SUB SECTION 6

REPORT 4

POP Project Meeting
March 2, 2001

Performance of Offshore Pipelines Project

P.o.P

Performance of Offshore Pipelines Project

A Joint Industry Project

POP Project Meeting

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March 2, 2001
Houston, Texas

POP Project Meeting Notes: Outline

- Project Objectives
- MSL Engineering Database Analysis
- Burst Pressure of Pipeline 25 Analysis
- Appendix
  - References
  - Literature Reviews
  - Database Analysis for Bias (supplemental information)
  - Pipeline 25: Burst Pressure Prediction (supplemental information)

POP Project Objectives (U.C. Berkeley)

- Before pipeline inspection & testing phase
  - Review pipeline design and service information
  - Develop corrosion prediction for pipelines
  - Predict burst pressure for pipelines (intact, corroded, deterministic, probabilistic)
- Document results

POP Project Objectives (U.C. Berkeley)

- During pipeline inspection & testing phase
  - Observe field & lab testing
  - Review results from field & lab testing
    - In-line instrumentation results
    - Hydro-testing results
    - Material testing results
- Document results

POP Project Objectives (U.C. Berkeley)

- After pipeline inspection & testing phase
  - Revise corrosion model
  - Perform burst pressure hindcasts
  - Reconcile predictions
  - Revise bust pressure models as necessary (deterministic, probabilistic)
- Document results

POP Research (May 2001)

- Review Work Completed:
  - Tasks completed through December 2000:
    - Literature reviews
    - MSL database analysis for Bias
    - Burst pressure prediction(intact, for un-instrumented pipeline 25)
  - Tasks to be completed through May:
    - Burst pressure prediction(corroded, for un-instrumented pipeline 25, deterministic, probabilistic)

Analysis: MSL Database

- MSL Engineering's database: analysis for Bias:
  - MSL Engineering's database of corroded pipelines was analyzed
    - MSL Engineering's database: a database containing burst pressures of over 500 corroded pipelines
  - Analysis objective: calculate the bias from the MSL database

Analysis: Definition of Bias

$$Bias = \frac{Actual\ Burst\ \Pr essure}{\Pr edicted\ Burst\ \Pr essure}$$

Analysis: Screening of the Database

- More than 500 burst tests of corroded pipelines.
  - For a given data point, there was often missing information (e.g. material strengths, depth of corrosion, corrosion, actual burst pressure)
- Database screened (not included in the analysis for for bias), when any of the following criteria were missing: depth or length of corroded area, actual pipeline burst pressure.
- Data was further screened to exclude test data that that included imposed loading states, and test data data based on finite element simulations.

Analysis: Screened Database

	Pipeline Characteristics						Corrosion		
Sequence		Diameter, D	*Wall Thickness, t*	*Material Grade*	SMYS	SMTS	Length	Depth	
Number	TYPE	Inches	Inches		PSI	PSI	Inches	Inches	d/t
390	Test	48	0.462	X65	65000	71800	6	0.231	0.50
391	Test	48	0.462	X65	65000	71800	6	0.231	0.50
392	Test	48	0.462	X65	65000	71800	6	0.231	0.50
393	Test	48	0.462	X65	65000	71800	6	0.231	0.50
394	Test	48	0.462	X65	65000	71800	30	0.0693	0.15
395	Test	48	0.462	X65	65000	71800	6	0.231	0.50
396	Test	48	0.462	X65	65000	71800	30	0.231	0.50
397	Test	48	0.462	X65	65000	71800	15	0.0693	0.15
398	Test	48	0.462	X65	65000	71800	15	0.0693	0.15
399	Test	48	0.462	X65	65000	71800	15	0.2079	0.45
400	Test	48	0.462	X65	65000	71800	15	0.0693	0.15
720	Test	30	0.37	X52	52000	68400	2.5	0.146	0.39
721	Test	30	0.37	X52	52000	68400	2.25	0.146	0.39
722	Test	24	0.365	X35	35000	50800	3	0.271	0.74
723	Test	24	0.365	X35	35000	50800	4.75	0.251	0.69
724	Test	24	0.37	X35	35000	50800	1.75	0.261	0.71
725	Test	30	0.375	X52	52000	68400	1.6	0.209	0.56
726	Test	20	0.325	X35	35000	50800	5.75	0.209	0.64
727	Test	20	0.325	X35	35000	50800	6.5	0.219	0.67
728	Test	16	0.31	X25	25000	38300	4.5	0.23	0.74
729	Test	16	0.31	X25	25000	38300	5	0.24	0.77
730	Test	16	0.31	X25	25000	38300	2.75	0.272	0.88

Analysis: pipeline equations

- ASME B-31G:

$$P' = 1.1P\left[\frac{1-\frac{2}{3}\left(\frac{d}{t}\right)}{1-\frac{2}{3}\left(\frac{d}{t\sqrt{A^2+1}}\right)}\right] \qquad A = 0.893\left(\frac{Lm}{\sqrt{Dt}}\right) \leq 4$$

Where:

P’ = safe maximum pressure for the corroded area

Lm = measured longitudinal extent of the corroded area, inches

D = nominal outside diameter of the pipe, inches

t = nominal wall thickness of the pipe, inches

d = measured depth of the corroded area

P = the greater of either the established MAOP of P = SMYS*2t*F/D

(F is the design factor, usually equal to .72)

Analysis: pipeline equations

- DNV RP-F101, Equation 7.2:

$$Pf = \frac{2 \cdot t \cdot UTS\left(1-(d/t)\right)}{(D-t)\left(1-\frac{(d/t)}{Q}\right)} \qquad Q = \sqrt{1+.31\left(\frac{1}{\sqrt{D \cdot t}}\right)^2}$$

Pf = failure pressure of the corroded pipe

t = uncorroded, measured, pipe wall thickness

d = depth of corroded region

D = nominal outside diameter

Q = length correction factor

UTS = ultimate tensile strength

Analysis: RAM PIPE equation

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF}$$

p_{bd} = burst pressure of corroded pipeline

t_{nom} = pipe wall nominal thickness

D_o = mean pipeline diameter (D-t)

SMYS = Specified Minimum Yield Strength of pipeline material

SCF = Stress Concentration Factor = $SCF = 1 + 2 \cdot (d/R)^{.5}$

d = depth of corrosion R = Do/t

Results: Bias analysis

	ASME B-31G		DNV RP-F101		RAM PIPE	
	POP Report	MSL	POP Report	MSL	POP Report	MSL
Median	1.52	1.4	1.48	1.72	1.0	N/A
Mean	1.53	1.49	1.73	1.78	0.91	N/A
Std. Dev.	0.55	0.35	0.98	0.27	0.31	N/A
COV	0.36	0.23	0.57	0.15	0.34	N/A

Results: Bias analysis

- Possible reasons for existence of equation biases:
  - ASME B31G: Imperfect application
    - Predicts safe operating pressures
  - DNV RP-F101:
    - Equations developed based on machined defects
      - Machined defects create higher SCFs relative to electrochemically formed defects; as equation accounts for higher SCFs, conservatism is introduced into the equation.
      - Conservatism is quantified by the bias calculation

Analyses Overview: pipeline 25 burst pressure analyses

- Intact, deterministic
- Intact, probabilistic
- Corroded, deterministic
- Corroded, probabilistic

Analysis: predicted burst pressures of pipeline 25- characteristics of pipeline

Pipeline 25 Characteristics: (as of 2/18/01)				
	Diameter, D	*Wall Thickness, t*	*SMYS*	*SMTS*
	Inches	Inches	ksi	ksi
Main Section (9200 ft.)	8.63	0.5	42	52
Riser Section (100 ft.)	8.63	0.322	42	52
Other Information:				
ANSI 900 System				
Material Type: Grade B steel				
Length of Time in Service: 22 years (1974-1996)				
Location: Gulf of Mexico				
Assume: 1) Zero External Corrosion on Riser (mastic coating)				
2) Known values of SMYS and SMTS				

Analysis: predicted burst pressures of pipeline 25- characteristics of pipeline

1” thick mastic coating

WC171B Satellite Platform

Analysis: predicted burst pressures of pipeline 25- characteristics of pipeline

Riser/Flange at +10 deck of WC171A

1” thick mastic coating below clamp

Analysis: predicted burst pressures of pipeline 25 - intact - deterministic & probabilistic

Governing Equation (deterministic):

$$P_B = \frac{SMTS \cdot t}{R}$$

$$P_B = Burst\ \Pr essure$$

$$SMTS = Specified\ \ Minimum\ \ Tensile\ \ Strength$$

$$t = wall\ \ thickness\ \ ,\ R = Radius$$

Analysis: predicted burst pressures of pipeline 25 - intact - deterministic

Intact Pipeline Burst Pressure:

Main Section (9200 ft.)

$$P_B = \frac{SMTS \cdot t}{R} = \frac{52000\,psi \cdot .500\,in.}{4.31\,in.} = 6033\,psi$$

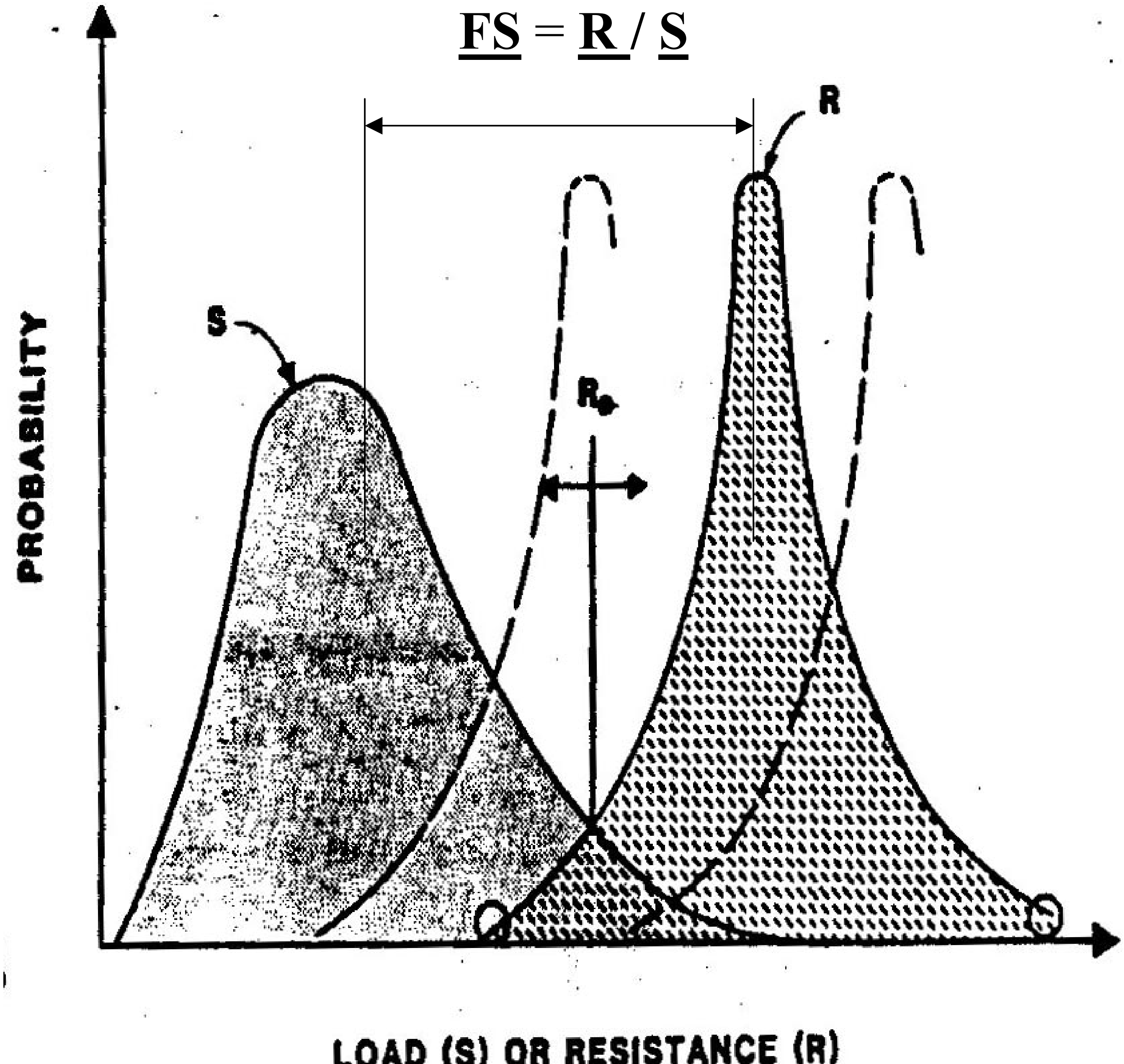
Riser Section (100 ft.)

$$P_B = \frac{SMTS \cdot t}{R} = \frac{52000\,psi \cdot .322\,in.}{4.31\,in.} = 3885\,psi$$

Analysis: predicted burst pressures of pipeline 25 - intact - probabilistic

- Burst Pressure Prediction for Pipeline 25:
  - Probabilistic Approach:
    - Calculate probability of failure

Probability of Failure
Failure



Probability of Failure

- Reliability measure: Safety Index, β
  - For log normally distributed, uncorrelated demands and and capacities:

$$\beta = \frac{\ln\left(\frac{\underline{R}}{\underline{S}}\right)}{\sqrt{\sigma_{\ln R}^{2} + \sigma_{\ln S}^{2}}}$$

where:

$\underline{R}$ = median capacity

$\underline{S}$ = median demand

$\sigma_{\ln R}$ = standard deviation of capacity

$\sigma_{\ln S}$ = standard deviation of demand

Probability of Failure
Failure

- Uncertainties associated with structural loadings and capacities:
  - Type I: natural or inherent randomness
    - E.g. Thickness of steel, yield strength of a material
  - Type II: measurement or modeling uncertainty
    - E.g. simplification of analytical models used in practice, wrong assumptions used in an analysis
- Uncertainty characterization: Coefficient of Variation(COV = standard deviation / mean value) value)

Probability of Failure

- Probability of Failure, P_f

$$P_f = 1 - \Phi(\beta)$$

$\Phi(\beta)$ = standard normal distribution cumulative probability of the variable, β

Probability of Failure: Pipeline 25, intact, mainline

Probability of Failure: Pipeline 25

New (Uncorroded) Pipeline: Mainline

Pipeline Characteristics (median values)				**Steel Material Strengths (median values)**			
Diameter, D50	$V_{D,I}$	Wall Thickness, t50	$V_{t,I}$	Yield Strength, YS50	$V_{YS,I}$	Tensile Strength, TS50	$V_{TS,I}$
Inches		Inches		PSI		PSI	
8.625	10%	0.5	12%	42000	8%	52000	8%

	Reliability Parameters			
	Uncertainty Summary		**Standard Deviation**	
	Type I	Type II	$\sigma_{\ln S}$	$\sigma_{\ln R}$
Demands, S_{50}	10%	0%	0.100	0.215
Capacities, R_{50}	19%	10%		

Distrubution Type: Lognormal

Correlation: $\rho_{rs}=0$

Loading State				**Probability of Failure**		
Uncorroded Pipeline Capacity		Pipeline Demand	$V_{S,I}$			
R_{50}		S_{50}		β	$\Phi(\beta)$	P_f
6029		6033	10%	0.00	0.4989	0.501

Note 1: Pipeline characteristics and steel material strengths are median values

Probability of Failure: Pipeline 25, intact, riser section

Probability of Failure

New (Uncorroded) Pipeline: Riser Section

Pipeline Characteristics (median values)				**Steel Material Strengths (median values)**			
Diameter, D50	$V_{D,I}$	Wall Thickness, t50	$V_{t,I}$	Yield Strength, YS50	$V_{YS,I}$	Tensile Strength, TS50	$V_{TS,I}$
Inches		Inches		PSI		PSI	
8.625	10%	0.322	12%	42000	8%	52000	8%

	Reliability Parameters			
	Uncertainty Summary		**Standard Deviation**	
	Type I	Type II	$\sigma_{\ln S}$	$\sigma_{\ln R}$
Demands, S_{50}	10%	0%	0.100	0.215
Capacities, R_{50}	19%	10%		

Distrubution Type: Lognormal

Correlation: $\rho_{rs}=0$

Loading State			**Probability of Failure**		
Uncorroded Pipeline Capacity	Pipeline Demand	$V_{S,I}$			
R_{50}	S_{50}		β	$\Phi(\beta)$	P_f
3883	3885	10%	0.00	0.499	0.501

Note 1: Pipeline characteristics and steel material strengths are median values

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

- Loss of wall thickness due to internal corrosion:

$$tc_i = \alpha_i \cdot \nu_i \cdot (L_s - L_p)$$

Source: (Bea, et.al., OTC, 1998)

where:

tc_i =loss of wall thickness due to internal corrosion

α_i =effectiveness of the inhibitor or protection

ν_i=average corrosion rate

L_s=average service life of the pipeline

L_p = life of the initial protection provided to the pipeline

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

Internal Inhibitor Efficiency	
Descriptor	Inhibitor Efficiency
Very Low	10
Low	8
Moderate	5
High	2
Very High	1

(Bea, et. al., OTC, 1998)

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

Corrosion Rates and Variabilities		
Descriptor	Corrosion Rate	Corrosion Rate Variability
Very Low	3.94E-5 in./year	10%
Low	3.94E-4 in./year	20%
Moderate	3.94E-3 in./year	30%
High	.0394 in./year	40%
Very High	.394 in./year	50%

(Bea, et. al., OTC, 1998)

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

Expected Life of Protective System (Lp), or Service Life of the Pipeline(Ls)	
Descriptor	Lp or Ls (years)
Very Short	1
Short	5
Moderate	10
Long	15
Very Long	>20

(Bea, et. al., OTC, 1998)

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

Corroded Analysis Composed of Three Corrosion Scenarios:

1) Internal (total) corrosion is 30% of wall thickness

2) Internal corrosion is 60% of wall thickness

3) Internal corrosion is 90% of wall thickness

Assumptions: No external corrosion on riser or mainline

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

- Loss of Internal Wall Thickness of Line 25 (mainline-**low** corrosion):

α_i = 3.0 (inhibitor efficiency)

ν_i = 3.94 E-3 inches/year (moderate)

L_s = 22 years (total time in service)

L_p = 10 years (moderate)

$$tc_i = \alpha_i \cdot \nu_i \cdot \left(L_s - L_p\right) = .15\,in. = 30\% \cdot t_{MAIN}$$

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

- Loss of Internal Wall Thickness of Line 25 (mainline-**medium** corrosion):

α_i = 7.0 (*inhibitor efficiency*)

ν_i = 3.94E-3 inches/year (moderate)

L_s = 22 years (total time in service)

L_p = 12 years (moderate)

$$tc_i = \alpha_i \cdot \nu_i \cdot \left(L_s - L_p\right) = .30\, in. = 60\% \cdot t_{MAIN}$$

Analysis: predicted burst pressure of pipeline 25 - corroded - deterministic & probabilistic

- Loss of Internal Wall Thickness of Line 25 (mainline-**high** corrosion):

α_i = 7.0 (*inhibitor efficiency*)

ν_i = 3.94E-3 inches/year (moderate)

L_s = 22 years (total time in service)

L_p = 6 years (*short*)

$$tc_i = \alpha_i \cdot \nu_i \cdot \left(L_s - L_p\right) = .45\,in. = 90\% \cdot t_{MAIN}$$

RAM PIPE Formulation: burst pressure, corroded

- Mainline: (30% loss of wall thickness)

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF} = \frac{3.2 * .500 * 42000}{8.625 * \left[1 + 2\left(\frac{.150}{4.31}\right)^{.5}\right]} = 5674\ psi$$

- Riser Section: (30% loss of wall thickness)

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF} = \frac{3.2 * .322 * 42000}{8.625 * \left[1 + 2\left(\frac{.097}{4.31}\right)^{.5}\right]} = 3859\ psi$$

RAM PIPE Formulation: burst pressure, corroded

- Mainline: (60% loss of wall thickness)

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF} = \frac{3.2 * .500 * 42000}{8.625 * \left[1 + 2\left(\frac{.300}{4.31}\right)^{.5}\right]} = 5100\, psi$$

- Riser Section: (60% loss of wall thickness)

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF} = \frac{3.2 * .322 * 42000}{8.625 * \left[1 + 2\left(\frac{.193}{4.31}\right)^{.5}\right]} = 3526\, psi$$

RAM PIPE Formulation: burst pressure, corroded

- Mainline: (90% loss of wall thickness)

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF} = \frac{3.2 * .500 * 42000}{8.625 * \left[1 + 2\left(\frac{.450}{4.31} \right)^{.5} \right]} = 4732\, psi$$

- Riser Section:(90% loss of wall thickness)

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF} = \frac{3.2 * .322 * 42000}{8.625 * \left[1 + 2\left(\frac{.289}{4.31} \right)^{.5} \right]} = 3306\, psi$$

Probability of Failure: Pipeline 25, corroded, mainline

Probability of Failure

Corroded Pipeline: Mainline

Pipeline Characteristics (median values)				Steel Material Strengths (median values)				Pipeline Defect		
Diameter, D_{50}	$V_{D,I}$	Wall Thickness, t50	$V_{t,I}$	Yield Strength, YS_{50}	$V_{YS,I}$	Tensile Strength, TS_{50}	$V_{TS,I}$	Defect Type: Corrosion		
Inches		Inches		PSI		PSI		Depth, d	d/t	$V_{d,I}$
8.625	10%	0.5	12%	42000	8%	52000	8%	0.10	30%	40%
								0.193	60%	40%
								0.289	90%	40%

Reliability Parameters

	Uncertainty Summary		Standard Deviation	
	Type I	Type II	$\sigma_{\ln S}$	$\sigma_{\ln R}$
Demands, S_{50}	10%	0%	0.100	0.481
Capacities, R_{50}	10%	50%		

Distrubution Type: Lognormal

Correlation: $\rho_{rs}=0$

	Loading State			Probability of Failure		
	Corroded Pipeline Capacity	Pipeline Demand	$V_{S,I}$			
d/t	R_{50}	S_{50}		β	$\Phi(\beta)$	P_f
30%	5674.0	6033	10%	-0.12	0.450280	0.549720
60%	5100	6033		-0.34	0.366108	0.633892
90%	4732	6033		-0.49	0.310400	0.689600

Probability of Failure: Pipeline 25
Sensitivity: COV, Hydrotest pressure

Probability of Failure

Corroded Pipeline: Mainline

Pipeline Characteristics (median values)				Steel Material Strengths (median values)				Pipeline Defect		
Diameter, D_{50}	$V_{D,I}$	Wall Thickness, t_{50}	$V_{t,I}$	Yield Strength, YS_{50}	$V_{YS,I}$	Tensile Strength, TS_{50}	$V_{TS,I}$	Defect Type: Corrosion		
Inches		Inches		PSI		PSI		Depth, d	d/t	$V_{d,I}$
8.625	10%	0.5	12%	42000	8%	52000	8%	0.10	30%	40%
								0.193	60%	40%
								0.289	90%	40%

	Reliability Parameters			
	Uncertainty Summary		Standard Deviation	
	Type I	Type II	$\sigma_{\ln S}$	$\sigma_{\ln R}$
Demands, S_{50}	5%	0%	0.050	0.481
Capacities, R_{50}	10%	50%		

Distrubution Type: Lognormal

Correlation: $\rho_{rs}=0$

	Loading State			Probability of Failure		
	Corroded Pipeline Capacity	Pipeline Demand	$V_{S,I}$			
d/t	R_{50}	S_{50}		β	$\Phi(\beta)$	P_f
30%	5674.0	6033	5%	-0.13	0.449497	0.550503
60%	5100	6033		-0.35	0.364072	0.635928
90%	4732	6033		-0.50	0.307641	0.692359

Probability of Failure: Pipeline 25, corroded, riser

Probability of Failure

Corroded Pipeline: Riser Section

Pipeline Characteristics (median values)				**Steel Material Strengths (median values)**				**Pipeline Defect**		
Diameter, D_{50}	$V_{D,I}$	Wall Thickness, t_{50}	$V_{t,I}$	Yield Strength, YS_{50}	$V_{YS,I}$	Tensile Strength, TS_{50}	$V_{TS,I}$	Defect Type: Corrosion		
Inches		Inches		PSI		PSI		Depth, d	d/t	$V_{d,I}$
8.625	10%	0.322	12%	42000	8%	52000	8%	0.10	30%	40%
								0.193	60%	40%
								0.289	90%	40%

	Reliability Parameters			
	Uncertainty Summary		**Standard Deviation**	
	Type I	Type II	$\sigma_{\ln S}$	$\sigma_{\ln R}$
Demands, S_{50}	10%	0%	0.100	0.481
Capacities, R_{50}	10%	50%		

Distrubution Type: Lognormal

Correlation: $\rho_{rs}=0$

	Loading State			**Probability of Failure**		
	Corroded Pipeline Capacity	Pipeline Demand	$V_{S,I}$			
d/t	R_{50}	S_{50}		β	$\Phi(\beta)$	P_f
30%	3859.0	3885	10%	-0.01	0.494544	0.505456
60%	3526	3885		-0.20	0.421726	0.578274
90%	3306	3885		-0.33	0.371192	0.628808

Results: pipeline 25 burst pressure analyses summary

- Intact, deterministic
- Intact, probabilistic
- Corroded, deterministic
- Corroded, probabilistic

Results: pipeline 25 burst pressure analyses

Pipeline 25: Summary of Failure Predictions			
		Deterministic	**Probability of Failure**
		PSI	P_f
Uncorroded (New)			
	Mainline	**6033**	**0.501**
	Riser	**3885**	**0.501**
Internally Corroded			
Mainline	**d/t**		
	30%	**5674**	**0.55**
	60%	**5100**	**0.63**
	90%	**4732**	**0.69**
Riser	**d/t**		
	30%	**3859**	**0.5**
	60%	**3526**	**0.58**
	90%	**3306**	**0.63**

Conclusions

- Predicting internal corrosion (level) is difficult, variable.
  - In-line instrumentation is key (series system: pipeline condition + in-line instrumentation)
- Importance of Field Testing
  - Validation of Analytical Equations
    - Biases
  - Improve upon existing practices of pipeline requalification, and pipeline in-line instrumentation

Questions & discussions notes

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Questions & discussions notes

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Appendix

- References
- Literature Review
- MSL Database Analysis For Bias
  - Supplemental Information
- Predicted Burst Pressure of Pipeline 25
  - Supplemental Information

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- Woodson, Ross. “Offshore Pipeline Failures,” (Research Report), U.C. Berkeley, 1990.

Appendix: Literature Reviews

POP Literature Reviews

- Purpose of Literature Reviews:
  - Gather information to aid in achieving research objectives
  - Review references to aid in developing an analysis system to deal with the information to be obtained from field testing

Literature Review: Pipeline Defect Assessment

- Text Title: *Pipelines and Risers*, by Prof. Yong Bai
  - Concerning Assessment Method ASME B-31G:
  - Problems with B-31G:
    - Established based on knowledge developed over 20 years ago.
    - Cannot be applied to pipelines under combined loads: axial, pressure, and bending loads.
    - May lead to overly conservative results

Literature Review: Pipeline Defect Assessment

- Text Title: *Det Norske Veritas RP-F10: Corroded Pipelines* (DNV RP-F101)
  - Assessment Method: DNV RP-F101
    - Potential Problems with DNV
      - DNV RP-F101 was developed using a database of burst tests on pipes containing **machined corrosion defects.**
      - In addition, DNV criteria were developed using a database of 3D non-linear finite element analyses.
    - Advantages to DNV RP-F101:
      - Can predict actual pipeline burst pressure
      - Can be used with internal pressure loading and superimposed longitudinal compressive stresses

Literature Review: Defect Assessment

- Other Assessment Methods:
  - UCB RAM PIPE Formulations:
    - Predicts burst pressure of corroded, dented, gouged, cracked pipelines (deterministic, probabilistic)
    - Statistically (lab test results) proven to be able to develop ‘unbiased’ predictions of pipeline burst pressures with low variabilities
  - ABS 2000 Equations
    - Predicts maximum allowable operating pressure for corroded pipes

Literature Review:
Stress Concentration Factors(SCF)

- Article Title: "Variations in Stress Concentration Factors Near Simulated Corrosion Pits as Monitored by Magnetic Flux Leakage, Magnetic Barkhausen Noise and Neutron Diffraction,"

  1998 ASME IPC, Authors: L. Clapham, et.al.

- Key Points:
  - The conditions under which a pit defect is formed in a pipe can influence local stress concentrations.
  - Specifically, mechanical machining of simulated corrosion pits creates considerable machining stresses around the defect.
  - Conversely, electrochemical machining produces no measureable residual stresses.

Literature Review: Stress Concentration Factors

– There are significant differences in local stress concentrations depending on whether the pit was electrochemically machined prior to stress application, or while the sample was under stress.

(1998 ASME IPC)

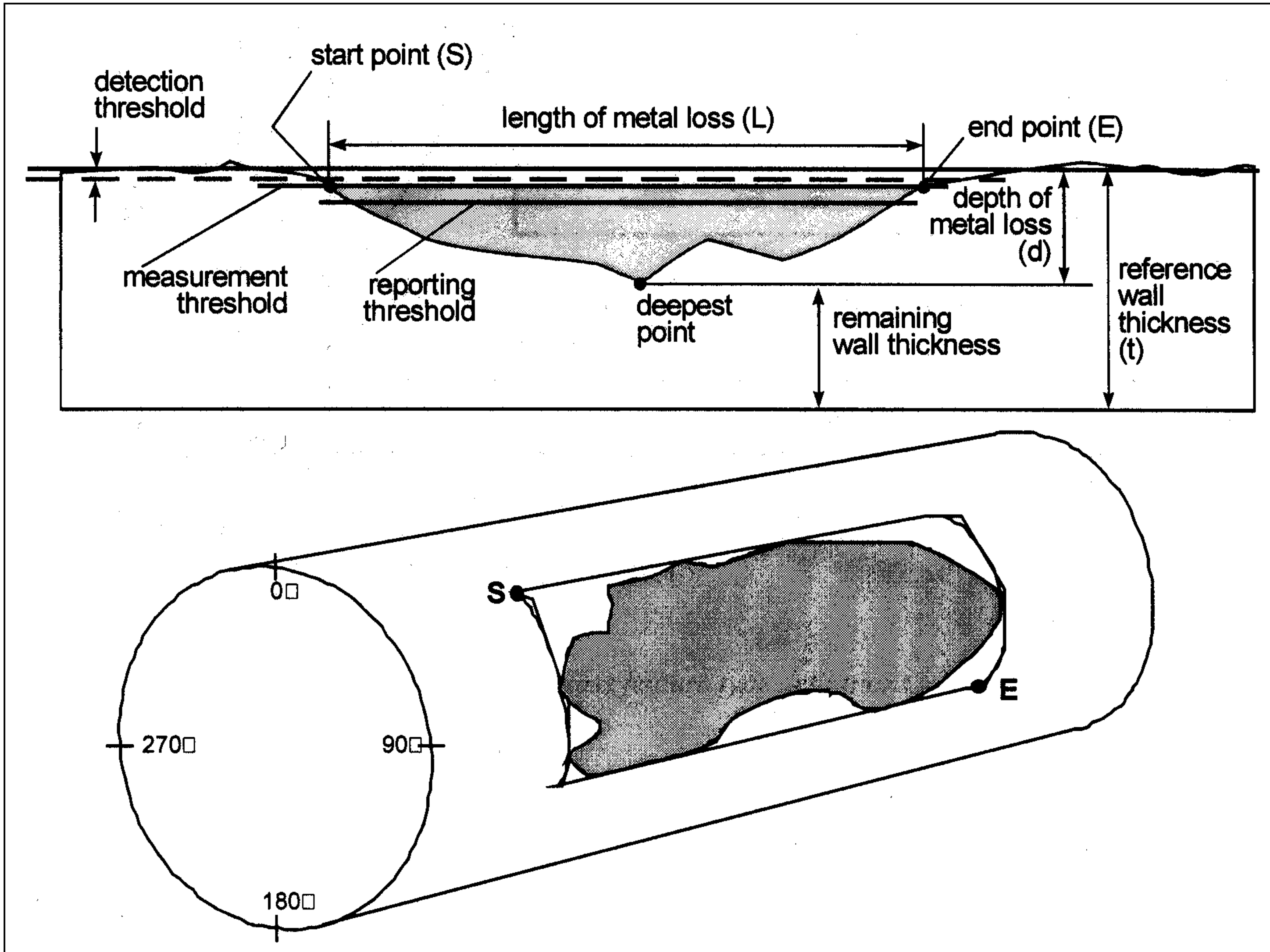
Literature Reviews: Pipeline Instrumentation

- DNV, ASME, RAM PIPE and ABS equations common input parameter:

  d, depth of corrosion

- Where does ‘d’ originate?
  - Depth of corrosion is measured by pipeline instrumentation (intelligent pig).

Literature Reviews: Pipeline Instrumentation



Location and Dimensions of Metal Loss Features (Shell International, 1998)

Literature Review: Pipeline Instrumentation

- Standard Definitions:

  Corrosion: An electrochemical reaction of the pipe wall with its environment, causing loss of metal

  Dent: Distortion of pipe wall resulting in change of internal diameter but not necessarily resulting in localized reduction of wall thickness.

  Feature: An indication, generated by pipeline examination, of an anomaly

  Gouge: Mechanically induced metal loss, which causes localized elongated grooves or cavities.

  Probability of Detection: The probability of a feature being detected by the intelligent pig

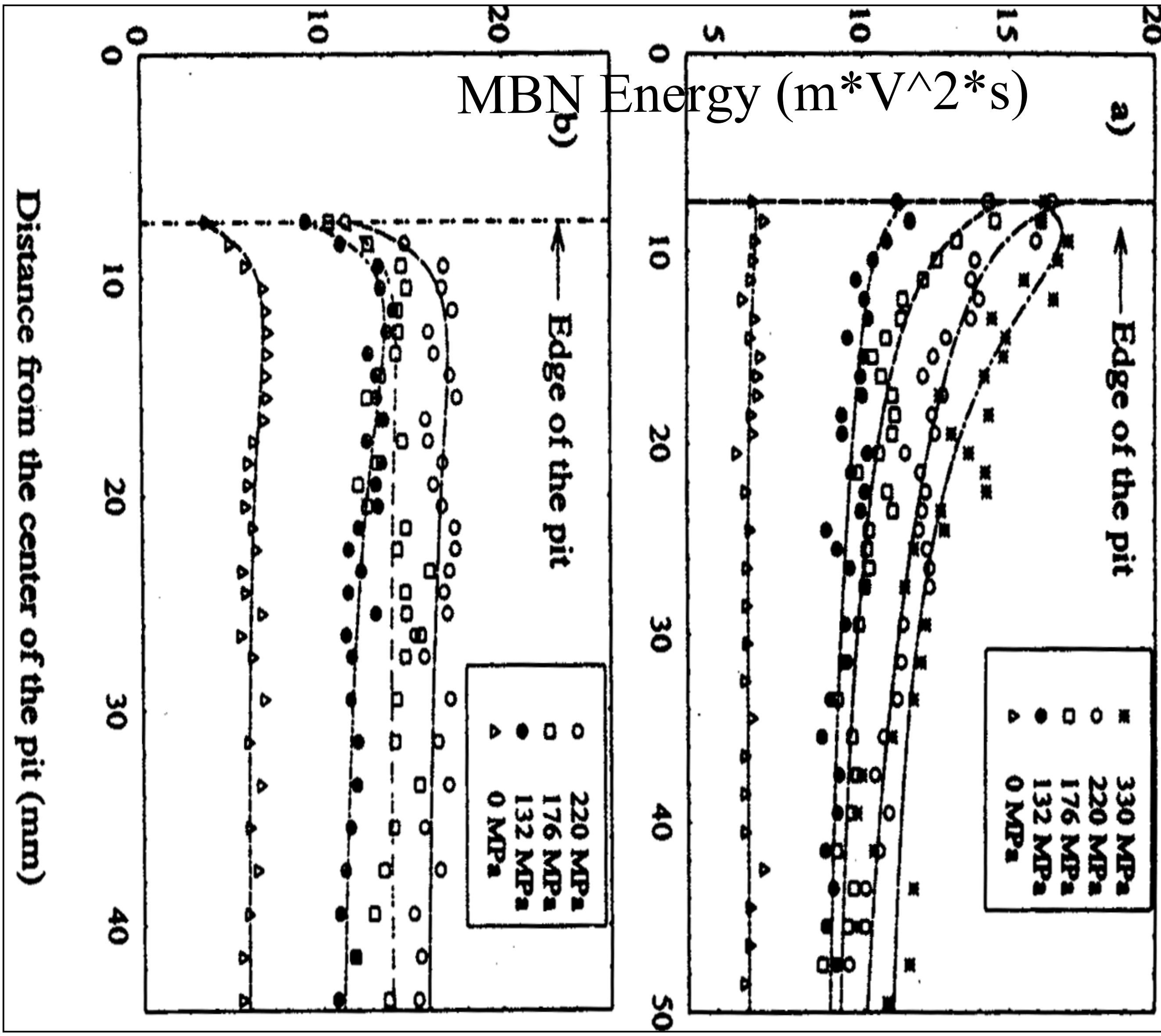
  Sizing Accuracy: Given by the interval within which a fixed percentage of all metal-loss features will be sized (stated as the confidence level).

  (Shell International, 1998)

Literature Review: Pipeline Instrumentation

- Instrumentation Limitations
  - Probability of Detection, POD
    - Probability of detection data is difficult to acquire
    - POD varies with feature type, feature location (internal, external)
  - "Unpiggable" due to:
    - Change of diameter
    - Damage (e.g. dent causing change in diameter)
    - Risk of getting stuck

SCFs: Machined Defects VS. Electrochemically Formed Defects



Magnetic Barkhausen Noise (MBN) scan results for samples drilled at zero stress and then loaded: a) Electrochemically machined defect b) mechanically drilled defect

1998 ASME International Pipeline Conference Proceedings, V. I, p. 509

Appendix: Database Analysis (supplemental information)

Analysis: development of Bias characteristics

- Three ‘pressure equations’used to calculate ‘predicted burst pressure’:
  - ASME B31G
  - DNV RP-F101
  - RAM PIPE
- ‘Actual burst pressure’ given by the MSL database

Appendix: Burst Prediction of Pipeline 25 (supplemental information)

Probability of Failure

- Calculation of standard deviation:

$$\sigma_{\ln X} = \sqrt{\ln(1 + V_x^2)}$$

$$V_x = \text{coefficient of variation}$$

Probability of Failure: *must specify*

- Pipeline internal pressure (stress, strain) conditions
- Pipeline characteristics: diameter, thickness, thickness, SMYS, SMTS, depth of corrosion

Analysis: predicted burst pressures of pipeline 25 - corroded - no inline instrumentation results

- Loss of pipeline wall thickness due to corrosion:

  Where:

$$tc = tc_i + tc_e$$

tc =loss of wall thickness due to corrosion

tc_i =loss of wall thickness due to internal corrosion

tc_e =loss of wall thickness due to external corrosion

RAM PIPE Formulation: burst pressure, corroded (deterministic)

$$p_{bd} = \frac{3.2 \cdot t_{nom} \cdot SMYS}{D_o \cdot SCF}$$

p_{bd} = burst pressure of corroded pipeline

t_{nom} = pipe wall nominal thickness

D_o = mean pipeline diameter (D-t)

SMYS = Specified Minimum Yield Strength of pipeline material

SCF = Stress Concentration Factor = $\mathrm{SCF} = 1 + 2 \cdot (\mathrm{d} / \mathrm{R})^{.5}$
d = depth of corrosion, R = Do/2

End of Meeting Notes