Operation of pipelines at above 72% SMYS in the UK

Norman Sanderson, BP EPTG, UK

Phil Hopkins, Penspen, UK

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Washington. March 21st 2006.

Overview

Presentation overview:
UK Pipelines
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Conclusions and recommendations

UK Pipeline Systems

Almost 40,000 km of transmission lines in the UK:

Onshore liquid	10,000km
Onshore natural gas (>100psi)	19,000km
Offshore	10,000km

500,000 kilometre years of operation of gas transmission lines without an ignited release of gas

- Good design practice using deterministic design based codes to a design pressure up to a maximum of 72% SMYS
- Safe operations supported by:
  - Pre-service hydrostatic pressure test
  - Protection against corrosion
  - Inspection and maintenance policies
  - Regular surveillance

UK Pipeline Systems: National Grid Gas plc

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This is the 'old' BG high pressure system

UK Pipeline Systems: BP

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UK Pipeline Safety Regulations

- **The 'Health and Safety Executive' (HSE) enforces health and safety regulation in Great Britain.**
  - The HSE has a staff of 4,000
  - It is responsible for pipelines: 'cradle to grave'
- **UK Pipeline Safety Regulations 1996**
  - 'Goal setting' and a 'risk based' approach to safety.
  - Requires operators to design, build and operate pipelines to ensure that they are safe 'so far as is reasonably practicable' **['SFAIRP']**
  - ….. to ensure that risks are 'as low as reasonably practicable' **['ALARP']**

[UK Pipeline Regulations can be viewed at: http://www.opsi.gov.uk/si/si1996/Uksi_19960825_en_1.htm]

['ALARP' principles are explained at: http://www.hse.gov.uk/risk/theory/alarp.htm]

UK Pipeline Safety Regulations

UK Health and Safety Framework

- Individual risks and societal concern must be taken into account in assessing whether a risk is unacceptable, tolerable, or broadly acceptable
- For every hazard:
  - ✓ A suitable and sufficient risk assessment must be undertaken to ensure that the risks are adequately controlled.
  - ✓ Suitable controls in place to address all significant hazards
  - ✓ As a minimum, the controls must include relevant good practice precautions
- High design factor pipelines: onus on the operator to make the case
  - ✓ to justify and to demonstrate continued pipeline integrity

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‘Standards’ Recognised by HSE

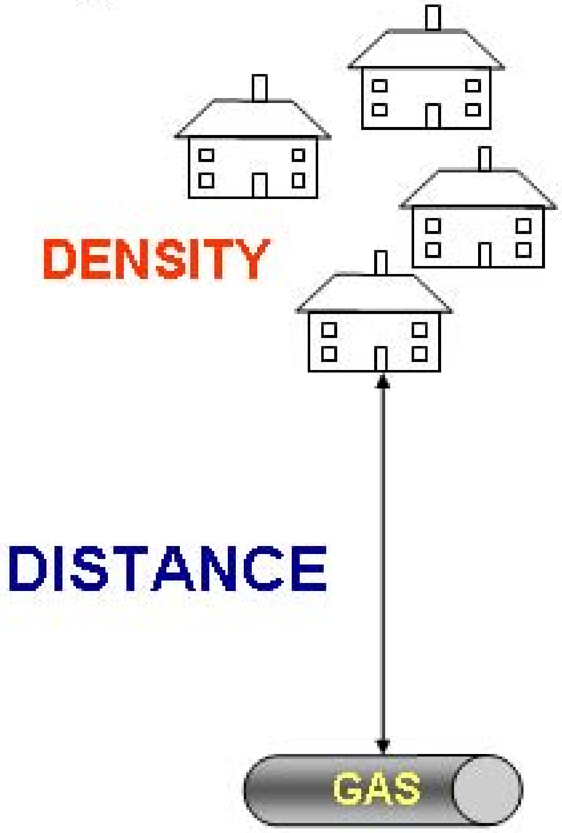
Some design documents recognised by the Health & Safety Executive as good practice:

- ***Steel Pipelines for High Pressure Gas Transmission***, IGE/TD/1 Edition 4, Institution of Gas Engineers, 2001
- ***Code of Practice for Pipelines – Part 1: Steel pipelines on land,*** **British Standard PD8010-1:2004**
- ***Gas supply systems - Pipelines for maximum operating pressure over 16 bar – Functional requirements,*** **British Standard EN 1594, 2000**
- ***Petroleum and natural gas industries – Pipeline transportation systems,*** **British Standard EN 14161:2003**

Particular importance given to reducing risks through consideration of health and safety in design

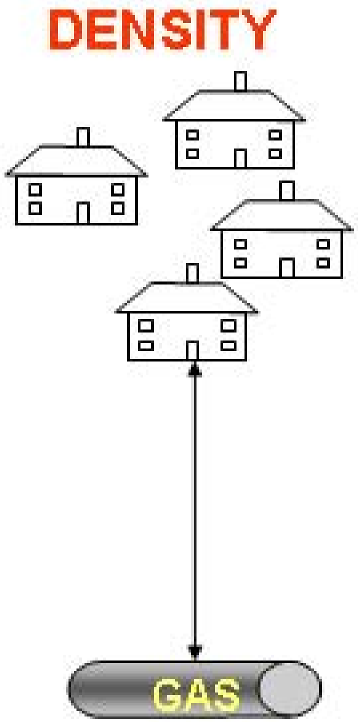
UK ‘Standards’ for Gas Lines

These standards have requirements for the location of gas lines:



UK Standards: Location Classification for Natural Gas (≤0.72)

BS PD 8010 Location	BS PD 8010 Population Density	Max. Design Factor
Class 1	<2.5 persons/hectare	0.72 (0.80 with 'SRA')
Class 2	≥2.5 persons/hectare or areas highly developed (e.g. with shops)	0.30 (0.72 with 'SRA')
Class 3	Central areas of towns, with high population, building density, etc.	Avoid these locations



1 hectare = 10,000 m^2 ~ 12,000 yds^2 'SRA' = structural reliability analysis

UK Standards: 'Proximity' Distances for Natural Gas (≤0.72)

UK Standards: Design Factor

STANDARD	Hoop stress (σ_θ) equation[3]	Hoop Stress Design Factor [using t_{code}]	Hoop Stress Design Factor [using t_{nom}]
ASME B31.8	$\sigma_\theta = pD/2t_{nom}$	0.80	0.80
BS PD 8010-1	$\sigma_\theta = pD/2t_{min}$	0.72 (0.80)	0.65 (0.72)
CSA Z662	$\sigma_\theta = pD/2t_{nom}$	0.80	0.80

UK standards use 'min' wall: this gives lower design factor compared to North America

UK standards allow higher design factors using 'structural reliability analysis'

UK Standards & Regulations

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The UK allows

- **–quantitative risk assessment (QRA), and**
- **–structural reliability assessments (SRA)**

to be used in designing new pipelines, and uprating existing pipelines, to 0.80 design factor.

1. Risk = Probability of a failure x Consequences of a failure

Probability of a failure:
- External interference
- Corrosion
- Etc.

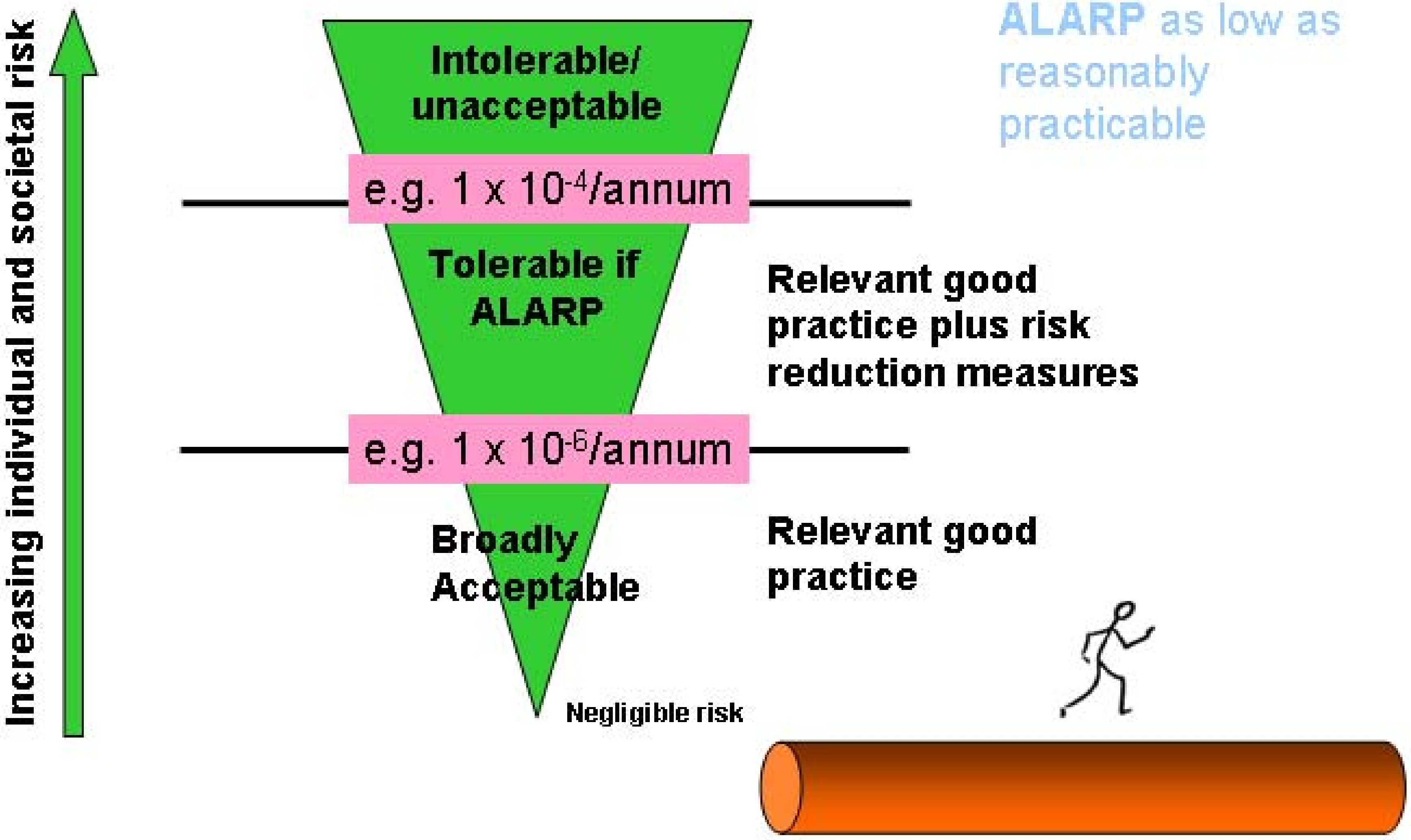
Consequences of a failure:
- Harm to people

2. Compare calculated risk with ‘acceptable’:

–**‘individual’ risk:** how an individual sees a risk affecting them

–**‘societal’ risk:** how society views the risk

Types of ALARP Demonstration



ALARP as low as reasonably practicable

[Anon., 'Reducing Risks, protecting people. HSE's decision-making process'. HSE Books. UK. 2001. Download from http://www.hse.gov.uk/risk/theory/r2p2.pdf]

UK Standards & Regulations

–The UK allows

- –quantitative risk assessment (QRA), and
- –structural reliability assessments (SRA)

–to be used in designing new pipelines, and uprating existing pipelines, to 0.80 design factor.

SRA determines possibility and frequency of pipeline failure.

When used on an 'uprating'…

- – Identify all failure modes (external interference, SCC, etc.)
- – Calculate probability of failure at current design factor (≤ 0.72), $P_{0.72}$
- – Calculate probability of failure at new design factor (0.72≤ 0.80), $P_{0.80}$
- – If the increase in $P_{0.80}$ is not 'significantly' above $P_{0.72}$ … **uprate**

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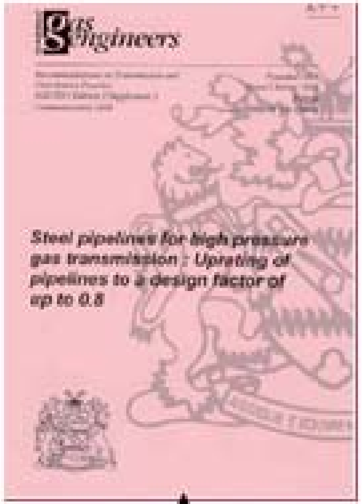
Uprated (>0.72) Pipelines in UK

Pipeline Diameter	Length Uprated (km)	Uprated Pressure (bar)
36 inch	1217	85
42 inch	374	80
In progress: ~60km		



UK Guidelines for uprating to 0.80

+ 3 compressor stations
+ ~100 above ground installations

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Use of probabilistic ('SRA') methods: Examples in UK

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NEW CONSTRUCTION:

Design of the Britannia gas export pipeline (185 km) in the UK sector of the North Sea in mid-90s

- Design used 'limit state' (structural reliability analysis)
- Design to 81% SMYS based on minimum wall thickness
- Accepted by UK H&SE on a project specific basis

UPRATING EXISTING SYSTEM:

Uprating of sections of the National Grid Gas Transmission System

- Increased demand for gas
- Solution? Upgrade existing ~20-year old pipeline sections from 72% to 79% SMYS
- Strategy based on goal setting regime provided by the UK Pipeline Safety Regulations 1996
- Using structural reliability analyses

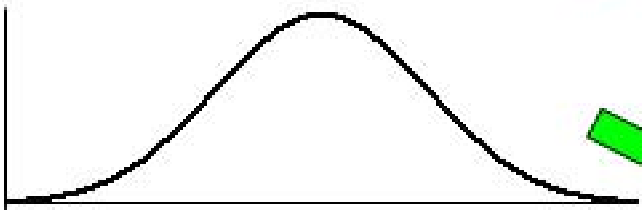
Moving to 'SRA'

1. Traditional code approach

$$p, D, t \rightarrow \sigma_H = \frac{pD}{2t} \rightarrow$$

Hoop stress must be less than 72% SMYS

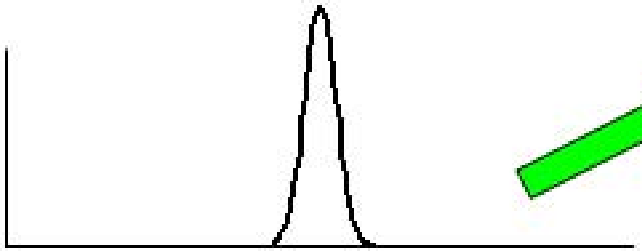
2. Structural reliability analysis approach:



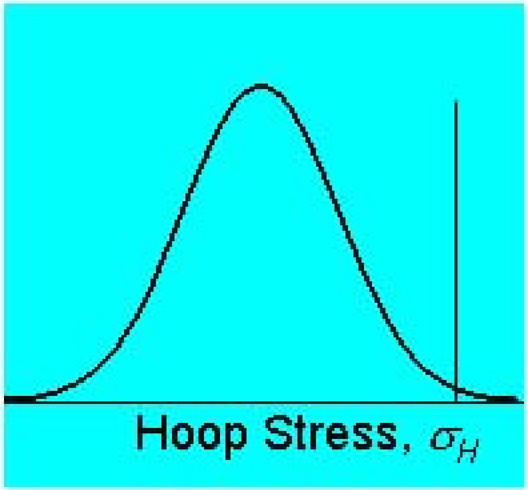
Wall Thickness, t

Assume pressure is fixed, p

$$\rightarrow \sigma_H = \frac{pD}{2t}$$



Diameter, D



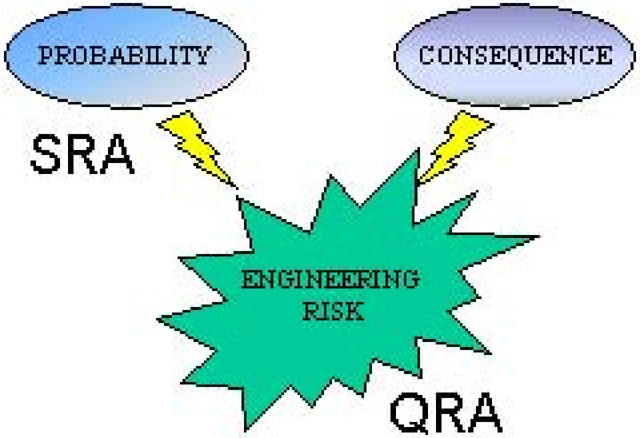
The probability that the hoop stress (the load) exceeds a certain value (the resistance) must be less than a specified limit.

Moving to 'SRA'

Traditional approach to pipeline design using **design factors**, is believed to give a conservative design, but the user has little understanding of the pipelines vulnerability to the various failure mechanisms

$$\sigma_\theta = \frac{pD}{2t}$$

Structural reliability analyses ('limit state' methods) provide the user with the potential for a complete understanding of the reliability of the pipeline system



Uprating methodology for >0.72

VIABILITY: Review original design: are there any characteristics that prevent uprating?

ASSESSMENT: Completely survey the pipeline: are there any components that need replacement/re-design?

STRUCTURAL RELIABILITY ANALYSIS: Is increase in failure probability at higher pressure 'significant'

REVALIDATION: Revalidate the line by internal inspection or hydrotest

MODIFICATION: Modify/replace any component that is not fit for service at uprated pressure

UPRATING: Raising pressure to new MAOP is conducted under controlled

All previous upratings in UK have been conducted with the full involvement of the UK Regulatory Authorities and have been subject to external, independent audit.

Identification of credible failure modes and operating loads

Failure modes

- Pipe wall bursting
- External corrosion
- External interference damage
- Fracture propagation
- Fatigue crack growth
- Stress corrosion cracking
- Hydrogen induced cracking

Loading conditions

- Fluctuating loadings
- Ground movement
- Overpressure

Note that increasing wall thickness is more effective in mitigating against failure than design factor

Wall Thickness (inch)	Failure Rate in Onshore European Gas Line (per 1000km year)
0 to 0.2	0.62
0.2 to 0.4	0.17
0.4 to 0.6	0.02

USA and SRA?

UK Lessons Learnt

- The development of high design factor pipelines was a partnership between the pipeline industry and the UK regulator
- Use of SRA is not essential for designing/uprating pipelines to >0.72 in UK, but is popular in UK
- If USA wants to use the UK methodology (SRA), the strengths and limitations of 'SRA' must be understood by both operators and regulators:
  - 'SRA' needs good quality and extensive pipeline data
  - 'SRA' is subjective: the numbers obtained require consideration and agreement.
- The Regulator needs to:
  - develop a methodology for designing (e.g. ASME B31.8?) and uprating (e.g. SRA?) to 0.8 design factor
  - consider 'acceptable' failure probabilities and risk levels in pipelines (not easy!)
  - If SRA is to be used: conduct a pilot study on a pipeline for uprating using SRA (again, not easy!)

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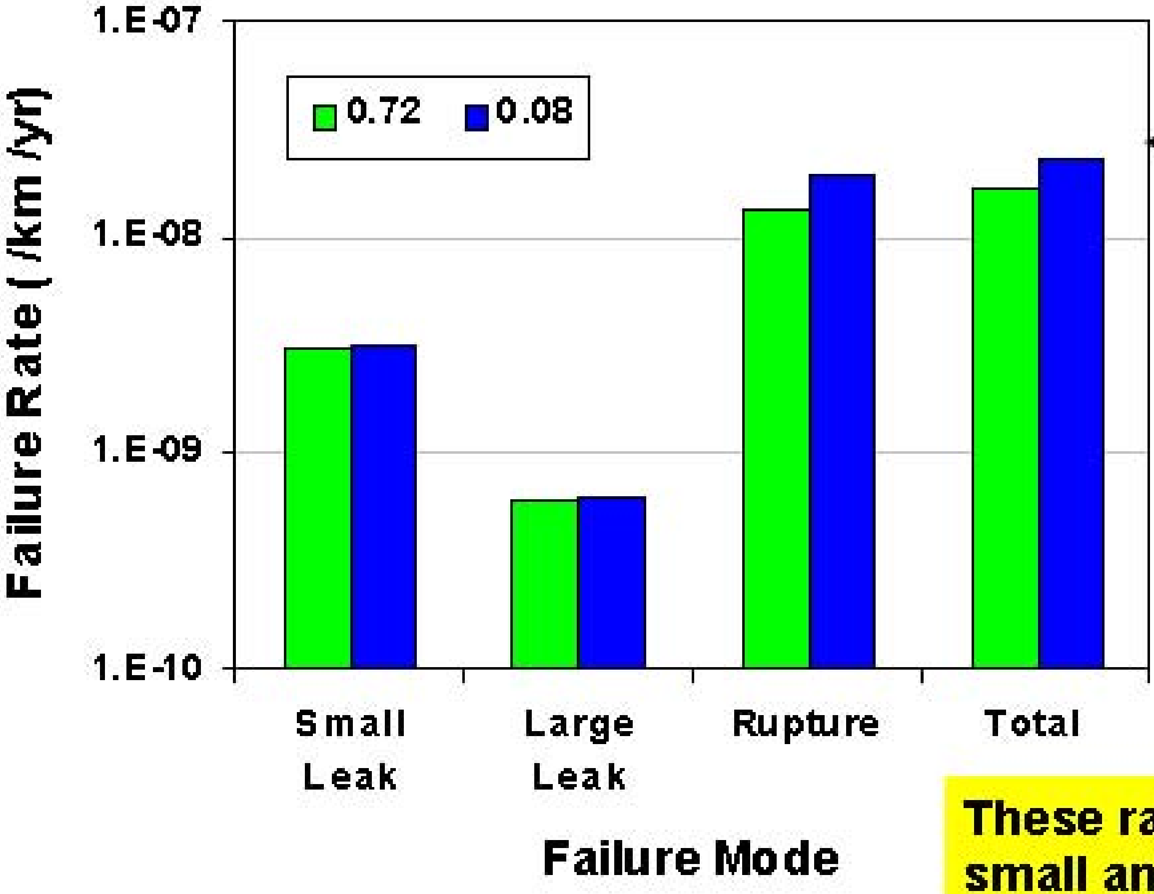
BP Work on High Stress Pipelines

- **BP work has concluded**
  - A change in design factor from 0.72 to 0.80 is likely to have a minimal effect on the calculated failure rates and risk levels.
  - It is feasible to use structural reliability-based design procedures to justify an increase in the basic design factor from approximately 0.72 to 0.85, for a large diameter pipeline in a remote area.
  - It is essential to consider damage and time dependent deterioration.

BP Work on High Stress Pipelines

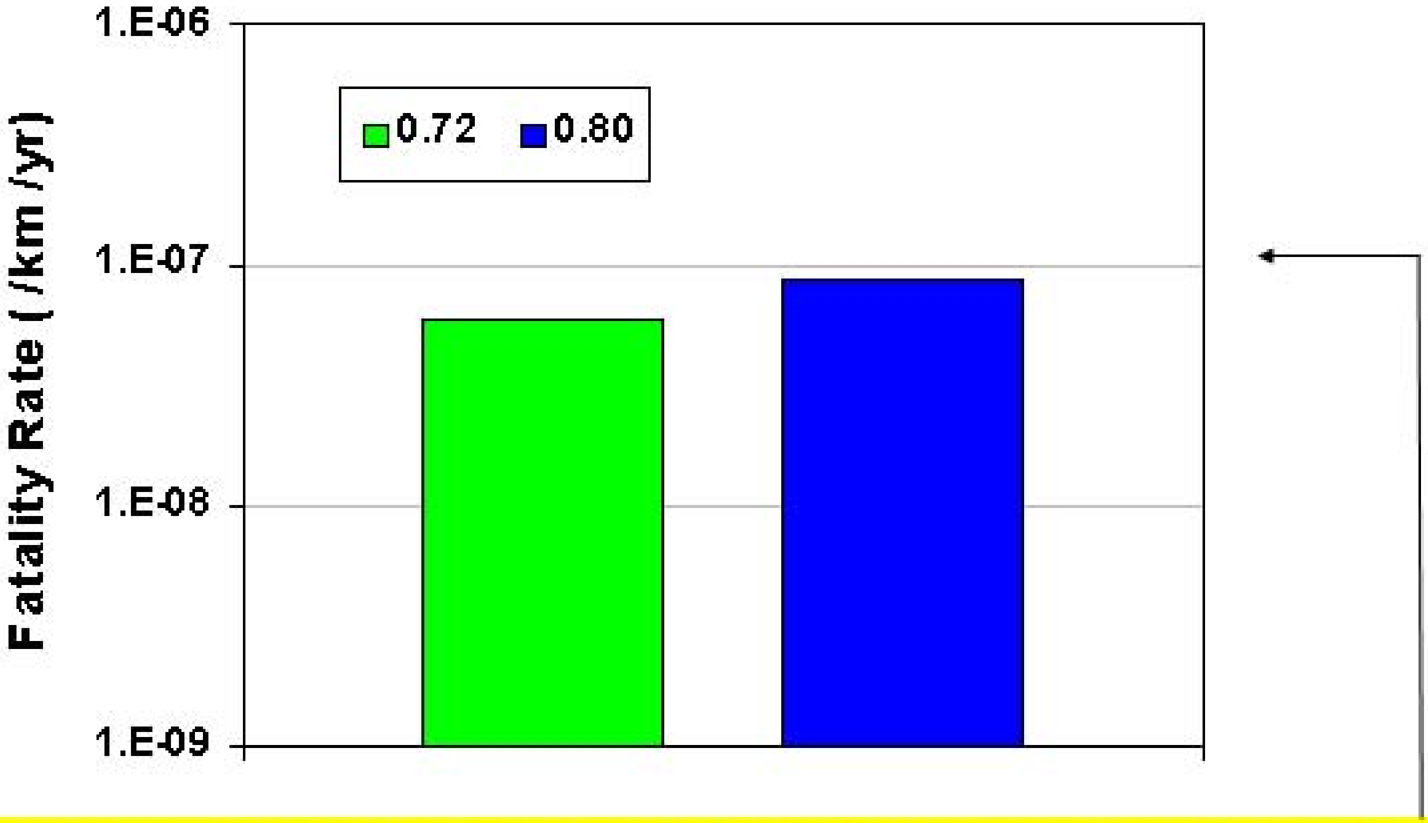
- **High design factor can be justified provided that:**
  - Corrosion rates are not severe;
  - Adequate measures are taken to limit the magnitude and frequency of external interference damage; and
  - An appropriate inspection and maintenance program is in place with the ability to identify, locate and repair damage features before they become critical.

Failure from third party interference



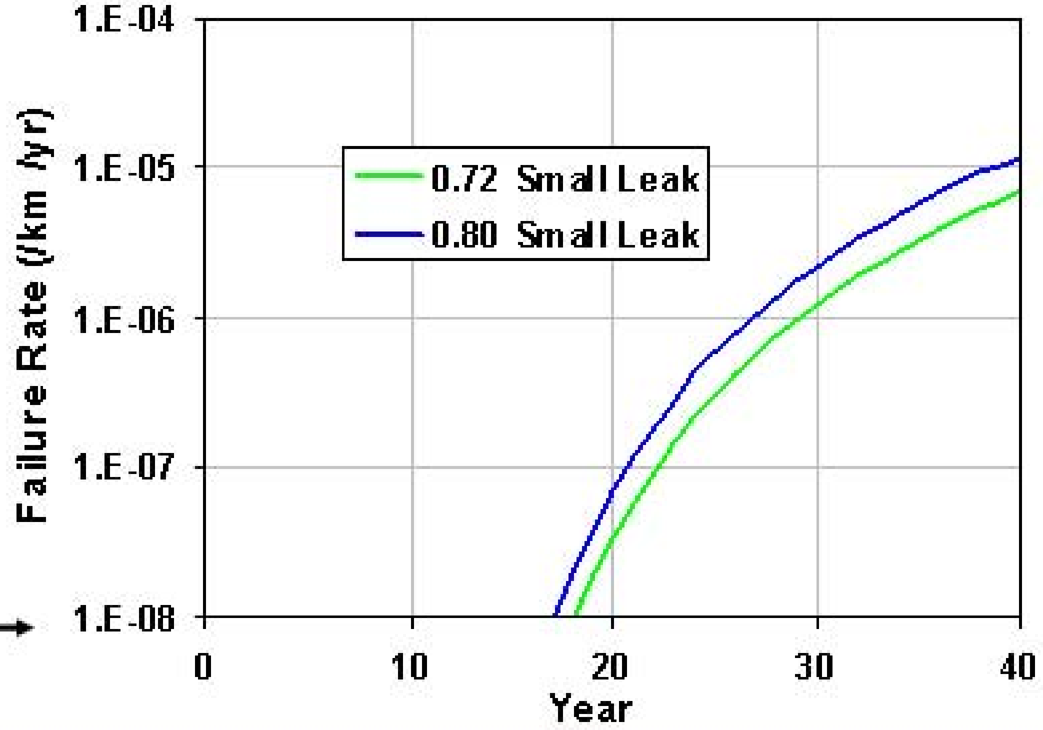
These rates are very small and are not significantly different for the two design factors

Failure from third party interference



The estimated fatality rate is< 10^{-7} per km-year for both design factors.
Individual risks of <10^{-6} per year are quoted as 'tolerable' (IGE TD 1)

Failure from corrosion



The rates for LARGE leaks & ruptures are <10^{-8} per km-year for the first 40 years of the pipeline life (and hence do not appear on the Figure).

The rate of SMALL leaks peaks at a low value of 10^{-5} per km-year after 40 years.

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- UK experience has shown that pipelines can be safely operated at greater than 72% SMYS
- The use of structural reliability analysis ('limit state' probabilistic design methods) allow the operator and regulator to gain a quantitative understanding of the vulnerability of a pipeline to the credible failure mechanisms
- High stresses are not the major threat to pipelines: it is damage that is the main threat
  - Consequently, a comprehensive pipeline integrity monitoring system should be applied to high design factor pipelines to avoid development of failure mechanisms

Contacts

Norman Sanderson	norman.sanderson@uk.bp.com
Phil Hopkins	p.hopkins@penspen.com