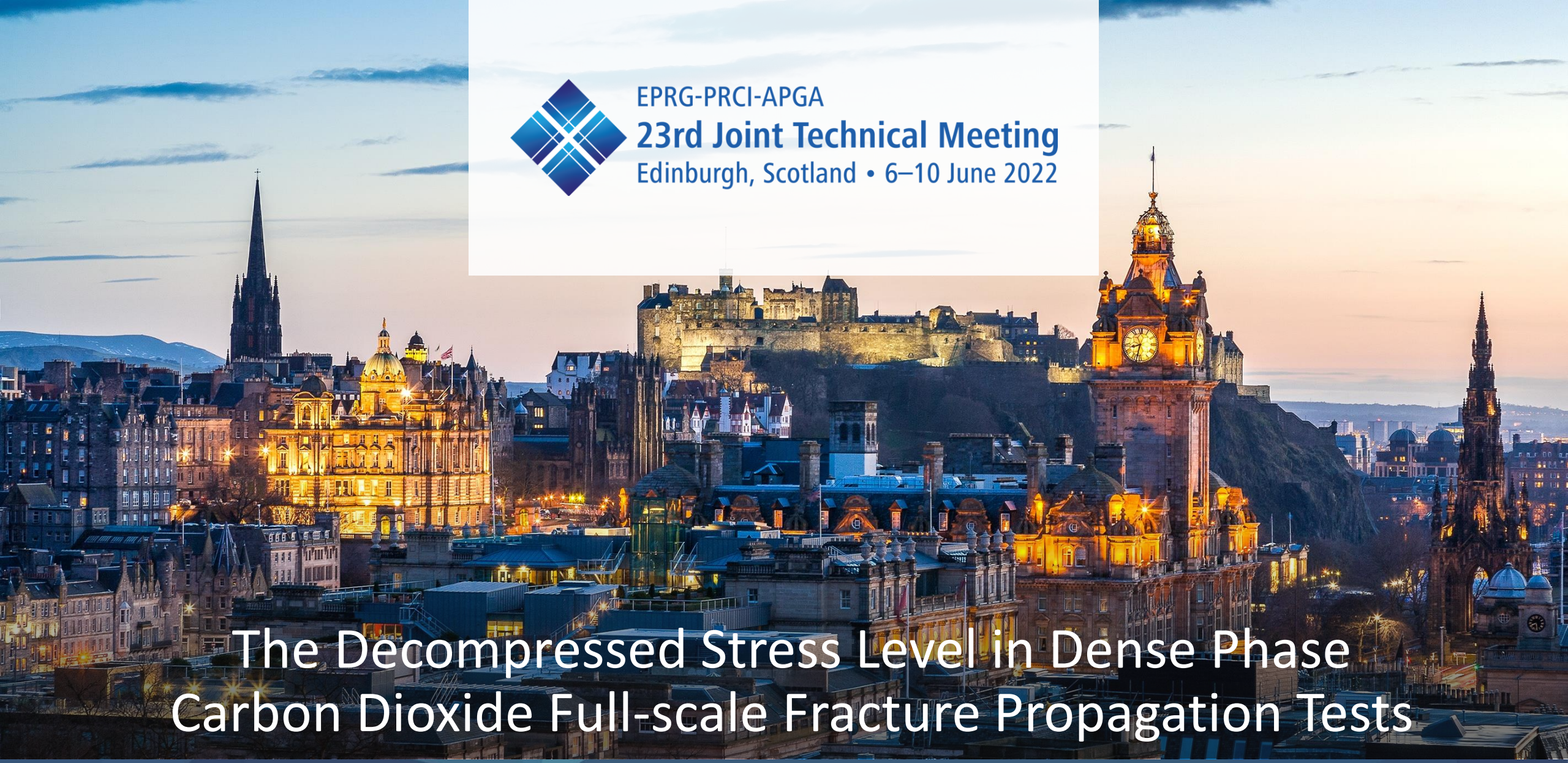

EPRG-PRCI-APGA
23rd Joint Technical Meeting
Edinburgh, Scotland • 6–10 June 2022

The Decompressed Stress Level in Dense Phase Carbon Dioxide Full-scale Fracture Propagation Tests

Cosham, Michal, Østby and Barnett

Acknowledgements

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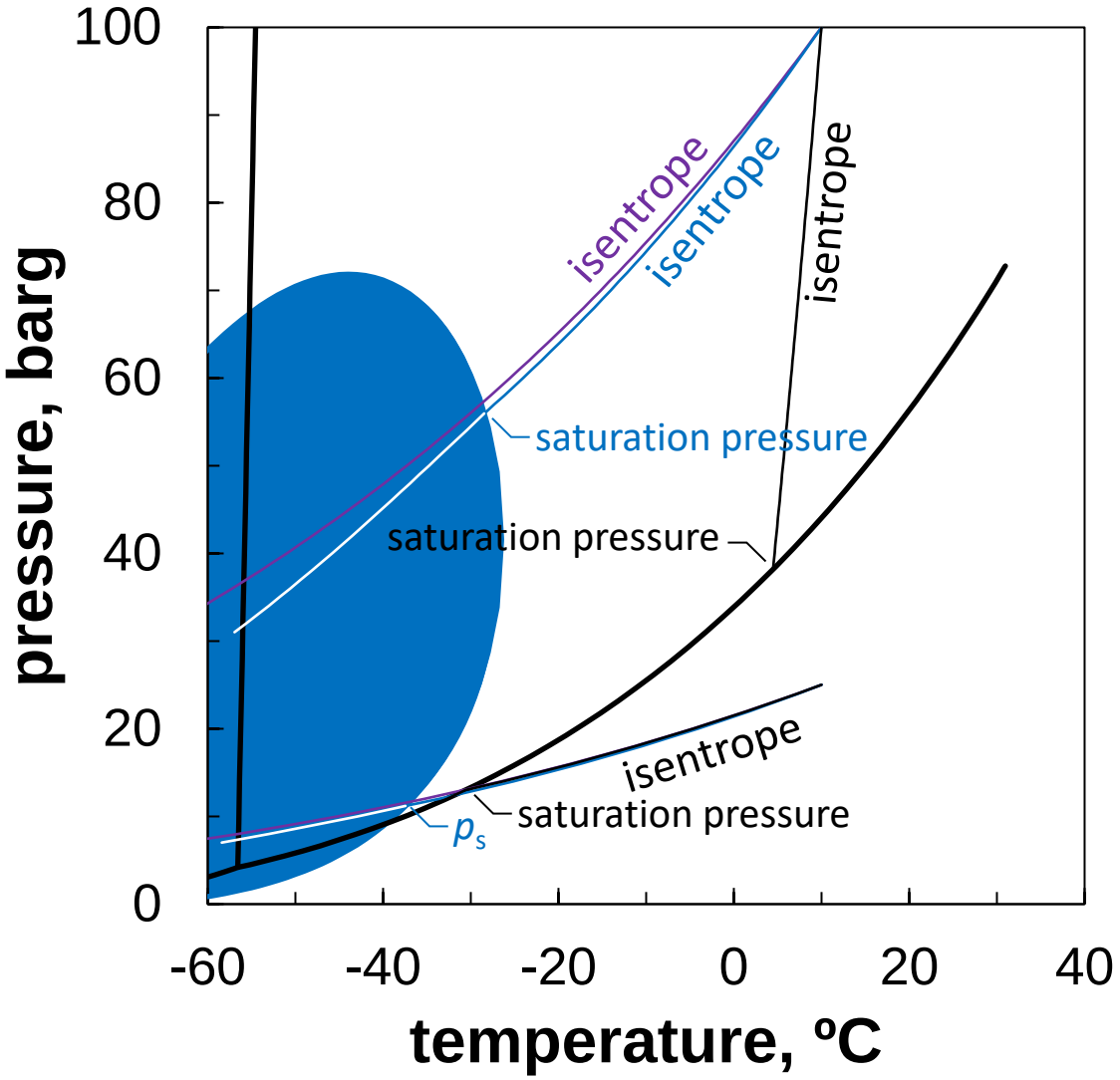
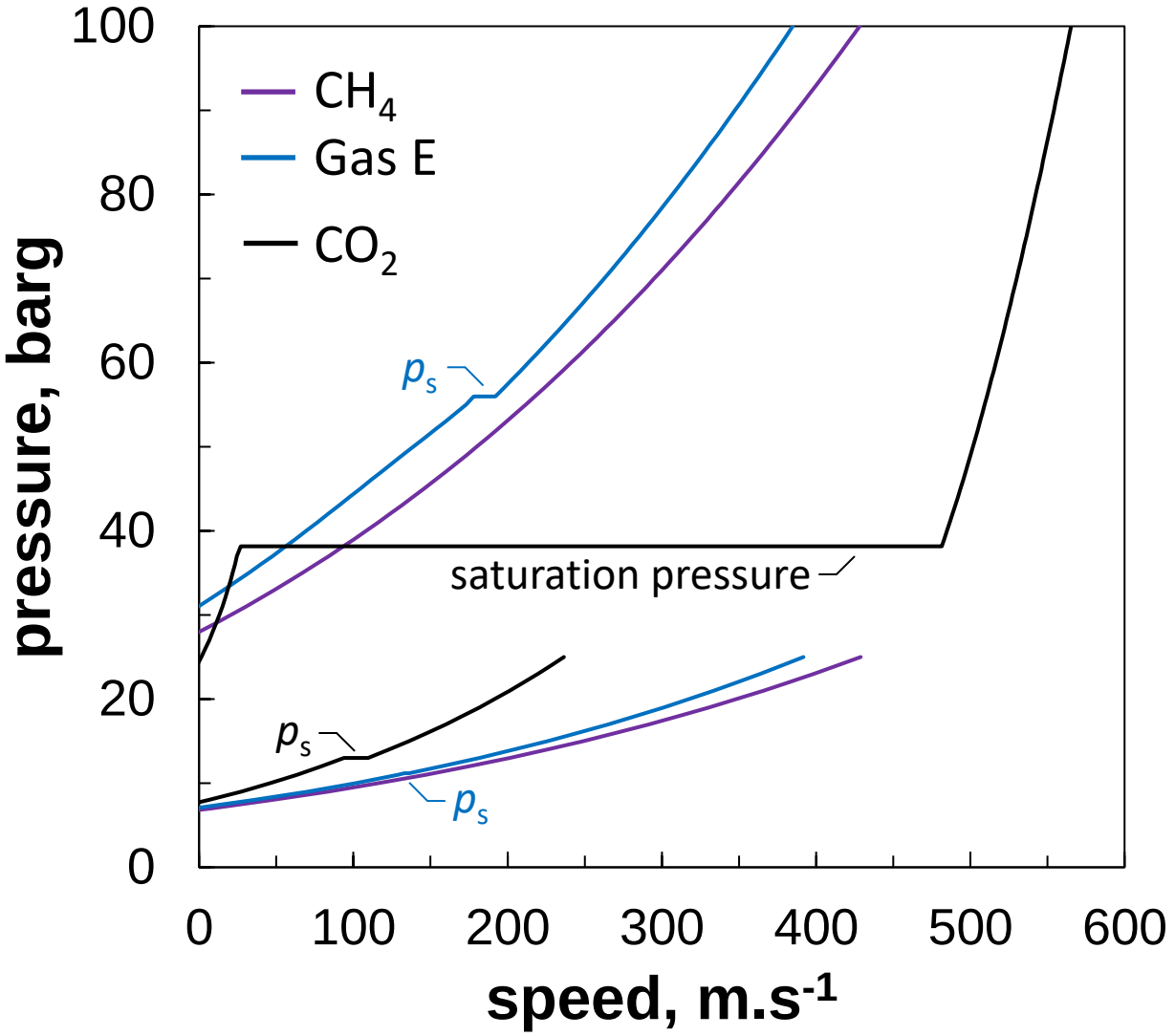
Introduction

- The decompression behaviour of CO_2 and the Two Curve Model
- The decompressed stress level (the estimated pressure at the crack tip)
- Figure J.12 *Determination of the Arrest Stress Level* [Maxey, 1974]
- Figure 5-3 *Scheme for evaluation of running ductile fracture arrest in dense CO2 pipelines*, Table 5-5 *Limitations of the assessment model* [DNV-RP-F104]
- Full-scale fracture propagation tests, CO_2
- The effective crack length
- A Pragmatic Approach?

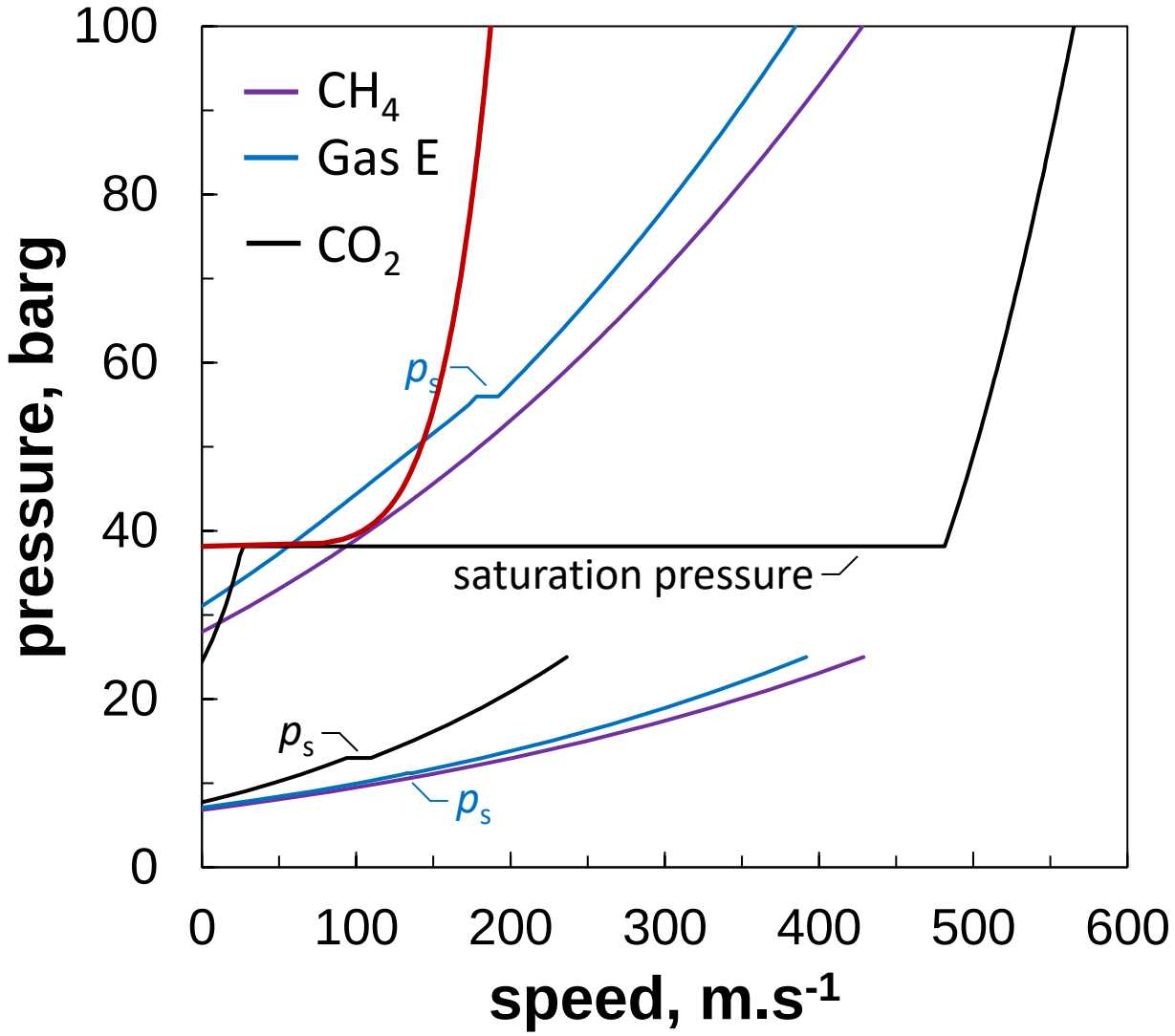
The decompression behaviour of CO_2, etc.



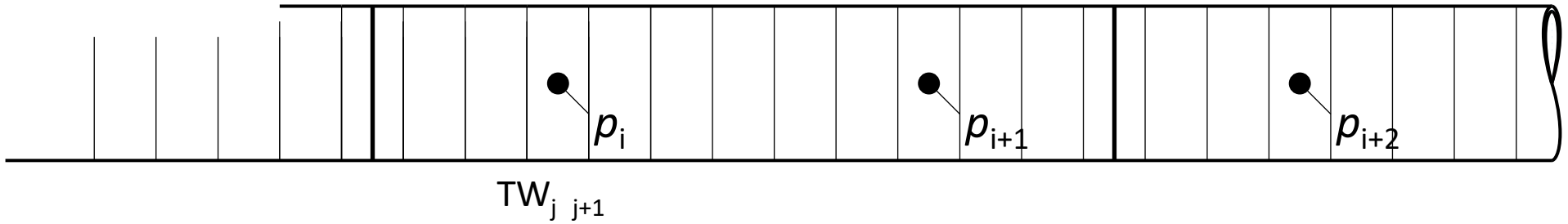


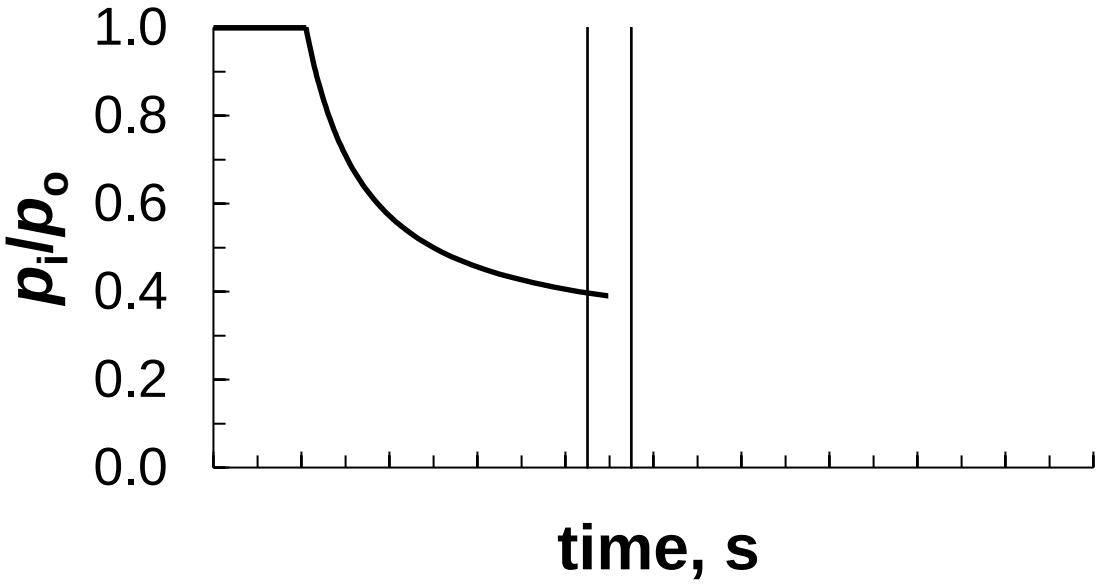
The Two Curve Model

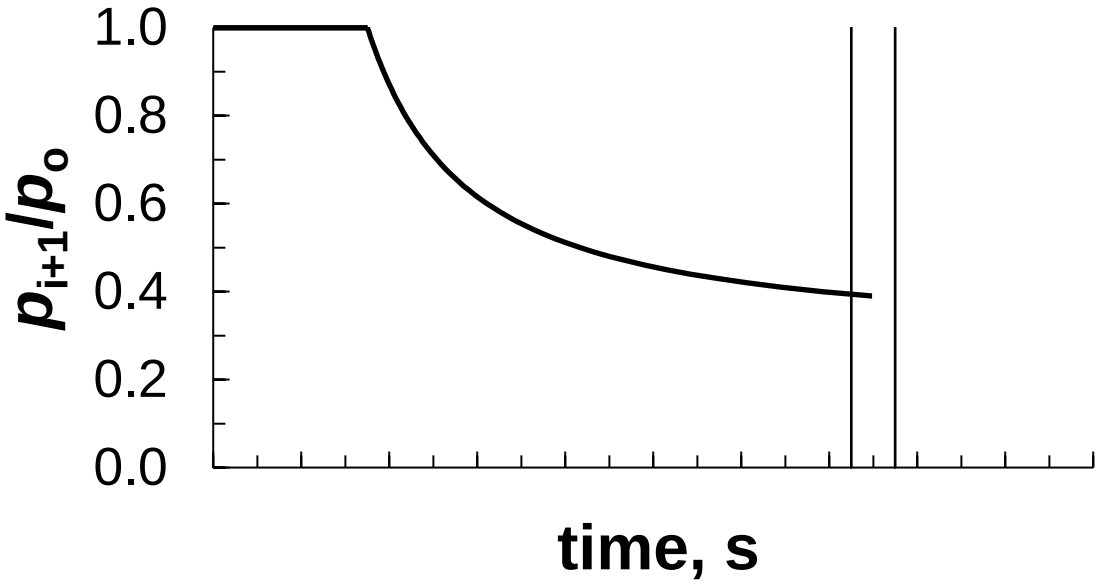
$p_a = p_s$



The decompressed stress level



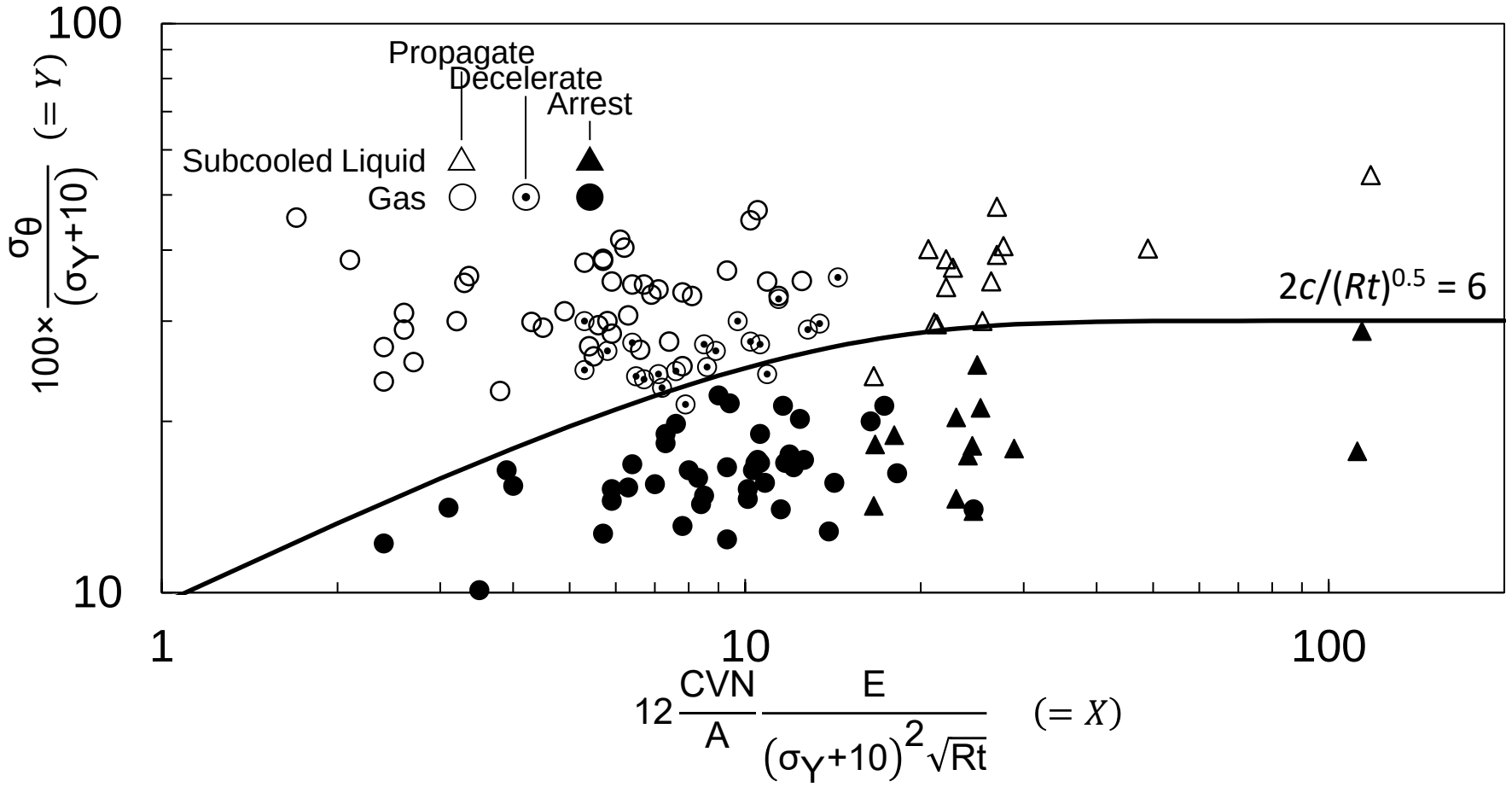




DNV-RP-F104 Design and operation of carbon dioxide pipelines

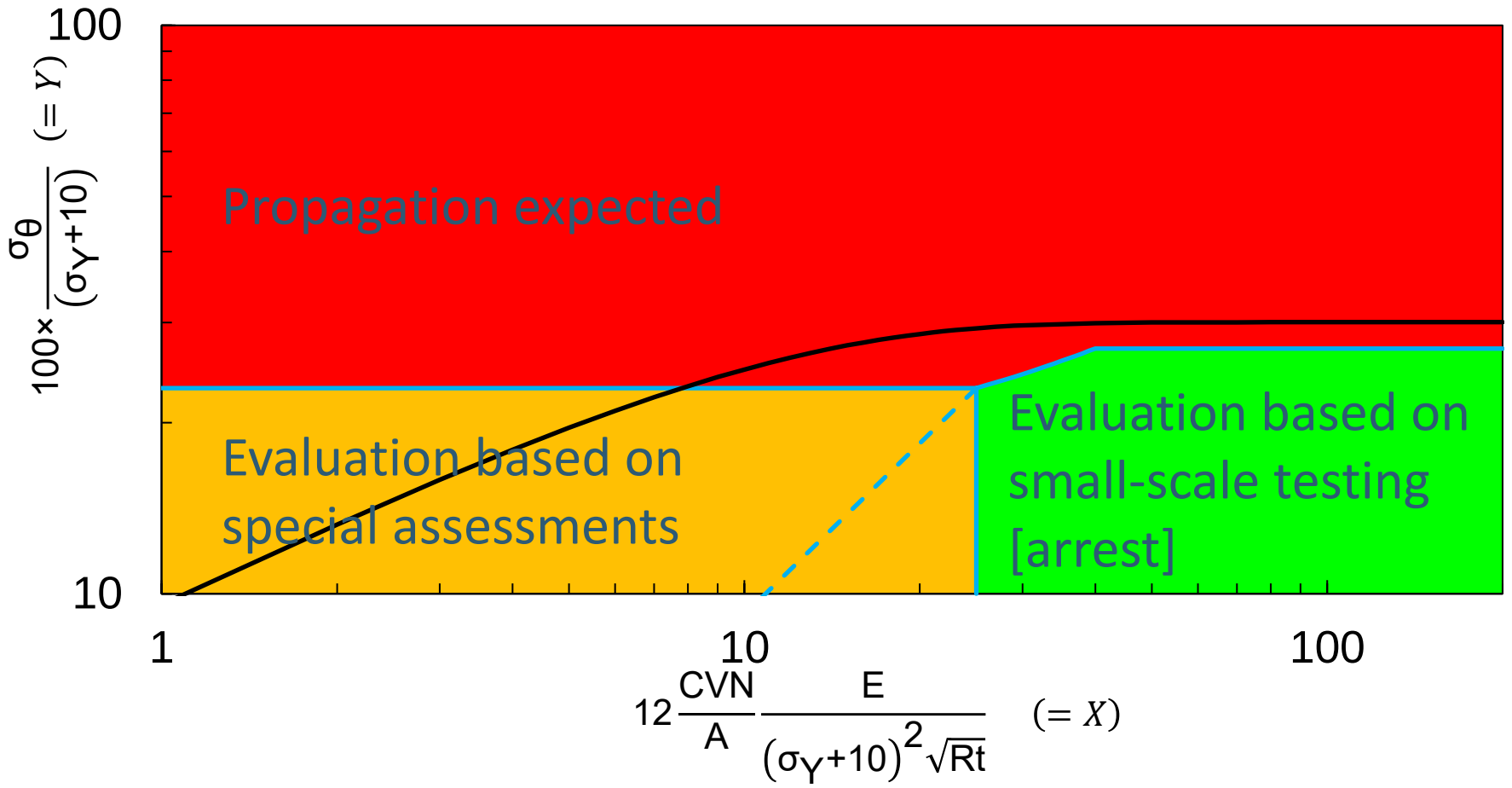
- 5.6.5 Procedure for evaluating ductile fracture propagation control
- Figure 5-3 *Scheme for evaluation of running ductile fracture arrest in dense CO2 pipelines*
- Table 5-3 *Characteristic values of input parameters*
- Table 5-4 *Evaluation of assessment results*
- Table 5-5 *Limitations of the assessment model*

Figure J.12 *Determination of the Arrest Stress Level*



Maxey, W.A., 1974. Fracture initiation, propagation and arrest. Paper J. In *Fifth Symposium on Line Pipe Research*. Houston, Texas, USA, 20-22 November 1974. Catalogue No. L30174. Chantilly, Virginia, USA: Pipeline Research Council International.

Figure 5-3 *Scheme for evaluation of running ductile fracture …*



DNV, 2021. Recommended Practice DNV-RP-F104 September 2021 Design and operation of carbon dioxide pipelines. Høvik, Norway: DNV GL.
Michal, G., Østsby, E., Davis, B.J., Rønеid, S. and Lu, C., 2020. An empirical fracture control model for dense-phase CO2 carrying pipelines. Paper No. IPC2020-9421. In *Proceedings of the 2020 13th International Pipeline Conference*. IPC2020. Calgary, Alberta, Canada, 28-30 September 2020. New York, NY, USA: American Society of Mechanical Engineers.

Table 5-5 *Limitations of the assessment model*

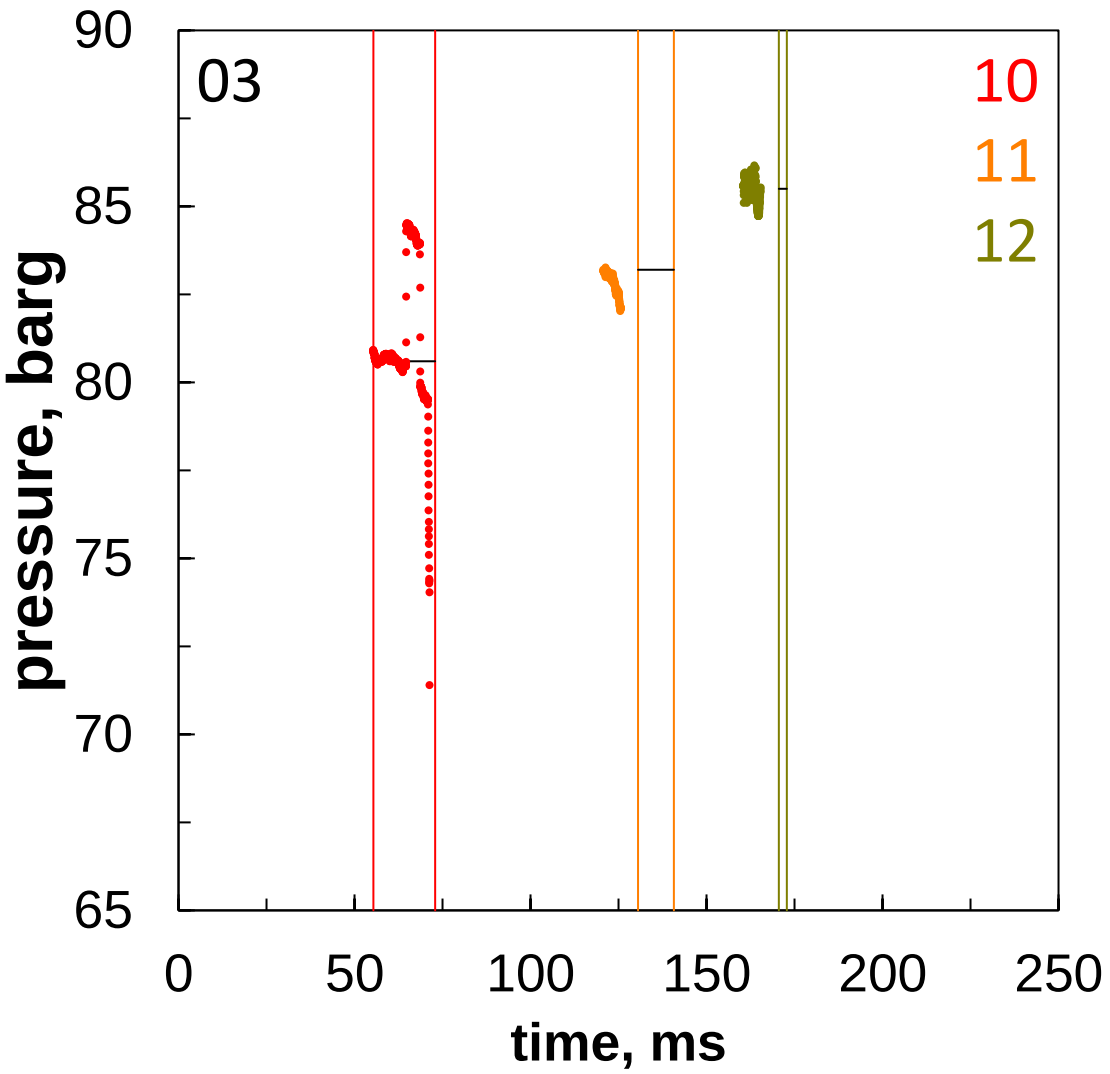
Limitation	Comment
Characteristic CVN energy: 250 J or above	Crack arrest … only been observed in … pipes with CVN energy of approximately 300 J or higher. …
Pipeline outer diameter, D: 16" to 36"	… the range considered in large-scale test[s]
Pipeline wall thickness, t: 10 mm to 26 mm	… the … range considered in large-scale test[s] … some extrapolation to smaller wall thicknesses.
Pipes grades: X60 to X65	… the primary grades used in large-scale testing.
C-Mn submerged arc-welded TMCP pipes	… HFW pipes … not considered … due to the possibility of the pipes having high Y/T ratios … The differences in alloying philosophy and microstructure for QT or seamless pipes … applicability … uncertain …
Pipeline content: fluids containing overwhelmingly CO_2	
Backfill conditions: no specific restrictions	… few results … point to backfill having an effect on the crack velocity, but potentially less on … arrest.

Full-Scale Fracture Propagation Tests, CO_2

CO2PIPETRANS 1	406.4x6.2-12.7 mm	Grades X60 (L415) & X65 (L450), HFI & SMLS
CO2PIPETRANS 2	406.4x6.2-12.7 mm	Grades X60 (L415) & X65 (L450), HFI & SMLS
COOLTRANS Test 01	914.0x25.4 mm	Grade L450, SAWL
COOLTRANS Test 02	914.0x25.4 mm	Grade L450, SAWL
COOLTRANS Test 03	610.0x19.1 mm	Grade L450, SAWL
SARCO2B 1	610.0x12.7-13.7 mm	Grade L450, HFI & SAWL
SARCO2B 2	610.0x12.5-13.7 mm	Grade L450, HFI & SAWL
CO2SafeArrest 1	610.0x13.5-15.0 mm	Grade L450, SAWL
CO2SafeArrest 2	610.0x14.5 mm	Grade L450, SAWL

nine (9) … ?!

The estimated pressure at the crack tip, e.g. COOLTRANS Test 01

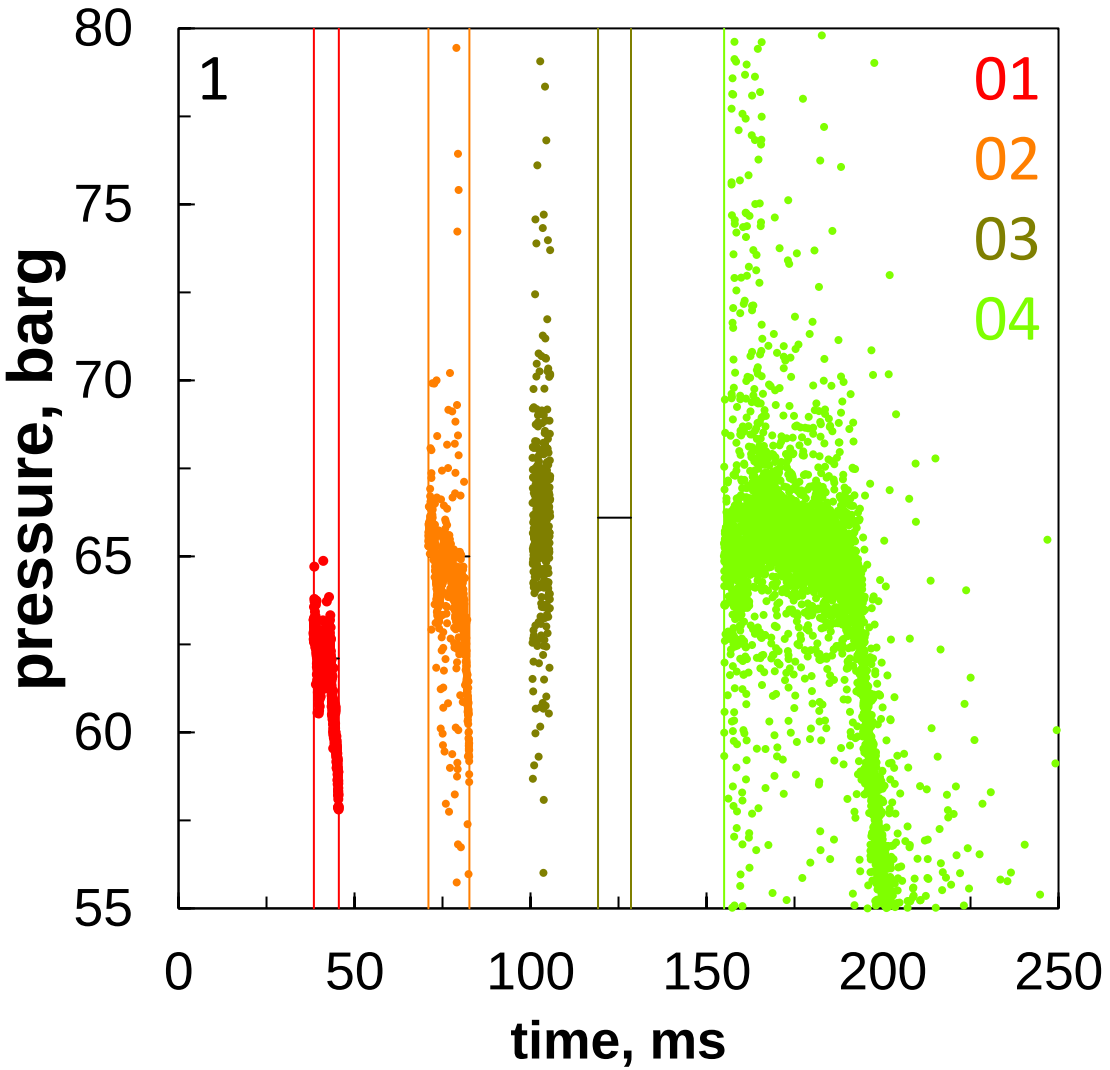


10 [the mean of the data between the leading timing wire broke and the time halfway between the times when the leading and trailing timing wires broke]

11 [the mean of the last 5 ms of data, before a significant decrease in pressure]

12 [the mean of the last 5 ms of data]

The estimated pressure at the crack tip, e.g. CO2SafeArrest 1



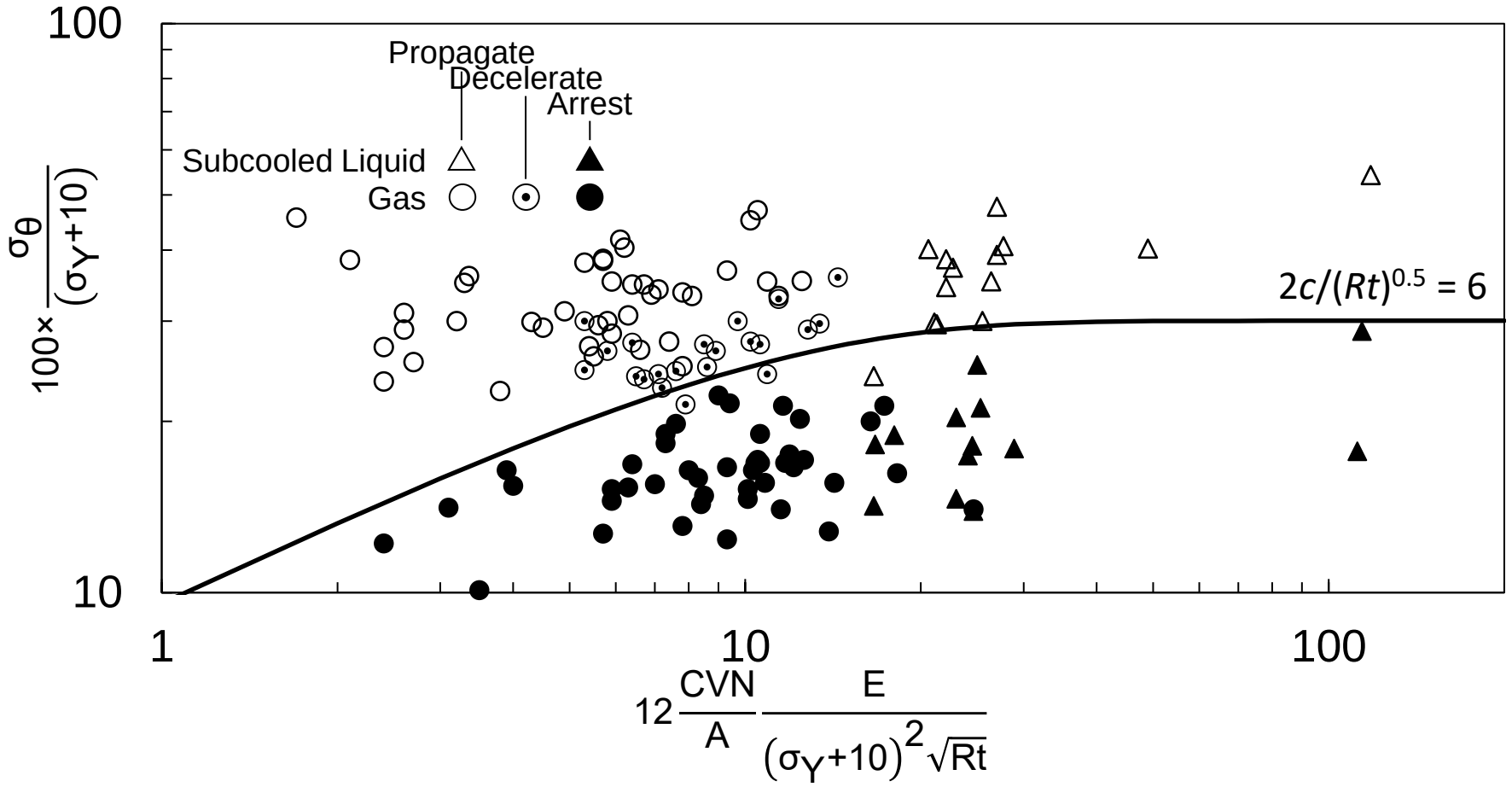
01 [the mean of the data between the leading timing wire broke and the time halfway between the times when the leading and trailing timing wires broke]

02 [as above]

03 [the mean of the last 5 ms of data]

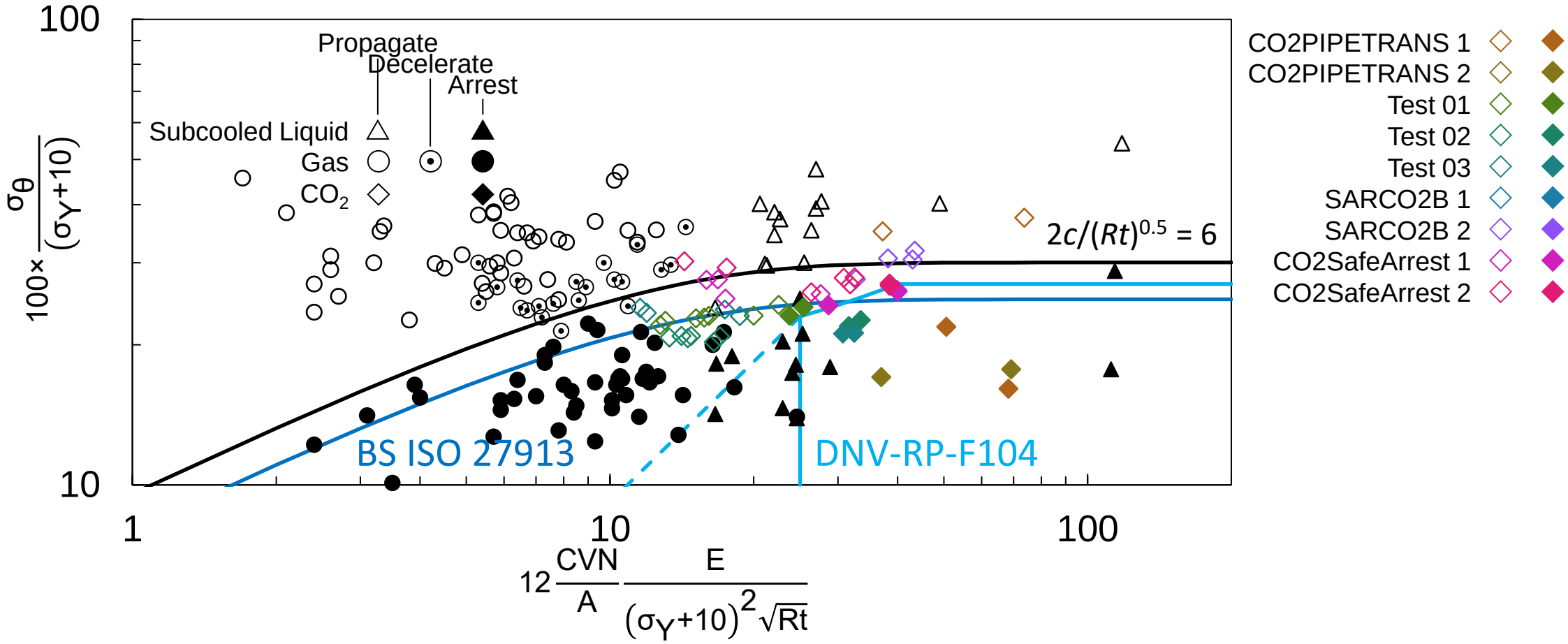
04 [the mean of the 5ms of data after the leading timing wire broke]

Figure J.12 *Determination of the Arrest Stress Level*

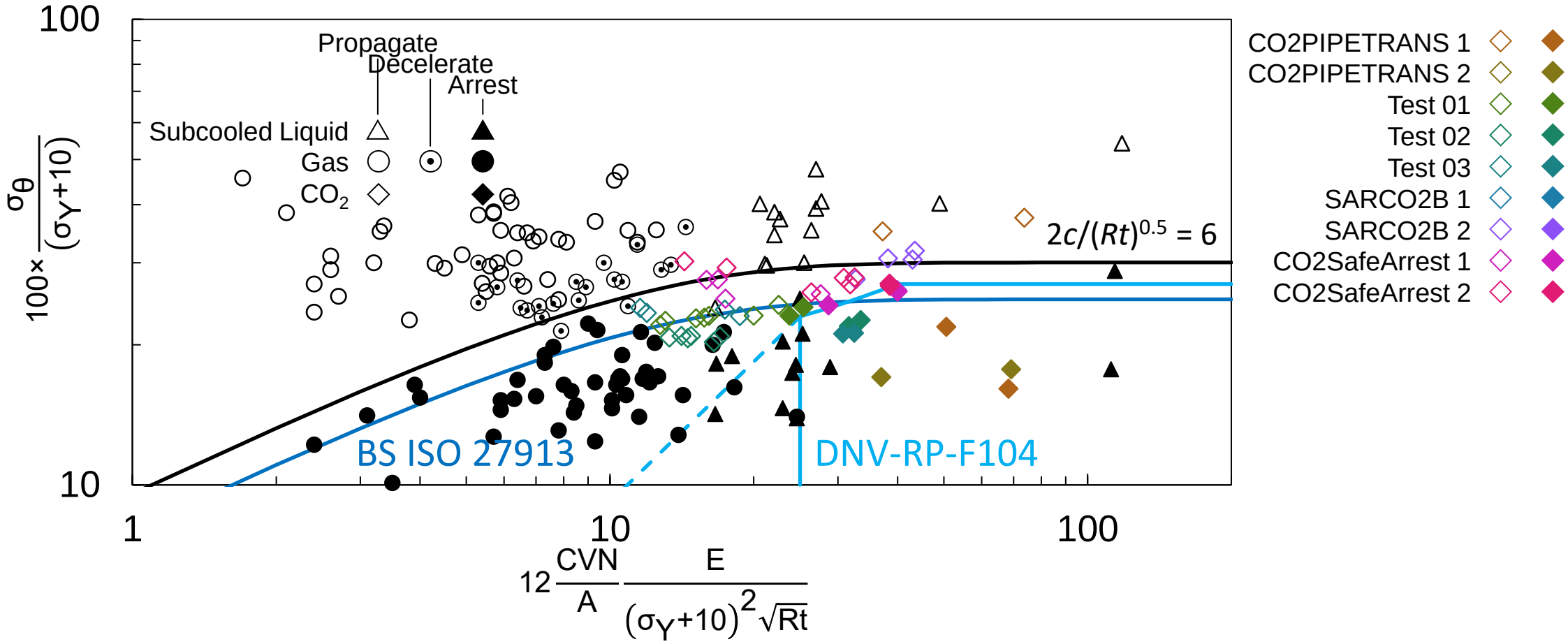


Maxey, W.A., 1974. Fracture initiation, propagation and arrest. Paper J. In *Fifth Symposium on Line Pipe Research*. Houston, Texas, USA, 20-22 November 1974. Catalogue No. L30174. Chantilly, Virginia, USA: Pipeline Research Council International.

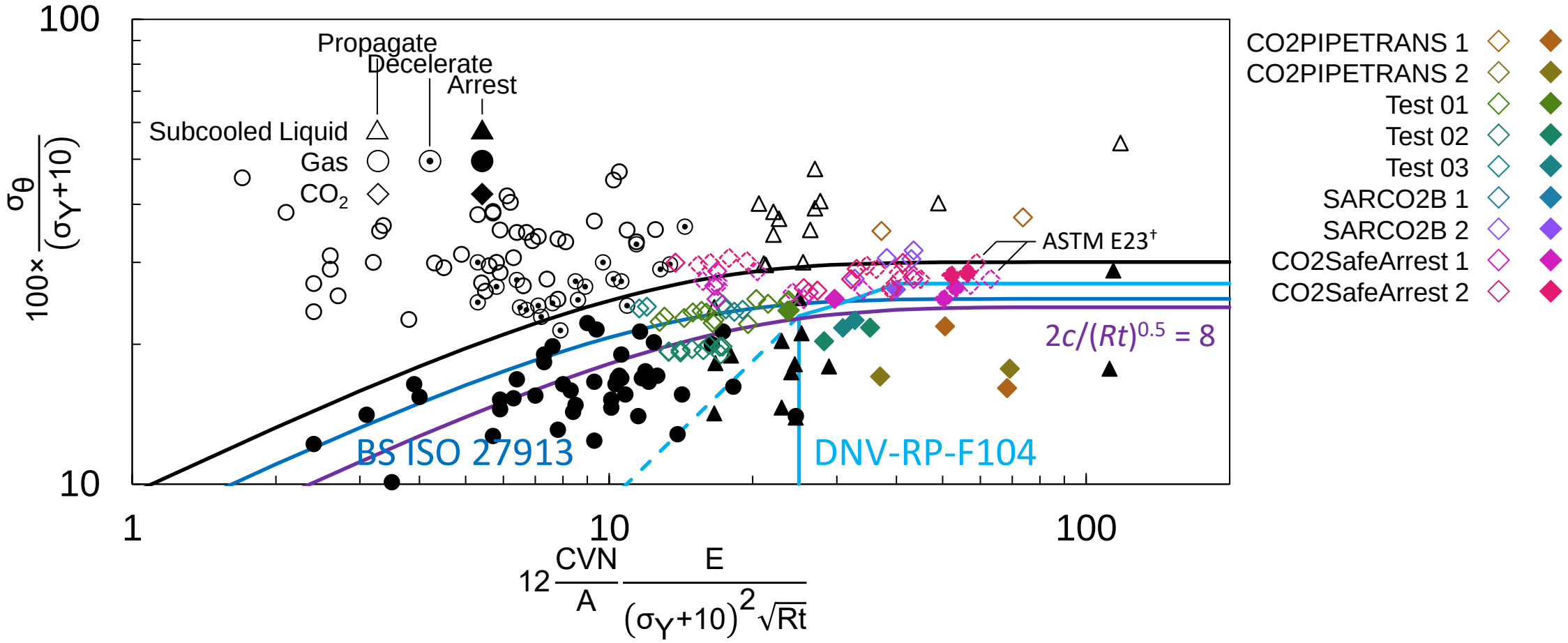
A plot of the decompressed stress level, cf. Michal et al. 2020



A plot of the decompressed stress level, cf. Michal et al. 2020

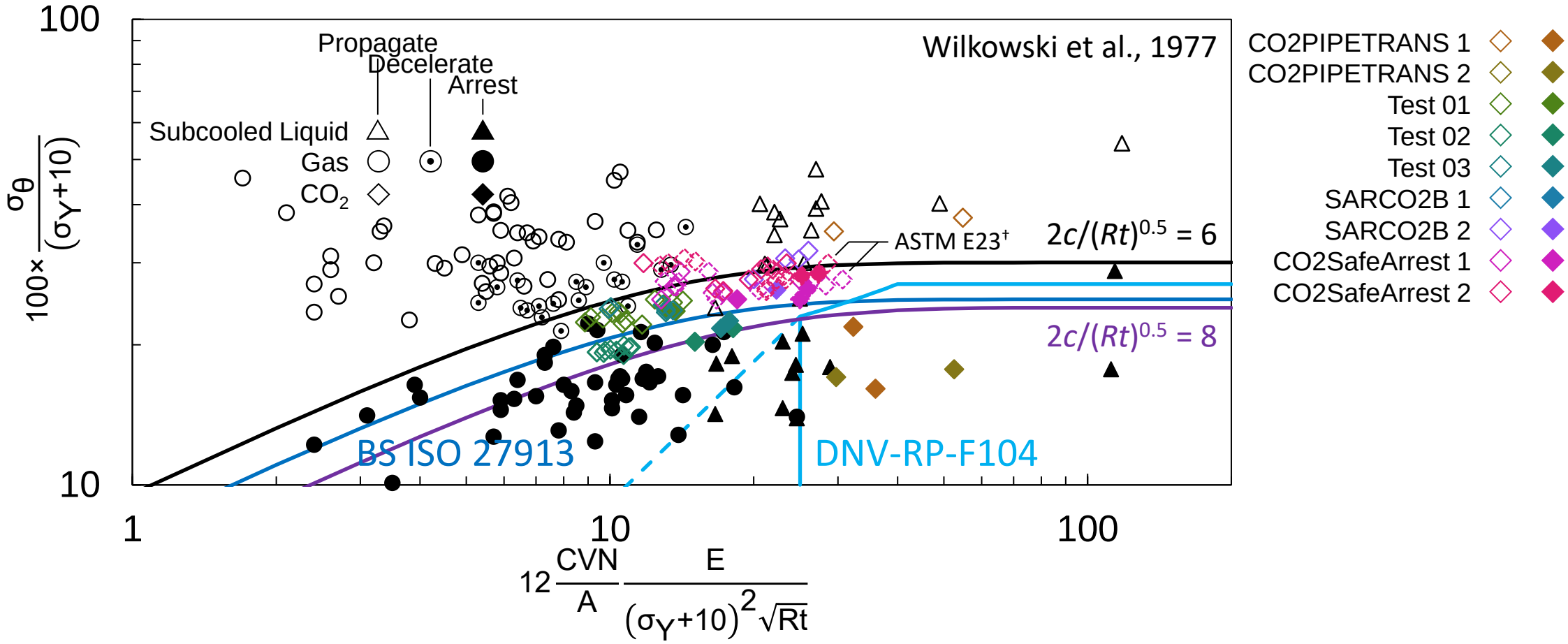


A re-plot of the decompressed stress level



†ASTM E23 specifies a striker with a radius of 8 mm. BS EN ISO 148-1 specifies 2 or 8 mm. BS EN ISO 3183 specifies 2 mm.

… with a correction factor



†ASTM E23 specifies a striker with a radius of 8 mm. BS EN ISO 148-1 specifies 2 or 8 mm. BS EN ISO 3183 specifies 2 mm.

A Pragmatic Approach?

1. Figure 5-3 of DNV-RP-F104 within the limits defined in Table 5-5; and
2. A modified form of the Two Curve Model, with an effective length equal to 8.0 and the correction factor due to Wilkowski et al., 1977. Table 5-5 does not apply

   The modified form of the Two Curve Model has limited experimental validation. Additional test data is required

   The modified form of the Two Curve Model should not be applied to grades that exceed Grade L450 (X65) or to diameters that exceed 914.4 mm (36"). It should also not be used if the corrected full-size equivalent Charpy V-notch impact energy is greater than 200-250 J

British Standards Institution, 2022. *BS EN ISO 7010:2020+A3:2022Graphical symbols – Safety colours and safety signs – Registered safety signs*. London, UK: British Standards Institution. [W043. Warning; Thin Ice]

Thank you for your attention.