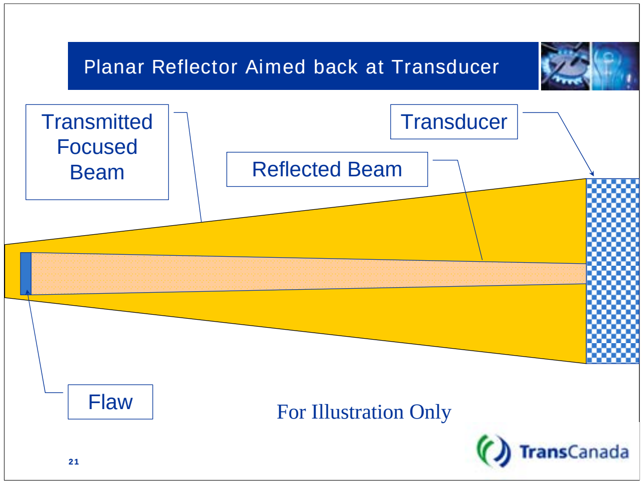
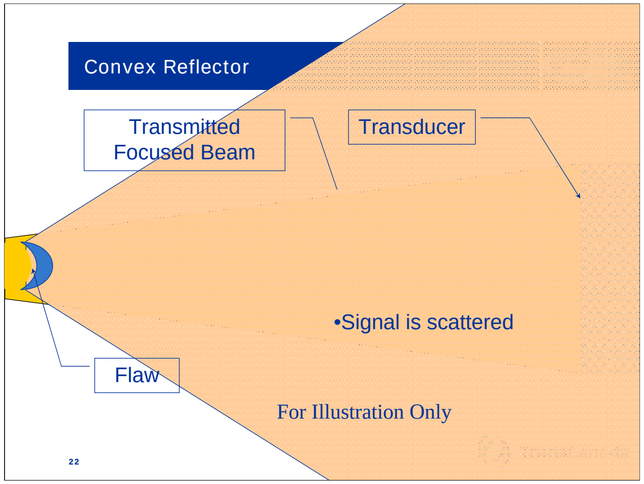
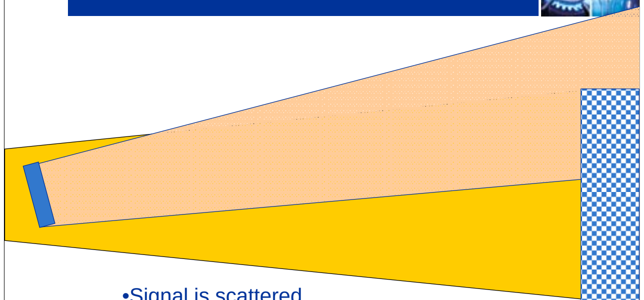


This “cartoon” is for illustration only. It illustrates a flaw located at, and slightly smaller than, the target area. The flaw is a “good” reflector, and therefore a good strong signal is received back at the transducer.



This slide illustrates a flaw of the same size as the previous slide, however it is a poor reflector and the signal is scattered. It is impossible to determine the size of the flaw on the basis of amplitude based sizing. The scattering is exaggerated, but it shows the concept.

Tilt or Skew



•Signal is scattered

For Illustration Only

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This slide illustrates a flaw of the same size as the previous two slides, however it is angled slightly off of the ideal oriented . Although it is a good reflector, the reflected beam is not aimed directly at the receiver. It is impossible to determine the size of the flaw on the basis of amplitude based sizing.

Inspection Challenges and Gaps AUT

Challenges

- Numerous options available in design and setup of system
- Accuracy in sizing – adding error allowance can be a large penalty for strain based design
- How to account for human factor in assessment
- Perceptions within industry
- Alternative Integrity Validation (no construction hydrotest)

GAPS

- Need standard procedures for design of system
- Need guidance on quantifying accuracy and precision reliability
- Qualification of operators

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Assessment

- Many new advances in weld flaw assessment:
  - Modeling and Experimental Capabilities
- Implemented through:
  - Stress based standards
    - API 1104 Appendix A currently being revised
    - CSA Z662-03
  - Strain based standards
    - CSA Z662-07 in draft
    - DNV OS F101

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Stress-Based Assessment

Challenges:

- Measurement of pipe/weld/HAZ properties
- Accounting for variability
- Geometric variability
  - High/Low
- Defect interaction rules poorly defined
- Quantification of appropriate safety factors

Gaps:

- Need better understanding of essential variables in weld procedure
- Need to quantify high/low effect
- Need to quantify flaw interaction

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Strain-Based Design Assessment

Challenges:

- All challenges from stress based design
- Extra sensitivity to flaw size accuracy
- Appropriate toughness measurement
- Tolerable flaw size may be difficult for some welding systems

Gaps:

- All gaps from stress based design
- Need low constraint small specimen toughness test standard
- Need Reliability Based Design and Assessment standard

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A long term view….

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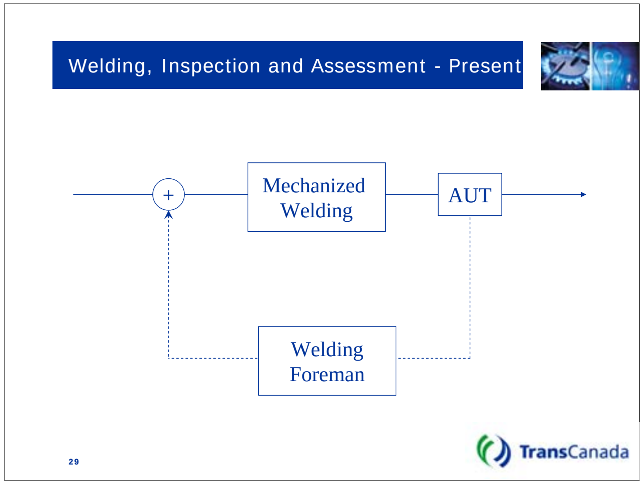
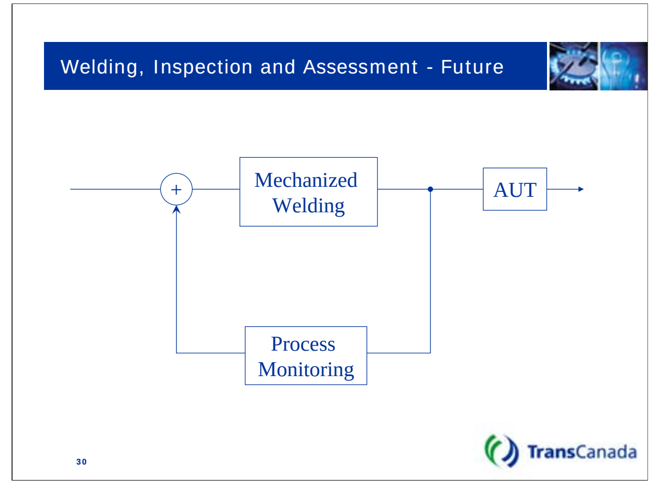
These next few slides represent what may be possible over the next 10-15 years.

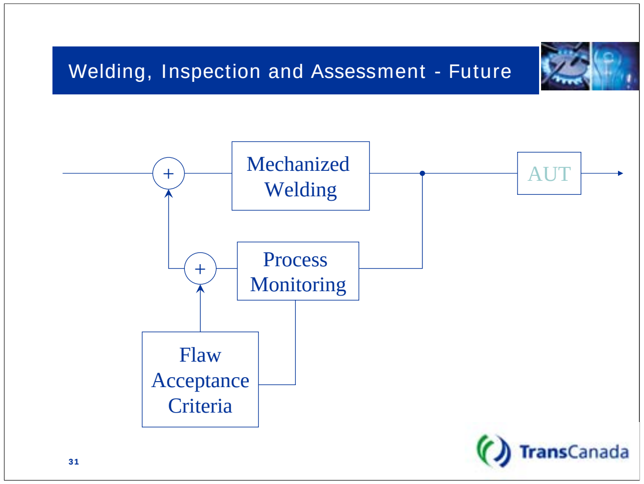


These next several slides utilize the concept of a closed-loop feedback system.

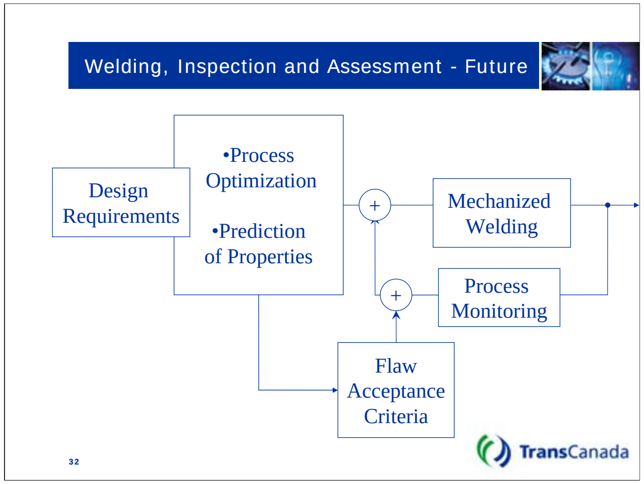
Today, on most pipeline projects utilizing mechanized welding and AUT, the welding foreman frequently visits the AUT shack. He obtains inspection data on the last few welds, including which side of the pipe the flaws lie, and their location with respect to the wall thickness. He uses this information to determine which pass and welding operator is responsible for the flaw. He investigates the problem with the welding operator, thus completing the feedback loop.



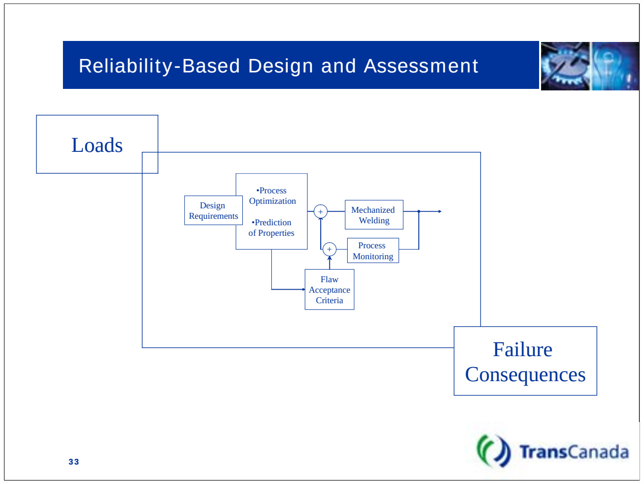
So-called intelligent welding systems are already in use in other industries. They make use of data collected during the making of the weld to self-correct the process, and thereby avoid creation of large flaws.



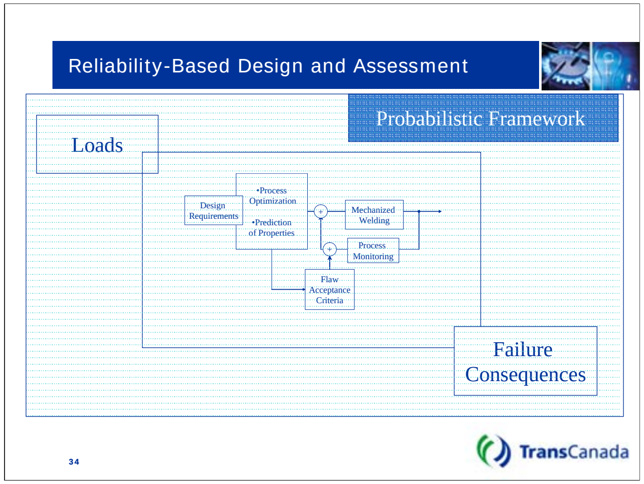
If the data from monitoring the weld process is interpreted to determine if flaws are present, then the flaws can be compared to the flaw acceptance criteria to determine if a repair is necessary. The AUT remains, but is only a secondary validation that defects are not present.



A current PRCI/DOE project is expected to deliver enhanced tools for the prediction of microstructure and material properties on the basis of the welding process. The inputs are material compositions, welding parameters. This could be used for optimization of the welding process and initial material selections, to meet project specific pipeline design requirements. In the context of on-line assessment this technology could be used to predict materials properties, and these could be fed into the flaw assessment routine. Of course each of these predictions and processes are subject to variation and scatter. However…



… if the loads and failure consequences are defined…



… in terms of statistical variations, the entire design can be incorporated into a probabilistic framework. Weld flaw inspection and assessment will form only one part of the overall pipeline Reliability Based Design and Assessment.

This may seem like a bold long term objective, as it requires numerous tools to come together. Some of the technologies are new to the pipeline industry, and others will rely on intensive computation capabilities, i.e. on-line prediction of properties and tolerable flaws being fed into the welding control system. However, remember where we were fifteen years ago; it was rare to have PC on our desk, cell phones, or PDA's.

Reliability Based Design and Assessment:

•Quantifies the reliability for all relevant "failure" conditions (limit states)

•Takes into account all mitigation measures:

- •Pipe material and geometric – e.g. grade, WT
- •Inspection – e.g. AUT, ILI, ROW surveillance
- •Protection – burial

•Adaptable to include unique design conditions and new technology

•Optimization of combined design, construction and maintenance programs to achieve acceptable reliability/risk levels

This is a very important goal for the pipeline industry, as project economics and pipeline operation and maintenance can be greatly improved by use of this integrated tool. It allows resources to be allocated to where they are most effective in improving pipeline integrity and economics.