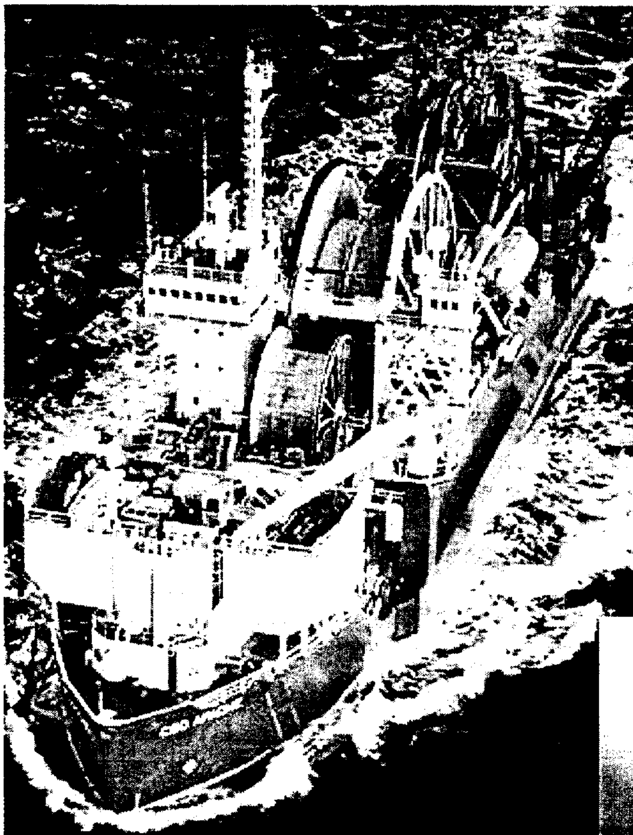
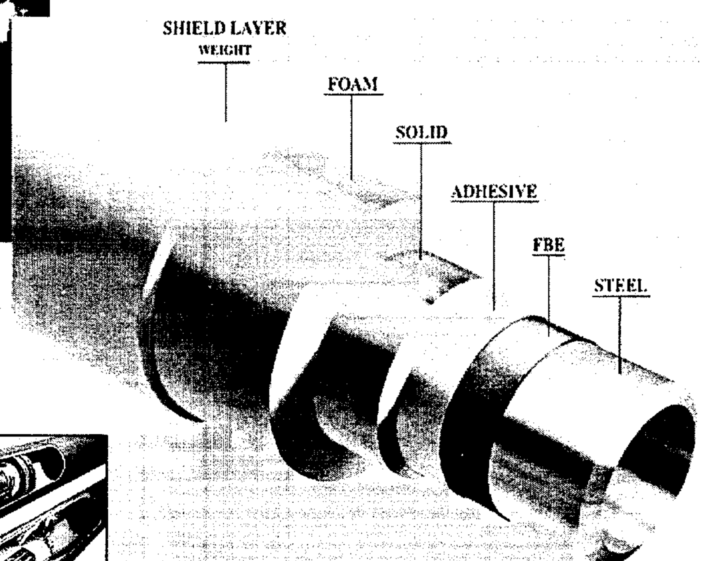
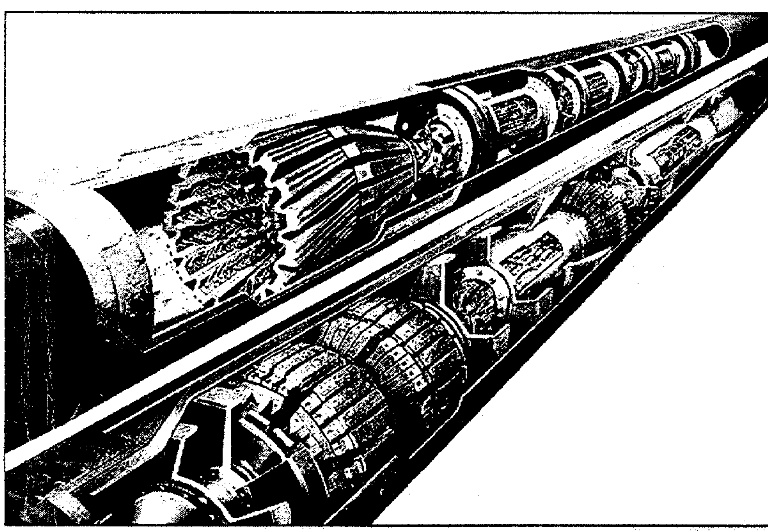


Pipeline Inspection, Maintenance & Performance Information System



MEETING NOTES



June 23, 1998

By
Prof. Robert Bea &
Botond Farkas

Marine Technology and Management Group
University of California at Berkeley

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Pipeline Inspection, Maintenance & Performance Information System - *PIMPIS*

- Introduction
  - Agenda
  - Project Objectives
  - Work Performed
  - Work Planned
  - Deliverables

Agenda - morning

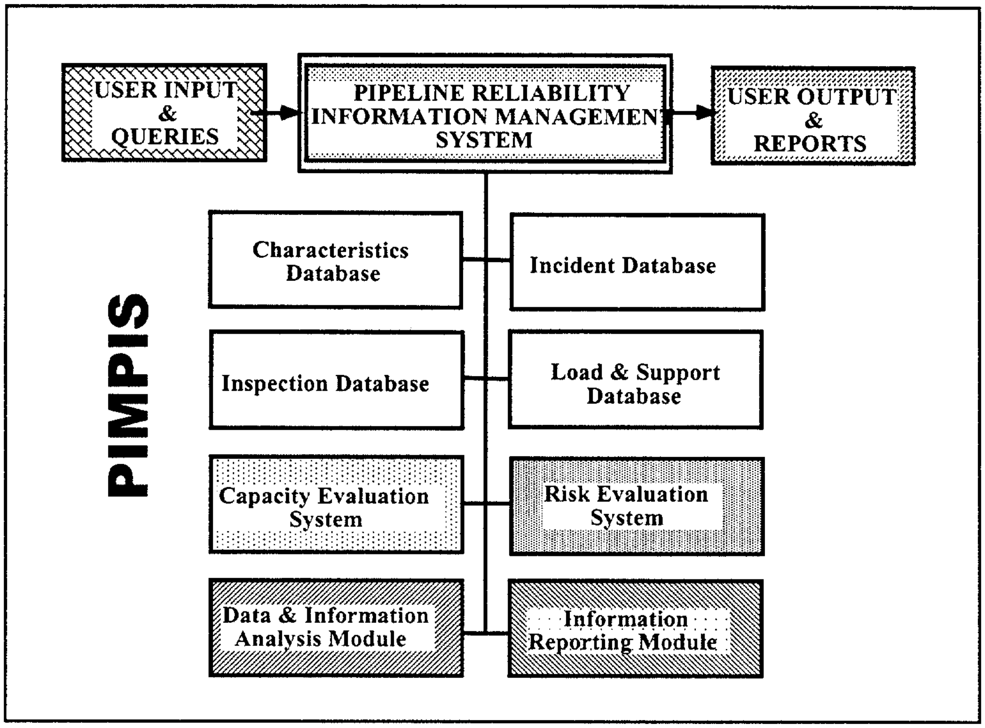
- **10:00 Introductions -** Bob Bea
- **10:30 Risk Assessment & Management -** Botond Farkas
- **11:30 Discussion**
- **12:00 Lunch**

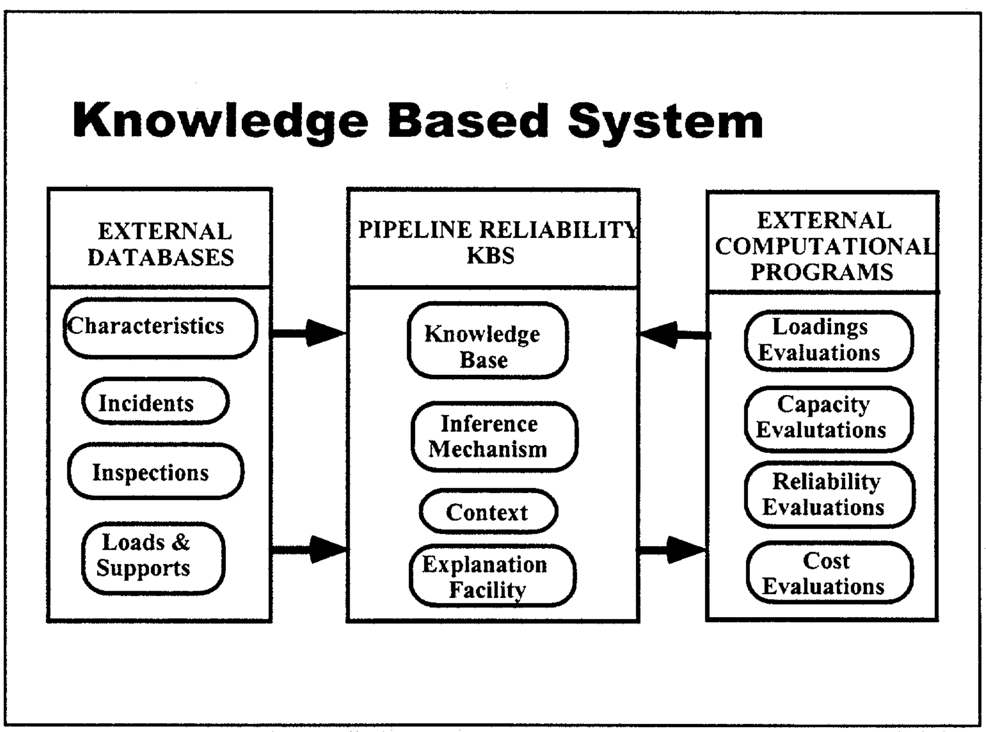
Agenda - afternoon

- **1:00 Corrosion Loss: Quantitative / Qualitative Estimates-** Botond Farkas
- **2:30 Break**
- **2:45 Burst Pressure and Probability of Leaks -** Botond Farkas
- **3:30 Discussion**
- **4:00 Risk Assessment & Management Workshop -** Bob Bea
- **4:30 Adjourn**

Project Objectives

- Develop a knowledge based system to help manage pipeline integrity
  - Risk assessment - pipeline corrosion
  - Risk management - corrosion mitigation
  - Database interfaces - MMS, others

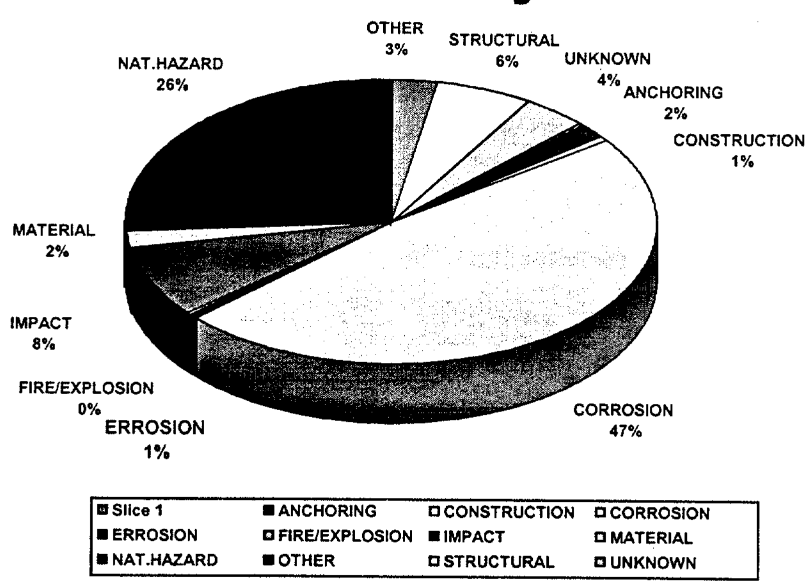

USER INPUT & QUERIES
PIPELINE RELIABILITY INFORMATION MANAGEMENT SYSTEM
USER OUTPUT & REPORTS
PIMPIS
Characteristics Database
Incident Database
Inspection Database
Load & Support Database
Capacity Evaluation System
Risk Evaluation System
Data & Information Analysis Module
Information Reporting Module

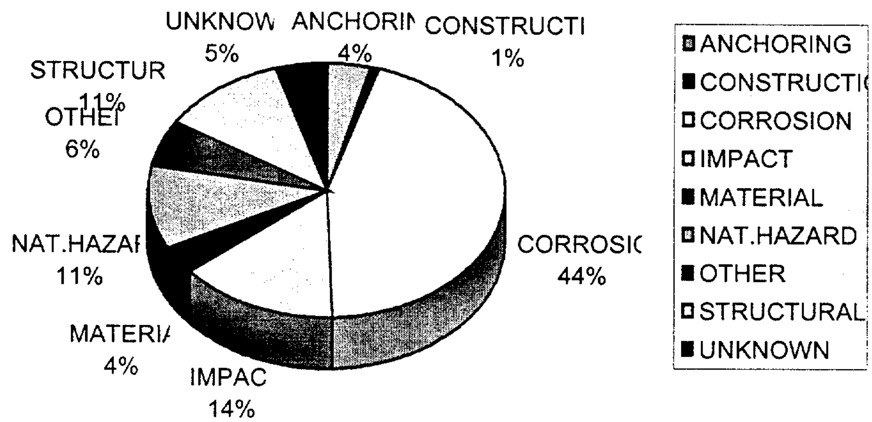

Knowledge Based System
EXTERNAL DATABASES
Characteristics
Incidents
Inspections
Loads & Supports
PIPELINE RELIABILITY KBS
Knowledge Base
Inference Mechanism
Context
Explanation Facility
EXTERNAL COMPUTATIONAL PROGRAMS
Loadings Evaluations
Capacity Evalutations
Reliability Evaluations
Cost Evaluations

Work Performed

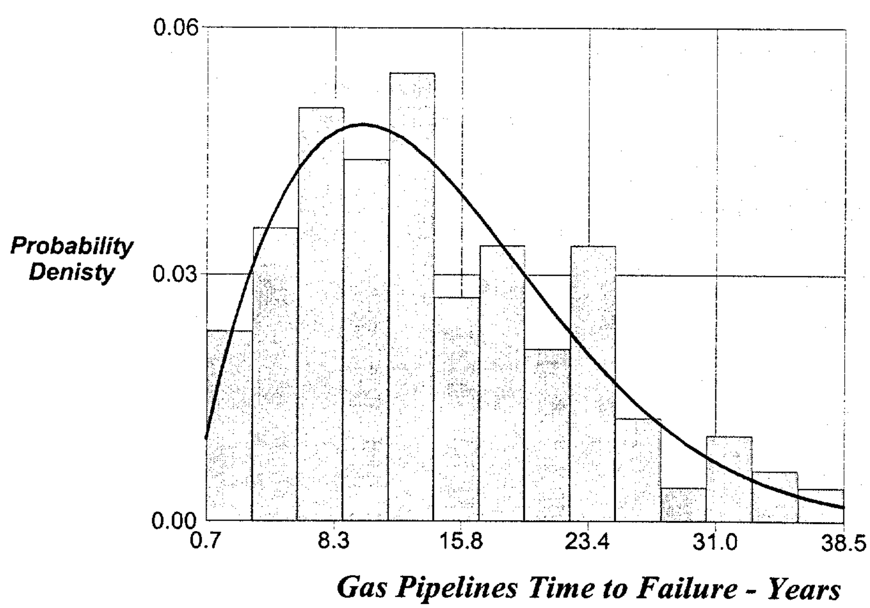
- Analyses of MMS database
- Qualitative and quantitative corrosion loss evaluations (piggable and unpiggable)
- Burst strength of corroded pipelines / risers
- Risk Assessment & Management (RAM) system

MMS Database Analyses

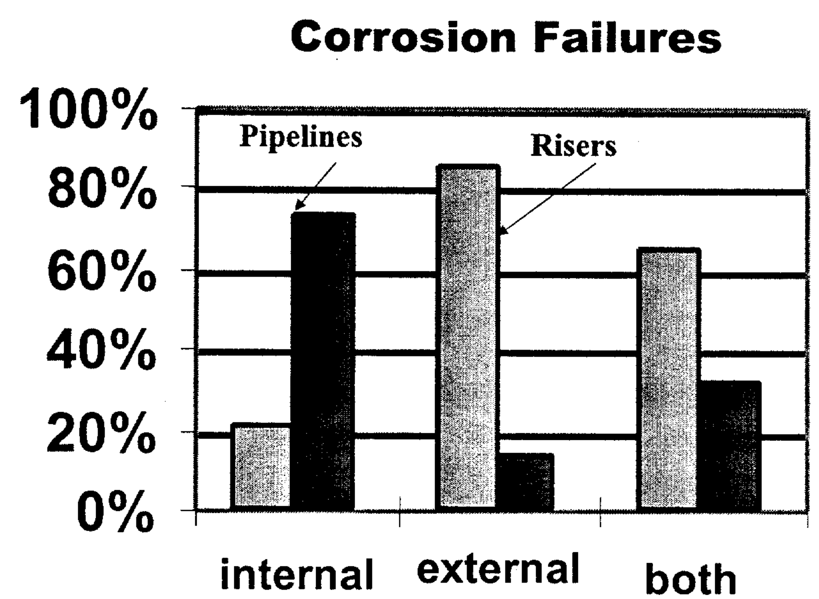


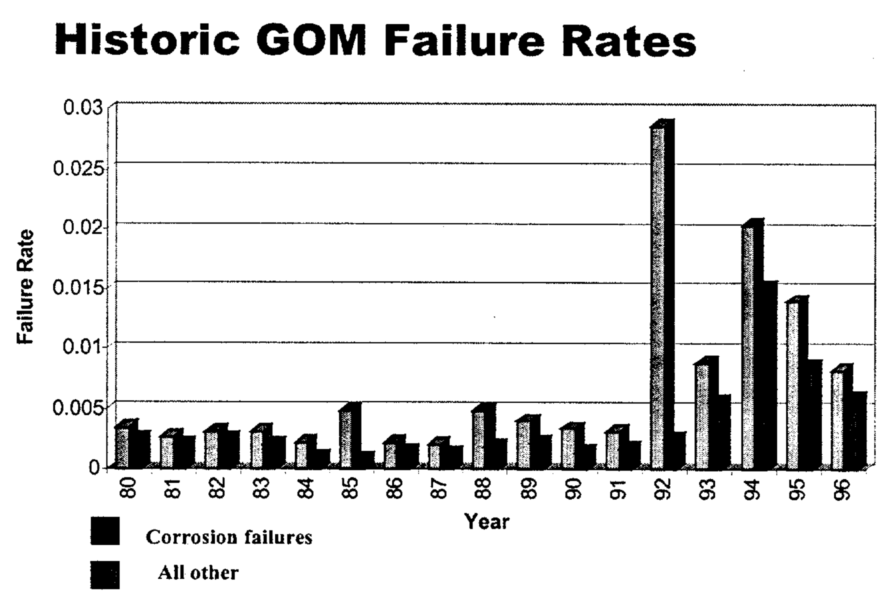


Gulf of Mexico oil pipelines



Both processed & unprocessed gas





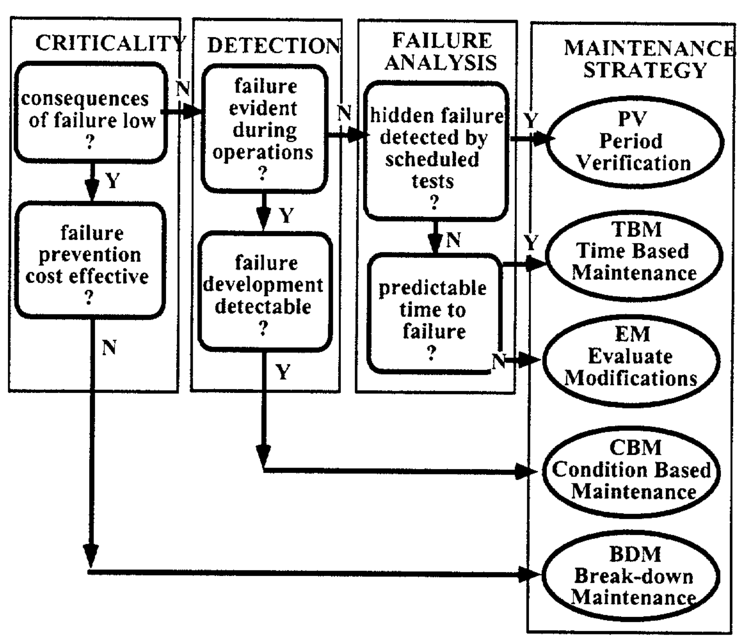
Cut back
in maintenance

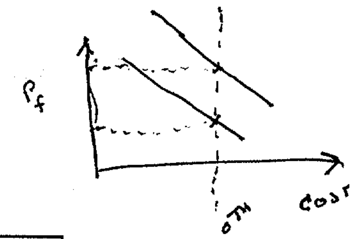
Situation [illegible] [illegible]
But took several years
to occur

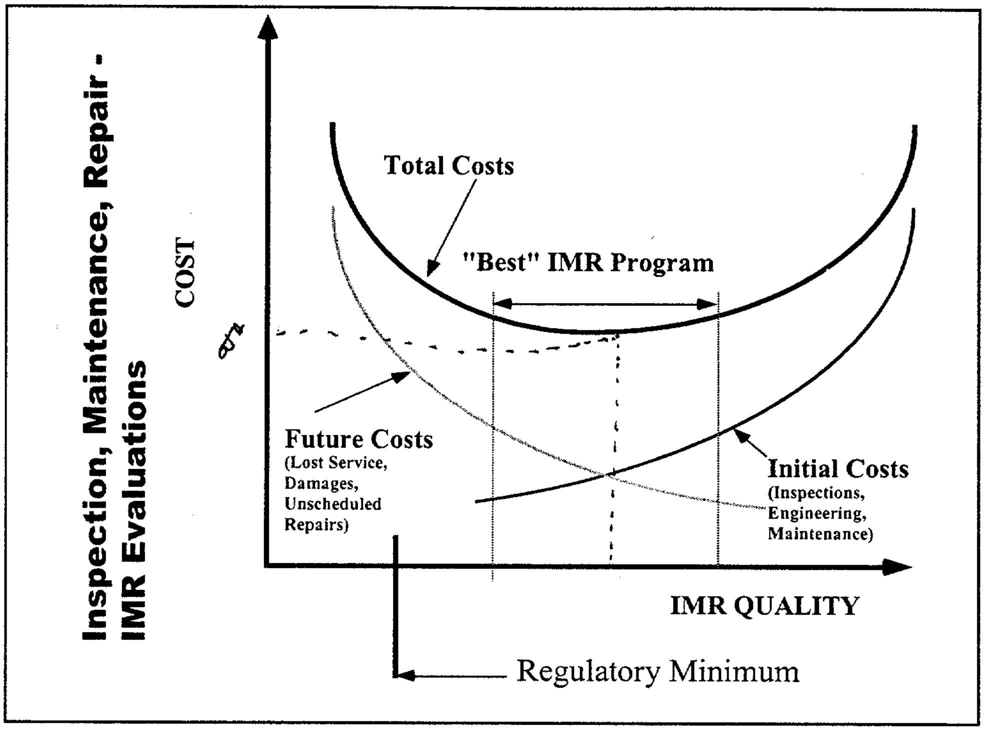
Future Work (end December)

- Detail Risk Management part of system - Reliability Centered Maintenance
- Implement RAM system on an ACCESS database
- Verify and document the pipeline corrosion RAM system computer program
- Organize & conduct workshop on pipeline risk management (Nov. 5 & 6, Houston)

Reliability Centered Maintenance - RCM







Deliverables

- Pipeline corrosion RAM computer program
- Project technical report
- Pipeline workshop
- Pipeline workshop proceedings

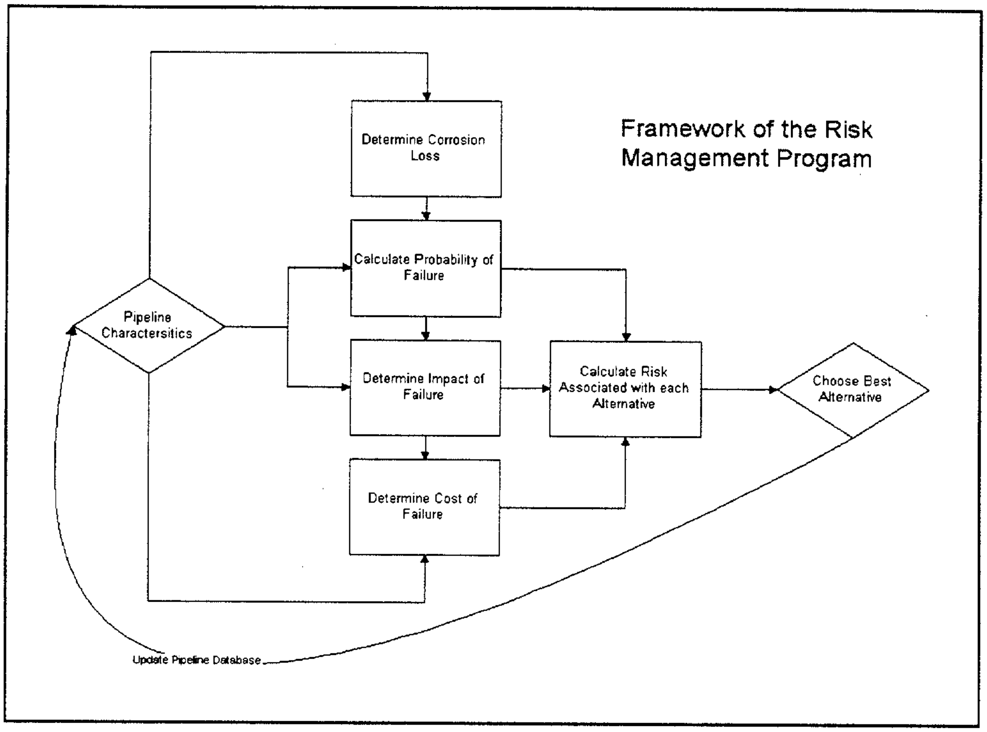
Notes:

1) Need well "documented case histories" of pipeline failures to use in verifications

2)

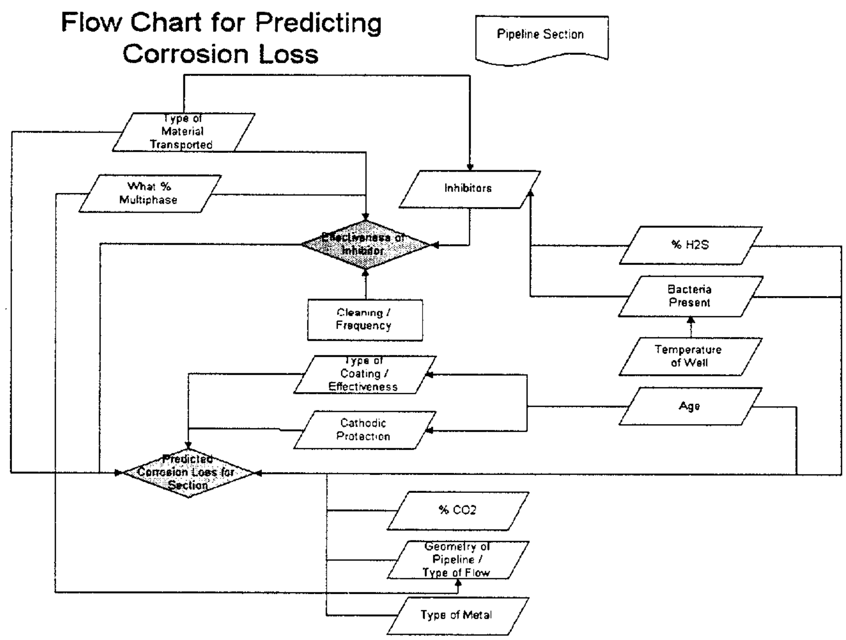
Why Develop a Computerized Pipeline RAM System?

- Reduce redundant data acquisition
- Multiple uses and users of information
- Improved communications
- Improved life-cycle management



Determining Corrosion Loss

- Corrosion loss depends on many factors
  - Type of material being transported
  - Multiphase pipeline or not
  - Inhibitor effectiveness
  - Cathodic protection
  - Presence of sulfate reducing bacteria (SRB)
  - Pipeline age
  - Coating effectiveness
  - Operating conditions
- Key is to determine relationship between various influencing factors



Calculation of the Probability of Failure

- Input needed:
  - Burst pressure (mean, standard deviation) a.k.a. resistance
  - Hydrostatic external pressure
  - Flow conditions to obtain pressure gradient along pipeline length
  - Operating pressure (mean, standard deviation) a.k.a. loading

Calculation of the Probability of Failure

$$P_f = P[R \le S] = \int_0^{\infty} F_R(t) f_S(t) dt$$

$$F_R(t) = P[R \le t]$$

$$f_S(t) dt = P[t < S < t + dt]$$

Calculation of the Probability of Failure

$$P_f = 1 - F_U \left[\frac{\overline{R} - \overline{S}}{\sqrt{\sigma_R^2 + \sigma_S^2}} \right]$$

$\overline{R}$ and $\overline{S}$ = mean resistance and loading

σ_R and σ_S = mean standard deviation of resistance and loading

Definition of Failure

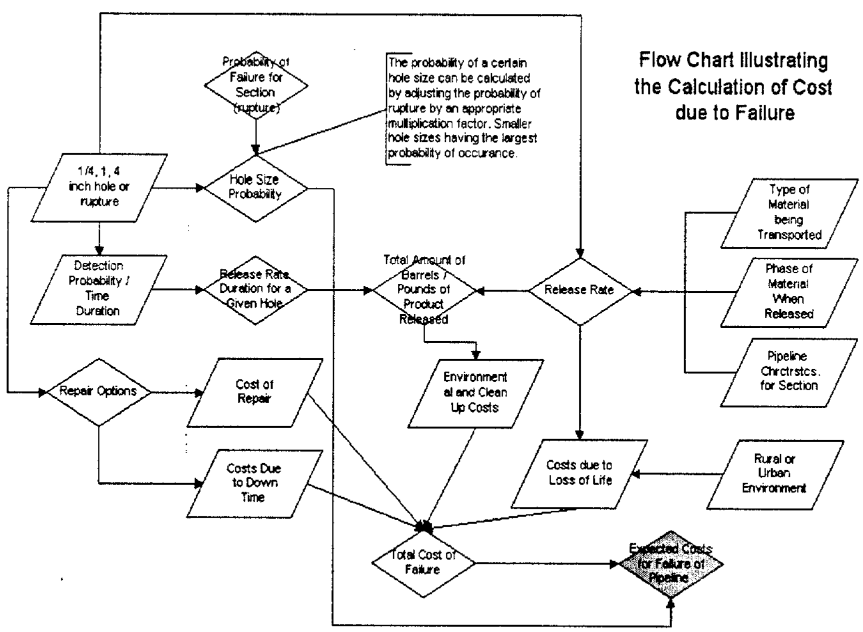
- Failure can have various magnitudes
  - Pinhole leak i.e. 1/4 inch hole
  - 1 inch hole
  - 4 inch hole
  - Rupture
- Larger hole sizes have smaller frequencies, but release rates are different, therefore the impact is different
- Hole size can be taken as a function of pipe diameter and thickness

Impacts of Failure

- Depends on:
  - presence of people
  - method of leak detection
  - product effects upon leak
  - product properties
  - clean up of product
  - product dispersal
  - how leak stopped
  - how leak repaired

Impact of Failure

- Pipe content characteristics that affect the impact that the failure has are:
  - Liquids
  - Gases
  - Two-phase systems
  - Multi-phase systems
- Release Rate Influence due to
  - Continuous release (all small holes)
  - Instantaneous release (<3 minutes to release 10,000 lbs.)
- What detection methods are being employed and how soon can a leak be detected?



Consequences of Failure

- Each consequence will have a cost associated with it
  - Injuries to personnel and environment
  - Loss/damage of property
  - Loss of service (down time lost revenue)
  - Environmental cleanup
  - Penalties
  - Increased insurance rates
  - Increased operational expenses

Detection Systems

- Detection system rating in order of decreasing efficiency
  - Instrumentation to detect changes in operating conditions
  - Suitably located detectors to determine when material is leaking
  - Visual detection, detectors with marginal coverage

Isolation Systems

- Isolation system rating in order of decreasing efficiency
  - Isolation or shutdown systems activated without operator intervention; detectors and instrumentation
  - Isolation or shutdown systems activated by operators from a control room
  - Isolation dependent on manually operated valves

Repair of Failed Section

- Repair improves reliability of pipeline section therefore warranting an update of the system
- Quality of work performed is variable
- Applicability of solution might not be practical; are all parameters known for choosing appropriate solution
- Be aware of new and emerging techniques

Updating The Reliability Of a Pipeline after an Incident and Repair

- Bayesian Updating: $$P(A|B) = \frac{P(A)P(B|A)}{P(B)}$$
  - P(A) = Probability of failure associated with a certain flaw size
  - P(B) = Probability that detection will occur
  - P(B | A) = Probability that detection occurs given the a certain flaw size
  - P(A | B) = Probability of failure for a certain flaw size given a certain detection time; by knowing this value we can obtain the true probability of failure associated with the flaw, given that all the other input parameters are correct

Notes:

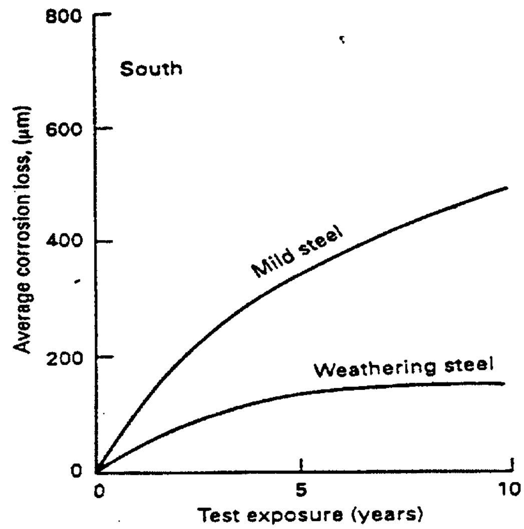
Introduction: Predicting Corrosion Loss in a Multiphase Sour Pipeline

- Many corrosion loss equations have been developed
- Corrosion loss as measured in the field is usually greater than corrosion loss for the same simulated conditions measured in the lab
- Very little published data if any is available on internal corrosion of marine pipelines
- If a pipeline is unpiggable the task of predicting corrosion loss is more difficult
- Systems are dynamic, constantly changing

Developing an Equation to Predict Corrosion Loss

- Problem Summary
  - Equation must be able to fit the general shape of a corrosion loss graph
  - Once defining equation has been developed, how can it be manipulated to represent different environmental conditions
  - How can the equation be adapted to various metal types
  - What are the important parameters that need to be modeled

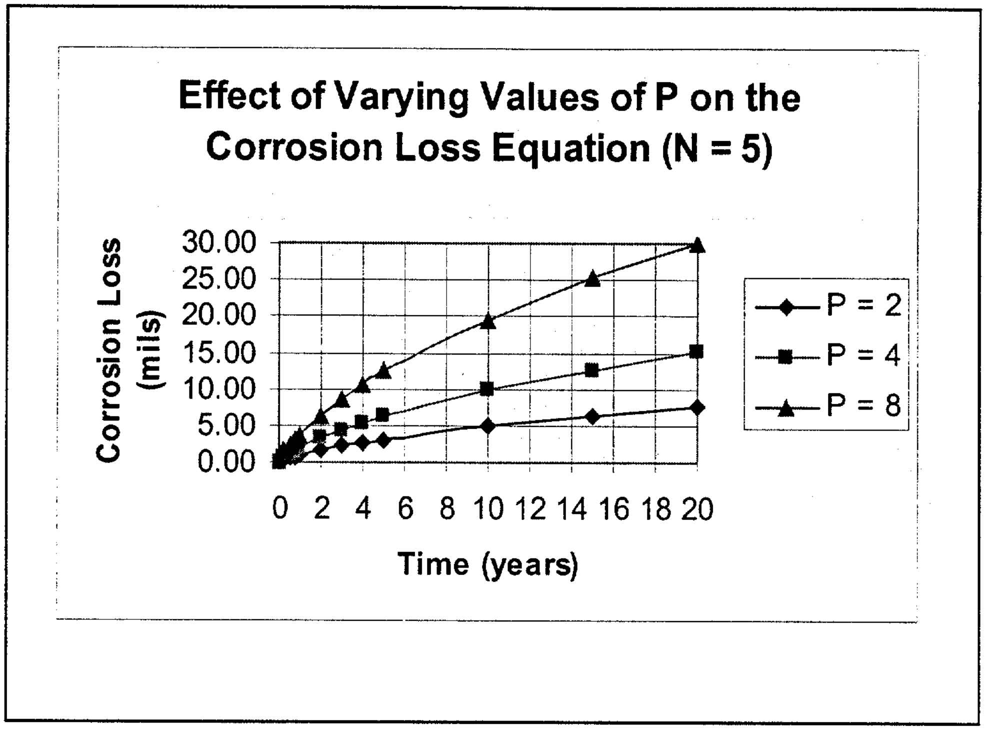
General Shape of a Corrosion Loss Graph

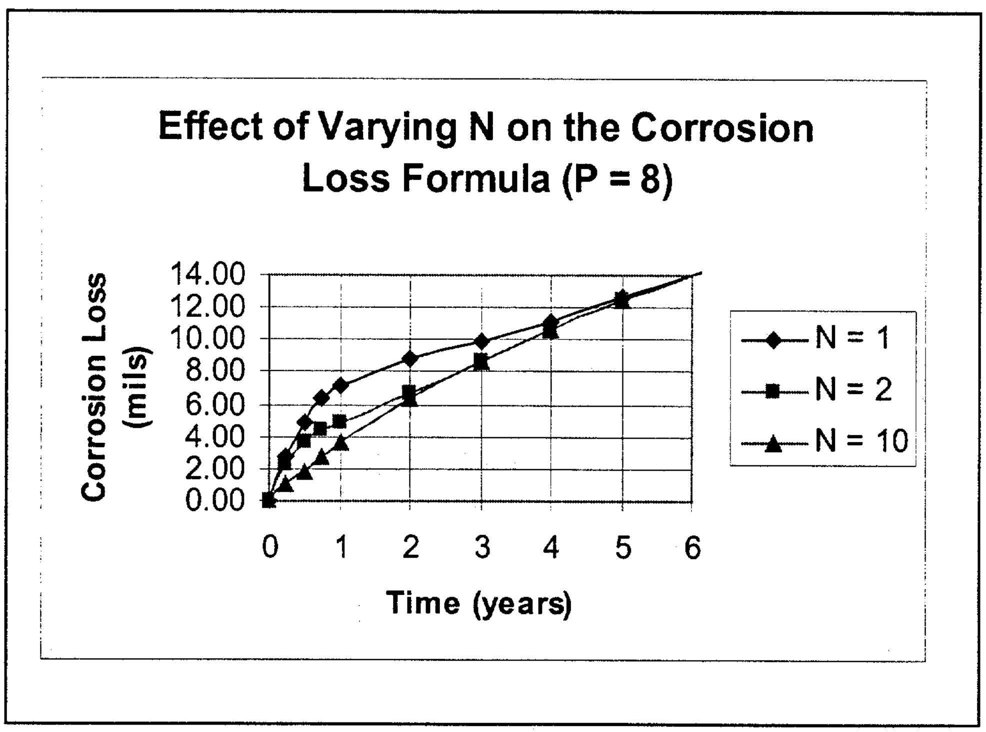


The Corrosion Loss Equation

$$\text{Corrosion Loss} = \left[1 + e^{(1-Nt)}\right]\left[\log(1+t)^{P}\right]\left[1 + \frac{1}{(1+t)}\right]\left[t^{\frac{1}{3}}\right]$$

where N and P are fitting parameters and
t is measured in years and the corrosion loss is measured in mils


Effect of Varying Values of P on the Corrosion Loss Equation (N = 5)
Corrosion Loss (mils)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0 2 4 6 8 10 12 14 16 18 20
Time (years)
P = 2
P = 4
P = 8

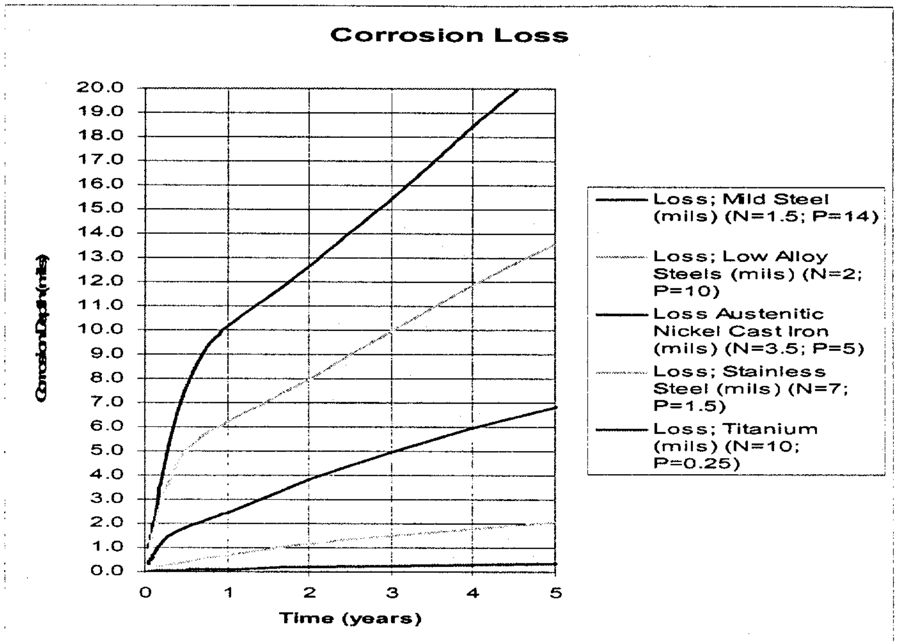

Effect of Varying N on the Corrosion Loss Formula (P = 8)
Corrosion Loss (mils)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0 1 2 3 4 5 6
Time (years)
N = 1
N = 2
N = 10

Adjusting the Corrosion Loss Equation for Various Metal Types

- Obstacles:
  - Data on corrosion is mostly for atmospheric corrosion
  - Measured corrosion loss is obtained through measuring weight loss of coupon
  - Limited data for different metal types, although mild steel has more data in general than other types of metals
  - Usually only one point is given therefore fit for curve is based on one point
  - Time constraint restricted how many data points can be fitted

Results for Fitting Parameters for Different Metal Types

	P	N
Mild Steel	14	1.5
Low Alloy Steel	10	2
Nickel Iron Alloys	5	3.5
Stainless Steel	1.5	7
Titanium	0.25	10



The Influence of Sour Conditions on the Fitting Parameters P and N

- Important corrosion factors
  - Recovery techniques
  - Temperature of the well
  - Inhibitor effectiveness
  - Multiphase flow characteristics
  - Head loss over pipeline's length

Recovery Techniques

- The souring of wells:
  - Sulfate reducing bacteria trapped in connate water can cause souring
  - Bacteria can be "excited" through the introduction of seawater
  - Bacteria in the seawater flourish once injected into the well
  - Wells with lower temperatures, 86° F to 158° F have a higher chance of becoming sour

Bacteria Associated with Biocorrosion

- Desulfotomaculum - optimal growth at 130° F; the existence of these thermophilic strains is important to the injection waters used for secondary oil recovery, where planktonic and sessile sulfate reducing bacteria are frequently found at temperatures of 158° F and higher

Bacteria Associated with Biocorrosion

- These microorganisms can cause serious problems of biofouling and corrosion in the water injection lines
- Thiobacillus Ferrooxidans - during oil recovery operations, iron oxidizing bacteria can diminish the permeability of rock formations

Sulfate Reducing Bacteria

- SRB metabolism brings to the metal/solution interface several sulfur compounds of corrosive characteristics, either as final metabolic products (sulfides, bisulfides, or hydrogen sulfide) or intermediate metabolic compounds (thiosulfates, polythionates). These com-pounds are corrosive to carbon steel mainly through the transformation of sulfide anions that stimulate corrosion by a mechanism of anodic depolarization

Sulfate Reducing Bacteria

- Biocorrosion of carbon steel is strongly influenced by the nature and structure of sulfide films produced during the corrosion process. The action of sulfides in corrosion can be enhanced by other aggressive anions already present in the medium like the widely distributed chlorides

Sulfate Reducing Bacteria

- Thin adherent films of iron sulfide are protective, while bulky and loosely adhered precipitates enhance corrosion rates. The entrance of oxygen into the system strongly accelerates corrosion rates mainly through a change in the chemical nature of iron sulfides and through sulfur production. Both substances can provide additional cathodic reactants to the corrosion reaction, acting as electron carriers between the metal and the oxic interface within the biofilm.

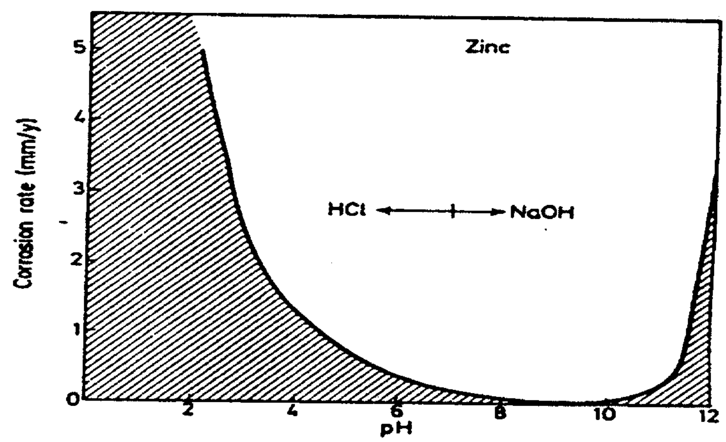
Hypothesis

- The lower the temperature of the well the more likely that there will be bacteria present and therefore there is a higher chance of souring to occur.
- Injection waters can increase the potential of souring.
- Water must be present for the organisms to thrive
- In a multiphase pipeline, corrosion is more likely to occur at points where water can settle out
- Oxygen content of injection water must be kept at a minimum

Hypothesis

Temperature Range of Well (°F)	Possible pH Range
86 - 122	0.5 - 5.0+
122 - 158	2.0 - 6.0+
158 - 194	4.0 - 7.0+
194 - 230	5.0 - 8.0
230 - 284	7.0 - 9.0

Effect of pH on the Corrosion Rate of Metals



Choosing Limits For Corrosion Rate

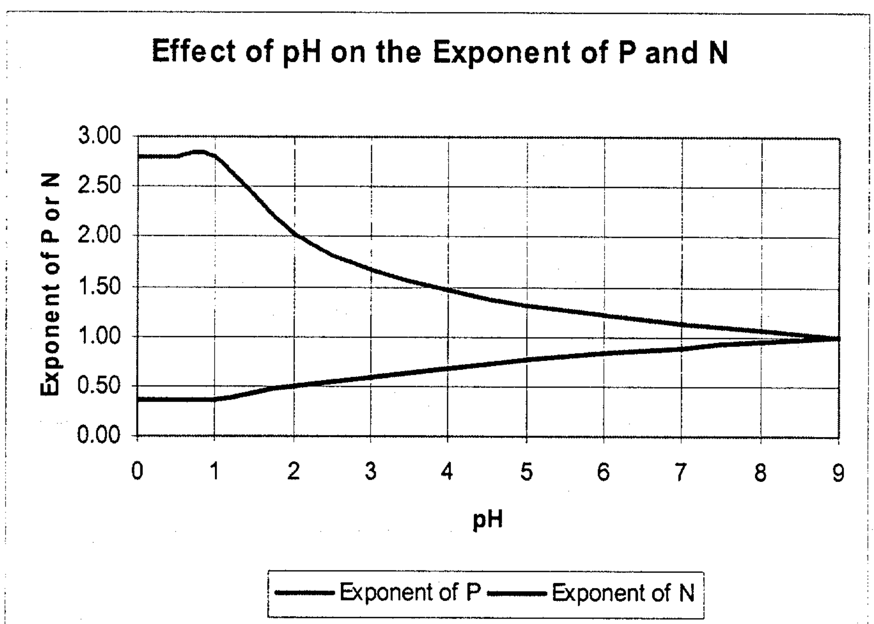
- Maximum amount of corrosion loss after one year was taken as 1.3 inches
- This value was assigned to mild steel in a pH environment of 1
- Minimum corrosion rate was assigned as the atmospheric corrosion rate given by the calculated P and N values

Effect of pH on P and N

- In order to attain high corrosion rates associated with low pH values P and N have to be raised to a power depending on the pH
- For mild steel the power that P has to be raised to in order to obtain a corrosion loss of 1.3 inches after one year is 2.8

$$Exponent_P = \frac{2.80}{pH^n} \qquad Exponent_N = \left[\frac{2.80}{pH^n}\right]^{-1}$$

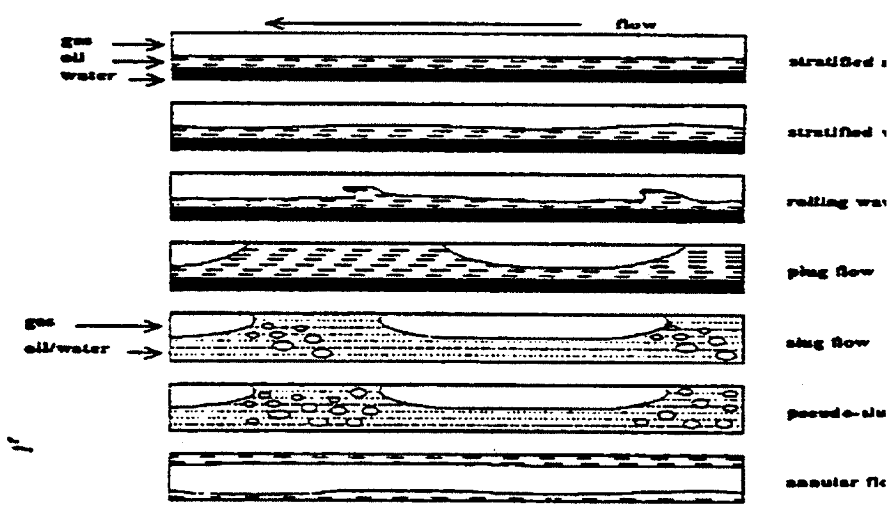
where n = 0.47 (at a pH= 9, exponent of P and N have a value of 1)



Effect of Flow Regime on Corrosion

- Convective mass transfer: rate of corrosion affected by either the convective transport of corrosive material to the metal surface or the rate of dissolved corrosion products away from the surface
- Phase transport: depends on the wetting of the metal surface by the phase containing corrosive material; strongly affected by multiphase flow
- Erosion: high velocity, high turbulence fluid flow and/or flow of abrasive material prevents the formation of a protective film, allowing fresh material to be continuously exposed to the corrosive environment

Typical Flow Patterns Observed in Oil\Water\Gas Flow



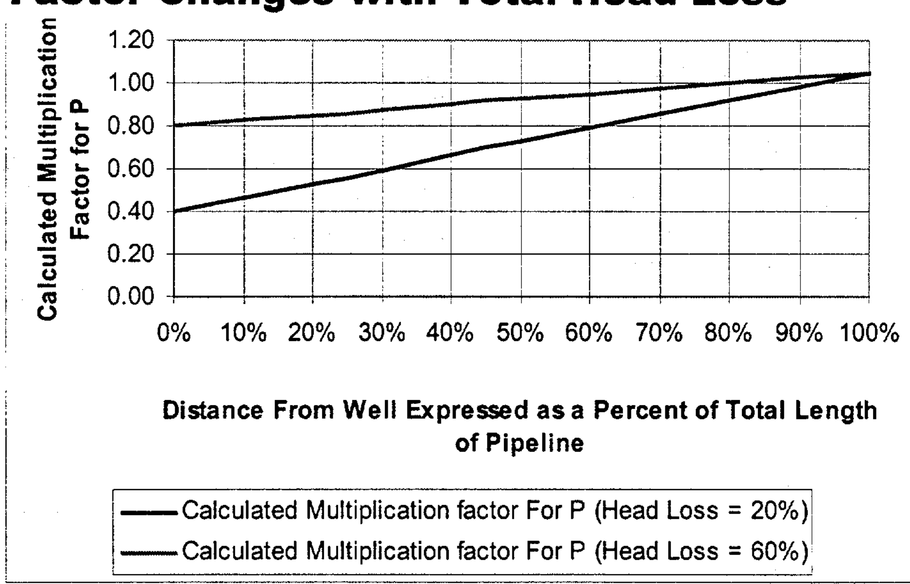
Hypothetical Equation Showing Effect of Flow Regime on P

Multiplication Factor for P

$$\left(1.05-\frac{\%HeadLoss}{100}\right)\frac{\%TotalLength}{100}+\left(\frac{\%HeadLoss}{100}+0.20\right)$$

with increasing head loss, the multiplication factor becomes larger and larger but still remains under unity, except near the end of the pipeline where water can settle out and aggravate corrosion

Illustration of How the Multiplication Factor Changes with Total Head Loss



Application of Corrosion Loss Formula

- Choose type of metal pipe is made of
- Determine temperature range of well, or if sour
- Adjust P and N according to possible pH range
- Calculate multiplication factor for P
  - What section of pipeline is the calculation being performed for?
  - What is the total head loss over the pipeline's length?
- Are there inhibitors being used/how effective?
- How old is the pipeline
- Calculate probable corrosion loss; loss represents average

Improvement of Corrosion Loss Prediction

- Performing specific measurements of parameters influencing sour corrosion
- Dividing pipeline into relevant sections and predicting flow characteristics in each section
- How efficient is the inhibitor in each section of pipe?
- What type of corrosion is the predominant cause of corrosion failures in the pipeline

Introduction: Predicting the Burst Pressure of a Corroded Pipe

- If pipeline is unpiggable it is difficult to know the distribution of flaws
- Even with pigging technology, there are uncertainties in the measurements of flaw sizes
- Long smooth corrosion grooves have a different strength as opposed to short pit like flaws
- ANSI/ASME B31G guideline is based on a semi-empirical burst formulae which exhibit a large scatter when compared to available data
- Procedures err grossly on the conservative side

Burst Strength Predictions

- The allowable pressure on a pipe before yielding occurs is given by:

$$P_{allowable} = \frac{\sigma_{yield} t}{R}$$

where t is the thickness of the pipe

R is the mean radius and σ_{yield} is the yield stress of the pipe material

Burst Strength Predictions

- General stress strain law can be employed for burst strength predictions; intended to fit the material data in the large strain region of interest

$\sigma = E\varepsilon$ changes to $\sigma = C\varepsilon^n$ where

σ is the true Cauchy stress and ε is the logarithmic strain. The constants n and C are given by:

$$n = \ln(1 + \varepsilon_{ult}) \qquad C = \left(\frac{e}{n}\right)^n \sigma_{uts}$$

with ε_{uts} being the engineering strain corresponding to the engineering ultimate stress, σ_{uts}

Burst Strength Predictions

Burst strength for crack like flaws:

$$P_b^{crack} = f_c \frac{t-a}{R}\left[\left(\frac{1}{2}\right)^{n+1} + \left(\frac{1}{\sqrt{3}}\right)^{n+1}\right]\sigma_{uts}$$ where f_c has been introduced to account for the case where the fracture toughness is less than that required for fracture stability at burst pressure for a pipe with uniform loss of wall thickness

$f_c = 1$ for all quenched and tempered casing, which has high toughness

Burst Strength Predictions

Burst strength with smooth wall loss:

$$P_b^{wl} = f_{wl} \frac{t_{min}}{R}\left[\left(\frac{1}{2}\right)^{n+1} + \left(\frac{1}{\sqrt{3}}\right)^{n+1}\right]\sigma_{uts}$$ where f_{wl} accounts for the increase in strength provided by the surrounding thicker wall

$$f_{wl} = \left(\frac{2}{1+\phi}\right)^n$$

Burst Strength Predictions

- Equations are only applicable for loss of thickness >20% and <80-90% of the original thickness of the pipe
- Account of external hydrostatic pressure must be made, which tends to help the burst strength
- Pressure gradient along the pipeline's length changes due to energy dissipating elements along the pipeline's length, therefore the pressure far away from a pump will be less than near it
- Corrosion can affect steel properties through the process of hydrogen embrittlement

Burst Strength Predictions

- A careful analysis must be made of the pipeline section to make sure that any free spans or deformations are accounted for which can reduce the amount of pressure needed to burst the pipe

Calculating the Probability of Failure

- Operating conditions must be known (demand)
  - what is the factor of safety on the operating pressure
- Capacity of the system must be predicted (resistance)
  - what is the bias on the steel strength
- Variation in the demand and resistance must be calculated or estimated
- What is the best representative distribution

Calculating the Probability of Failure

- What is the standard deviation of the operating pressure
  - For a lognormal distribution the standard deviation can be taken as 0.20
- What is the standard deviation of the burst pressure
  - The coefficient of variation of the burst pressure can be taken as: 0.20 + (%loss of thickness)/100
  - With increasing section loss, the variability in the burst pressure increases

Calculating the Probability of Failure

- Relevant equations for dealing with lognormal distributions

$$\sigma_{\ln x} = \left[\ln\left(1 + COV_x^2\right)\right]^{\frac{1}{2}}$$

$$COV = \frac{\sigma_x}{\overline{X}}$$

Calculating the Probability of Failure

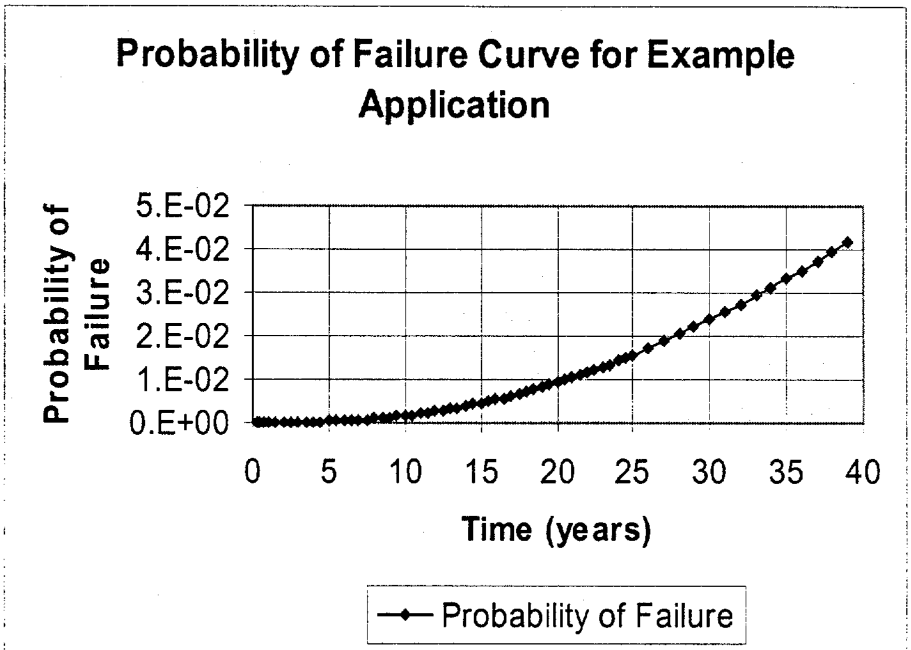
$p_f = 1 - \Phi(\beta)$ where β for a lognormal distribution is equal to:

$$\beta = \frac{\ln\left[\frac{P_{burst50}}{P_{operating50}}\right]}{\sqrt{\sigma^2_{\ln burst} + \sigma^2_{\ln operating}}}$$

(no correlation between the operating and the burst pressure)

Example Application

- Material type: Mild Steel (P=14, N=1.5)
  - FS = 2 on the operating pressure; D = 36 in.; t=0.75 in.; σ_{ult}=122,000 psi (Bias = 2 standard deviations)
- Temperature Range: 122 - 158 deg. F; pH range 2.0-6.0; choose localized pH = 3.4
- Inhibitor Effectiveness: 40%
- Head Loss: 25%
- Distance From Well: 80%
- Final Value of P and N is 42 and 1 respectively



Calculation of the Probability of Failure from a Pigging Inspection

- All depths of holes are measured, and a probability of failure for each flaw is calculated
- Then the probability of failure for the whole section is given by:

$P_{fSection} = 1-(1-P_{fIndividual})^{N}$ where the failure of the elements are independent

Conclusions

- It is important to be aware of the various corrosion mechanisms present in the system
- Include all corrosion mechanisms in the database, but choose the one that gives the most conservative results to be sure that there is no underestimation (hopefully they are accurate enough not to overestimate the actual corrosion loss)
- Collect and include in database corrosion characteristics of metal type that pipeline is constructed of
- How effective are the inhibition techniques used?

Conclusions

- Know how effective detection methods are and include in database, with constant updating
- Know how leaks of various sizes can be stopped and how do they impact the cost curve; must be constantly adjusted for current cost rates, and future rates
- Assess each section of pipeline to know cost factors playing a major part at that section
- What are the best construction techniques; not necessarily the cheapest in the short term
- Know what goals you want to reach, choose 'best'

Conclusions

- Key is to include all previously mentioned criteria in database under generic headings which can be changed periodically by adding specific items or removing them
- Create a link between MMS and database, with access available to the output, and to the incidents for each pipeline
- Key components of database would have to be approved by MMS periodically, but corporate secrets would not be public domain to retain the competitive edge over other companies

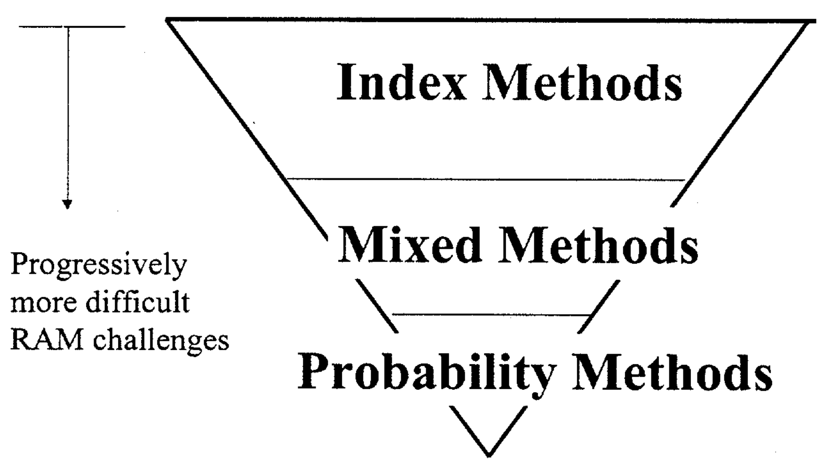
Notes:

1)

Pipeline RAM Workshop

- Amoco Clear Lake campus
- Proposed November 5 and 6
- By invitation (20 - 30 attend)
- Discuss three approaches to pipeline RAM

Explore Complimentary Elements



Proposed Workshop Format

- Protagonist presentations (written)
- Formal discussions (all, written)
- Case histories (all)
- Workshop discussions (summaries)
- Workshop conclusions
- RECOMMENDATIONS ←→

Draft Workshop Program

- First day morning
  - Index based methods (e.g. Muhlbauer)
  - Discussions
  - Conclusions
- Afternoon
  - Probability based methods (e.g. Nessim, Bai)
  - Discussions
  - Conclusions

Draft Workshop Program

- Second day morning
  - Mixed methods (e.g. Bea)
  - Discussions
  - Conclusions

Notes:

1)