Energiegase:
Methan, Biogas, Wasserstoff, Synthesegase.

TEIL 6 – Pipelines: Design & Safety

WS 2023/24

Ruhruniversität Bochum

Lehrstuhl für Energieanlagen und Energieprozesstechnik

Prof Dr Gerald Linke, CEO DVGW, German Gas and Water Association

DVGW

Teil 6 – Pipelines

Design & Safety

1. Design, costs and capacity
2. Pipeline laying
3. Components
4. Other design philosophies
5. EGIG statistic
6. DVGW statistic

Teil 6 – Pipelines

Design & Safety

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NORWAY
SWEDEN
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IRELAND
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THE NETHERLANDS
BELGIUM
LUX.
GERMANY
POLAND
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UKRAINE
CZECH REPUBLIC
SLOVAKIA
AUSTRIA
SWITZERLAND
HUNGARY
MOLDOVA
ROMANIA
FRANCE
SLOVENIA
CROATIA
BOSNIA AND HERZEGOVINA
SERBIA
MONTENEGRO
NORTH MACEDONIA
ALBANIA
BULGARIA
GREECE
ITALY
CORSICA
SARDINIA
MALTA
SPAIN
PORTUGAL
TURKEY
GEORGIA
ARMENIA
AZERBAIJAN
TURKMENISTAN
SYRIA
CYPRUS
LEBANON
IRAQ
IRAN
TUNISIA
ALGERIA
MOROCCO
MADEIRA
Atlantic Ocean
Bay of Biscay
Baltic Sea
Black Sea
Sea of Azov
Caspian Sea
Mediterranean Sea
Irish Sea
CRETA

The German Natural Gas Pipeline Infrastructure

9.000 biogas plants

(80 TWh/a)

250 bio methane

11 TWh/a

Diversified supply portfolio:

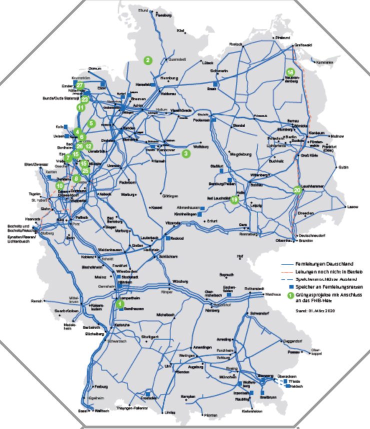
N | West EU | USA

providing

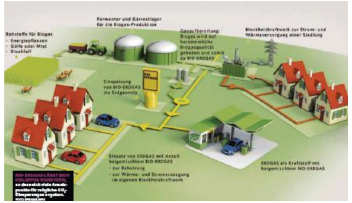
~866 TWh/a

> 40.000 km high pressure grid up to 100 bar

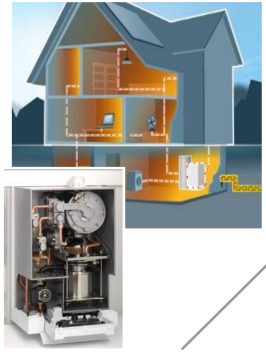
90.000 CNG vehicles



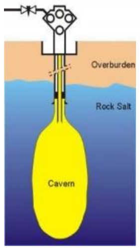
> 500.000 km grid



~50% share of heat market



23 billion m³ underground storage



Several thousand metering & pressure reduction stations

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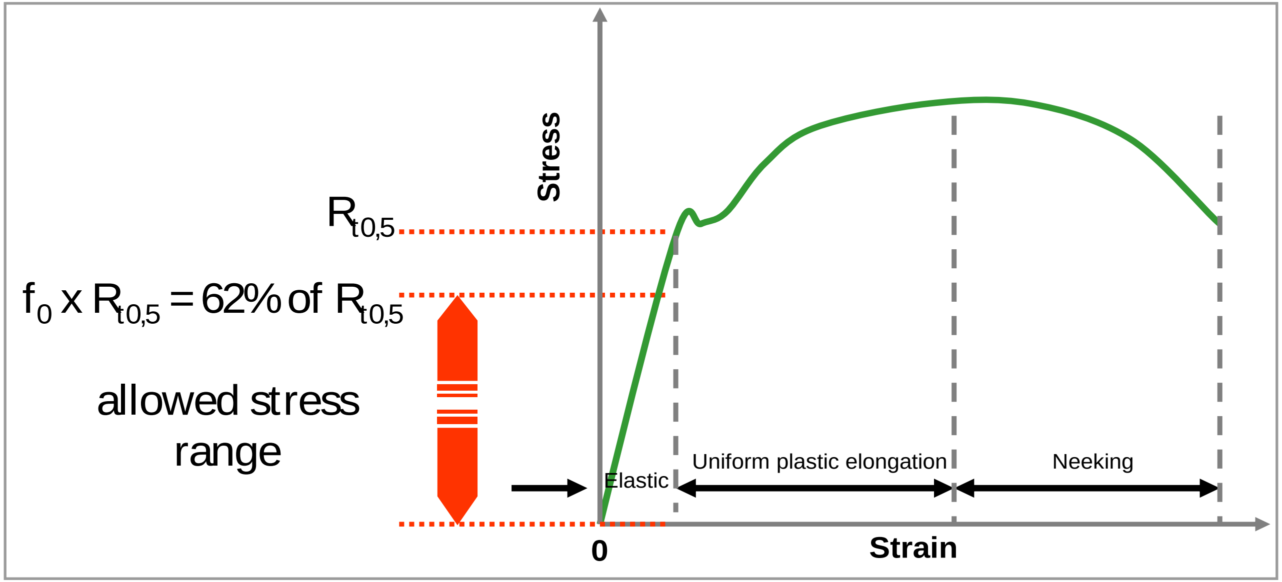
Pipeline Design

Typical construction of a large diameter onshore pipeline.

During operation gas with a pressure of to 100 bar (or even more) and with an average speed of several m/s will flow through this “vessel”.

The dominating material stress within a pipeline results from the internal pressure load. However, the system is operated in the elastic range with a safety factor of 1.6 below specified minimum yield strength



(German) Deterministic Design Philosophy

A deterministic design is characterised by one unique design factor. Safety margins are higher generally. “Primary safety” (design) is rated higher than “secondary safety” (e.g. likelihood reduction due to organisational measures). Typically, a deterministic approach is more suitable for a proven technology.

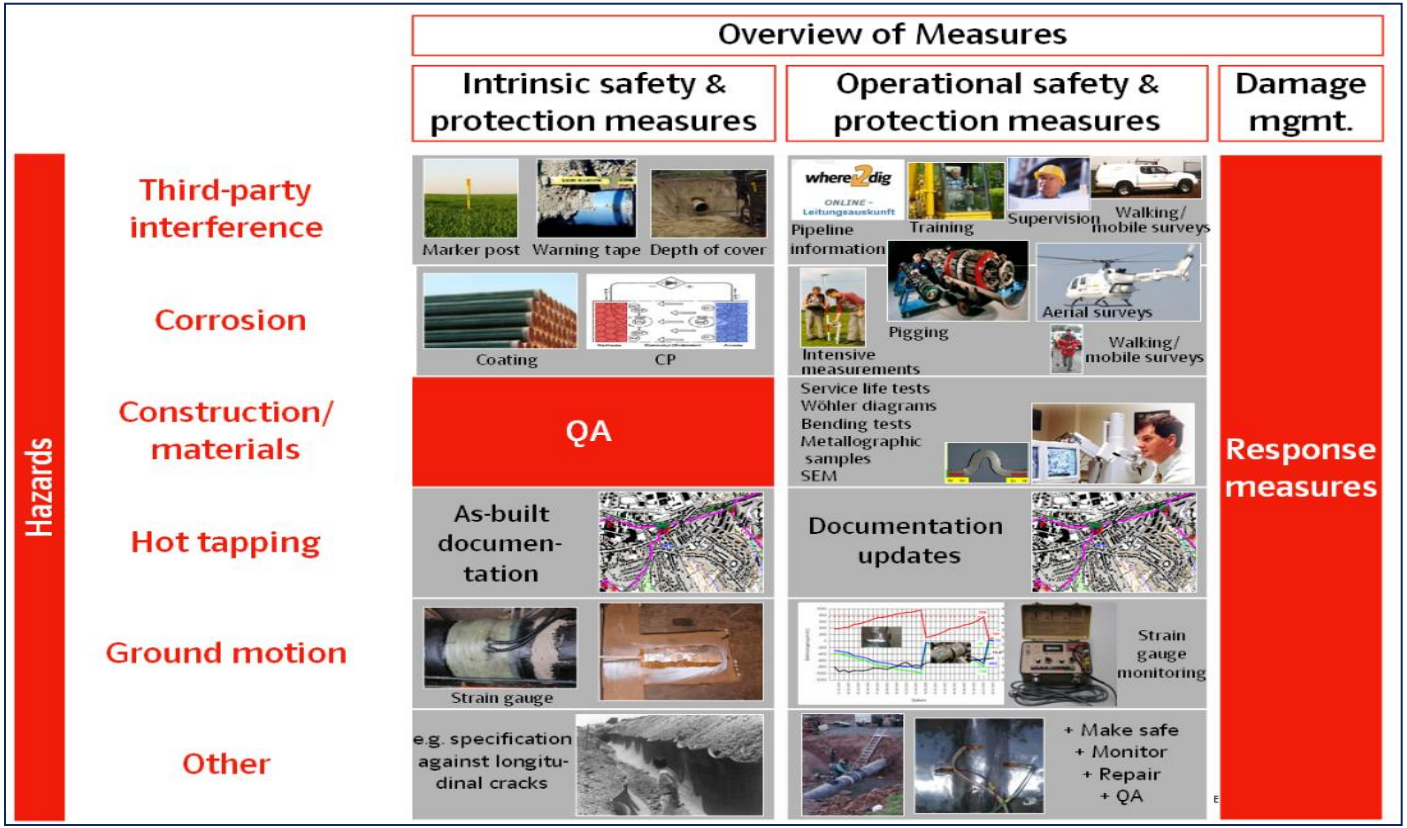
- [x] **System inherent safety during life-time**
- [x] **High safety margin 1.6**
  (or low design factors of 0,62)

Determinstic approach!

Primary safety!

Prevention & acceptance!

Primary & Secondary Safety Measures



Termination of pipeline wall thickness

Design concept can be found in EN 1594 or the German DVGW G 463

Once, diameter and pressure of a transmission have been terminated, the necessary wall thickness of the pipe itself is calculated with the "Barlow formula" ("vessel formula") [see EN 1594, Chapter 7 or copy to the right].

Kesselformel (Barlow formula)

Straight pipe

For normal load conditions the minimum wall thickness for straight pipe is calculated as follows:

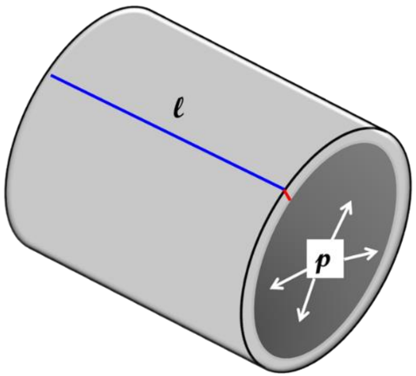
$$T_{\min} = \frac{DP \times D}{20 \times f_o \times R_{t0,5}(\theta)}$$

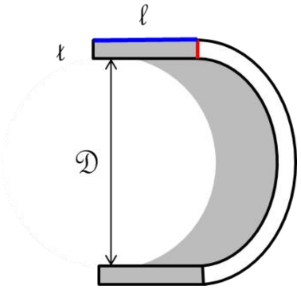
where:

- $T_{\min}$ is the calculated minimum wall thickness, in millimetres (mm);
- DP is the design pressure, in bar;
- D is the outside diameter of the pipe, in millimetres (mm).
  If D_i is preset, D shall equal $D_i + 2\ T_{\min}$, D_i being the inside diameter in millimetres (mm);
- f_o is the design factor;
- $R_{t\,0,5}(\theta)$ is the specified minimum yield strength at the design temperature, in Newton per square millimetre (N/mm^2).
- $R_{t\,0,5}$ is the specified minimum yield strength at ambient temperature, in Newton per square millimetre (N/mm^2) (ref. EN 10002-1).

The maximum design factor (f_o) for internal pressure to be used for the pipeline section in question is as follows:

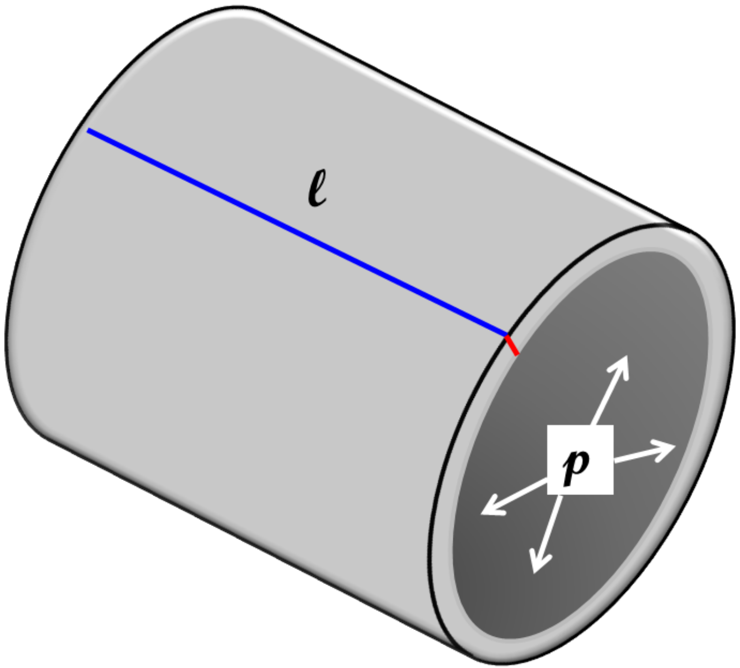
– underground sections, except stations ≤ 0,72;
– pipelines in tunnels continuously supported ≤ 0,72;
– stations ≤ 0,67

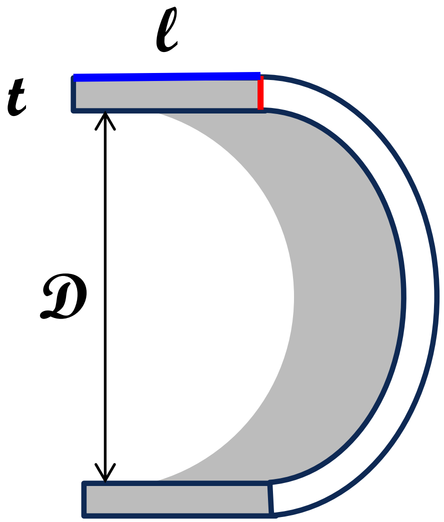




Explanation of Barlow Law

Inner pressure:	p
Length of pipe:	l
Diameter of pipe:	D
Wall thickness:	t
Material strength:	σ





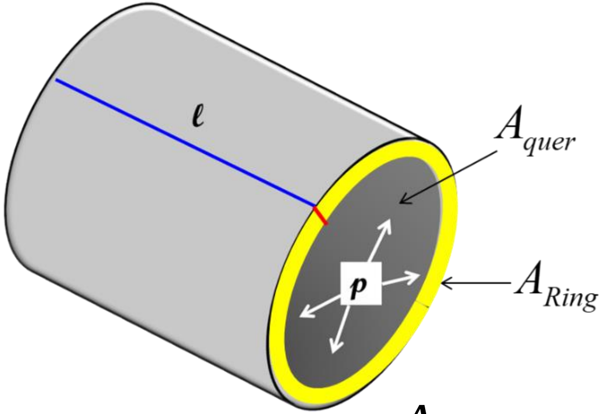
Calculation of material stress in a pipe in longitudinal direction caused by internal pressure when the geometry is given

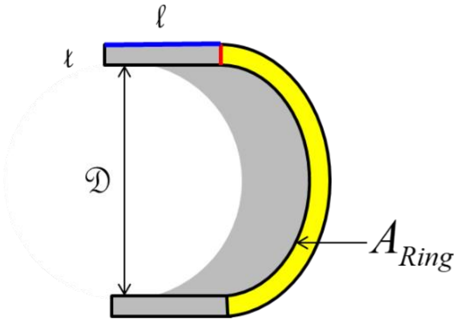
<u>Forces:</u>

$$F_{längs} = p \cdot A_{quer} = p \cdot \pi \cdot \left(\frac{D}{2}\right)^2$$

<u>Stress:</u>

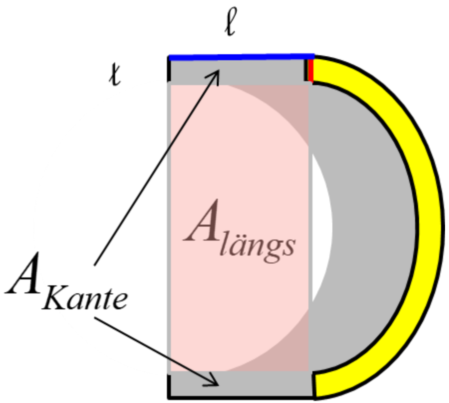
$$\sigma_{längs} = \frac{F_{längs}}{A_{Ring}} = \frac{p \cdot \pi \cdot D^2 / 4}{\pi \cdot D \cdot t} = \frac{p \cdot D}{4 \cdot t}$$





$$A_{Ring} \approx \pi \cdot D \cdot t$$

Calculation of stress in the pipe in radial direction



$$A_{Kante} = 2 \cdot t \cdot l$$

Forces:

$$F_{quer} = p \cdot A_{längs} = p \cdot D \cdot l$$

Stress:

$$\sigma_{quer} = \frac{F_{quer}}{A_{Kante}} = \frac{p \cdot D \cdot l}{2 \cdot t \cdot l} = \frac{p \cdot D}{2 \cdot t}$$

$$\sigma_{quer} = 2 \cdot \sigma_{längs}$$

The stress in radial direction is double the stress in longitudinal direction

And the other way around: Calculation of minimum wall thickness based on the pipe geometry and its material parameter "maximum yield strength"

The maximal stress that the pipe can take depends on is material properties. Thus, if this maximal yield stress is known precisely, the minimal wall thickness can be calculated:

$$t = \frac{p \cdot D}{2 \cdot \sigma_{material}}$$

Uncertainties are covered by a so-called safety factor (safety margin) ***S*** or its reciprocal, the design factor (utilization rate) ***f***.

$$t = \frac{p \cdot D}{2 \cdot \frac{\sigma_{material}}{S}} = S \cdot \frac{p \cdot D}{2 \cdot \sigma_{material}}$$

$$= \frac{1}{f} \cdot \frac{p \cdot D}{2 \cdot \sigma_{material}} = \frac{p \cdot D}{2 \cdot (f \cdot \sigma_{material})}$$

According to DVGW 463 ***S*** has be be larger than 1.6 or the design factor ***f*** has to be smaller than 0,62

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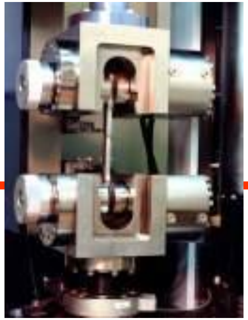
Pipeline construction and quality control

Steel manufacturing
melt control



Material testing

Quality Control
by manufacturer

Material
certification

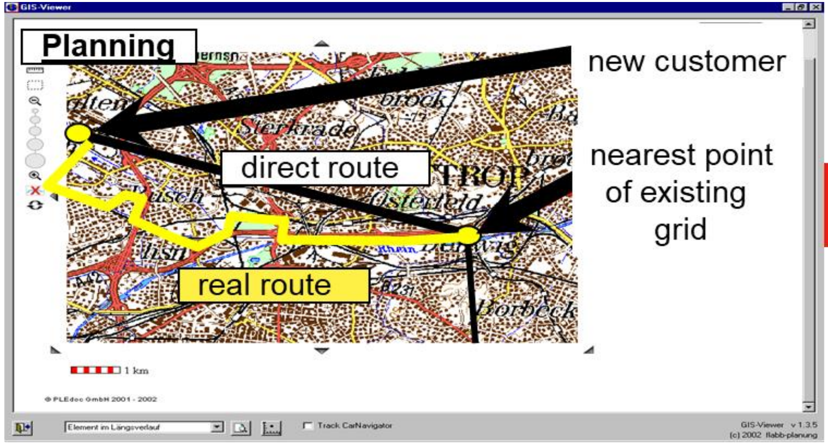
Control of
• staff
• welds

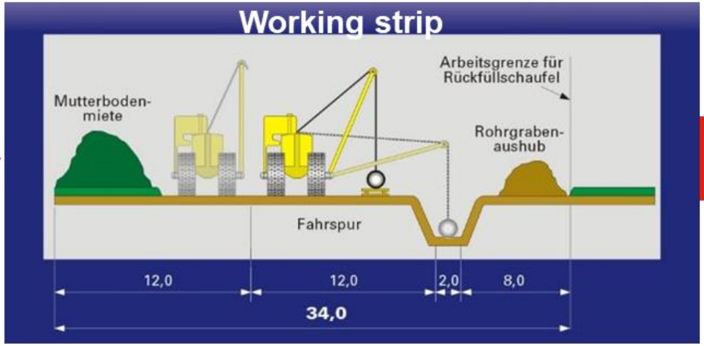
Supervision of
• construction company
• pipe laying

Stress testing
(tightness test)

TÜV certificate

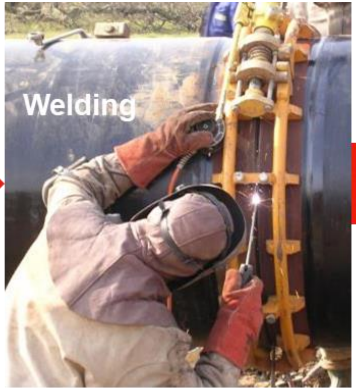
Route selection and termination of pipeline parameters





Soil removal along the route, water treatment and material logistics

Pipe placement, welding, trenching, laying and back filling



Stress and tightness tests and preliminary certificate

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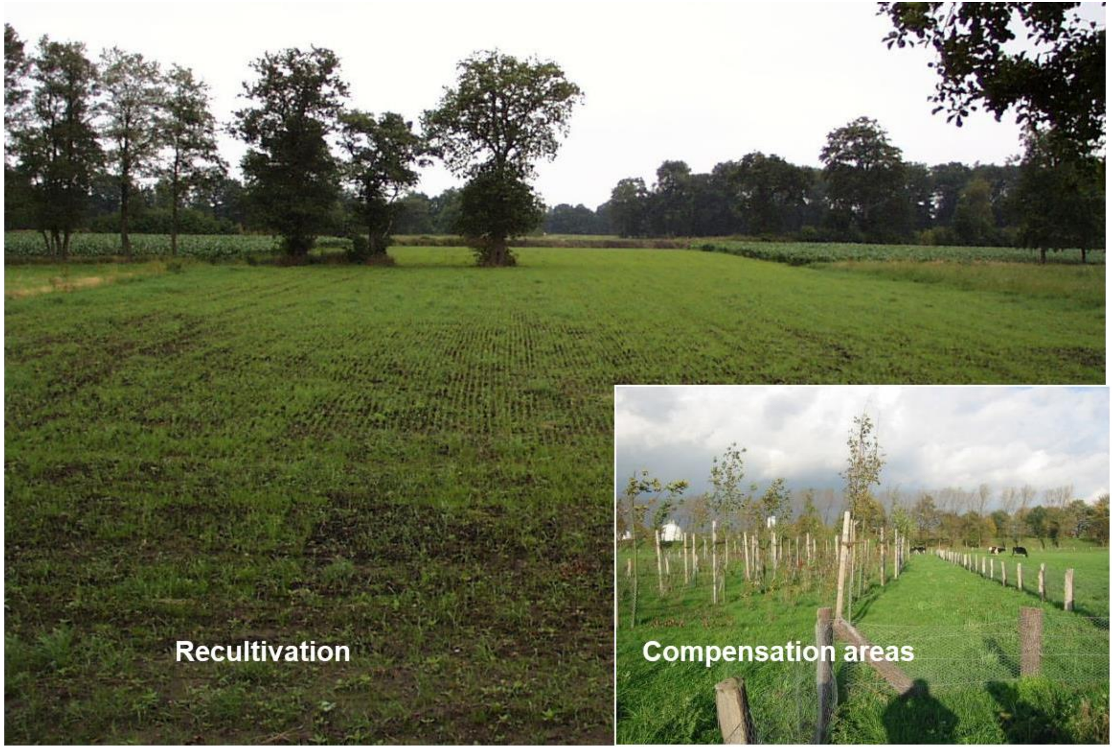
Compensation measures and re-cultivation



Compensation measures and re-cultivation

während des Leitungsbaus ….. ein Jahr danach !

Phases of Pipeline Construction

Removal of soil


Material stocks


Pipe placement


Welding


Trenching


Pipeline lowering


Backfilling


Crossings


Pressings


Hydro testing

Certification


Soil recovery


Re-cultivation (Compensation areas)

Characteristics of high pressure gas pipelines in Germany

Druck:	> 16 bar (aktuell bis 100 bar)
Nennweiten:	DN 100 bis DN 1400
Temperatur:	-10°C bis +60°C
Länge:	wenige Kilometer bis einige hundert Kilometer

Quelle: Open Grid Europe 2020

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Types of pipes

Werkstoff für Gasleitungen:

- bis 10 bar Betriebsdruck: Oftmals Kunststoff (DVGW G 472) und auch Stahl
- > 10 bar Betriebsdruck: Stahl (DVGW G 462 und G 463)

Unterschiedliche Gasleitungsrohre aus Stahl:

- Nahtlose Rohre
- Längsnahtgeschweißte Rohre oder
- Spiralnahtgeschweißte Rohre

Auswahl der Rohre nach verschiedenen Kriterien:

- Innendruck
- Werkstoff
- Wanddicke
- Schweißbarkeit
- Korrosionsschutz (aktiv-KKS / passiv-Rohrumhüllung)
- Preis

Quelle: Open Grid Europe 2020

Spezialthema Stresstests: Was heißt das genau?

Stresstests sind Wasserdruckprüfungen mit Beanspruchungen der Rohre und Baustellenbogen (Feldbogen) bis an den Bereich der Streckgrenze - bei ausreichendem Abstand zur Bruchfestigkeit - unter Beachtung der zulässigen integralen plastischen Verformung der Rohrleitung.

- Wasserdruckprüfung
- Belastung der Rohre und Feldbögen bis an den Bereich der Streckgrenze
- Ausreichender Abstand zur Bruchfestigkeit
- Beachtung der zulässigen plastischen Verformung der Rohrleitung

Quelle: TÜV Nord, Dr. Chr. Engel
DVGW Erfahrungsaustausch 2020

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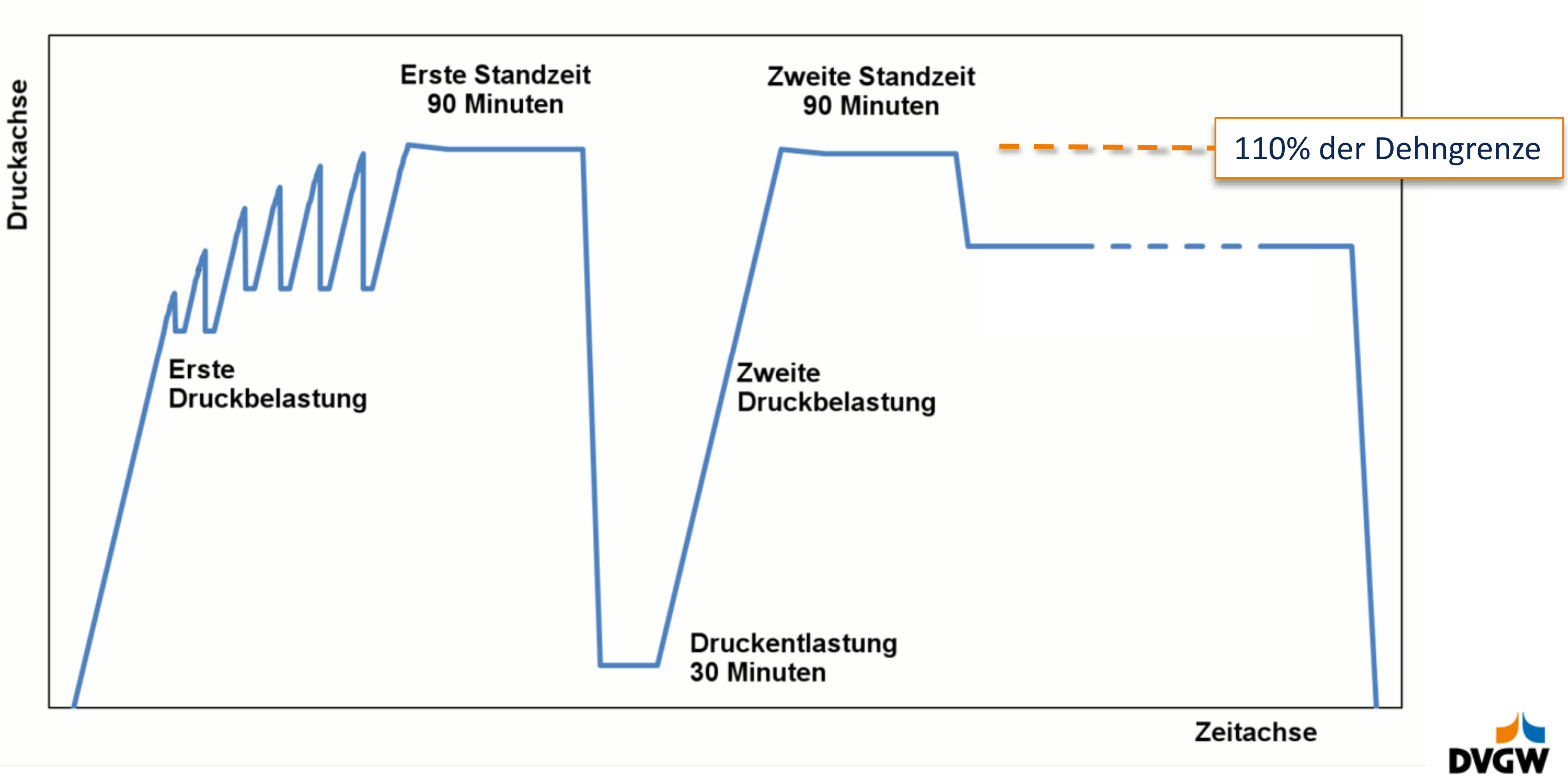
Spezialthema Stresstests: Voraussetzungen

- Molchbare Ausführung des Prüfabschnitts
- Annähernd gleiches Verformungsverhalten der verbauten Rohre (möglichst keine unterschiedlichen Durchmesser, Wanddicken, Festigkeiten)
- Begrenzte Höhenunterschiede (falls nicht vermeidbar Einsatz verschiedener Wanddicken)
- Ausreichende Überdimensionierung der Rohrbögen und sonstiger Komponenten (Armaturen, Molchschleusen, etc.) gegenüber den Rohren
- Berücksichtigung der Wasserquellen und Entsorgungsmöglichkeiten

Spezialthema Stresstests: Ziel des Stresstests

- Qualität, Integrität und Sicherheit der Rohrleitung nachweisen
- Verlegespannungen, Zusatzspannungen durch Formabweichungen, Eigenspannungen und Spannungsspitzen vermindern bzw. beseitigen
- Größere Fehlstellen durch Aufreißen beseitigen
- Kleinere Fehlstellen durch Plastifizierung im Risswachstum bei Betriebsdruck hindern
- sachgemäße Konstruktion, Verlegung und Fertigung bestätigen
- Aussagen über den Sicherheitsabstand zum Betriebsdruck und Vergleich mit der Berechnung ermöglichen
- Lieferung zusätzlicher Erkenntnisse bei der Bewertung bestehender Rohrleitungen (Rehabilitation)

Spezialthema Stresstests: Druck-Zeit-Verlauf eines Stresstests



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Spezialthema Stresstests: Beispiele für durch Stresstests gefundene Fehler

Bild 9. Ein schadhaftes Rohr innerhalb des Prüfabschnitts 1, an dem der Rohrbruch bei 194 atü nach der dritten Druckbelastung und 5 min Standzeit auftrat.

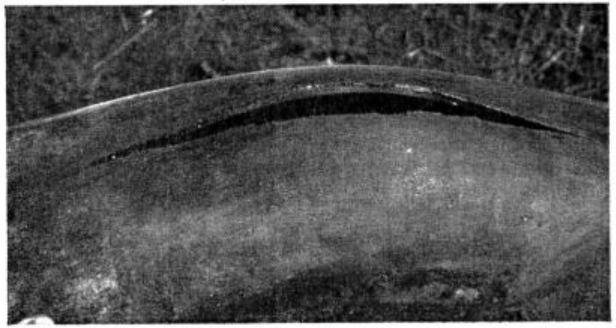

Bild 14. Der Verlauf des Risses am Rohrbogen.

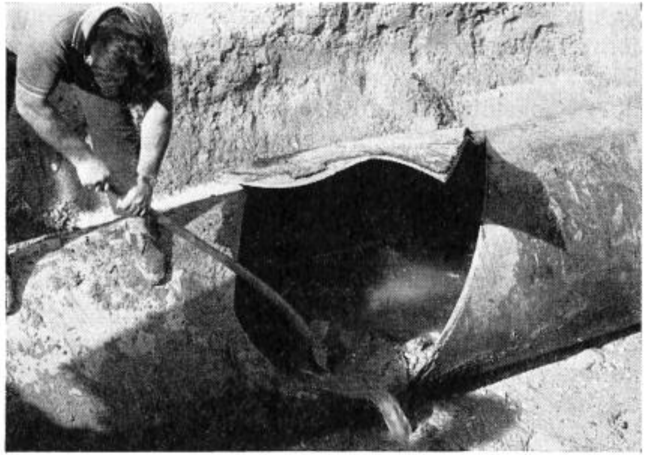

Bild 9. Der Verlauf des bei der Wasserdruckprüfung aufgetretenen Risses.

Quelle: Jahresberichte RWTÜV e.V. 1971 und 1973

Spezialthema Stresstests: … noch mehr Details?

STRESSTEST 2.0

Das VdTÜV-Merkblatt Rohrfernleitungen 1060 ist vom VdTÜV in der Fassung vom 20.04.2018 veröffentlicht worden und über den VdTÜV zu beziehen

VdTÜV-Merkblatt MB ROHR 1060

VdTÜV	Richtlinien für die Durchführung des Stresstests	Rohrfernleitungen 1060 2018-04-20

Diese Richtlinien sind mit Beteiligung von Vertretern des DVGW (Deutscher Verein des Gas- und Wasserfaches e.V., Bonn), der BASF und des SZMF (Salzgitter Mannesmann Forschung GmbH) vom VdTÜV aufgestellt worden.

Sie stellen nach bisherigen Erfahrungen im Regelfall geeignete Lösungen für den Stresstest dar. Im Zweifelsfall gilt mit der sinngemäßen Anwendung des Merkblattes die ingenieurmäßige Sorgfaltspflicht als erfüllt. Abweichungen sind zulässig, wenn sie ausreichend begründet werden.

Das Merkblatt wird laufend dem Stand der Technik angepasst. Anregungen hierzu sind zu richten an den Herausgeber:

Verband der TÜV e. V.
Friedrichstraße 136
10117 Berlin

Inhalt

Ersatz für Ausgabe 2007-02; I =Änderungen gegenüber der vorangehenden Ausgabe

Teil 6 – Pipelines

Design & Safety

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Bends and laying techniques

Horizontale / vertikale Richtungsänderungen durch Einbau von Bögen

Große Verlegeradien:

- Auslenkung des verschweißten Rohrstrangs mit zulässiger elastischer Verformung

Kleinere Verlegeradien:

- Baustellenbogen: Bogen werden aus umhüllten Rohr auf Baustelle mittels Biegemaschine kalt gebogen (1 - 1,5° je Biegeschritt, z.B. Bogen DN 500 → R ca. 25 m)
- Werksbogen, Schnittkrümmer, Hamburger Bogen; Herstellung im Werk, Rohrerwärmung durch induktives Glühen und anschließende Biegung. (z.B. Werksbogen R = 10 x D, Hamburger Bogen R = 1,5 x D)

Quelle: Open Grid Europe 2020

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T pieces and other components

- Abzweigstück (T-Stück), zweigt von Hauptleitung einer Leitung ab


Abzweigstück (T-Stück)

geteiltes T-Stück



molchbares T-Stück

- Reduzierstück, Einbau bei erforderlichen Durchmesseränderungen
- Verschlussböden
- Flansche mit Schrauben / Muttern und Dichtungen
- Isolierstücke (Isolierkupplungen) / Isolierflansche
- Ausbläser
- Kondensat- / Flüssigkeitssammler
- Dehner
- Molchschleusen


Molchschleuse


Kondensatsammler

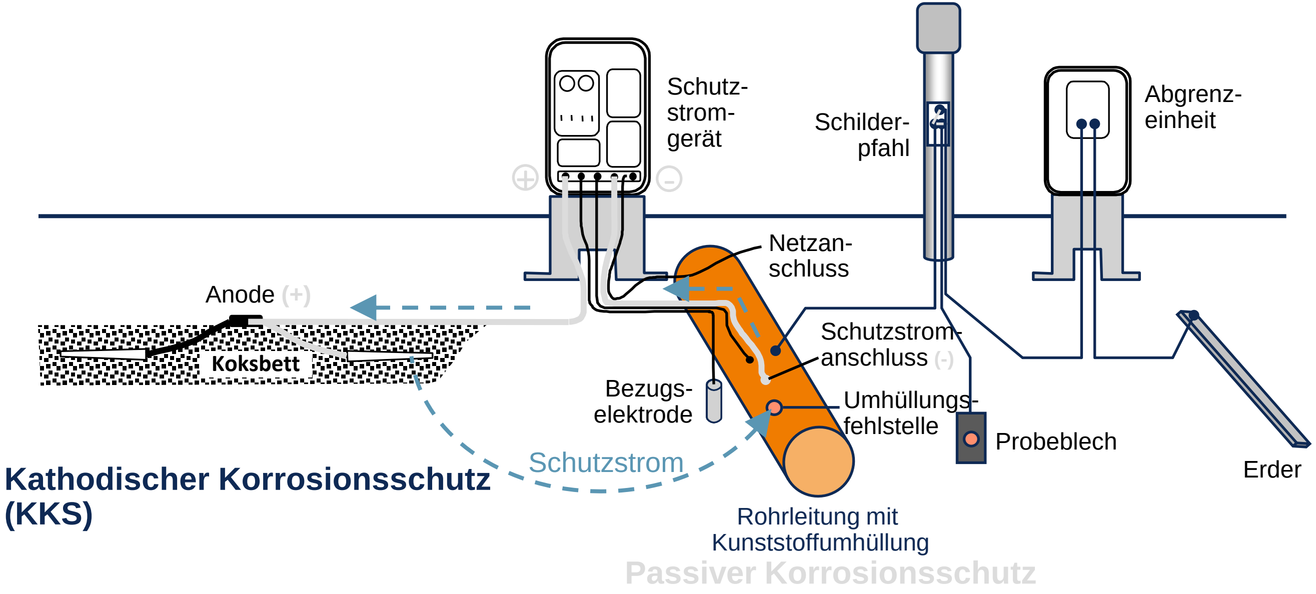

Ausbläser

Valves

- Unterscheidung nach Bauart (Kugelhahn - Schieber)
- Unterscheidung nach Funktion (Dichtarmatur – Verschleißarmatur)
- Große Gasleitungen
  ⇨ meistens Kugelhähne
  (Vorteil: niedrige Bauhöhe & geringeres Gewicht)

Kugelhahn

Cathodic protection



Erdverlegte Stahlrohrleitungen werden durch Kombination aus elektrochemischem Schutz (**kathodischer Korrosionsschutz**) und isolierenden Kunststoffumhüllung (passiver Korrosionsschutz) geschützt.

Teil 6 – Pipelines

Design & Safety

Rules of thumb for determining the costs for a new pipeline and a new compressor station

Invest for a new pipeline [mil. €/km] = **0,2** x **DN** [m] x Sqrt{ **PN** [bar] }

Invest for a new compressor station [mil. €/unit] = **1,4** x { ½ x **Power** [MW] + **10** }

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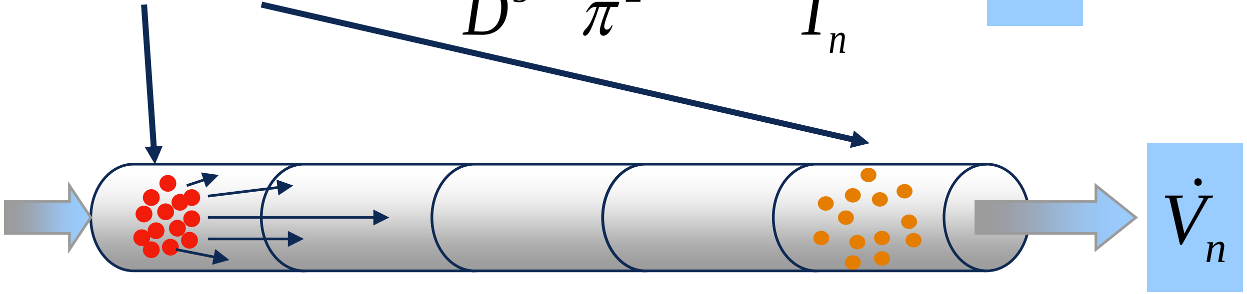
How Pipelines are designed: Capacity of a pipeline

The capacity of a pipeline depends on geometry but also on the inlet and outlet pressure (Darcy-Weissbach)

$$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot \rho_n \cdot \frac{T_m}{T_n} \cdot p_n \cdot \dot{V}_n^{\,2} \cdot K_m$$



Wobbe index and the capacity of a pipeline

Berechnung des Wobbe-Indexes:

$$W_S = \frac{H_S}{\sqrt{d}} = \frac{H_S}{\sqrt{\frac{\rho_{Brennstoff,n}}{\rho_{Luft,n}}}}$$

Hs = Brennwert
d = Dichteverhältnis r (Rho) des Brenngases zur Luft

1 $$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot \rho_n \cdot \frac{T_m}{T_n} \cdot p_n \cdot \dot{V}_n^{\,2} \cdot K_m$$

2 $$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot \rho_n \cdot \left(\frac{H_S}{H_S}\right)^2 \cdot \frac{T_m}{T_n} \cdot p_n \cdot \dot{V}_n^{\,2} \cdot K_m$$

3 $$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot \rho_n \cdot \frac{\rho_{Luft}}{\rho_{Luft}} \cdot \left(\frac{H_S}{H_S}\right)^2 \cdot \frac{T_m}{T_n} \cdot p_n \cdot \dot{V}_n^{\,2} \cdot K_m$$

4 $$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot d \cdot \rho_{Luft} \cdot \left(\frac{H_S}{H_S}\right)^2 \cdot \frac{T_m}{T_n} \cdot p_n \cdot \dot{V}_n^{\,2} \cdot K_m$$

5 $$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot \rho_{Luft} \cdot \left(\frac{\sqrt{d}}{H_S}\right)^2 \cdot \frac{T_m}{T_n} \cdot p_n \cdot H_S^{\,2} \cdot \dot{V}_n^{\,2} \cdot K_m$$

6 $$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot \rho_{Luft} \cdot \frac{T_m}{T_n} \cdot p_n \cdot \left(\frac{1}{W_S}\right)^2 \cdot K_m \cdot H_S^{\,2} \cdot \dot{V}_n^{\,2}$$

$$\dot{Q} = W_S \cdot \dot{V}_n$$

7 $$p_1^2 - p_2^2 = \lambda \cdot \frac{L}{D^5} \cdot \frac{16}{\pi^2} \cdot \rho_{Luft} \cdot \frac{T_m}{T_n} \cdot p_n \cdot \left(\frac{1}{W_S}\right)^2 \cdot K_m \cdot \dot{Q}^2$$

8 $$p_1^2 - p_2^2 = \hat{\lambda} \cdot \frac{L}{D^5} \cdot \left(\frac{1}{W_S}\right)^2 \cdot K_m \cdot \dot{Q}^2$$

9 $$\dot{Q} = W_S \cdot D^{2.5} \sqrt{\frac{(p_1^2 - p_2^2)}{\hat{\lambda} \cdot L \cdot K_m}}$$

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Comparison between NG and hydrogen pipelines with same inlet and outlet pressure

	Natural gas		Hydrogen	
Capacities	$\dot{Q}^{NG} = W_S^{NG} \cdot D^{2.5} \sqrt{\frac{(p_1^2 - p_2^2)}{\hat{\lambda} \cdot L \cdot K_m^{NG}}}$	(I)	$\dot{Q}^{H2} = W_S^{H2} \cdot D^{2.5} \sqrt{\frac{(p_1^2 - p_2^2)}{\hat{\lambda} \cdot L \cdot K_m^{H2}}}$	(II)
Compressibility numbers	$K_m^{NG} = 1 - \frac{p_m}{450\ bar}$	(III)	$K_m^{H2} = 1 + \frac{p_m}{1500\ bar}$	(IV)

(III + IV)

$$p_m = \frac{2}{3} \cdot \frac{p_1^3 - p_2^3}{p_1^2 - p_2^2}$$

$$K_m^{H2} = K_m^{NG} \cdot \left\{1 + \frac{13}{4500} \cdot \frac{p_m}{K_m^{NG}}\right\} \quad \text{(V)}$$

(II + V)

$$\dot{Q}^{H2} = \dot{Q}^{NG} \cdot \frac{W_S^{H2}}{W_S^{NG}} \cdot \frac{\sqrt{K_m^{NG}}}{\sqrt{K_m^{H2}}}$$

or

$$\dot{Q}^{H2} = \dot{Q}^{NG} \cdot \frac{W_S^{H2}}{W_S^{NG}} \cdot \frac{1}{\sqrt{1 + \frac{13}{4500} \cdot \frac{p_m}{K_m^{NG}}}}$$

Example for a pipeline

Initial pressure	$p_1 = 80\ [bar]$
End pressure	$p_2 = 60\ [bar]$
Average pressure	$p_m = 70.48\ [bar]$
Wobbe index	$W_S^{NG} = 12.91\ [\text{kWh/m}^3]$
	$W_S^{H2} = 10.95\ [\text{kWh/m}^3]$

$$\alpha = 0.85$$

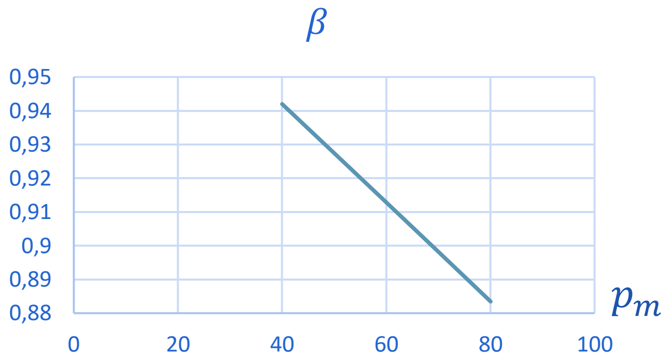
$$\beta = 0.90$$

capacity reduction factor	$\alpha \cdot \beta \approx 0.76$

loss of capacity is roughly 25%

$$\dot{Q}^{H2}=\dot{Q}^{NG}\cdot\frac{W_S^{H2}}{W_S^{NG}}\cdot\frac{1}{\sqrt{1+\frac{13}{4500}\cdot\frac{p_m}{K_m^{NG}}}}$$

constant α β pressure dependend



Compensation of lost capacity through change of pressure regime

If the hydrogen pipeline operated at the same inlet pressure should have the same capacity as the natural gas pipeline the outlet pressure has to be lowered

Rule of thumb: The new target outlet pressure $\tilde{p}_2$ can be estimated based on the Darcy-Weißbach equation

$$(p_1^2 - \tilde{p}_2^2) = \left(\frac{4}{3}\right)^2 \cdot (p_1^2 - p_2^2)$$

$$\tilde{p}_2 = \sqrt{p_1^2 - \left(\frac{4}{3}\right)^2 \cdot (p_1^2 - p_2^2)}$$

Example for the flow regime given about with

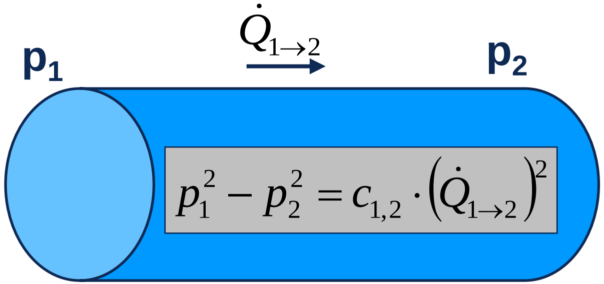
Initial pressure	$p_1 = 80\ [bar]$
End pressure	$p_2 = 60\ [bar]$

$$\tilde{p}_2 = 37.7\ [bar]$$

Other forms of the Darcy-Weissbach equation

The transport capacity of a single uniform pipeline depends on

- the inlet pressure
- the outlet pressure
- the diameter
- flow parameters



$p_{1,2}$ - inlet or outlet pressure
$c_{1,2}$ - friction parameter
$\dot{Q}_{1\rightarrow 2}$ - energy flow

$$p_1^2 - p_2^2 = \lambda \cdot \frac{16}{\pi^2 \cdot d^5} \cdot \frac{T}{T_n} \cdot p_n \cdot \rho_n \cdot l \cdot \dot{V}_n^2 \qquad \frac{N^2}{m^4}$$

Natural Gas Composition: Example Groningen Gas (L Gas)

Properties of Groningen natural gas (average composition).

Component	Formula	x_i % (vol.)	n_i % (mol)	g_i % (mass)
methane	CH_4	81.30	81.29	69.97
ethane	C_2H_6	2.85	2.87	4.63
propane	C_3H_8	0.37	0.38	0.90
butane	C_4H_{10}	0.14	0.15	0.47
pentane	C_5H_{12}	0.04	0.04	0.16
hexane	C_6H_{14}	0.05	0.05	0.23
nitrogen	N_2	14.35	14.32	21.52
oxygen	O_2	0.01	0.01	0.02
carbon-dioxide	CO_2	0.89	0.89	2.10
		100	100	100

Molar mass	18.637 kg/kmol
Real molar volume	22.363 m^3/kmol
Compressibility factor	0.9977 (44)
Pseudo critical pressure	4460 kPa
Pseudo critical temperature	187.0 K
Density	0.833 kg/m^3
Relative density	0.645
Acentric factor	0.0209
Gross calorific value	35.096 MJ/m^3
Net calorific value	31.669 MJ/m^3
Wobbe index	43.700 MJ/m^3
Air requirement: wet	8.528 m^3/m^3
dry	8.430 m^3/m^3
Flammability limits in air	
(fig. 3.15.4): upper limit	16.6 % (mol)
lower limit	4.7 % (mol)
Autoignition temperature	
(fig. 3.15.4)	890 K

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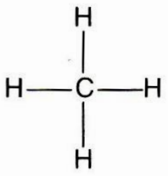
Natural Gas Composition

Classification of various hydrocarbons

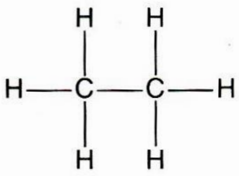
Paraffins: C_nH_{2n+2}

CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	2-methylpropane
C_4H_{10}	butane
etc.	

CH_4 – methane

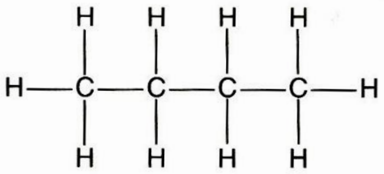


C_2H_6 – ethane

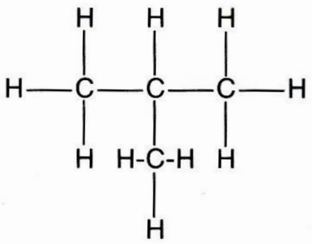


Butane is the first component that has an isomer. Isomers have the same chemical composition and the same molar mass as the normal molecule, differing only in certain properties.

C_4H_{10} – butane



C_4H_{10} – 2-methylpropane

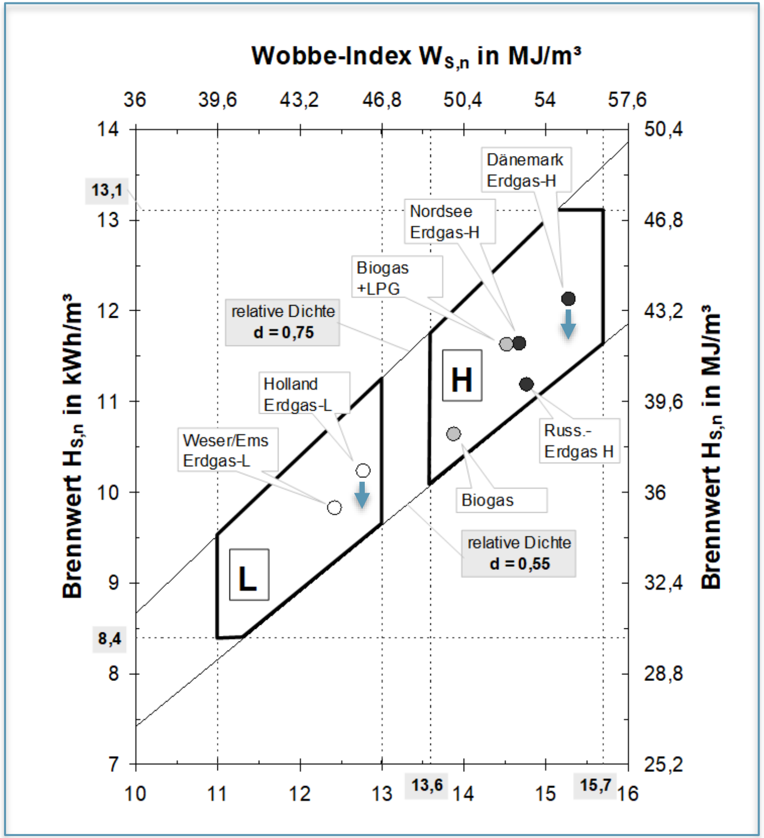


Natural Gas Properties and Quality Ranges for the Wobbe Index and the Calorific Value

Berechnung des Wobbe-Indexes:

$$W_S = \frac{H_S}{\sqrt{d}} = \frac{H_S}{\sqrt{\frac{\rho_{Brennstoff,n}}{\rho_{Luft,n}}}}$$

Hs = Brennwert
d = Dichteverhältnis r (Rho) des Brenngases zur Luft



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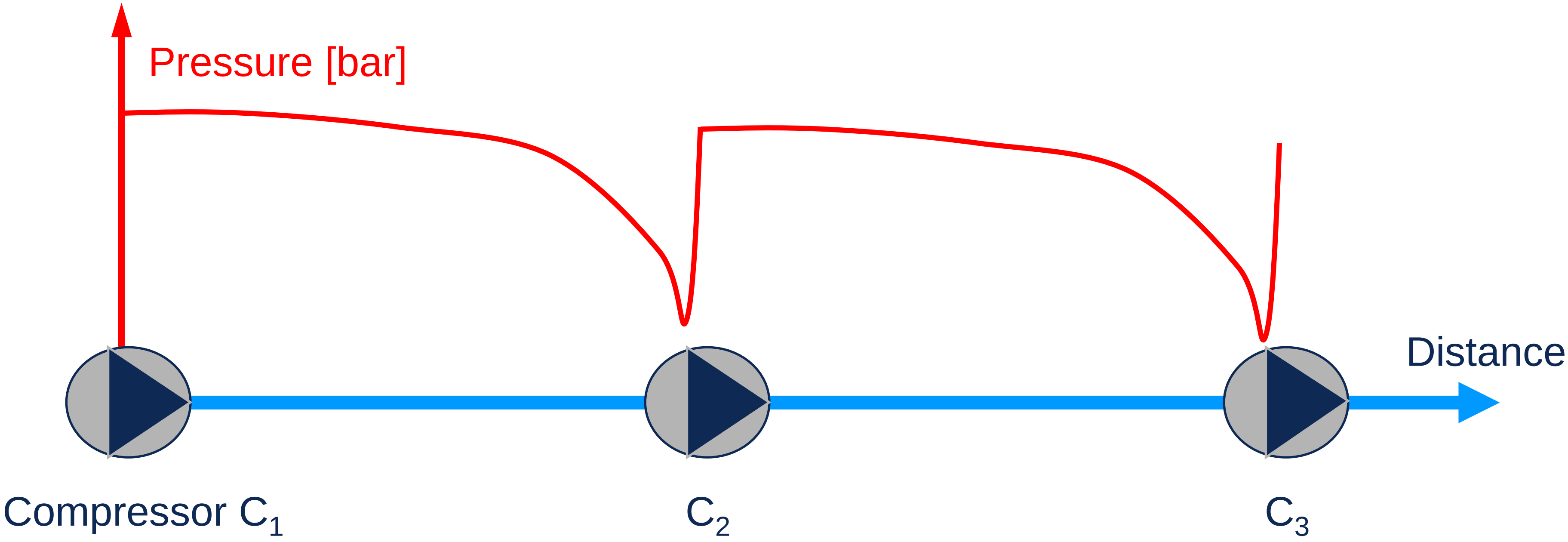
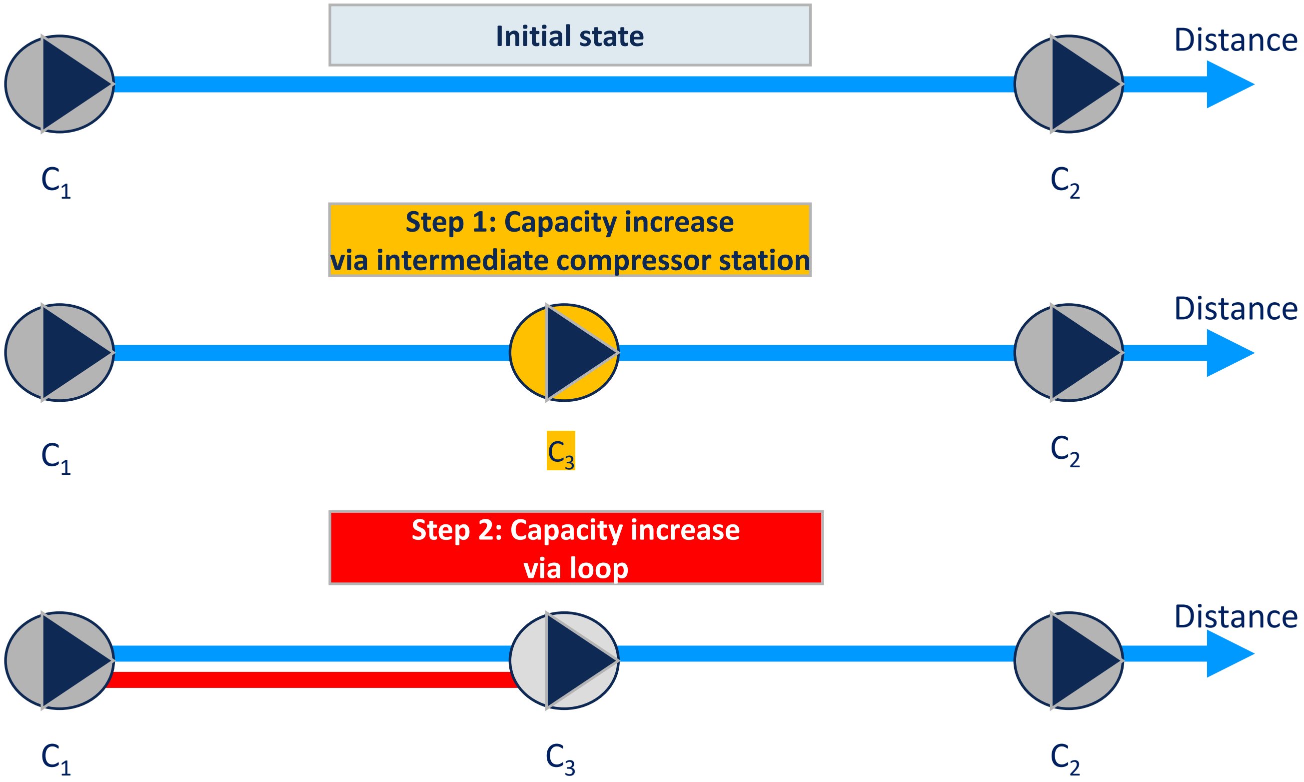
Compressor Station spaced out every 100 km raise up the operating pressure and ensure the transport capacity of the entire line



Capacity increase and looping of pipeline systems



Up-rating of pipeline systems – a delicate matter

The pressure up-rating can be successful, if the real yield strength data and wall thicknesses are higher than the nominal (or specified) data.

Design pressure

$$DP = \frac{20 \times f_o}{D} R_{t0,5}(\theta) \times T_{min}$$

Potential increased pressure

$$P_{real} = \frac{20 \times f_o}{D} R_{t,real}(\theta) \times T_{real}$$

T_{min} is the calculated minimum wall thickness [mm]

T_{real} is the real wall thickness [mm]

DP is the design pressure [bar]

D is the outside diameter of the pipe [mm]

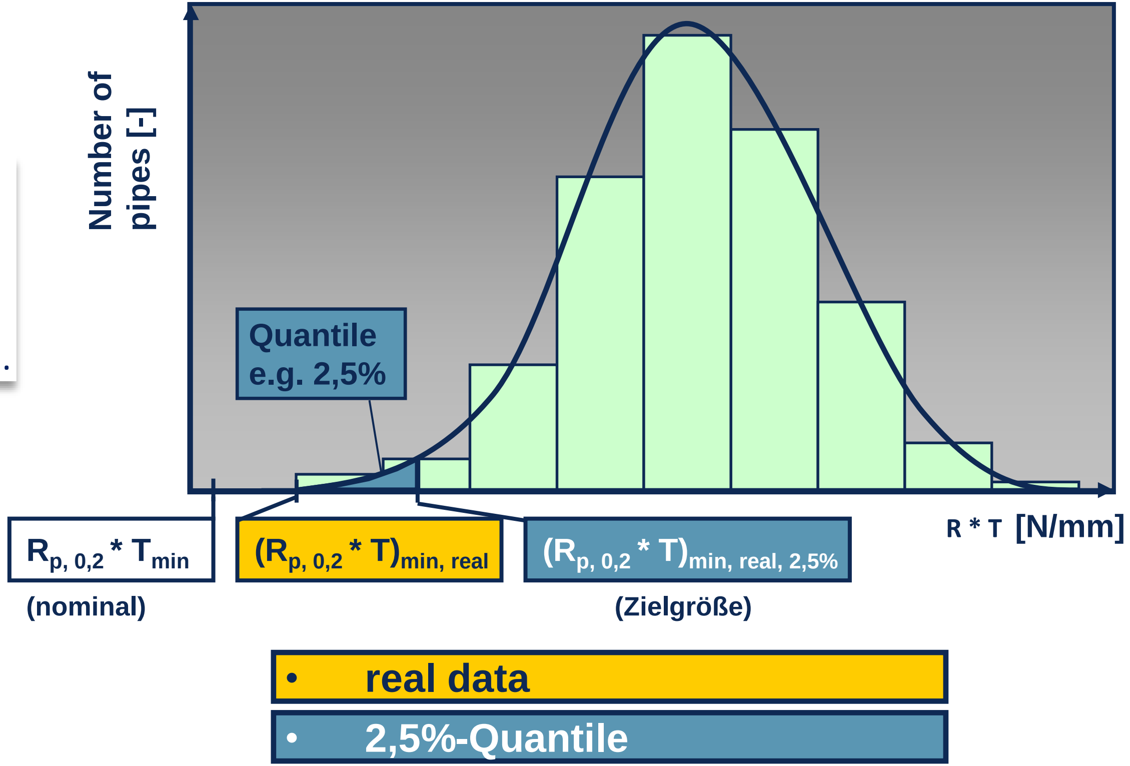
f_o is the design factor [ ]

$R_{t\,0,5}(\vartheta)$ is the specified minimum yield strength at the design temperature [N/mm2]

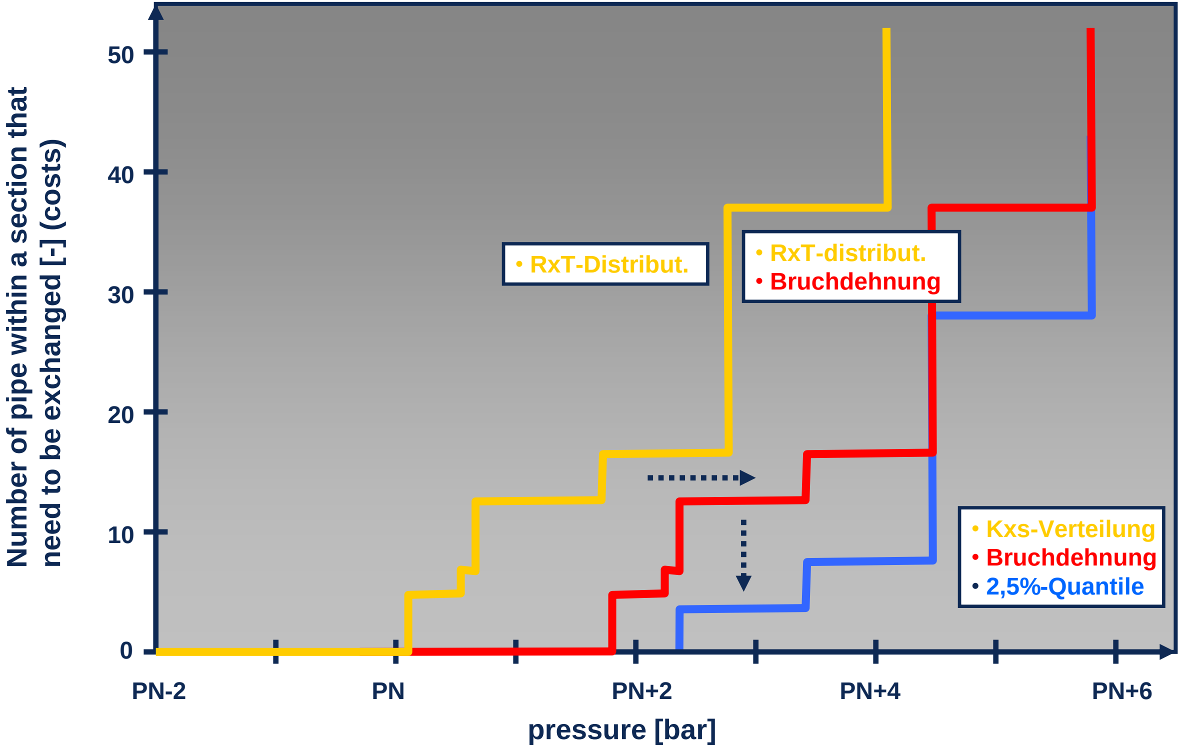
$R_{t,\,real}(\vartheta)$ is the real minimum yield strength at the design temperature [N/mm2]

Up-rating of pipeline systems – how it works

The pressure up-rating can be successful, if the real yield strength data and wall thicknesses are higher than the nominal (or specified) data.



Up-rating of pipeline systems – how it works



Up-rating of pipeline systems – example

Example for pressure up-rating

Old Darcy-Weisbach:

$$P_1^2 - P_2^2 = c_{1,2} \cdot \left(\dot{Q}_{1\to 2}\right)^2$$

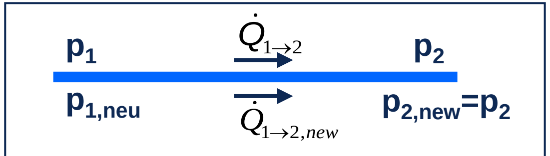
New Darcy-Weisbach:

$$P_{1,new}^2 - P_2^2 = c_{1,2} \cdot \left(\dot{Q}_{1\to 2,new}\right)^2$$

"Ansatz":

$$P_{1,new}^2 = (1+\lambda)^2 \cdot P_1^2 \quad \text{and}$$

$$\dot{Q}_{1\to 2,new} = (1+\mu) \cdot \dot{Q}_{1\to 2}$$



- $p_{1,2}$ - inlet and outlet pressure
- $c_{1,2}$ - friction parameter
- λ - % of inlet pressure increase
- μ - % of capacity growth
- $\dot{Q}$ - energy flow

Result:

$$c_{1,2} \cdot \left(\frac{\dot{Q}_{1\to 2}}{P_1}\right)^2 = 1 - \left(\frac{P_2}{P_1}\right)^2 = \frac{\lambda \cdot (2+\lambda)}{\mu \cdot (2+\mu)} \approx \frac{\lambda}{\mu}$$

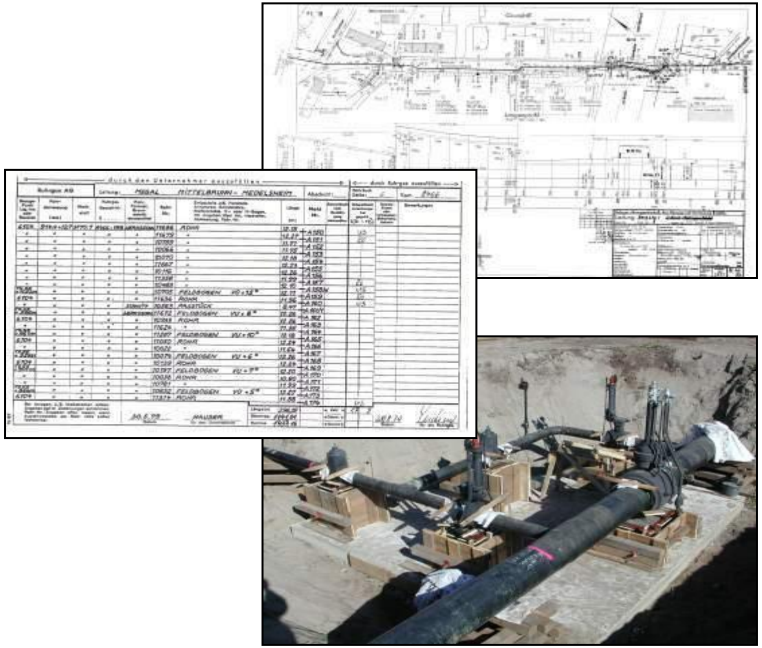
Example:

$$\text{Let } P_1 = 80 \text{ bar, } P_2 = 60 \text{ bar. Then :}$$

$$\mu \approx 2{,}3 \cdot \lambda \quad \Rightarrow \quad 5\% \Delta p \text{ results in } 11\% \Delta \dot{Q}$$

Up-rating of pipeline systems – it's like a new-build process and need to be certified by an expert

The up-rating processes can only be finished successfully if the "as build documentation" is complete and if all changes during operation have been documented accurately and if it can be proved that no "reduction of reserves" (no ageing) has taken place.



Measures for retroactive pressure increase

- Material examinations:
  - Comparison of desired and actual condition of existing materials
  - Recalculation of pipeline components such as valves, bends, flanges
  - Identification of components to be disassembled
- Approval of the major change
  - Notification to responsible mining office pursuant to Section 7.1 (preliminary clearance to be awaited)
  - Issue of certificate pursuant to Section 6.1 of the GasHL-VO by expert
  - Provision of new pressure safety certificate by expert

Summary - Pipeline Design

1 **Darcy Weißbach**

Soll anstelle des Dichteverhältnisses die Normdichte des Gases $\varrho_{n,G}$ eingesetzt werden, so erhält man für eine Gastemperatur von $T_G = 285{,}15\ \mathrm{K} \mathrel{\hat{=}} 12\,°\mathrm{C}$:

$$(3\text{–}22)\qquad p_1^2 - p_2^2 = 13{,}231 \cdot \lambda \cdot \frac{\varrho_{n,G}}{(100 \cdot d)^5} \cdot L \cdot \dot{V}_n^2\ \mathrm{bar}^2$$

und für $T_G = 278{,}15\ \mathrm{K} \mathrel{\hat{=}} 5\,°\mathrm{C}$:

$$(3\text{–}23)\qquad p_1^2 - p_2^2 = 12{,}906 \cdot \lambda \cdot \frac{\varrho_{n,G}}{(100 \cdot d)^5} \cdot L \cdot \dot{V}_n^2\ \mathrm{bar}^2$$

λ (roughness)
is less than 0,01
for internal coated pipes

L [km], d [m], dV/dt [m³/h], p [bar]

2 **Empirical law**

Invest for a new pipeline [mil. €/km] = **0,2** x **DN** [m] x Sqrt**{ PN** [bar] **}**

3 **Barlow law**

Straight pipe

For normal load conditions the minimum wall thickness for straight pipe is calculated as follows:

$$T_{min} = \frac{DP \times D}{20 \times f_o \times R_{t0,5}(\theta)}$$

***T*min**	**is the calculated minimum wall thickness [mm]**
DP	**is the design pressure [bar]**
D	**is the outside diameter of the pipe [mm]**
fo	**is the design factor**
R* t 0,5 *(θ)	**is the specified minimum yield strength [N/mm2].**

Teil 6 – Pipelines

Design & Safety

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Other pipeline design philosophies: The probabilistic approach

Also so-called probabilistic design philosophies are described in EN 1594:

In some countries the design factor f_0 depends on external conditions like population density or the likelihood of the occurrence of external threats, ignition sources, etc.

The design varies with the type of areas (→ area classification).

This pipeline design is called "probabilistic" [see EN 1594 or the following page].

7.2 Wall thickness determination

7.2.1 Straight pipe

For normal load conditions the minimum wall thickness for straight pipe is calculated as follows:

$$T_{\min} = \frac{DP \times D}{20 \times f_o \times R_{t0,5}(\theta)} \quad (1)$$

where

- $T_{\min}$ is the calculated minimum wall thickness, in millimetres (mm);
- DP is the design pressure, in bar;
- D is the outside diameter of the pipe, in millimetres (mm).

  If D_i is preset, D shall equal $D_i + 2\,T_{\min}$, D_i being the inside diameter in millimetres (mm);
- f_o is the design factor;
- $R_{t\,0,5}(\theta)$ is the specified minimum yield strength at the design temperature, in Newton per square millimetre (N/mm^2).

EN 1594, probabilistic design

Appropriate safety measures

Possible measures to ensure safety in design, construction and operation are listed below.
The list is not intended to be exhaustive nor will it be necessary to incorporate all the measures on each occasion.
When selecting measures, consideration shall be given to the safety and environmental conditions existing at the time of construction for which firm details are known:

a) a control zone shall be established to control all third-party activities in order to safeguard the pipeline against interference;
b) if a system of area classification is used, design factors shall be chosen relevant to the classification levels;
c) this design factor may be increased if additional measures are taken against third-party interference (for limitation on the design factor reference is made to 7.2);
d) the route of the pipeline shall be at an appropriate distance from buildings. The distance should be determined by the particular parameters and/or national requirements;
e) for high-strength pipe steels, appropriate toughness properties for fracture-arrest capability should be selected;
f) the minimum depth for the pipeline shall be greater than that of normal agricultural/horticultural activities expected in the area. The probability of third-party interference to the pipeline will decrease if a depth greater than the minimum specified in 7.7 is adopted;
g) additional forms of mechanical protection can reduce interference by third-party activity. Designers shall carefully select the forms of the additional protection to minimize any adverse effects on the efficiency of the cathodic protection;
h) the route of the pipeline should be identified by a locating system such as markers;

Pipeline safety can further be increased by ensuring an adequate frequency of surveillance.

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EN 1594, probabilistic design

TABLE 841.114B
DESIGN FACTORS FOR STEEL PIPE CONSTRUCTION

Facility	Location Class 1 Div. 1	Location Class 1 Div. 2	2	3	4
Pipelines, mains, and service lines [see para. 840-2(b)]	0.80	0.72	0.60	0.50	0.40
Crossings of roads, railroads without casing:					
(a) Private roads	0.80	0.72	0.60	0.50	0.40
(b) Unimproved public roads	0.60	0.60	0.60	0.50	0.40
(c) Roads, highways, or public streets, with hard surface and railroads	0.60	0.60	0.50	0.50	0.40
Crossings of roads, railroads with casing:					
(a) Private roads	0.80	0.72	0.60	0.50	0.40
(b) Unimproved public roads	0.72	0.72	0.60	0.50	0.40
(c) Roads, highways, or public streets, with hard surface and railroads	0.72	0.72	0.60	0.50	0.40
Parallel encroachment of pipelines and mains on roads and railroads:					
(a) Private roads	0.80	0.72	0.60	0.50	0.40
(b) Unimproved public roads	0.80	0.72	0.60	0.50	0.40
(c) Roads, highways, or public streets, with hard surface and railroads	0.60	0.60	0.60	0.50	0.40
Fabricated assemblies (see para. 841-121)	0.60	0.60	0.60	0.50	0.40
Pipelines on bridges (see para. 841-122)	0.60	0.60	0.60	0.50	0.40
Compressor station piping	0.50	0.50	0.50	0.50	0.40
Near concentration of people in Location Classes 1 and 2 [See para. 840.3(b)]	0.50	0.50	0.50	0.50	0.40

TABLE 841.111A
BASIC DESIGN FACTOR F

Location Class	Design Factor F
Location Class 1, Division 1	0.80
Location Class 1, Division 2	0.72
Location Class 2	0.60
Location Class 3	0.50
Location Class 4	0.40

EN 1594, probabilistic design

Probabilistic design is based on the idea that different technical or industrial installations can be made comparable by quantifying their associated risk (e.g. as consequence times probability of a worst case scenario). However, such a risk figure need to be assessed, measured or calculated.

Risk = Probability * Consequence

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Examples of simple risk assessment methods with scores

Is a risk high or low? To give an answer simply ranking procedures might be suitable to compare different design alternatives.

Likelihood	5	Almost certain	5	10	15	20	25
	4	Likely	4	8	12	16	20
	3	Possible	3	6	9	12	15
	2	Unlikely	2	4	6	8	10
	1	Rare	1	2	3	4	5
			Insignificant	Minor	Moderate	Major	Severe
			1	2	3	4	5
			Impact				

- Green = Low
- Yellow = Medium
- Orange = High (Major)
- Red = Critical

Quantitative Risk Assessment

Ideas on how to „measure“ risk

$$R = Leth \cdot P \qquad P = P_{failure} \cdot P_{ignition}$$

$$Leth = f(D)$$

$$D = \int_0^T (\dot{q}(t))^{4/3} \cdot dt$$

Symbol	meaning
R	risk
$Leth$	lethality
P	probability
D	dosage
$\dot{q}$	heat radiation or flux
T	exposure time

Quantitative Risk Assessment (QRA) of a pipeline is based on a “worst case” scenario.
A total loss of containment (rupture) and a ignition of the released gas is assumed.
The resulting heat flux has the potential to injure people in the vicinity to the accident.
“Damage” is expressed in terms of a lethality likelihood for an individual person next to the accident.
This type of consequence is weighted with the probability that the entire scenario might take place.

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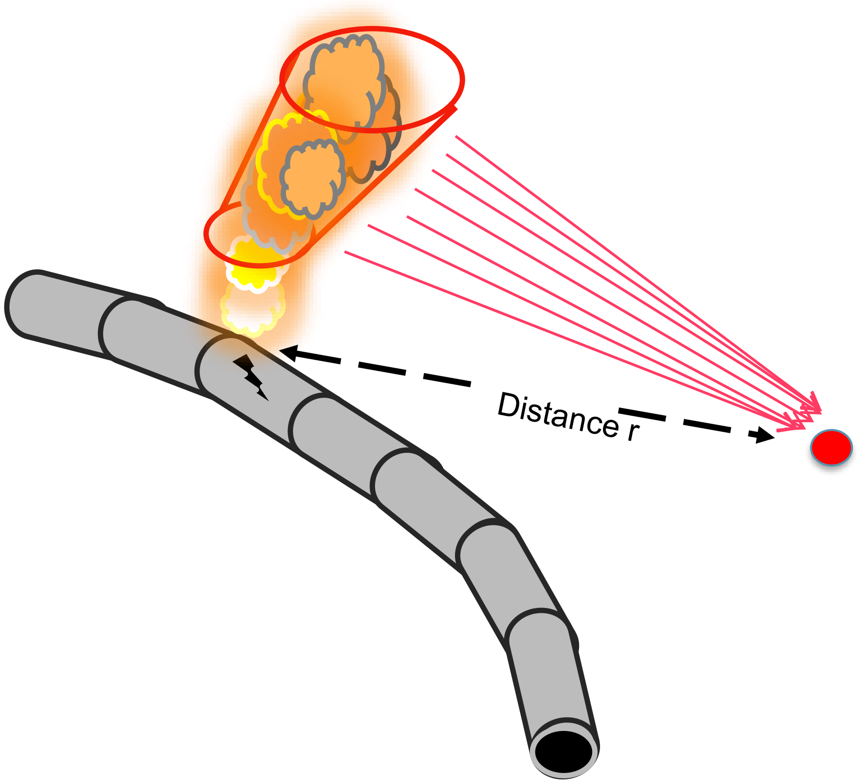
Quantitative Risk Assessment



Flux or heat radiation in kW/m²

Quantitative Risk Assessment: Calculation of gas contour

Estimation of the size of flammable cloud at zero wind velocit

According to Birch et al., the gas concentration above the vent source can be estimated

$$\eta = \frac{kd_{ps}}{z+a}\left(\frac{\rho_a}{\rho_g}\right)^{1/2} = \frac{kd}{z+a}\cdot\sqrt{C_D\left(\frac{P_{vessel}}{P_a}\right)\left(\frac{T_a}{T_{vessel}}\right)^{0.5}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/2(\gamma-1)}}\left(\frac{\rho_a}{\rho_g}\right)^{1/2}$$

with $\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/2(\gamma-1)} \approx 0.582; \quad C_D \approx 0.85; \quad k \approx 4.9; \quad \left(\frac{\rho_a}{\rho_g}\right)^{1/2} \approx 1.28;$

and $a = -0.1 \cdot d_{ps} \approx -0.0703 \cdot d\left(\frac{P_{vessel}}{P_a}\right)^{0.5}$

Variable η symbolises the concentration while z is the height above the orifice.

This formula can be simplified when neglecting the shift a:

$$\eta \approx \frac{1}{z}\cdot 4.4 \cdot d \cdot \sqrt{p}$$ [diameter in m and pressure in bar]

Birch, A.D.; Brown, D.R.; Dodson, M.G.; Swaffield, F.: The Structure and Concentration Decay of High Pressure Jets of Natural Gas. Combustion Science and Technology, 1984, Vol. 36, pp. 249-261

Quantitative Risk Assessment (QRA) requests a very good understanding of the physical processes in case of a pipeline rupture.

E.g. the size of flammable cloud needs to be calculated.
Its contour is important to estimate the heat radiation that is emitted from the flame (in case of ignition).

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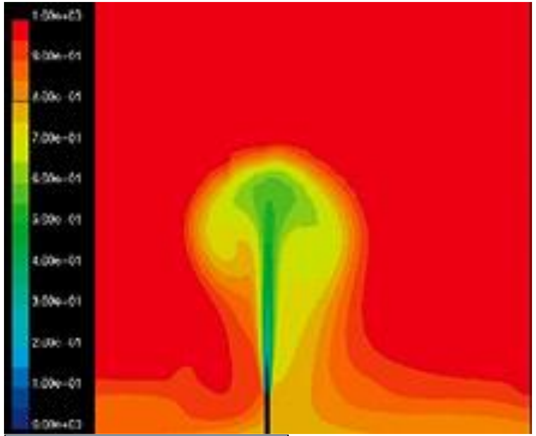
Quantitative Risk Assessment: Calculation of gas contour

On the other hand $d \cdot \sqrt{p}$ is related with the mass flow rate through the equation



$$\dot{M} = C_D A p_0 \sqrt{\frac{\kappa}{R_S T_0} \left(\frac{2}{\kappa + 1} \right)^{\frac{\kappa+1}{\kappa-1}}}$$

where

C_D is the contraction coefficient (approx. 0.85)

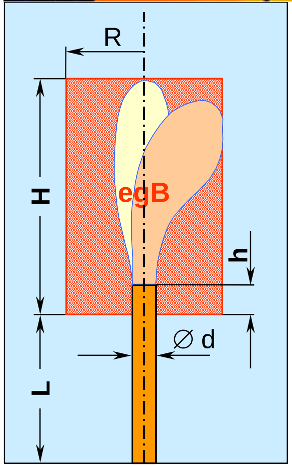
A is the release area

p_0 is the pressure in the pipeline

T_0 is the initial temperature

κ is the heat capacity ratio = approx. 1,3

$R_S = R \cdot M_{mol}$ = 519.6 J/Kg K



Combination of the equations above gives a simple formula to estimate the height of a gas cloud of concentration η:

$$z \approx \frac{1}{\eta} \cdot 0.41 \cdot \sqrt{\dot{m}} = \frac{1}{\eta} \cdot 0.367 \cdot \sqrt{\dot{V}}$$

Quantitative Risk Assessment: Calculation of flame hight and heat radiation

Flame length [m]

$$l_{flame} = \frac{4.76}{0.05} \cdot d_{eq} \cdot \sqrt{\frac{\rho_{air}}{\rho_{gas}}}$$

Equivalent diameter [m]

$$d_{eq} = d \cdot p \cdot \psi \cdot \sqrt{\frac{\kappa \, \rho_{gas} / \rho_{air}}{(\kappa+1) \cdot p \cdot \psi - 1}}$$

$$\psi = \left(\frac{2}{\kappa+1} \right)^{(\kappa/(\kappa-1))}$$

Heat radiation [kW/m²]

$$\dot{q}_0 = \frac{0.05 \cdot m_{g,Mol}{}^{0.2} \cdot \dot{m}_0 \cdot H_u}{\rho \cdot \frac{273}{T}} \frac{1}{4\pi r^2}$$

Ref.:

[1] Methods for the calculation of physical effects CPR 14 E (TNO Yellow Book), TNO 1992

[2] Sicherheit von Erdgas-Hochdruckleitungen (Rahmenbericht der Schweizerischen Erdgaswirtschaft), 1997

Quantitative Risk Assessment: Calculation of lethality as a function of the flux and therefore as a function of the mass flow

The lethality is calculated from the suffered dosage D using the well-known Eisenberg equation:

$$Leth = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y} \exp\left(-\frac{x^2}{2}\right) dx \equiv \frac{1}{2} erf(-\infty, Y)$$

with the auxiliary variable "probit", Y, which is a function of the dosage D:

Y = -19.9 + 2.56* LOG(D/10000).

The dosage is the integrale of the local and time-dependent power density $\dot{q}(\underline{r}, t)$:

$$D = \int_0^T \left[\dot{q}\left(\underline{r}(t), t\right)\right]^{4/3} dt \, .$$

T is the time of exposure.

Ref.:
F. Lees: Loss Prevention in the Process Industries I,II, Butherworths, 1980

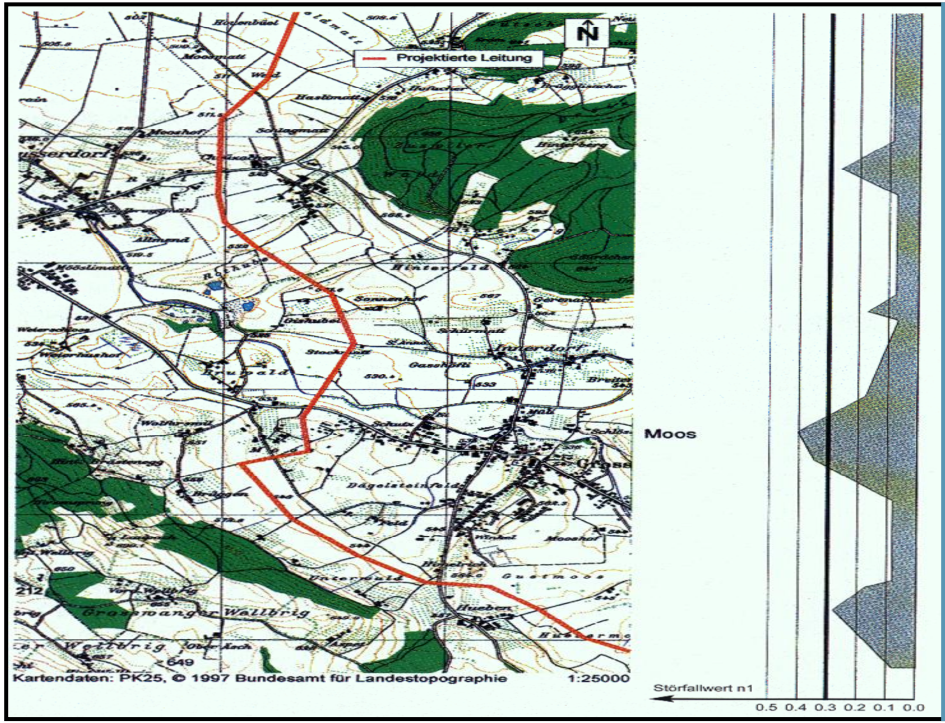
Heat radiation [kW/m²]

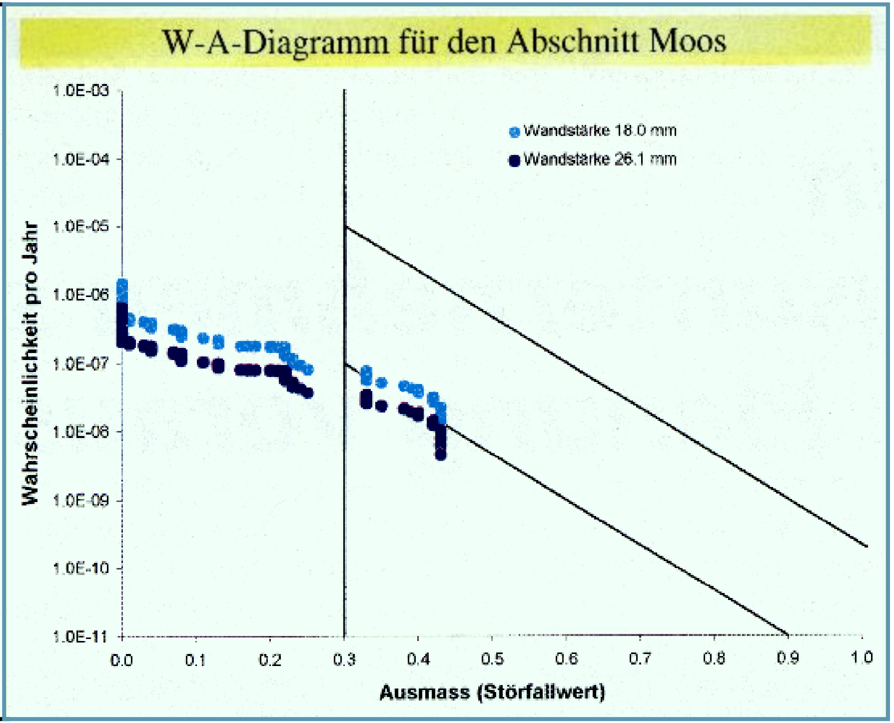
$$\dot{q}_0 = \frac{0.05 \cdot m_{g,Mol}{}^{0.2} \cdot \dot{m}_0 \cdot H_u}{\rho \cdot \frac{273}{T}} \frac{1}{4\pi r^2}$$

Ref.:
[1] Methods for the calculation of physical effects CPR 14 E (TNO Yellow Book), TNO 1992
[2] Sicherheit von Erdgas-Hochdruckleitungen (Rahmenbericht der Schweizerischen Erdgaswirtschaft), 1997

The mass flow is proportional to **p·D²**

Quantitative Risk Assessment in Switzerland





Visualisation of iso risk contours

Case from the PURPLE BOOK (TNO)

„Guidelines for quantitative risk assessment“

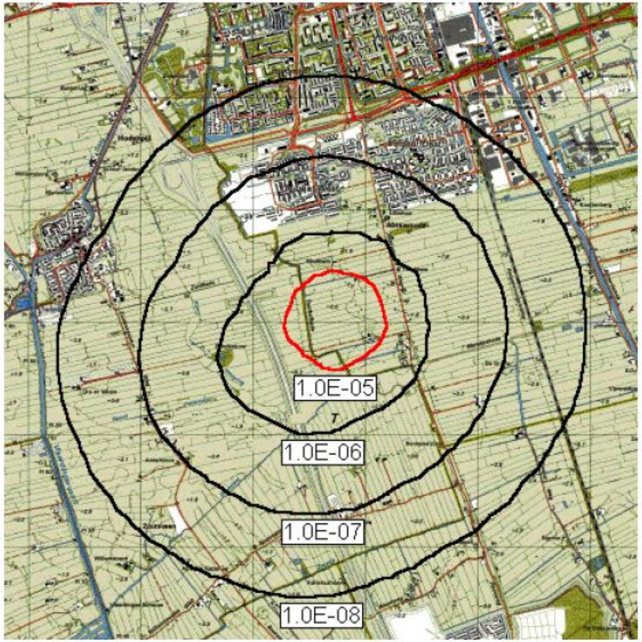


Figure 6.8 Presentation of the Individual Risk contours. Shown are the Individual Risk contours 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} y^{-1} of a fictive plant .

DVGW

Draw-back of risk models

Considering that, within the 30-year history of collection of statistical data on transmission pipelines Europe-wide, only one pipeline incident with lethalities occurred (Ghislenghien, Belgium, 2004) the risk discussions appear “strange”.
They ignore aspects like

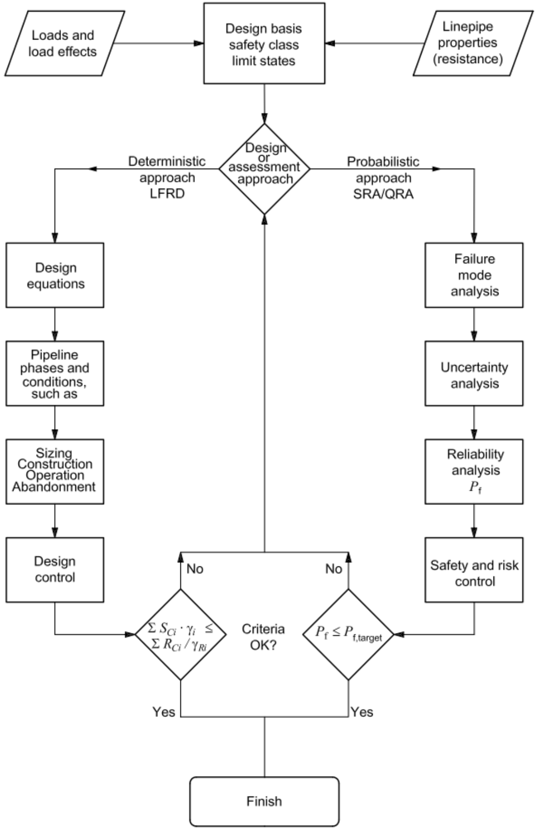
- expenditures
- to compensate for loss of containment,
- to repair destroyed installations,
- to balance contractual obligations,
- harm to company’s image,
- loss of market shares.

Once an accident occurs, the acceptance for new projects decreases significantly.
Therefore, pipeline operation must be safe!
Pipelines are everywhere.

Other design philosophies: Limit state design (used for off-shore pipelines) EN ISO 16708

Deterministic design is based on proven formulas:

(load and resistance-factor design → LFRD)



Probabilistic design is based on risk assessment

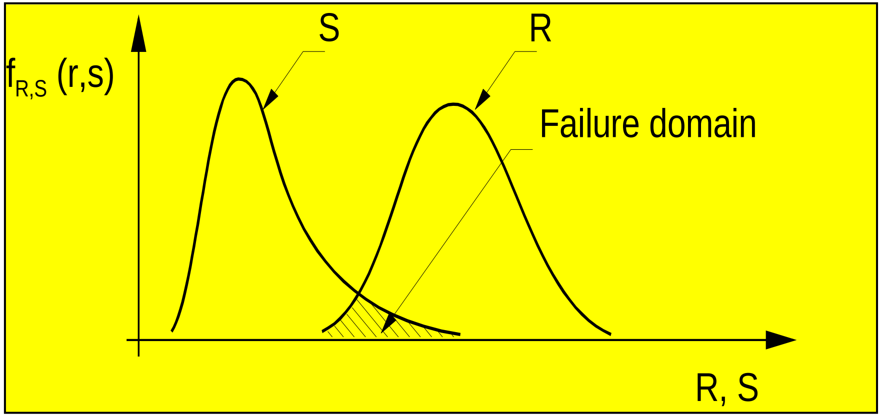
(structural-reliability analysis → SRA quantitative risk analysis → QRA)

Limit state design is based on reliability analysis

Limit state design is also founded on probabilistic methods. However, it is not the likelihood of an “external” damage – quantified in lethalities or injuries – but the likelihood of a system failure with is studied.
It is assumed that unknown additional stresses (on top of the internal pressure stress) reduce the classical safety margin. However, also the resistance of a pipe is assumed to be a random figure (e.g. due to the fact that tolerances in fabrication cause lead to thicker steal walls than specified).
Within this theory, a failure occurs when the random figure stress (S) exceed the random figure resistance (R) .

Weakness of the approach is:

- *The termination of the distribution functions of the random variables is difficult or ambigious.*
- *The real dynamic of the random variables (due to ageing) is not considered.*



ISO Standard
ISO 16708

Limit state design is based on reliability analysis

For a given limit state, a probabilistic design involves modelling of the generalised stochastic load, S, and generalized stochastic resistance, R. As a simple illustration, the corresponding limit state function can be expressed in the form of

$$g(x) = R - S \qquad \text{(A.13)}$$

When the distribution functions for R and S are established through uncertainty analysis, the failure probability is then calculated by

$$P_f = \int_{g(x)\leqslant 0} f_{R,S}(R,S)\,\mathrm{d}R\,\mathrm{d}S \qquad \text{(A.14)}$$

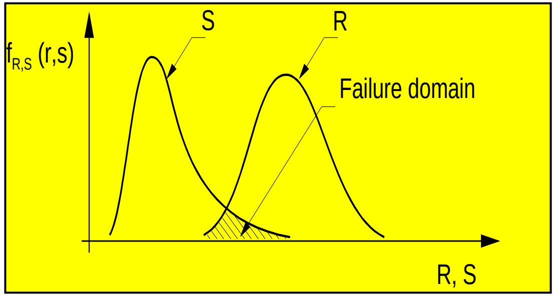
The probabilistic design check can then performed using the following design format:

$$P_{f,\text{calculated}} \leqslant P_{f,\text{target}} \qquad \text{(A.15)}$$

where

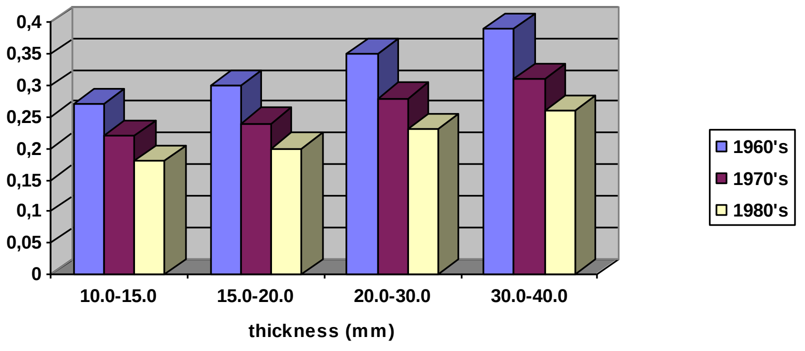
$P_{f,\text{calculated}}$ is the calculated probability of failure from the reliability analysis;

$P_{f,\text{target}}$ is the target value that should be satisfied for a design to be accepted.



Limit state design is based on reliability analysis … and a lot of assumptions

Typical maximum target standard deviation of wall thickness, in mm



Pipe under combined loads

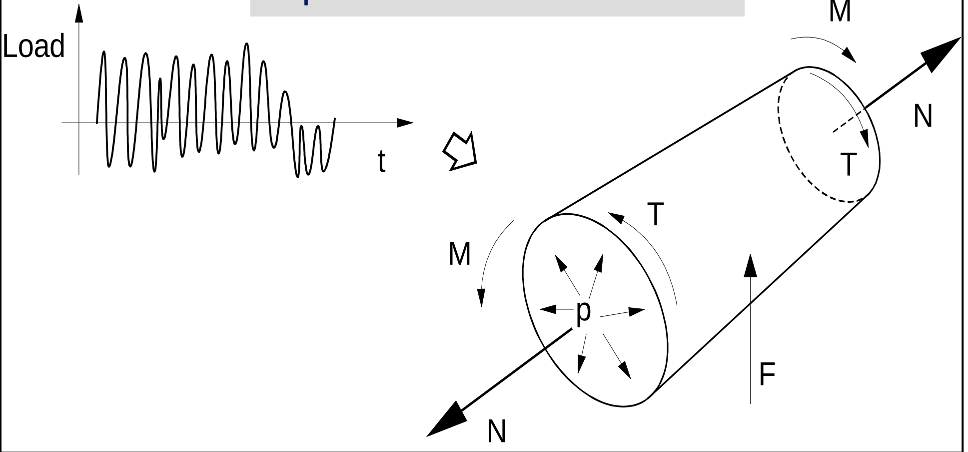


Table B.1 — Typical uncertainty values for dimensional properties — Seam-welded pipes

Variable	Distribution	Characteristic value x_c	Normalized variable	CoV = σ/μ %[a]	$(\mu - x_c)/\sigma$
Wall thickness, t	Normal	t_{min}	$X_t = t / t_{min}$	0,5 to 2	2 to 7
		t_{nom}	$X_t = t / t_{nom}$		0 to 2
Pipe diameter, D	Normal	D_{nom}	$X_D = D / D_{nom}$	< 0,1	0
Initial ovality, f_0	Lognormal	$f_{0,max}$	—	25 to 60	3 to 15

[a] σ is the standard deviation; μ is the mean value.

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The failure probability has to be below a given “target failure probability”

It is assumed that the possible consequences decrease as a function of $P \cdot D^3$, because the failure consequences for a given class increase as a linear function of the expected number of people affected, that is with a) with the size of the affected area, which is proportional to $P \cdot D^2$, and b) the probability of ignition, which is assumed to be roughly proportional to D.

The following equations relating the failure rate to the class location system are found: [25]

Safety class 1(low) $$P_{\mathrm{f,target}} = \frac{5 \times 10^{-3}}{P \cdot D^3} \quad \text{(C.1)}$$

Safety class 2 (medium) $$P_{\mathrm{f,target}} = \frac{5 \times 10^{-4}}{P \cdot D^3} \quad \text{(C.2)}$$

Safety class 3 (high) $$P_{\mathrm{f,target}} = \frac{5 \times 10^{-5}}{P \cdot D^3} \quad \text{(C.3)}$$

Safety class 4 (very high) $$P_{\mathrm{f,target}} = \frac{5 \times 10^{-6}}{P \cdot D^3} \quad \text{(C.4)}$$

Individual risk $$P_{\mathrm{f,target}} = \frac{5{,}2 \times 10^{-4}}{\left(P \cdot D^3\right)^{0{,}66}} \quad \text{(C.5)}$$

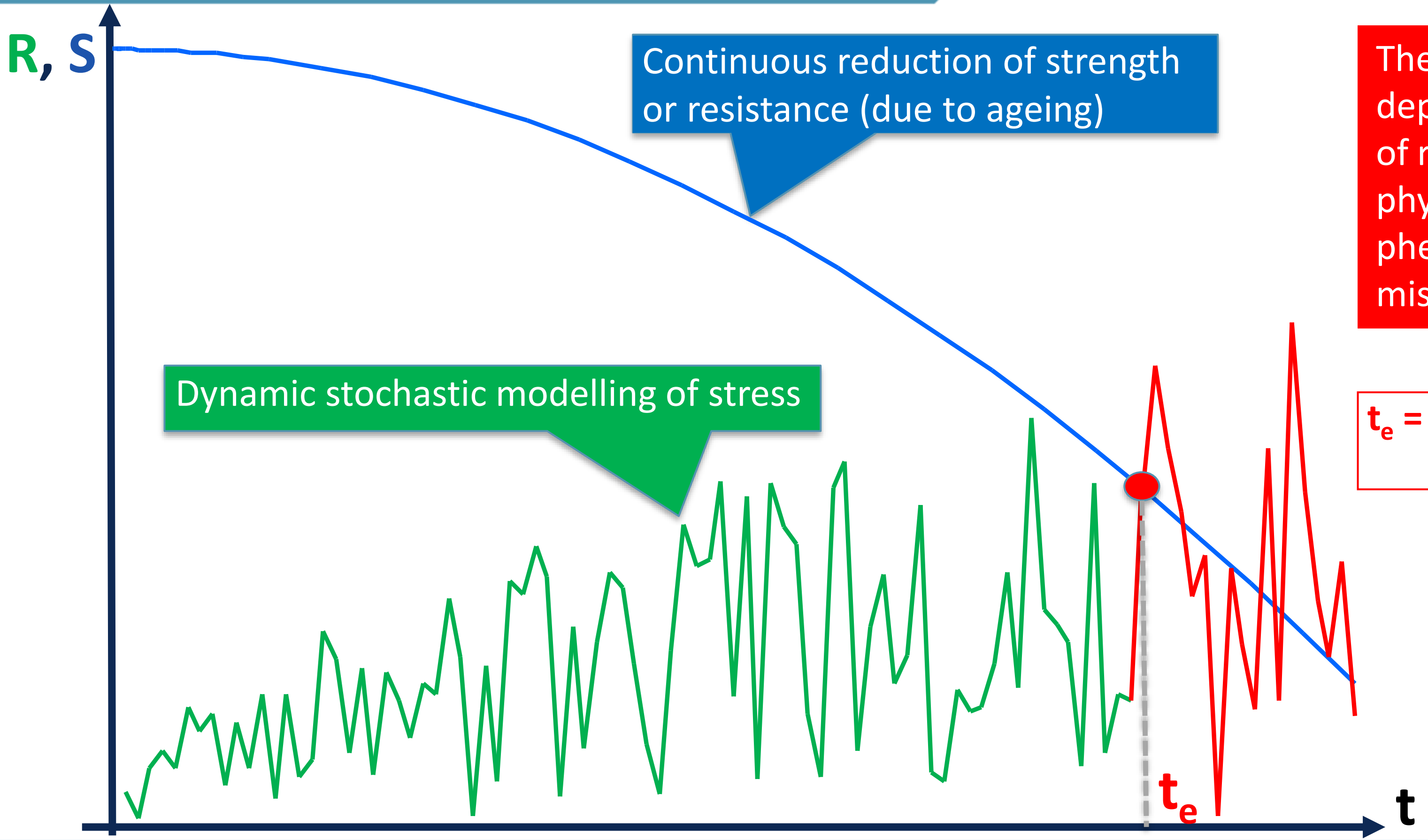
where

$P_{\mathrm{f,target}}$ is the maximum acceptable failure probability in failures per kilometre per year (excluding small leaks);

P is the internal pressure in bars;

D is the outside pipe diameter in metres.

Drawbacks of the limit state design approach



The time-dependence of real physical phenomena is missing!

t_e = Versagens-zeitpunkt

Teil 6 – Pipelines

Design & Safety

DVGW

Pipeline safety according to the EGIG Statistics

European pipeline operator have gathered pipeline failure since 1970.

There statistics are published every three years in the EGIG report
(European Gas Pipeline Incident Data Group)

Objective

The objective of EGIG is to collect and present data on loss of gas incidents in order to present the safety performance of the European gas transmission network to the general public and authorities.

Criteria

The required criteria for an incident to be recorded in the EGIG database are the following:

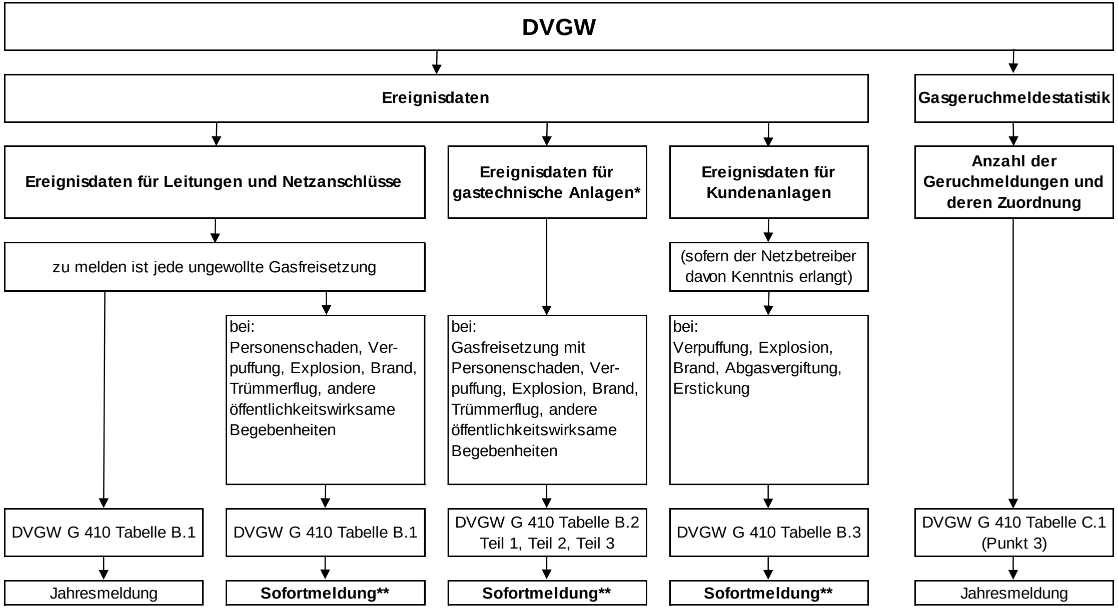
- The incident must lead to an unintentional gas release,
- The pipeline must fulfil the following conditions:
  - ✓ To be made of steel
  - ✓ To be onshore
  - ✓ To have a Maximum Operating Pressure higher than 15 bar
  - ✓ To be located outside the fences of the gas installations

Incidents on production lines or involving equipment or components (e.g. valve, compressor) are not recorded in the EGIG database.

Meldepflichtige und sofortmeldepflichtige Ereignisse

Definition

- Ein **meldepflichtiges Ereignis** für Leitungen und Netzanschlüsse ist eine ungewollte Gasfreisetzung
- **Meldepflichtige Ereignisse**, die mit Personenschaden, Verpuffung, Explosion, Brand, Trümmerflug oder anderen öffentlichkeitswirksamen Begebenheiten verbunden sind, müssen **sofort** nach dem Eintritt gemeldet werden

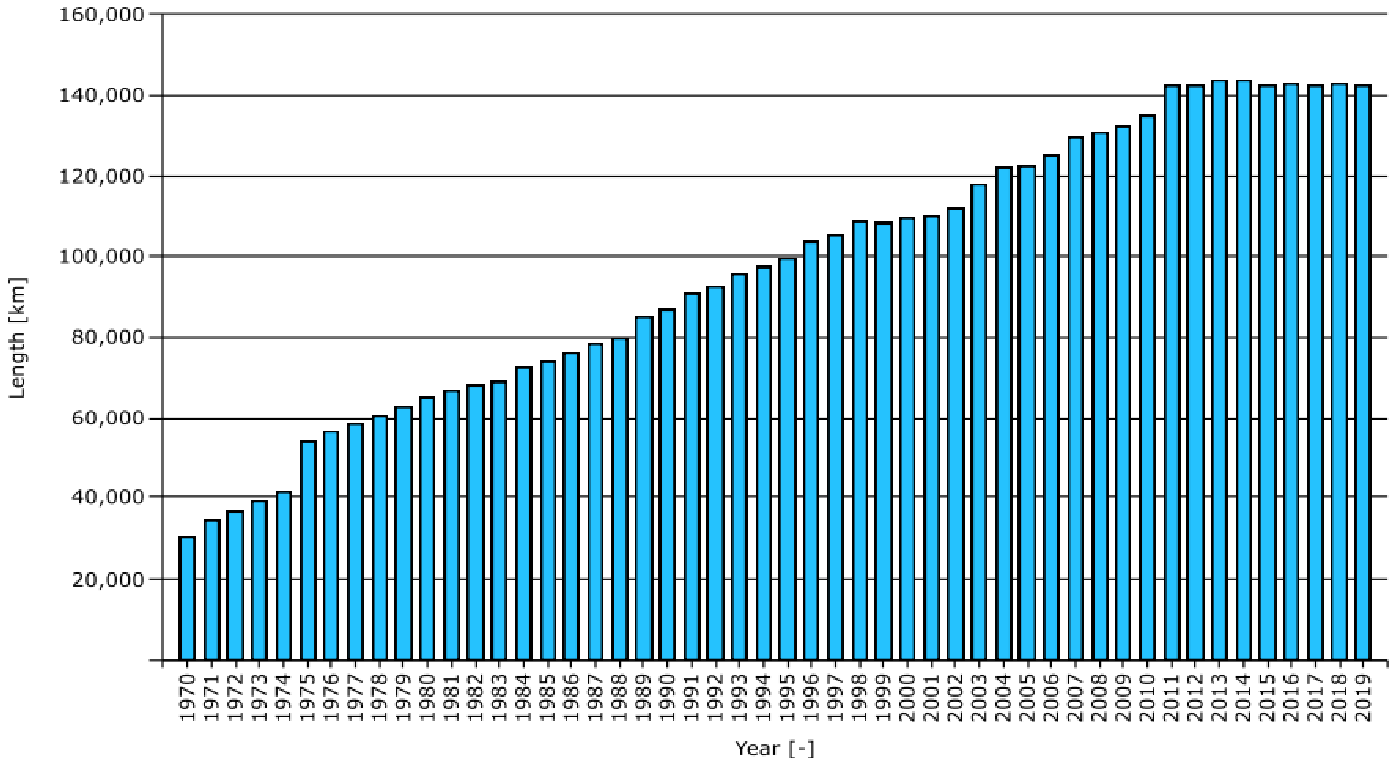


meldepflichtiges Ereignis … ist ein Ereignis, das an den DVGW und ggf. an die zuständige Behörde zu melden ist

* Molchstation, GDRA (einschl. HDR), GMA, GDRMA, Verdichteranlage, Erdgasspeicher, Biogaskonditionierungs- und –einspeiseanlage, Erdgastankstelle

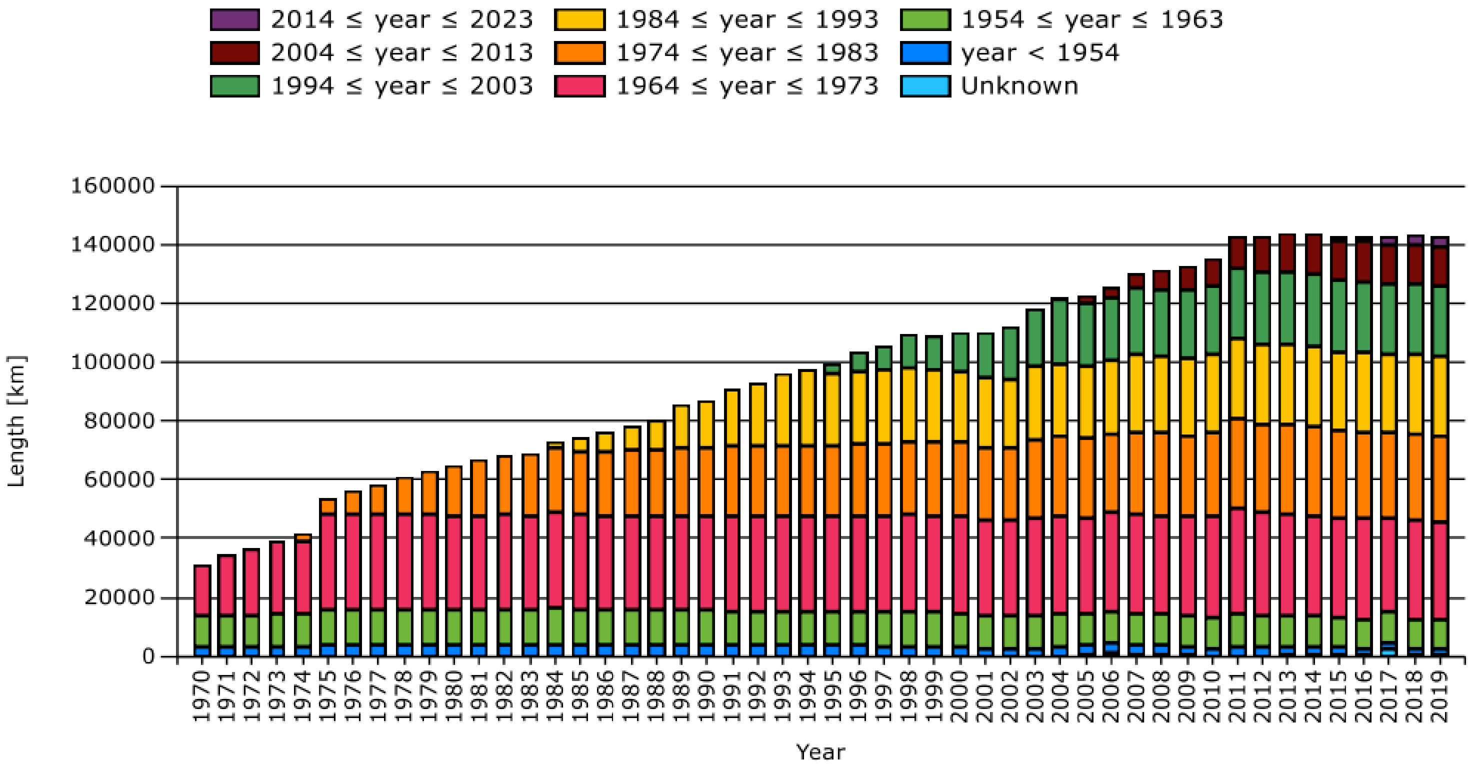
** zusätzlich: zuständiges Bundesministerium, Energieaufsicht, DVGW Hauptgeschäftsführung, DVGW-Landesgruppe

EGIG: Findings from the report from 2020



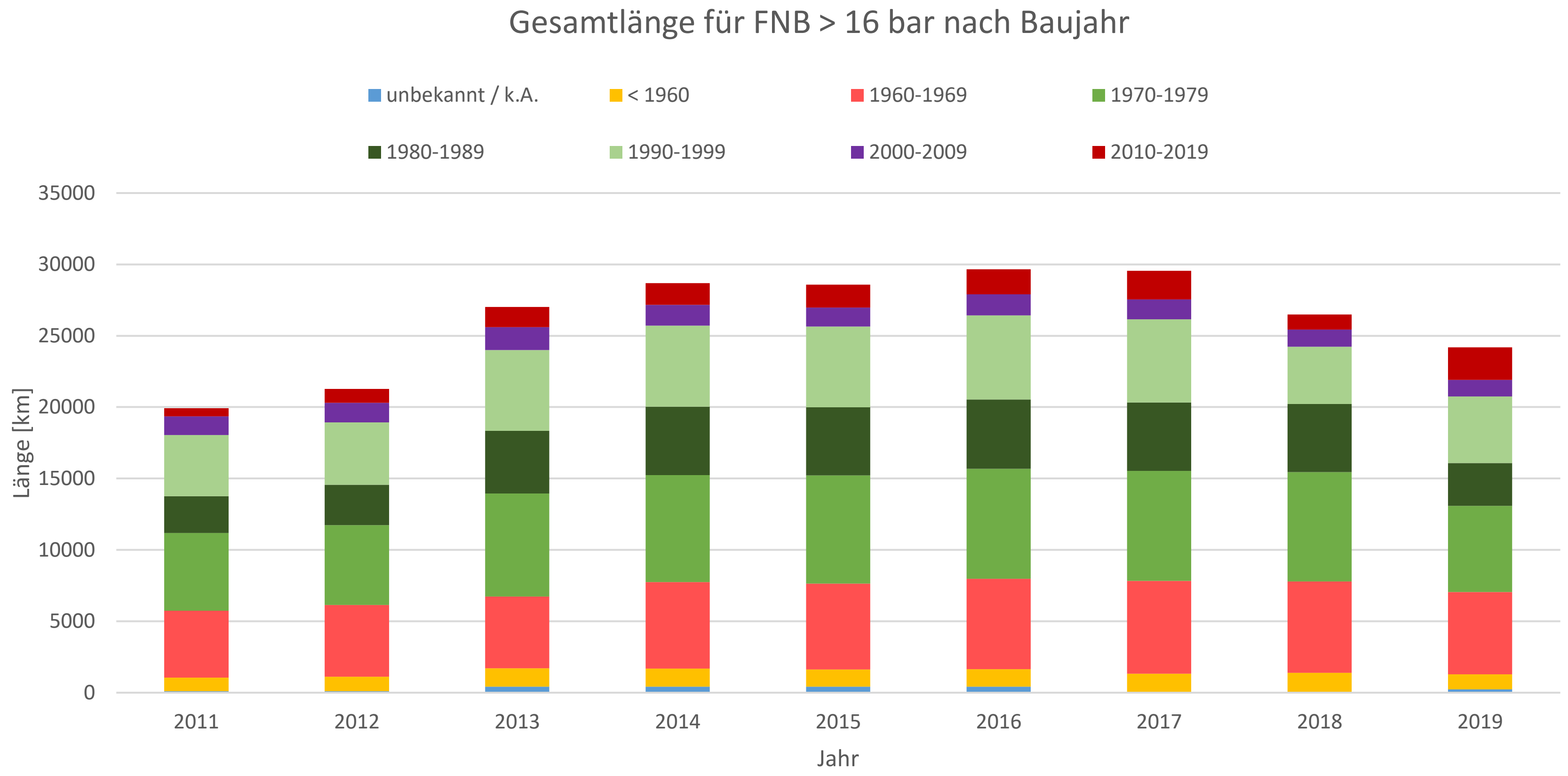
Total length of the European gas transmission system in EGIG

EGIG: Findings from the report from 2020

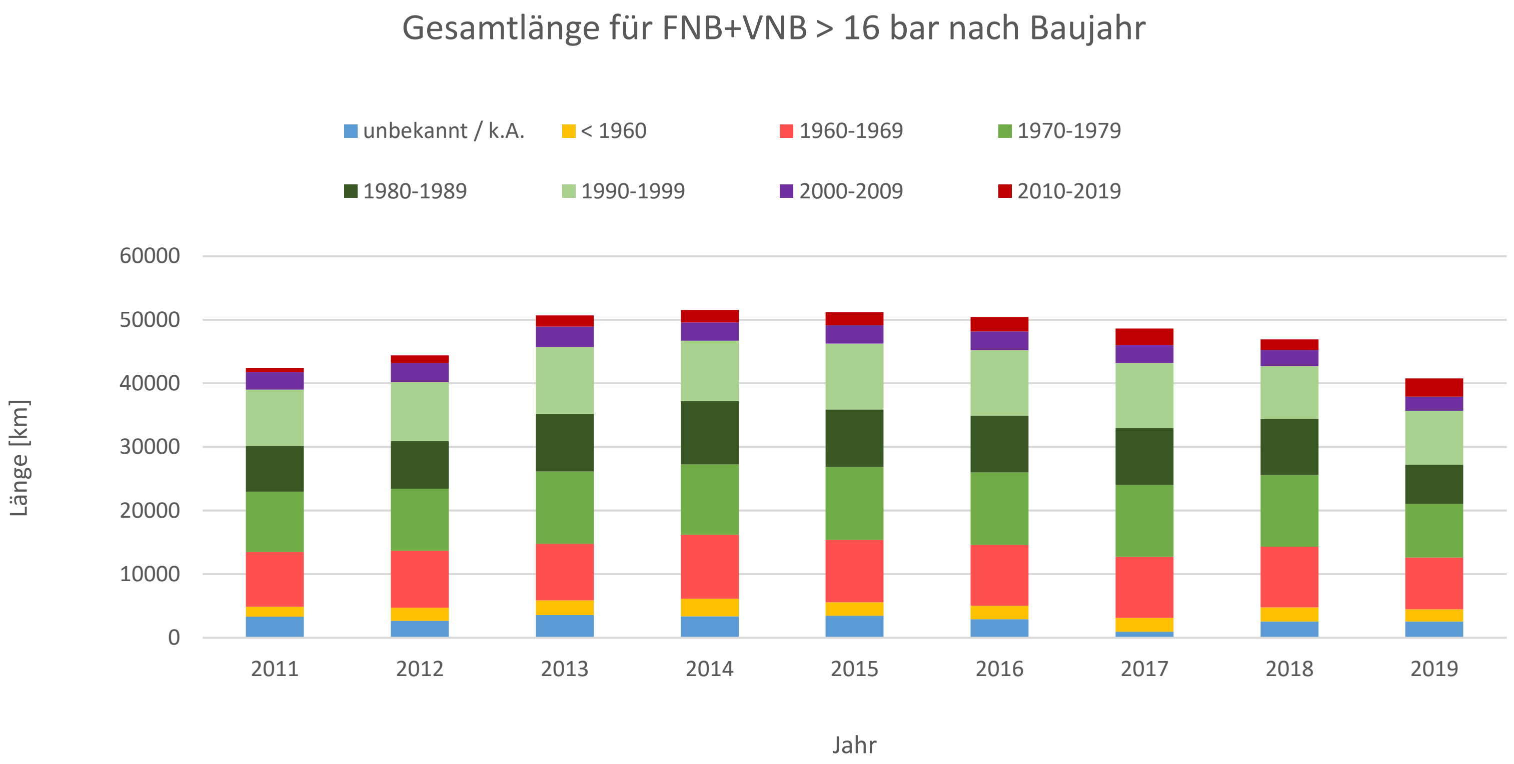


Total length per year of construction

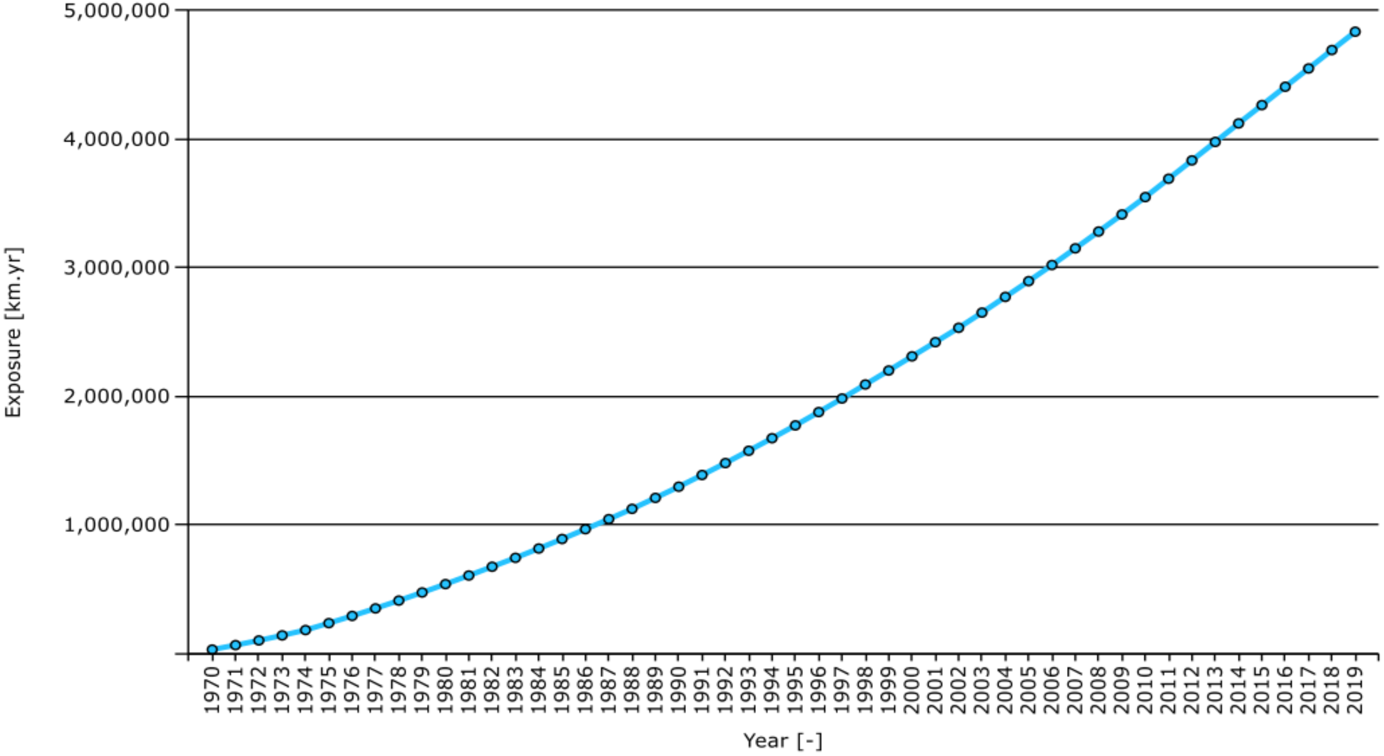
DVGW-Statistik: Gesamtlänge für FNB > 16 bar nach Baujahren



DVGW-Statistik: Gesamtlänge für FNB+VNB > 16 bar nach Baujahren



EGIG: Findings from the report from 2020



Evolution of the exposure

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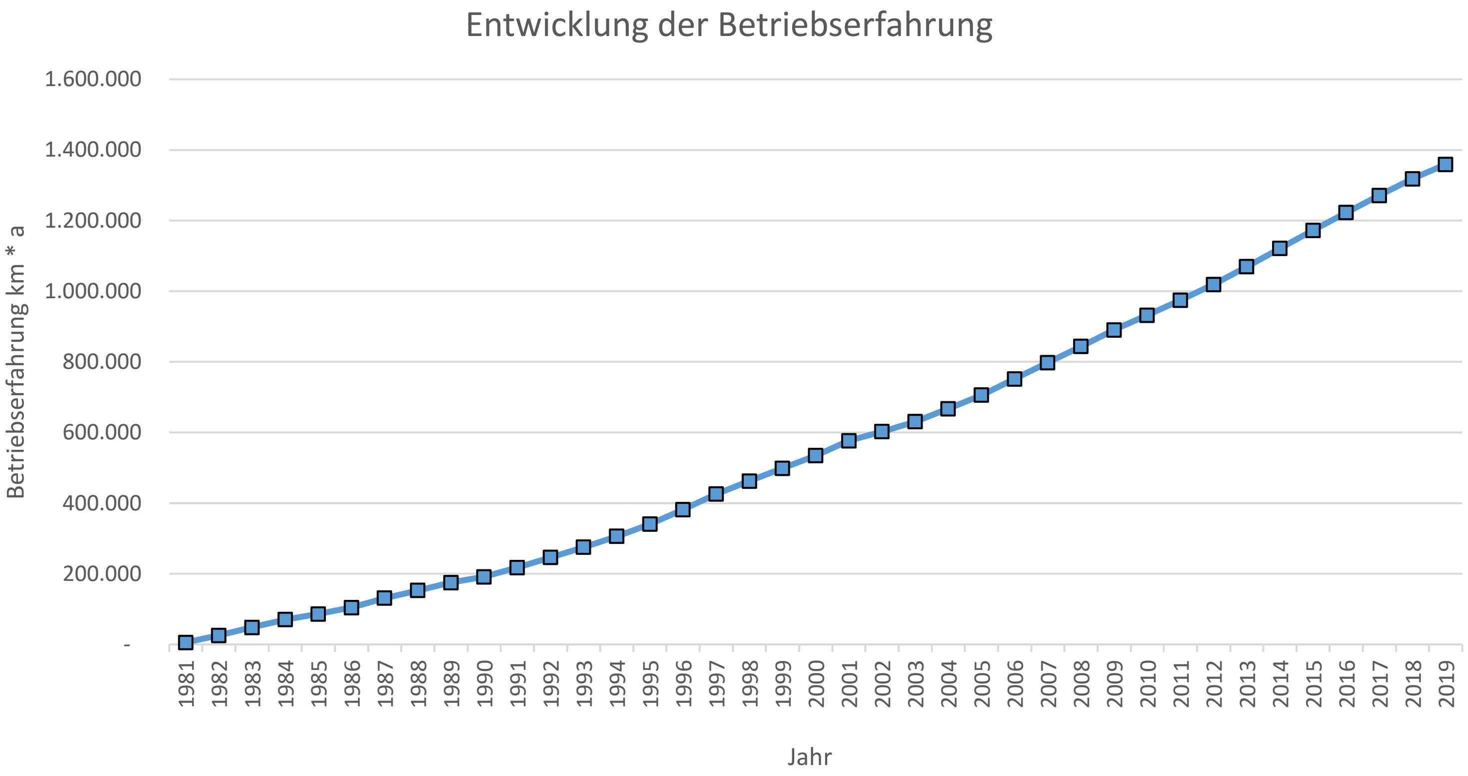
DVGW-Statistik: Betriebserfahrung (Exposure) FNB+VNB > 16 bar (1981-2019)



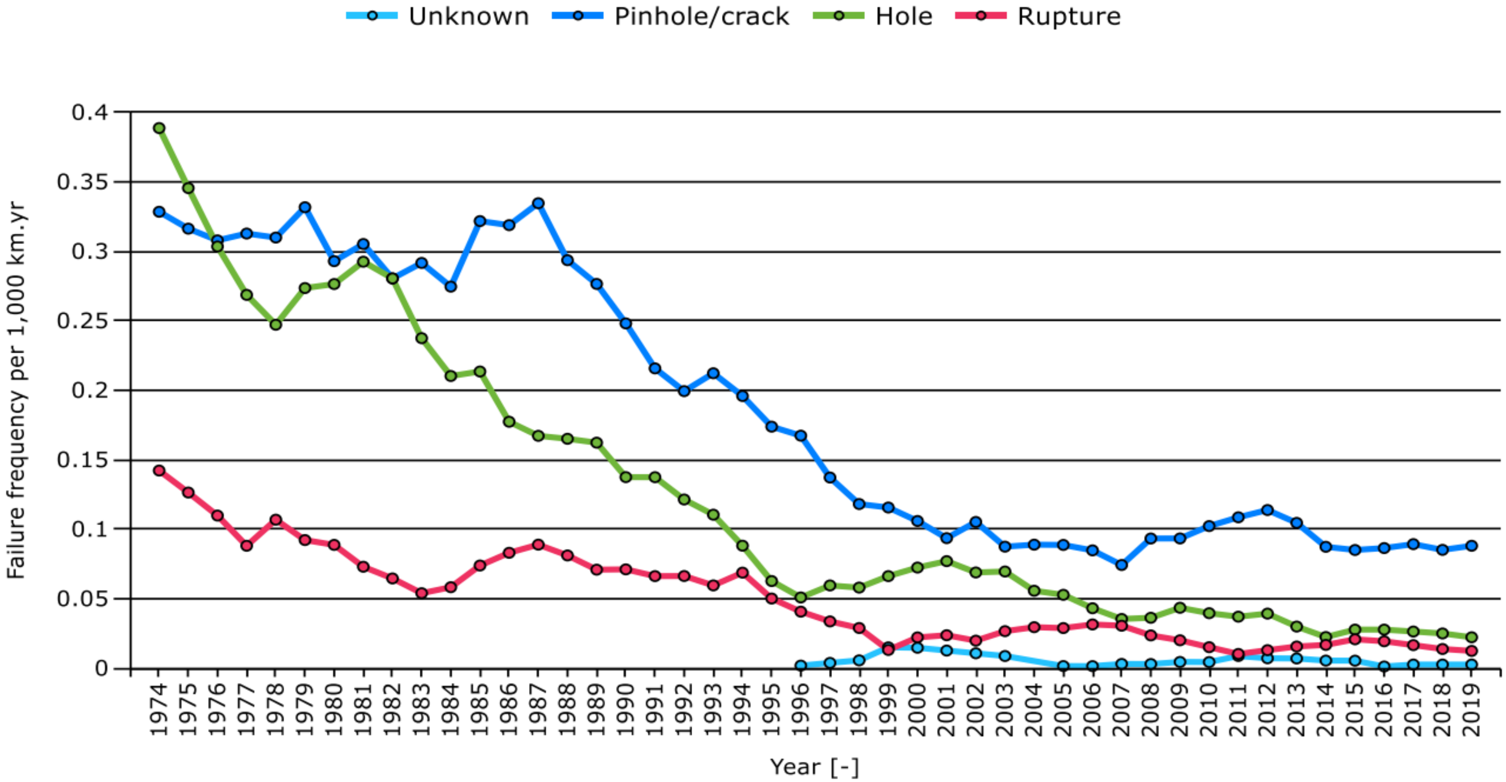
EGIG: Findings from the report from 2020

Period	Interval	Number of incidents	Total system exposure $\cdot 10^6$ km·yr	Primary failure frequency per 1,000 km·yr
1970 – 2007	7th report, 38 years	1,173	3.15	0.372
1970 – 2010	8th report, 41 years	1,249	3.55	0.351
1970 – 2013	9th report, 44 years	1,309	3.98	0.329
1970 – 2016	10th report, 47 years	1,366	4.41	0.310
1970 – 2019	11th report, 50 years	1,411	4.84	0.292
1980 – 2019	40 years	1,050	4.36	0.241
1990 – 2019	30 years	663	3.63	0.183
2000 – 2019	20 years	388	2.64	0.147
2010 – 2019	10 years	184	1.42	0.129
2015 – 2019	5 years	90	0.71	0.126

Primary failure frequencies

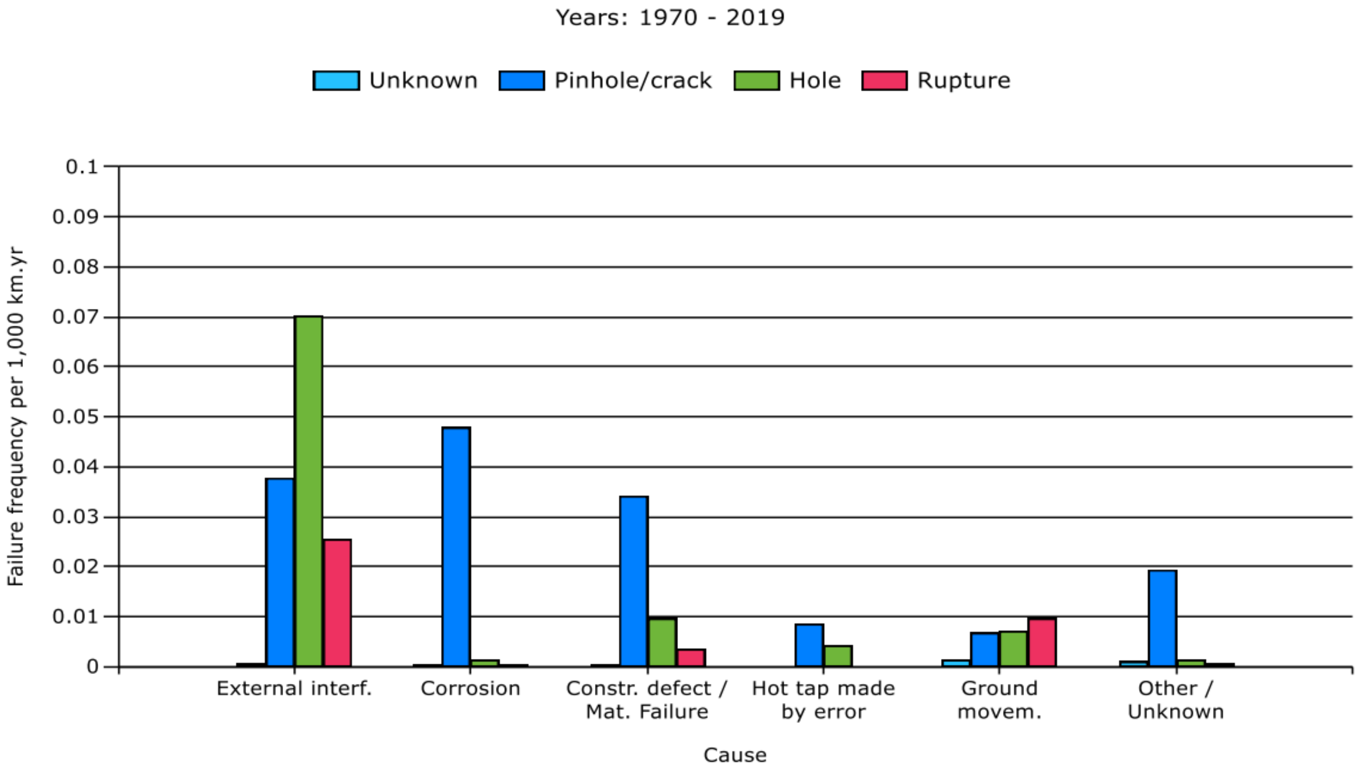
DVGW

EGIG: Findings from the report from 2020



Primary (5-year moving) failure frequency per leak size

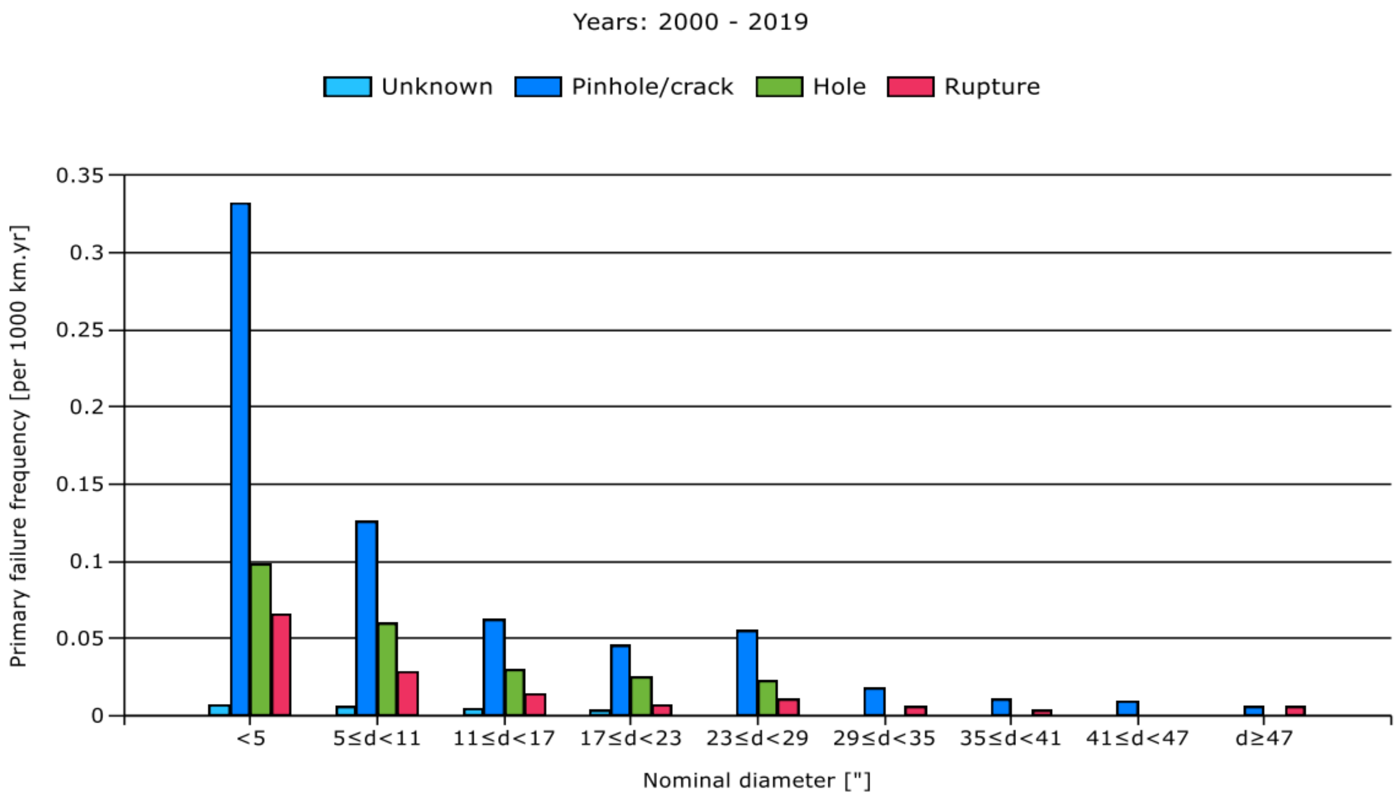
EGIG: Findings from the report from 2020



Relationship primary failure frequency, cause and size of leak (1970-2019)

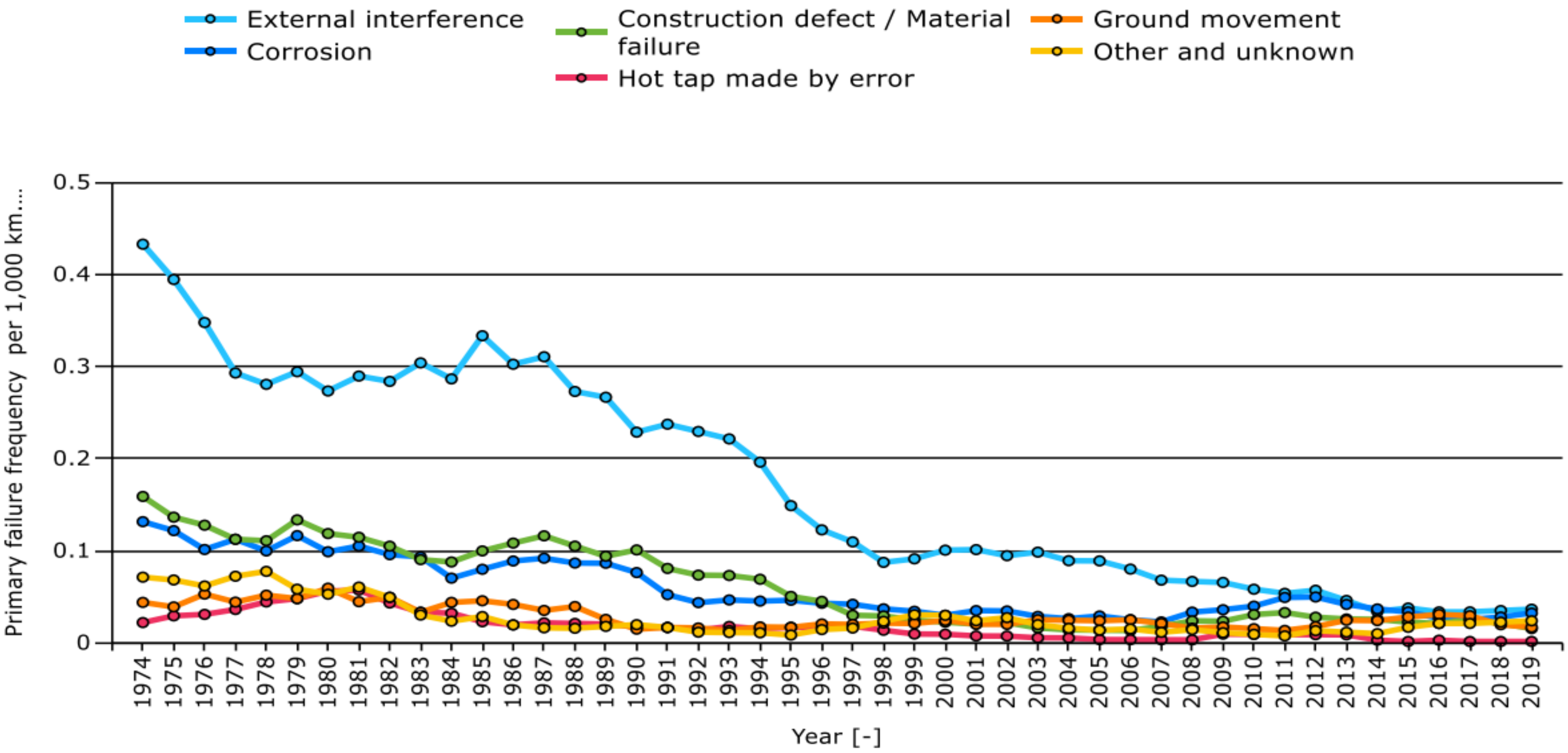
DVGW

EGIG: Findings from the report from 2020



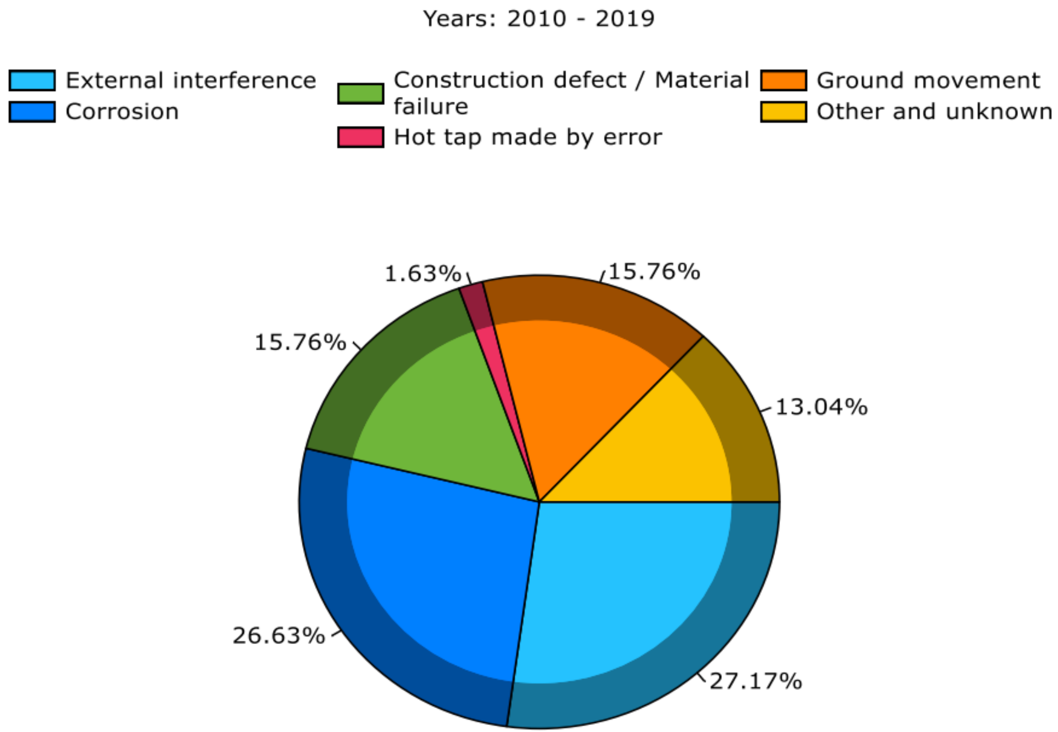
Secondary failure frequency, pipeline diameter and size of leak (1997-2019)

EGIG: Findings from the report from 2020



Primary failure frequency per cause (5-year moving)

EGIG: Findings from the report from 2020



Distribution of Incidents (2010 – 2019)

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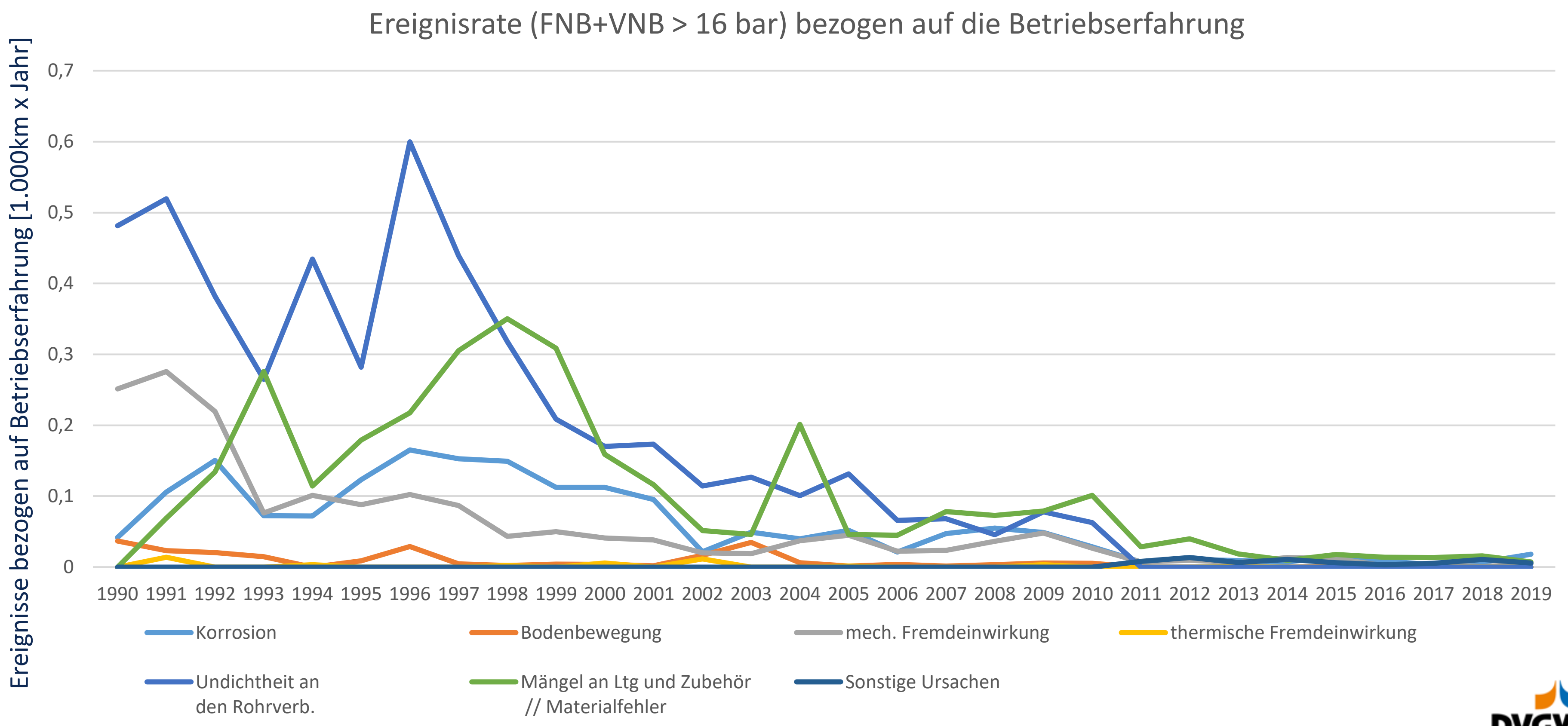
DVGW-Statistik: Schadensentwicklung (FNB+VNB > 16 bar) bezogen auf die Betriebserfahrung



EGIG: Findings from the report from 2020

Cause	Primary failure frequency			
	1970-2019 per 1,000 km·yr	2000-2019 per 1,000 km·yr	2010-2019 per 1,000 km·yr	2015-2019 per 1,000 km·yr
External interference	0.134	0.054	0.035	0.036
Corrosion	0.050	0.033	0.034	0.032
Construction defect / Material failure	0.048	0.020	0.020	0.015
Hot tap made by error	0.013	0.005	0.002	0.001
Ground movement	0.025	0.020	0.020	0.017
Other and unknown	0.022	0.015	0.017	0.024

Primary failure frequencies per cause (confidence intervals are given in APPENDIX 1)

DVGW

Conclusions 10th EGIG report, March 2018

- The EGIG database is a valuable source of information on European gas pipelines and incidents.
- EGIG has maintained and expanded the European Gas pipeline incident database. Seventeen gas transmission system operators in Europe now collect incident data on more than 142,711 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 4.84 million km·yr.
- In the EGIG database 1,411 pipeline incidents are recorded in the period from 1970-2019.
- The history of incidents collected in the database gives reliable failure frequencies. The overall failure frequency over the period 1970-2019 is equal to 0.29 incidents per year per 1,000 km.
- The five year moving average failure frequency in 2019, which represents the average failure frequency over the past 5 years, equals 0.126 per year per 1,000 km.
- The five year moving average and overall failure frequency have reduced consistently over the years, although it has tended to stabilise over recent years.
- Incidents caused by external interference and ground movement are characterised by potentially severe consequences. This emphasises their importance to pipeline operators and authorities.
- Corrosion as a primary cause has now the same frequency rate as external interference, although consequences are much less severe.
- Over the last ten years, external interference, corrosion, construction defects and ground movement, represent 27%, 27%, 16% and 16% respectively of the pipeline incidents reported

Teil 6 – Pipelines

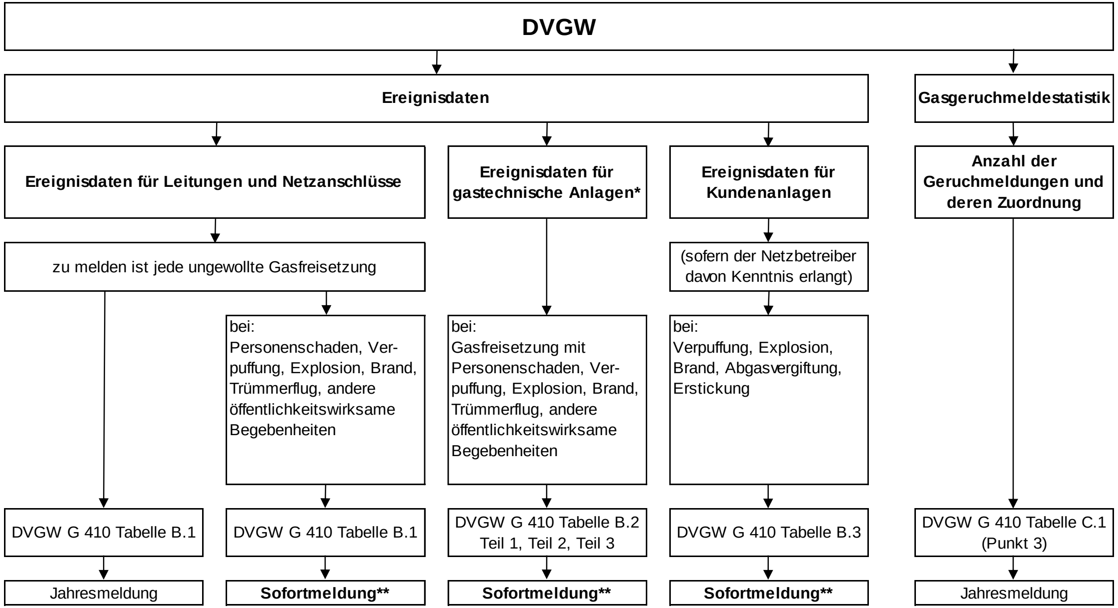
Design & Safety

Meldepflichtige und sofortmeldepflichtige Ereignisse

Definition

- Ein **meldepflichtiges Ereignis** für Leitungen und Netzanschlüsse ist eine ungewollte Gasfreisetzung

- **Meldepflichtige Ereignisse**, die mit Personenschaden, Verpuffung, Explosion, Brand, Trümmerflug oder anderen öffentlichkeitswirksamen Begebenheiten verbunden sind, müssen **sofort** nach dem Eintritt gemeldet werden



meldepflichtiges Ereignis … ist ein Ereignis, das an den DVGW und ggf. an die zuständige Behörde zu melden ist

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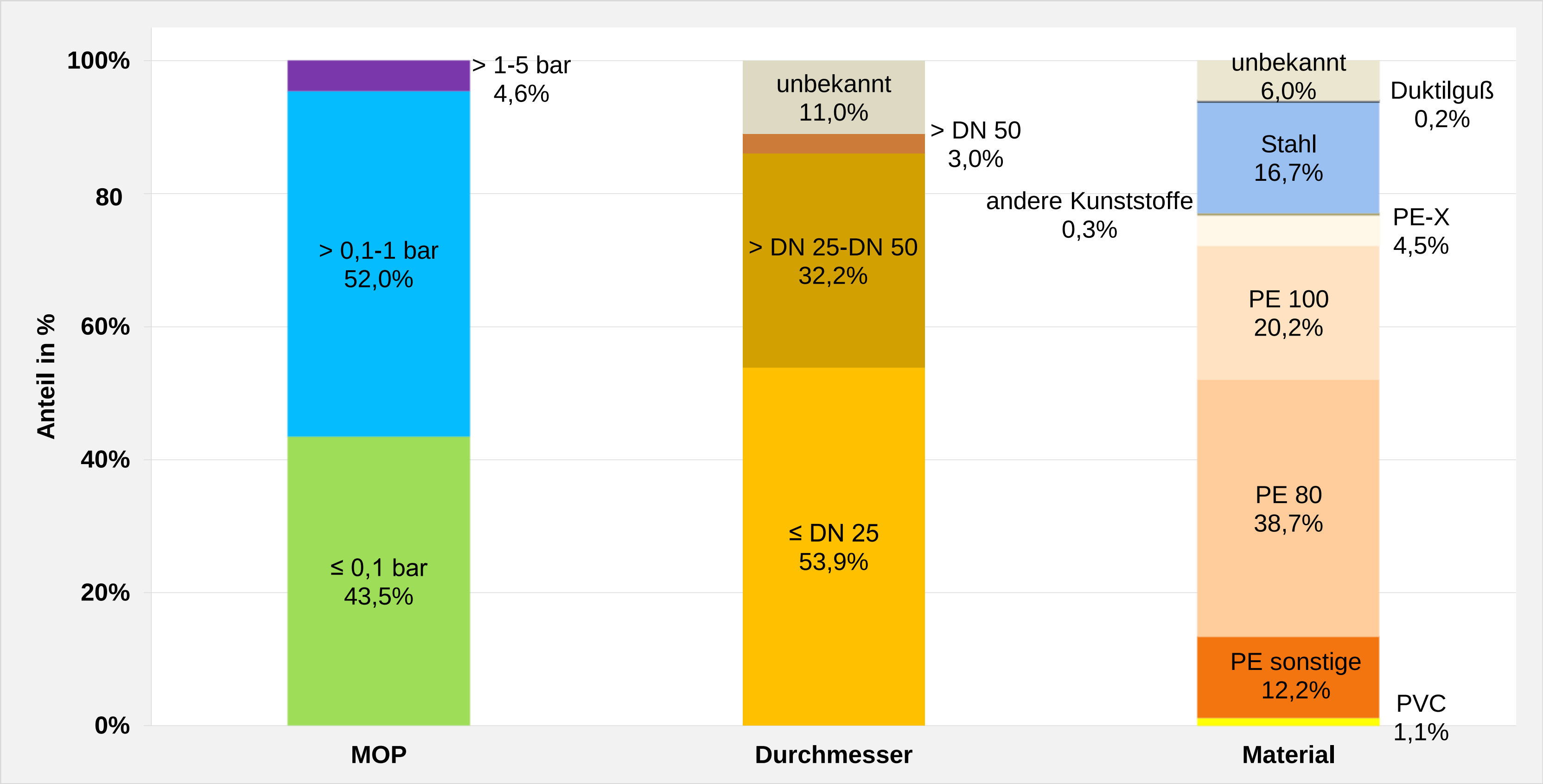
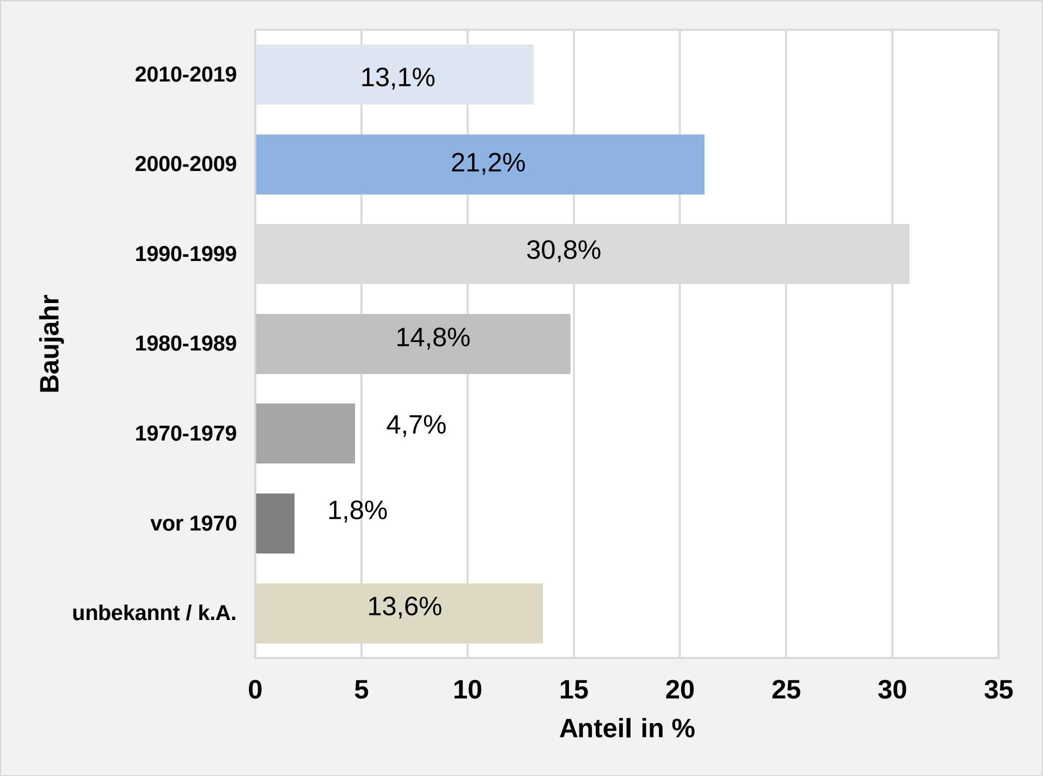
** zusätzlich: zuständiges Bundesministerium, Energieaufsicht, DVGW Hauptgeschäftsführung, DVGW-Landesgruppe

Aufteilung der Hausanschlüsse in Prozent

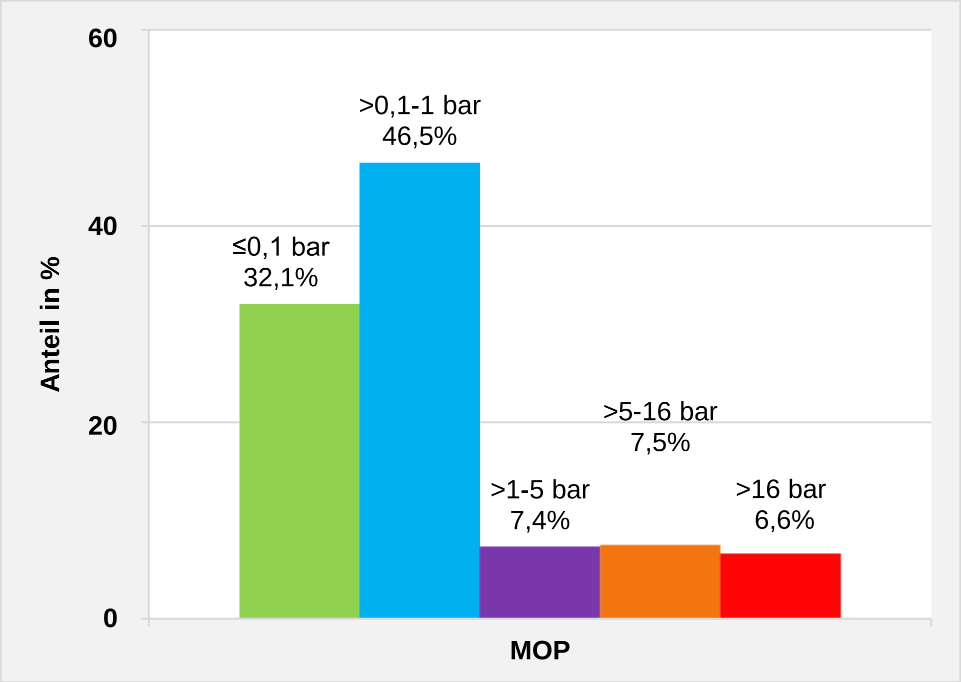


Hausanschlüsse nach MOP / durchschnittliche Länge in Metern

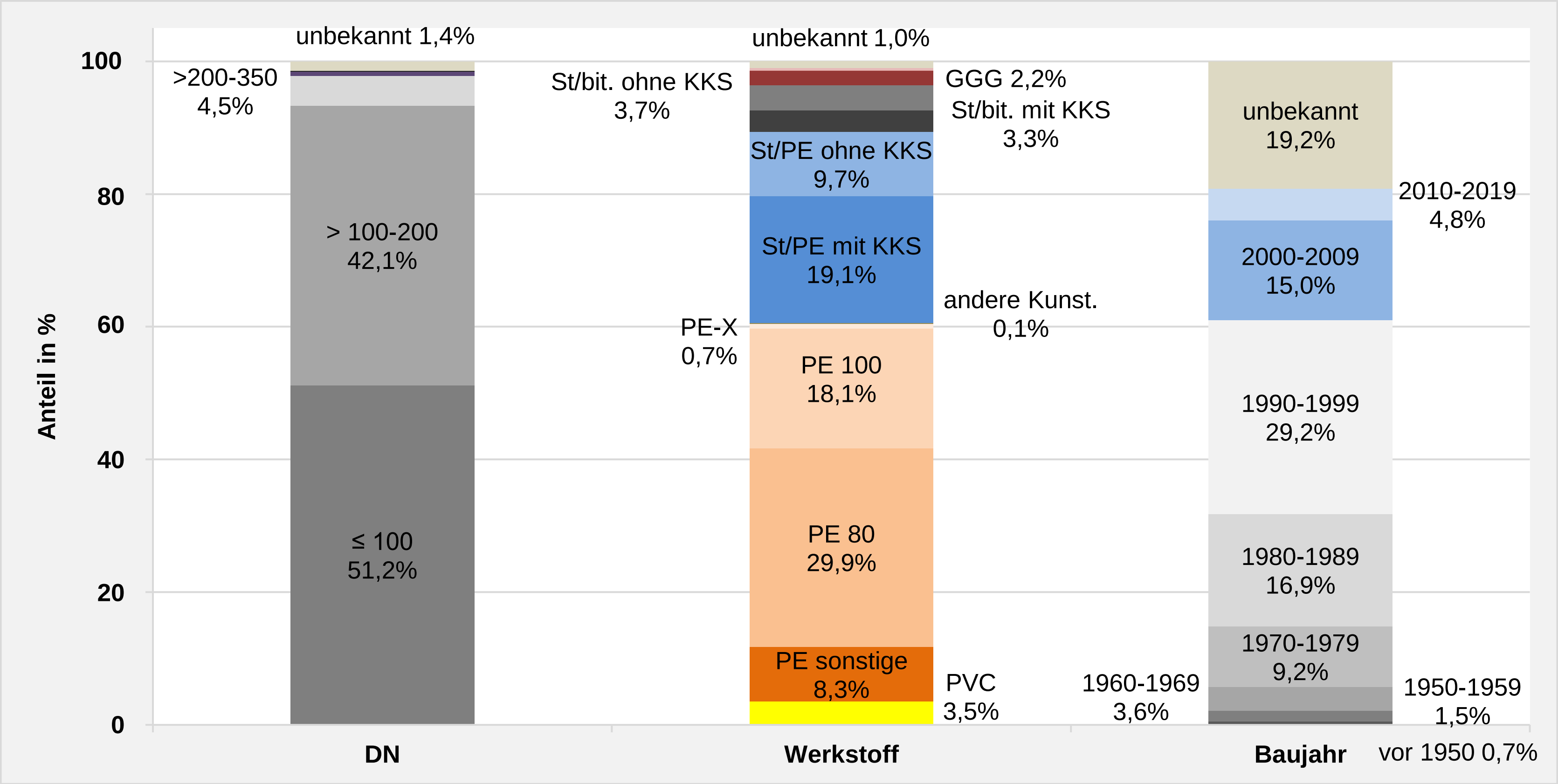
Aufteilung der Hausanschlüsse nach Baujahr (Datenbasis 2017) in Prozent



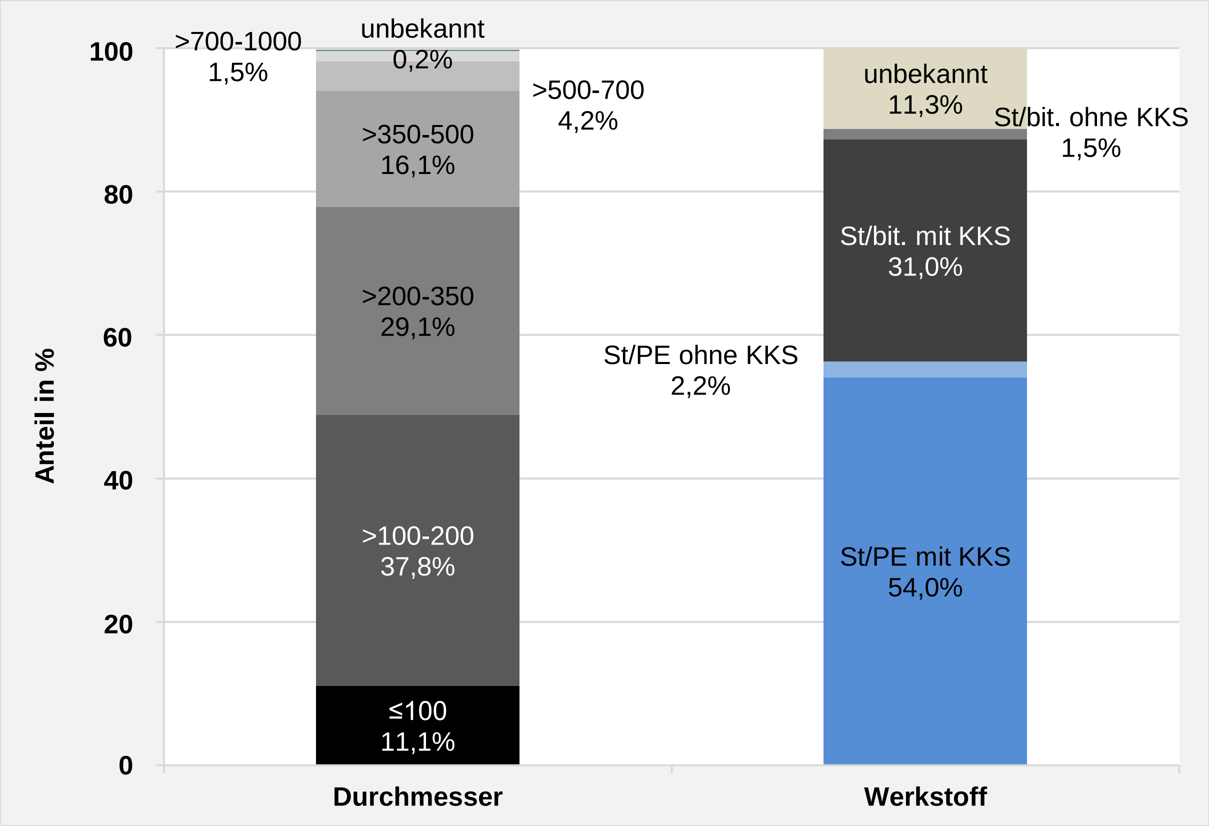
Leitungen der Verteilnetzbetreiber nach MOP / Länge in Prozent



Aufteilung der Leitungen der Verteilnetzbetreiber ≤ 16 bar in Prozent

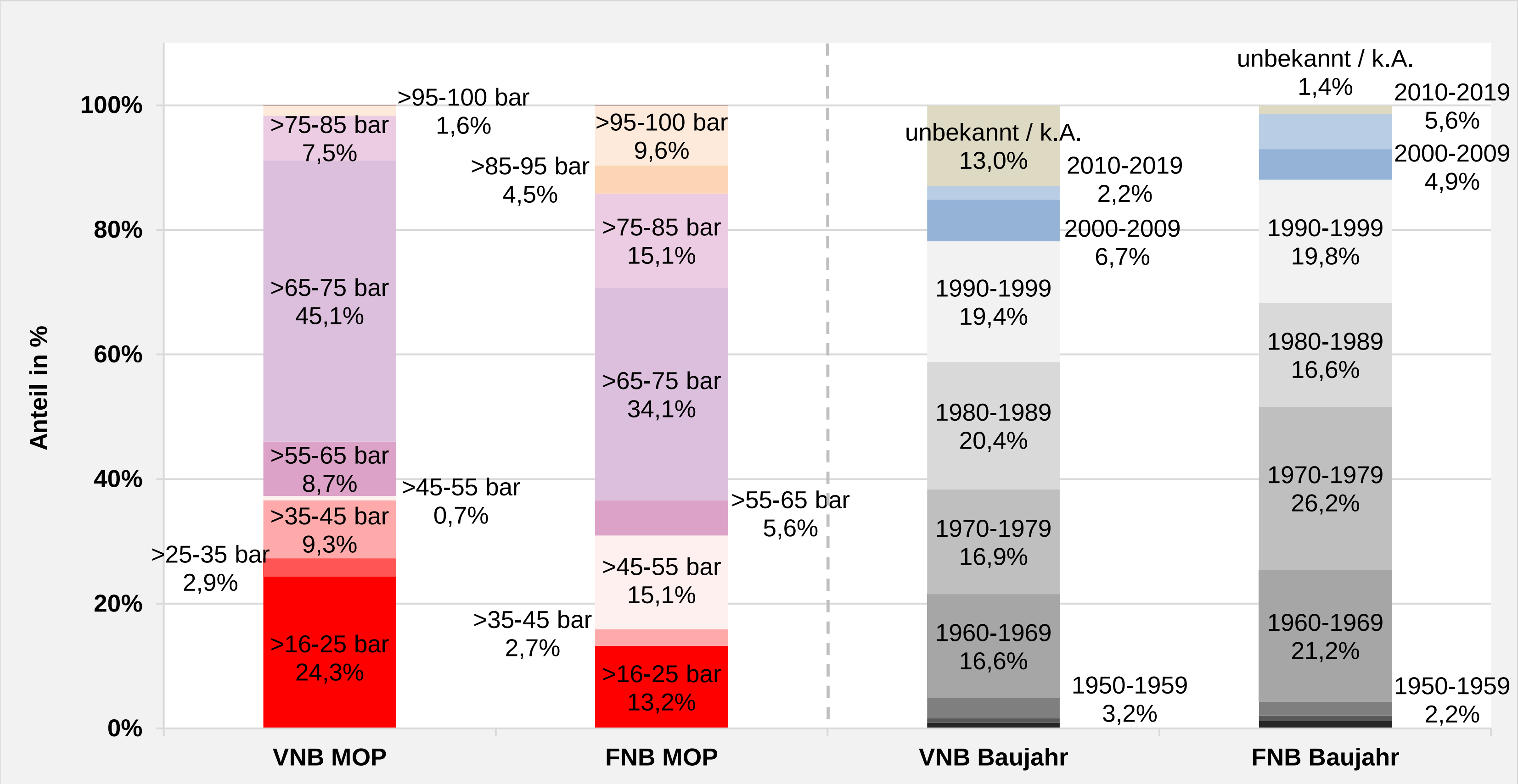


Aufteilung der Leitungen der Verteilnetzbetreiber >16 bar in Prozent

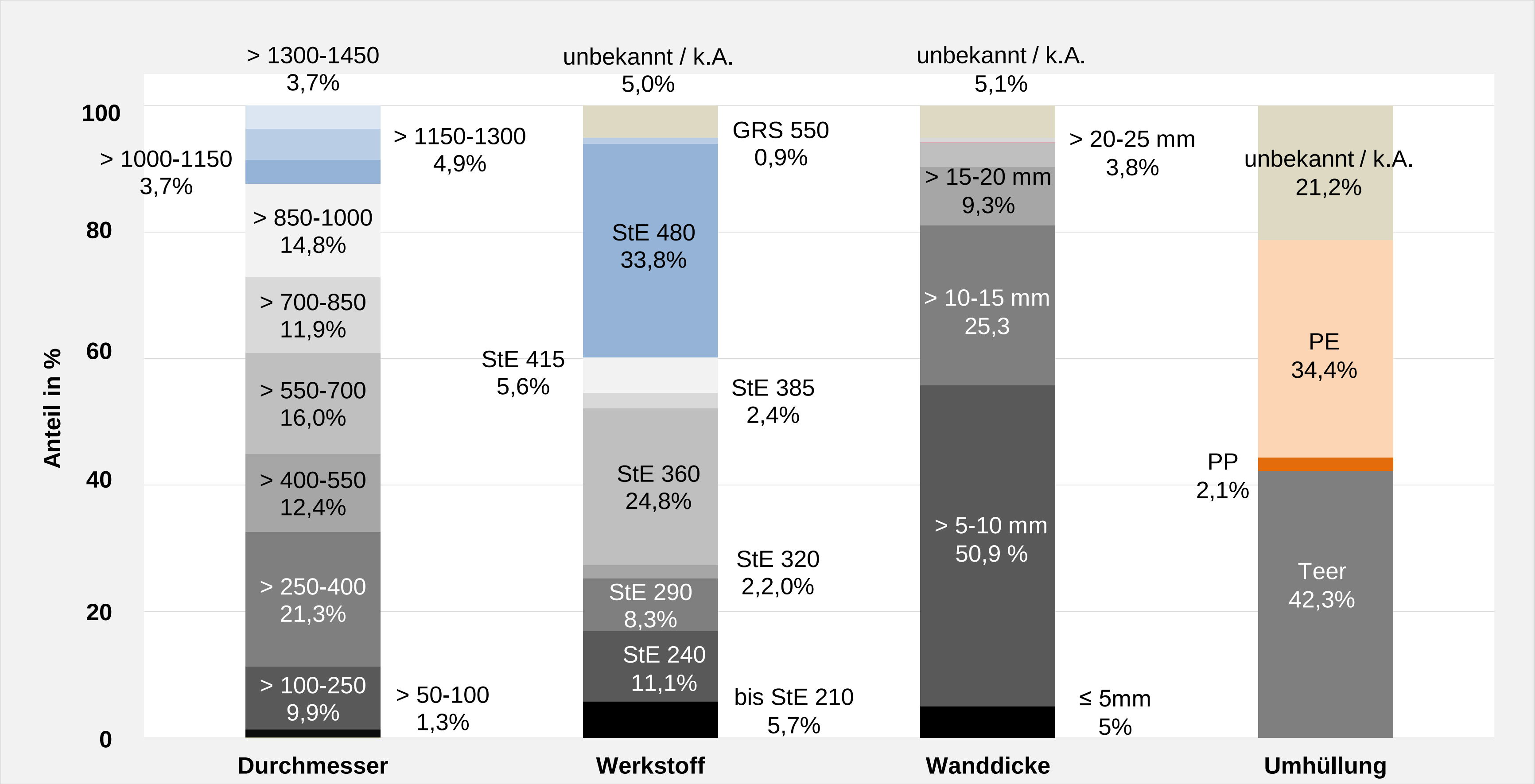


DVGW

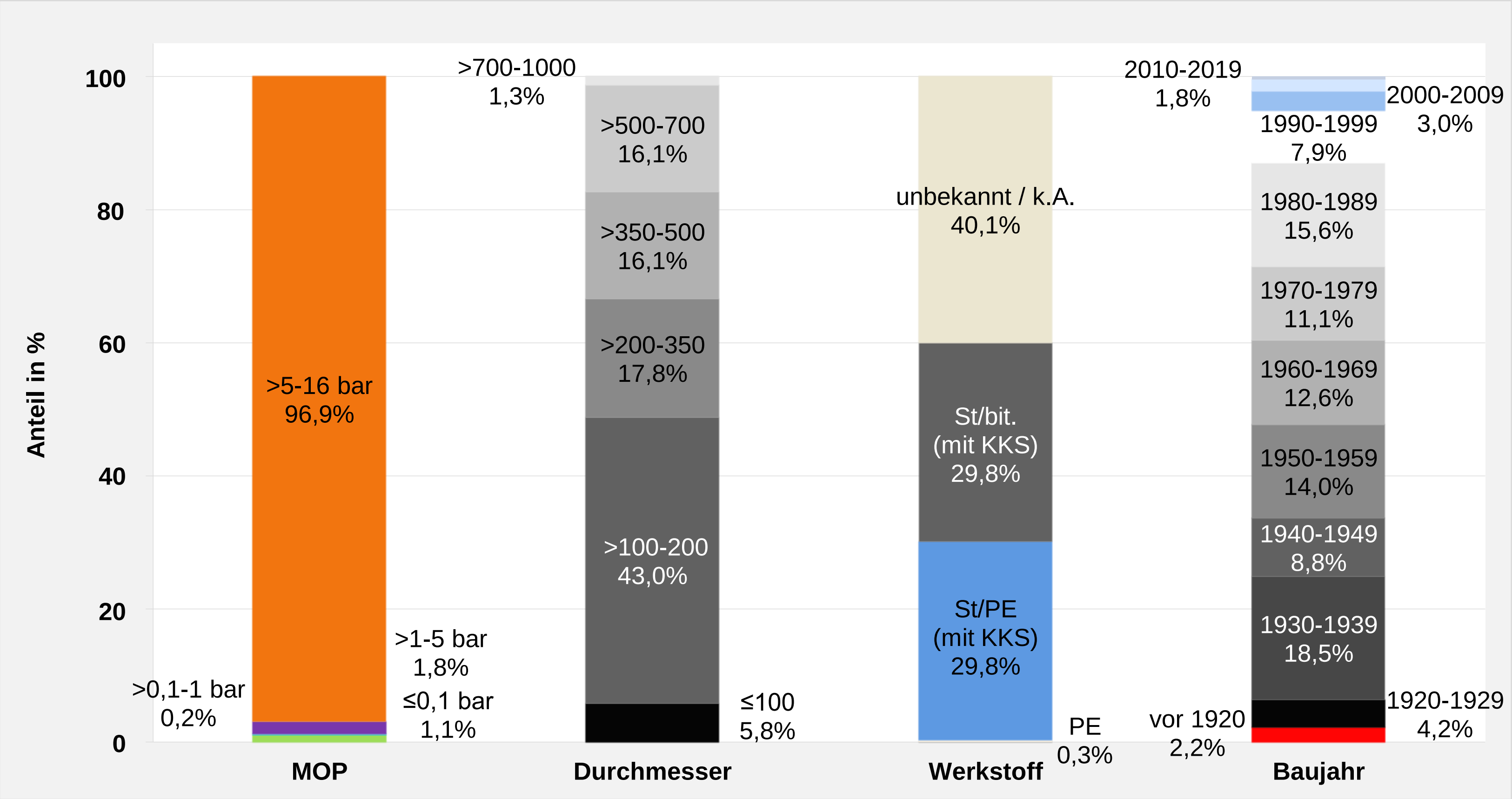
Gasleitungen >16 bar MOP, Baujahr in Prozent



Aufteilung der Leitungen der Fernleitungsnetzbetreiber > 16 bar in Prozent

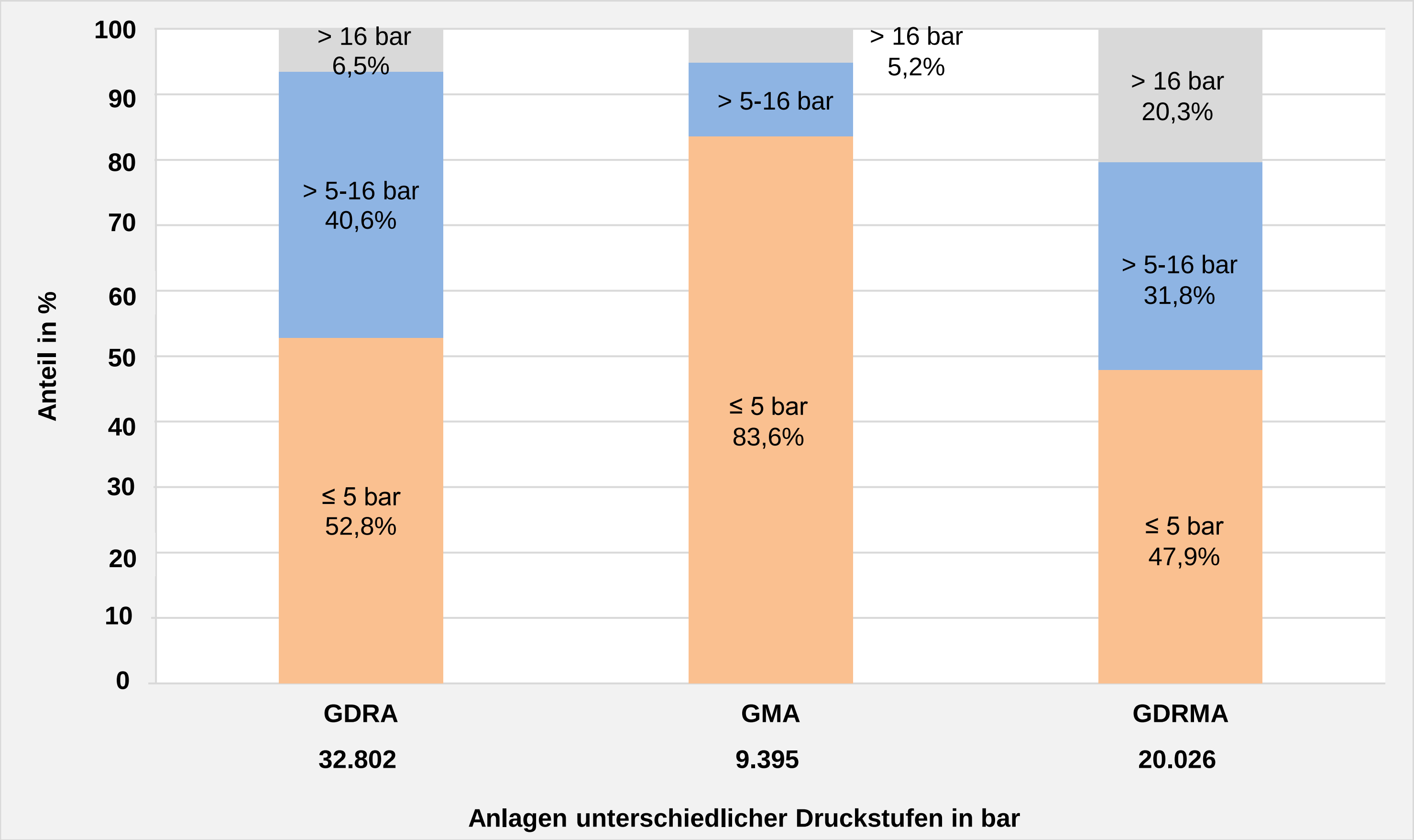


Aufteilung der Leitungen der Fernleitungsnetzbetreiber ≤ 16 bar in Prozent

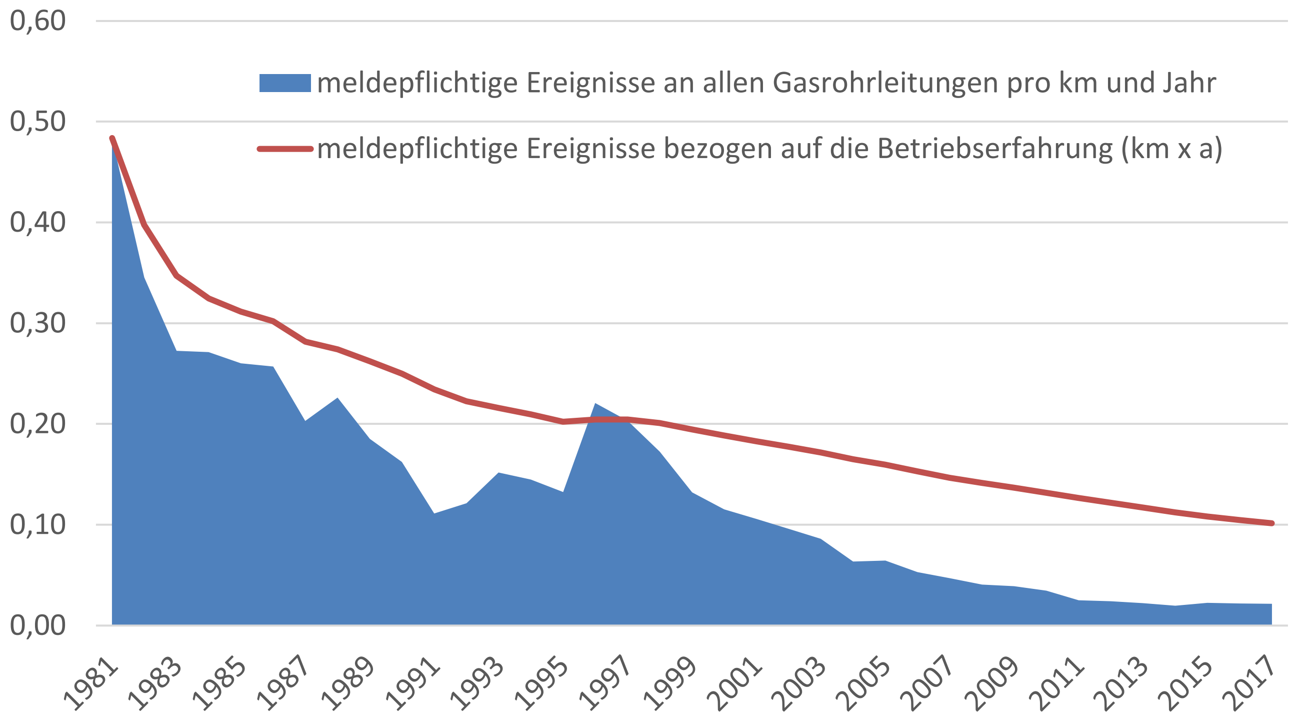


DVGW

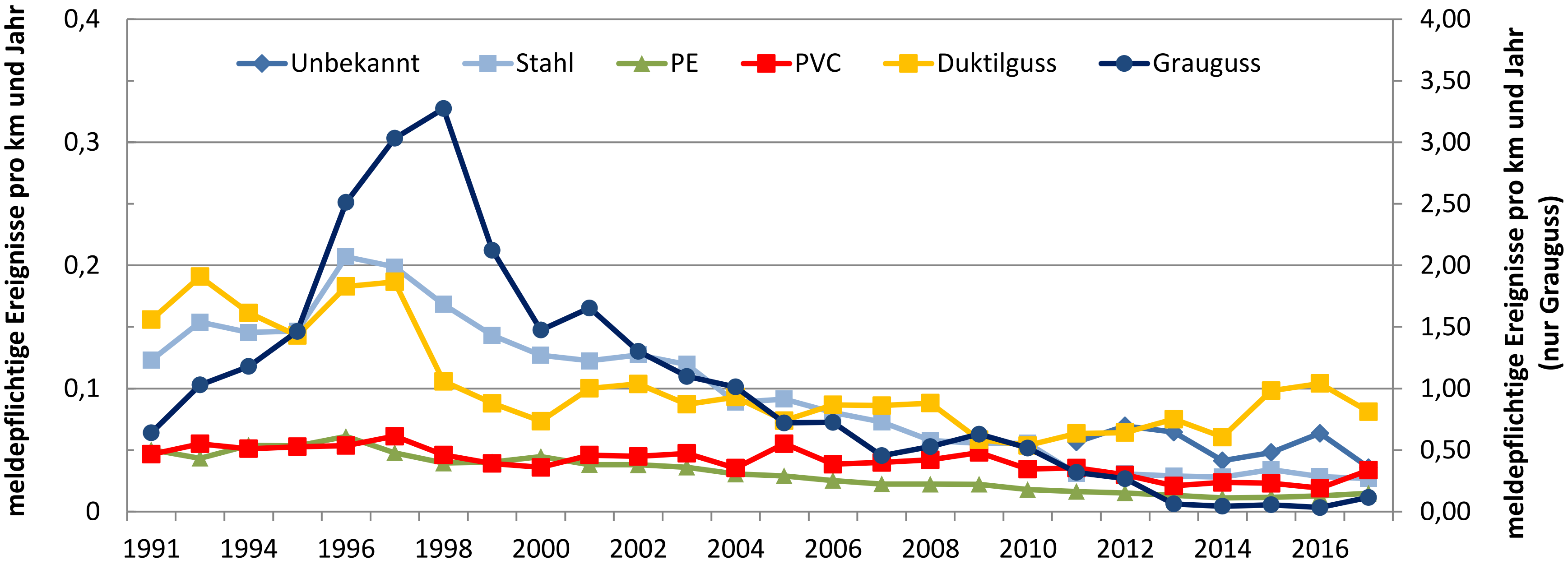
Anteil von Regel- und/oder Messanlagen unterschiedlicher Druckstufen in Prozent



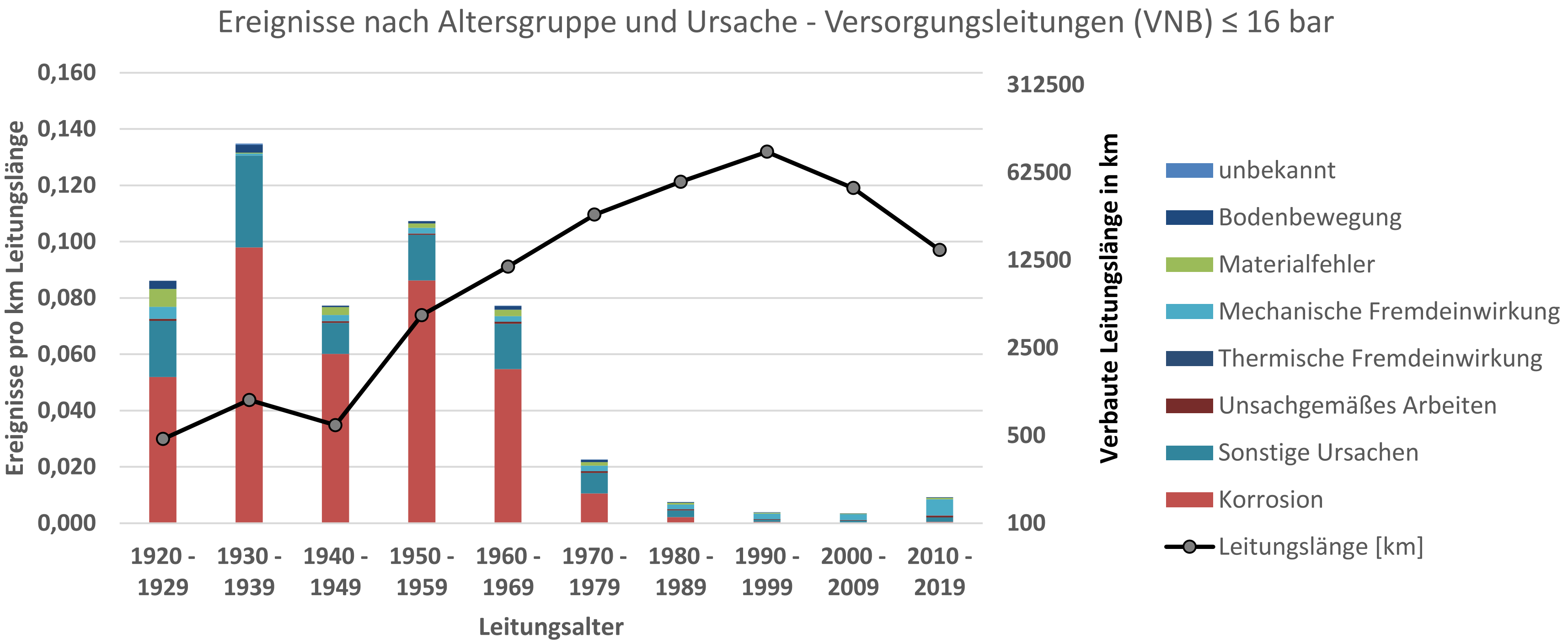
Meldepflichtige Ereignisentwicklung zwischen 1981 und 2017 an allen Gasleitungen



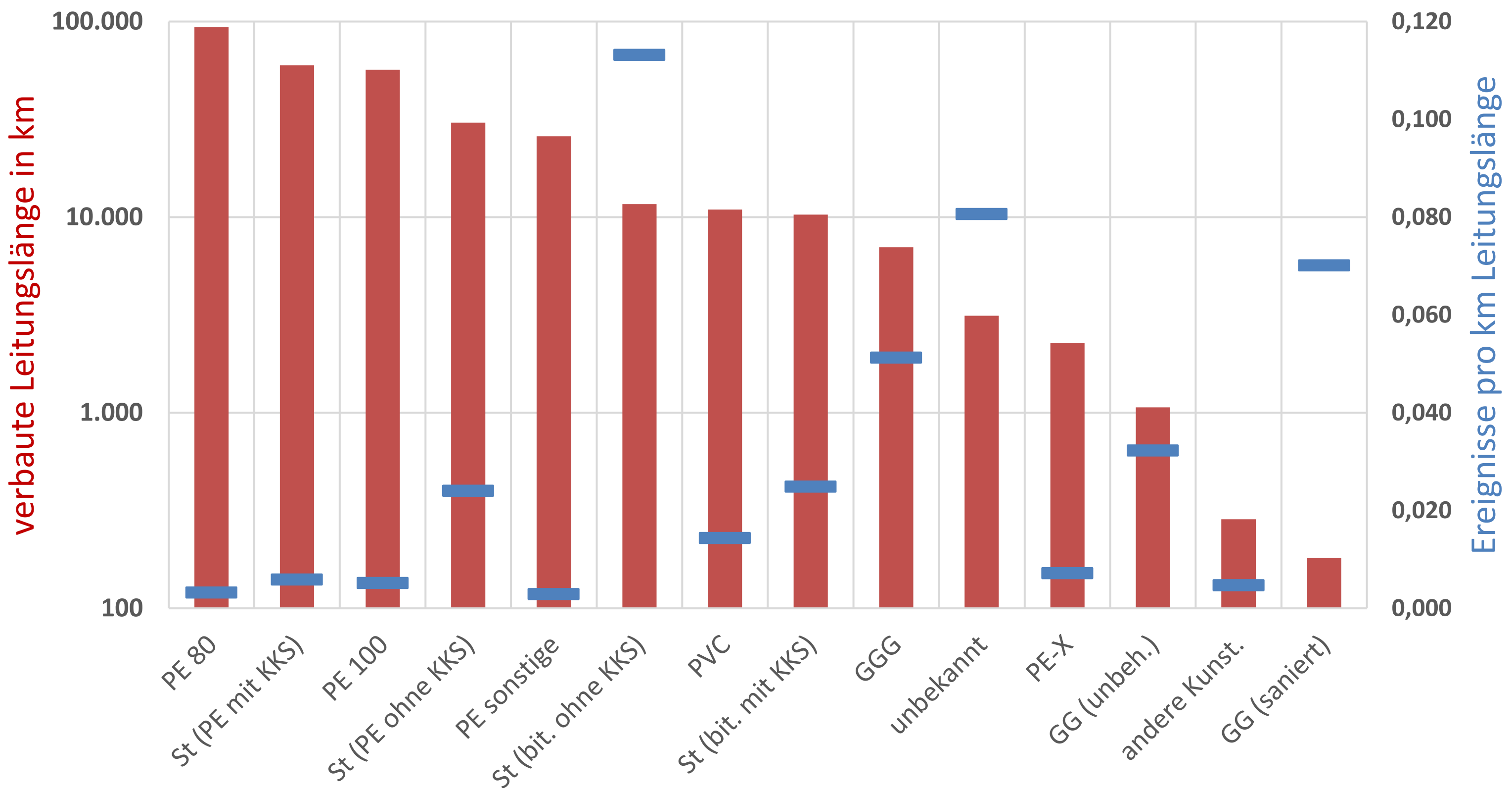
Meldepflichtige Ereignisentwicklung zwischen 1991 und 2017 an allen Gasleitungen nach Werkstoffgruppen



Ereignisse nach Altersgruppe und Ursache - Versorgungsleitungen (VNB) ≤ 16 bar

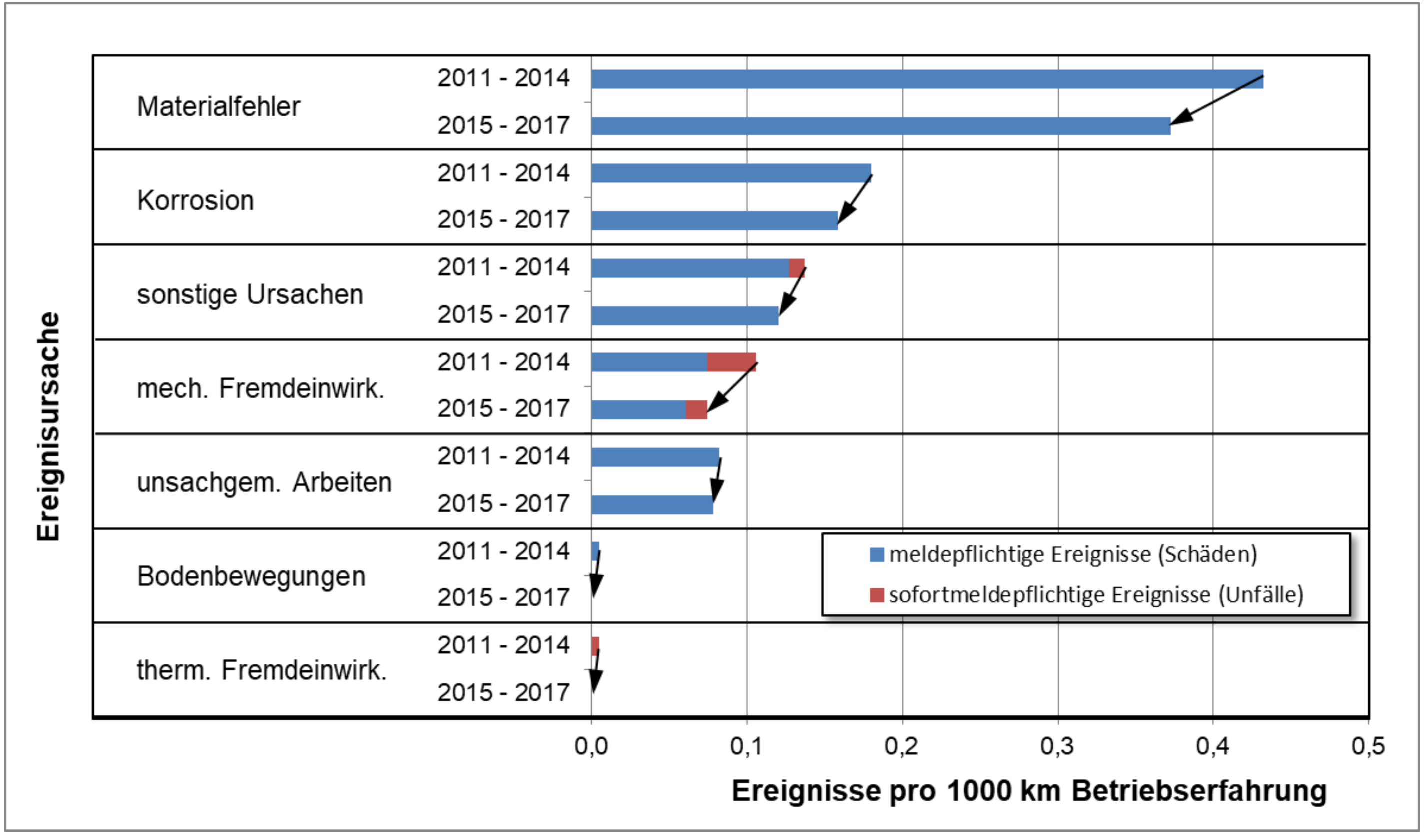


Ereignisse pro km für Leitungen der Verteilnetzbetreiber ≤ 16 bar nach Werkstoffen

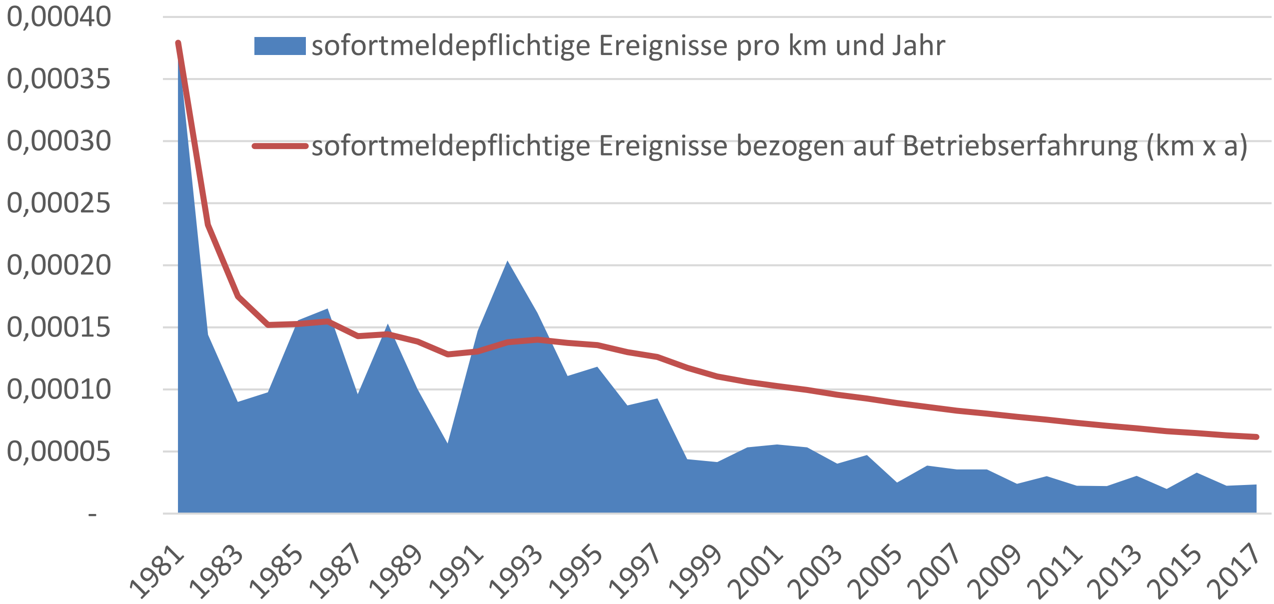


DVGW

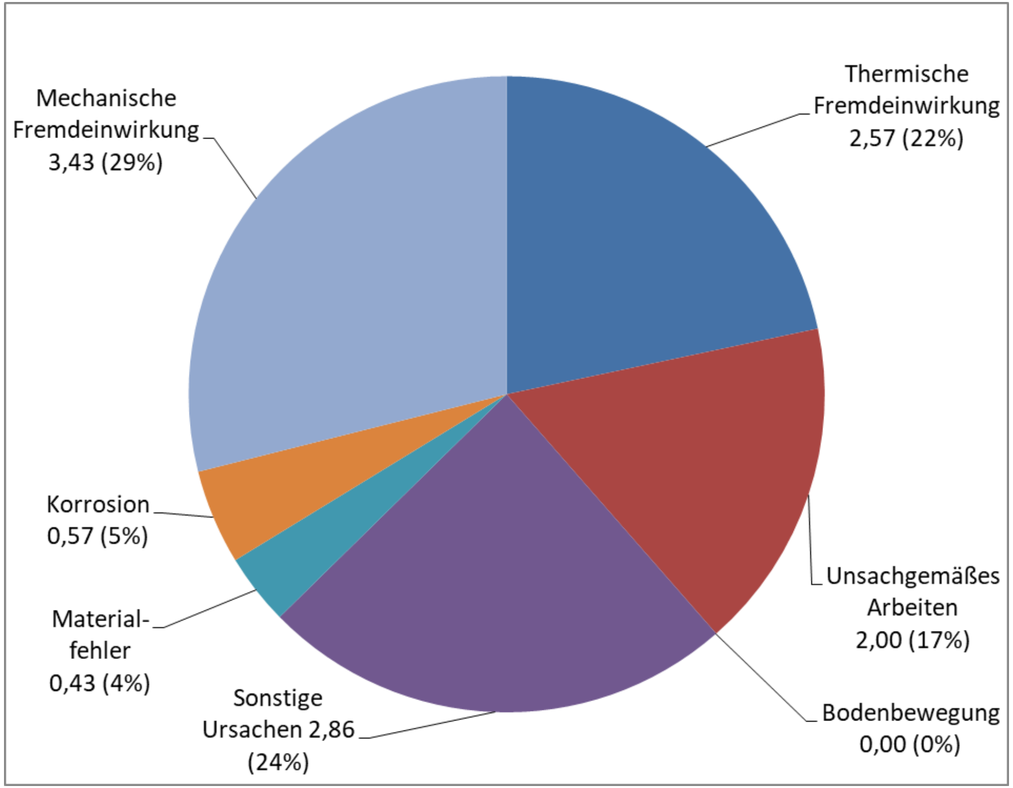
Meldepflichtige und sofortmeldepflichtige Ereignisse an Gashochdruckleitungen ab 16 bar (Ereignisse bezogen auf 1000 km Betriebserfahrung)



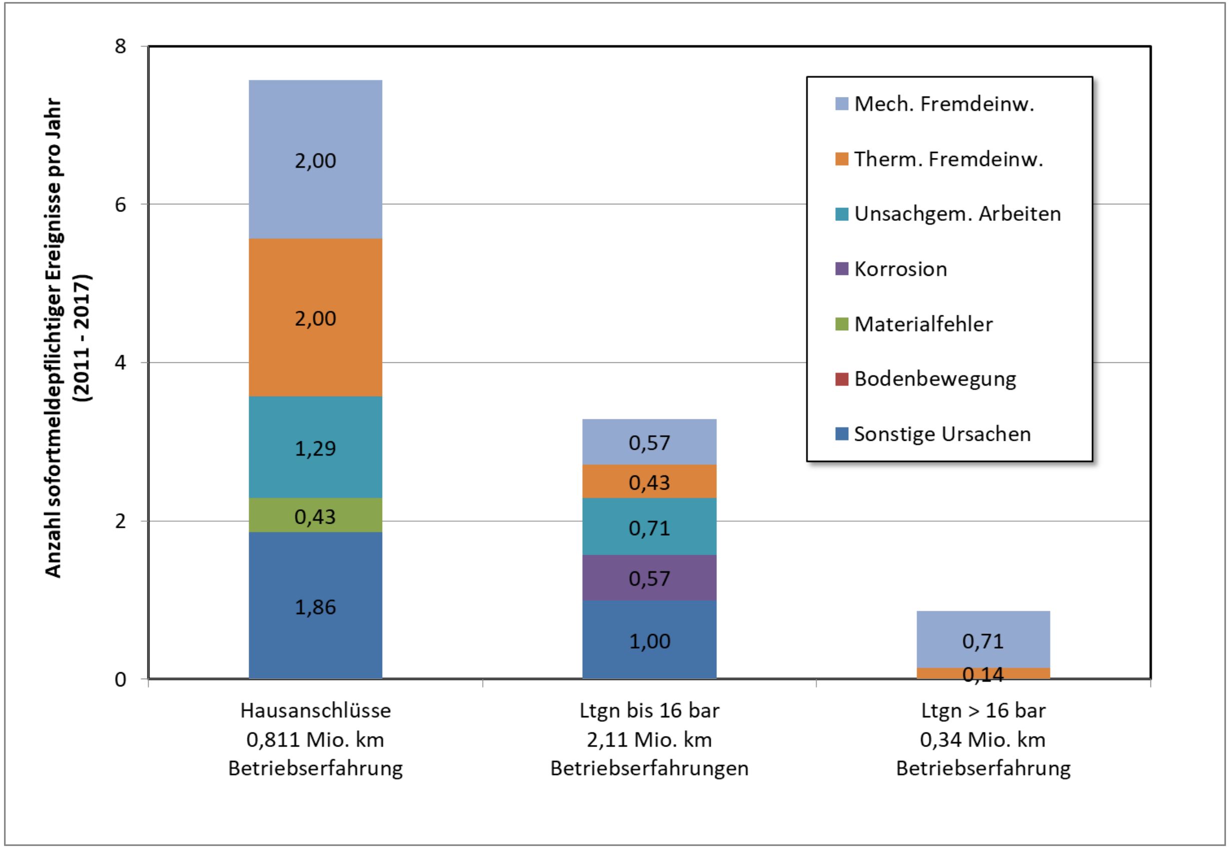
Verlauf der sofortmeldepflichtigen Ereignisse an allen Leitungen (1981-2017)



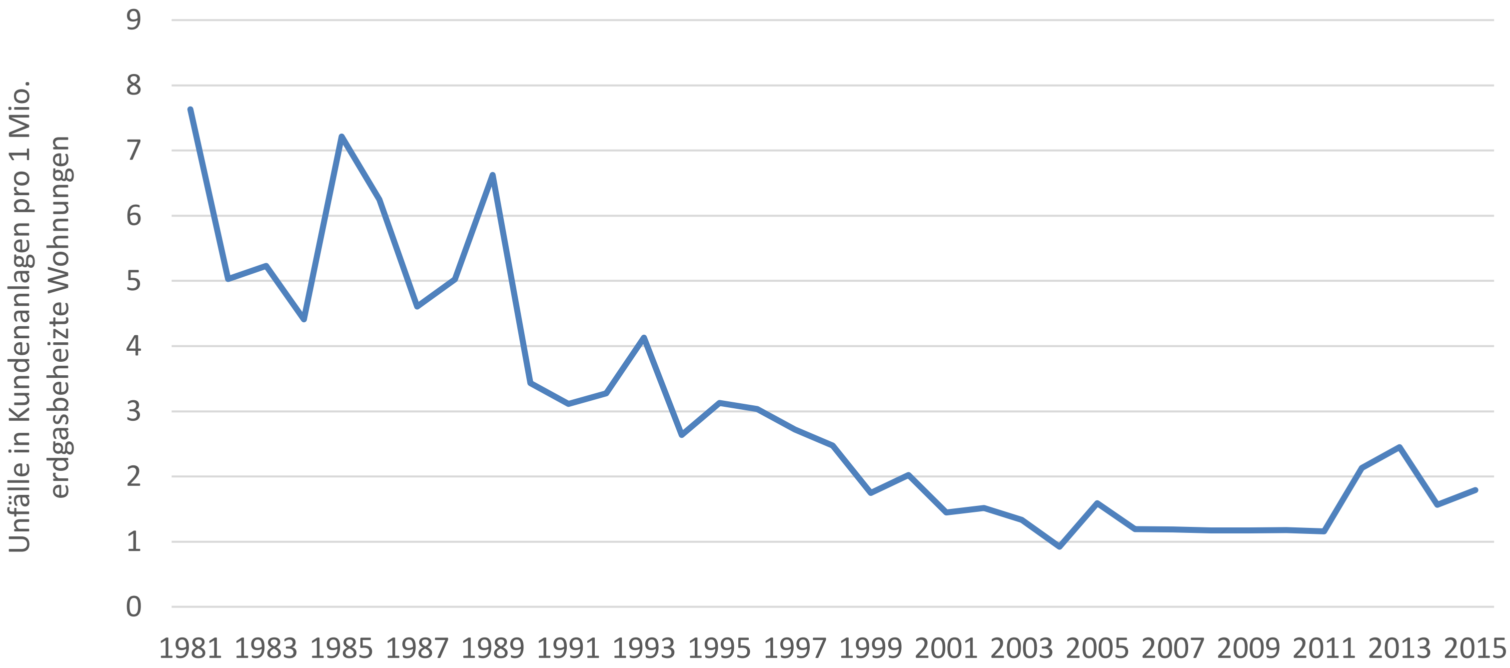
Verteilung aller sofortmeldepflichtigen Ereignisse an HA, VNB und FNB (Mittelwert pro Jahr über Berichtszeitraum)



Verteilung aller sofortmeldepflichtigen Ereignisse an Hausanschlüssen und Leitungen



Verhältnis der Unfälle in Kundenanlagen bezogen auf eine Million erdgasbeheizte Wohnungen



Verwendete Odorierungsmittel in Deutschland in Prozent