CPPC: Development of a Simple Computer Code for H_2 and CO Combustion in Severe Accidents

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CSNI WORKSHOP ON UNCERTAINTIES IN PSA-2 ANALYSES

What is CPPC?

- Developed by Polytechnic University of Madrid for CSN.
- Stand-alone code for fast calculations on pressure rises in the containment from H_2 and CO combustion in severe accidents.
- Most recent advances in the field of H_2 and CO combustion.
- Useful tool for PSA-2 assessments.

What is CPPC?

INPUT:

- Masses of H_2 and CO.
- Initial environmental conditions in the containment, before burning.
- Simple geometric data: volume of the enclosure.

OUTPUT:

- Combustion completeness.
- Adiabatic and isochoric combustion pressure.
- Chapman-Jouguet pressure.
- Chapman-Jouguet reflected pressure.
- Effective pressure.
- Combustion regime.

Main Assumptions

- Ideal gases.
- Gases homogeneously mixed in containment.
- Steam-saturated atmosphere previous to the combustion.
- Water properties from Steam Tables.

Flammability Limits

- Correlation for upward propagation:

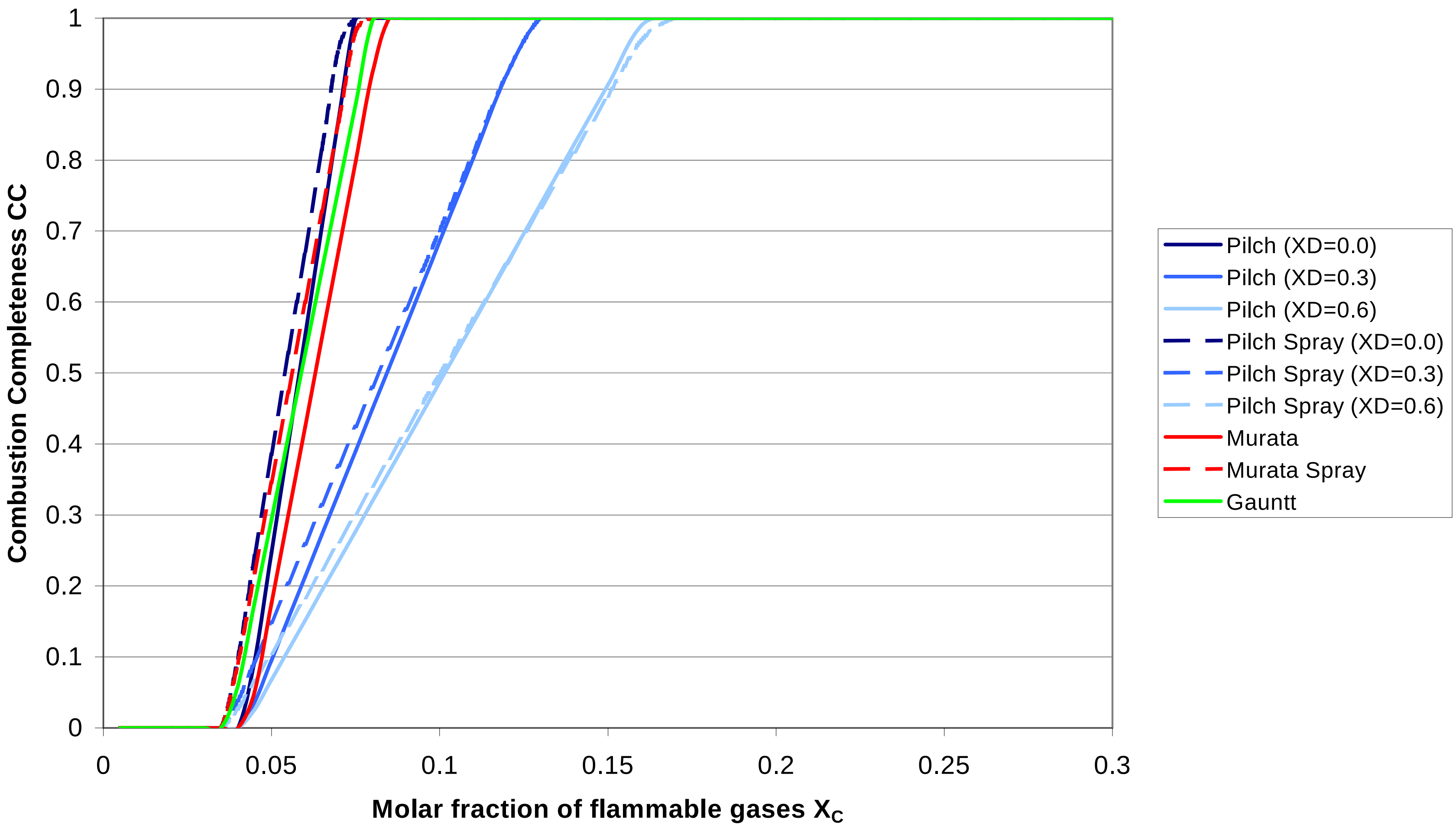
$$X_{H2O} = a_f + b_f X_{H2} + c_f \exp\left(d_f X_{H2} + b_f T_u\right)$$

- a_f, b_f, c_f, d_f fitted experimentally.

Combustion Completeness

- Pilch et al (1996).
- Murata et al (1997), taken from CONTAIN 2.0
- HECTR 1.5, taken from MELCOR 1.8.4 (Gauntt ,1997).

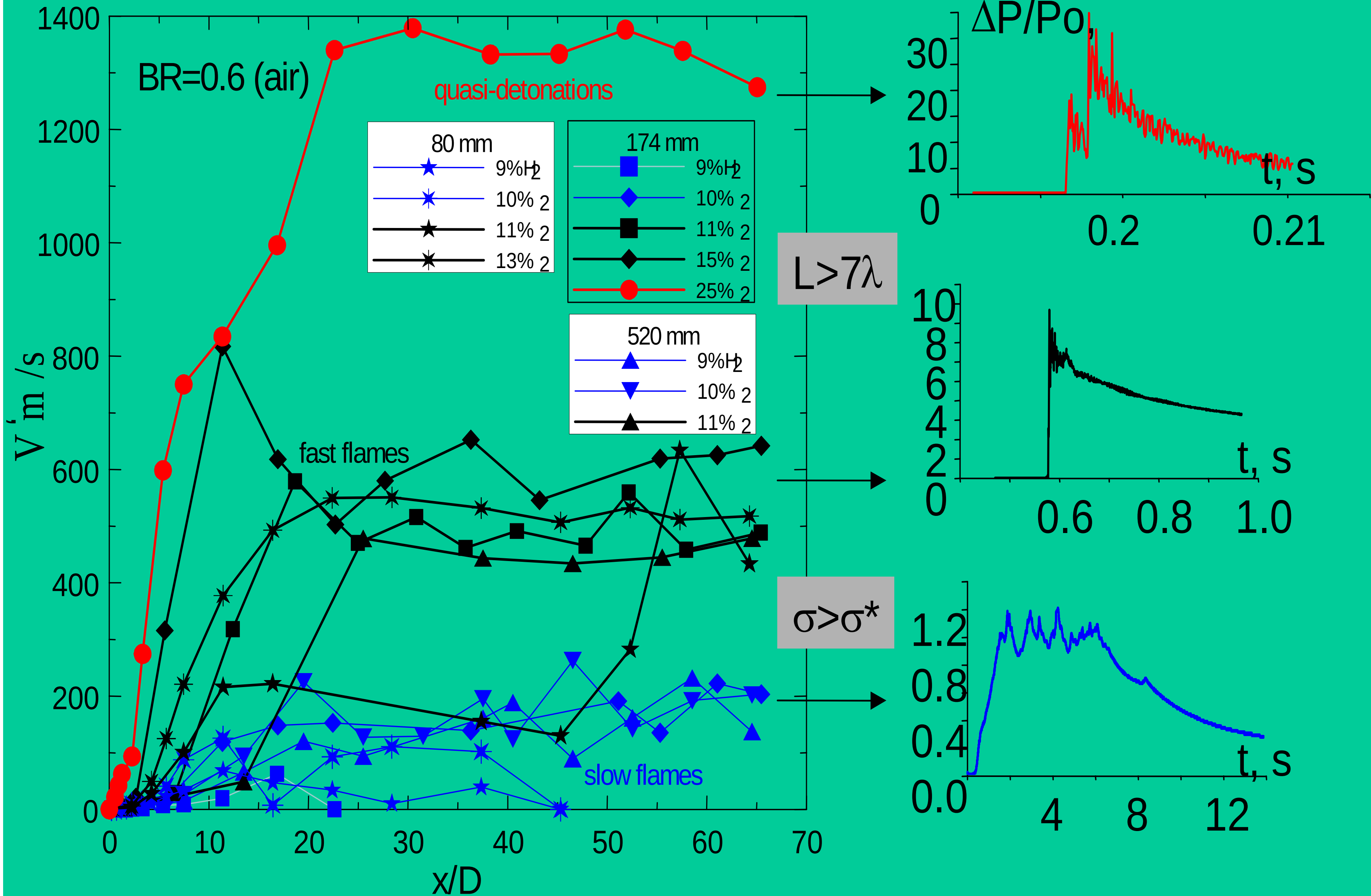
Combustion Completeness



Combustion Regimes

- Regimes considered:
  - Slow deflagrations
  - Flame Acceleration
  - DDT
  - Detonation
- For each gas mixture CPPC calculates:
  - Fulfillment of criterion for combustion regime.
  - Effective static pressure.

Combustion Regimes (Kuznetsov, 2003).



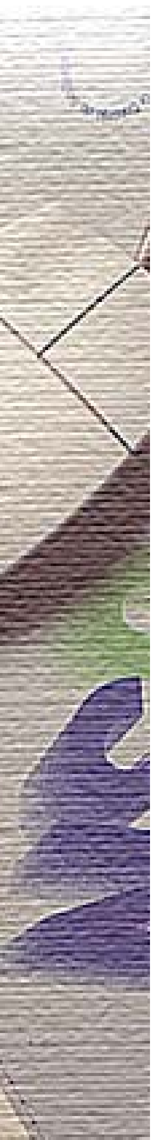
Flame Acceleration Criterion

- Selection of parameter (σ)

$$\sigma = \frac{v_b}{v_u} = \frac{\rho_u}{\rho_b}$$

- Establishing of σ critical

$$\sigma^* = a_\sigma + b_\sigma \left(\frac{E_a}{T_u} \right)^{c_\sigma}$$



Flame Acceleration Criterion

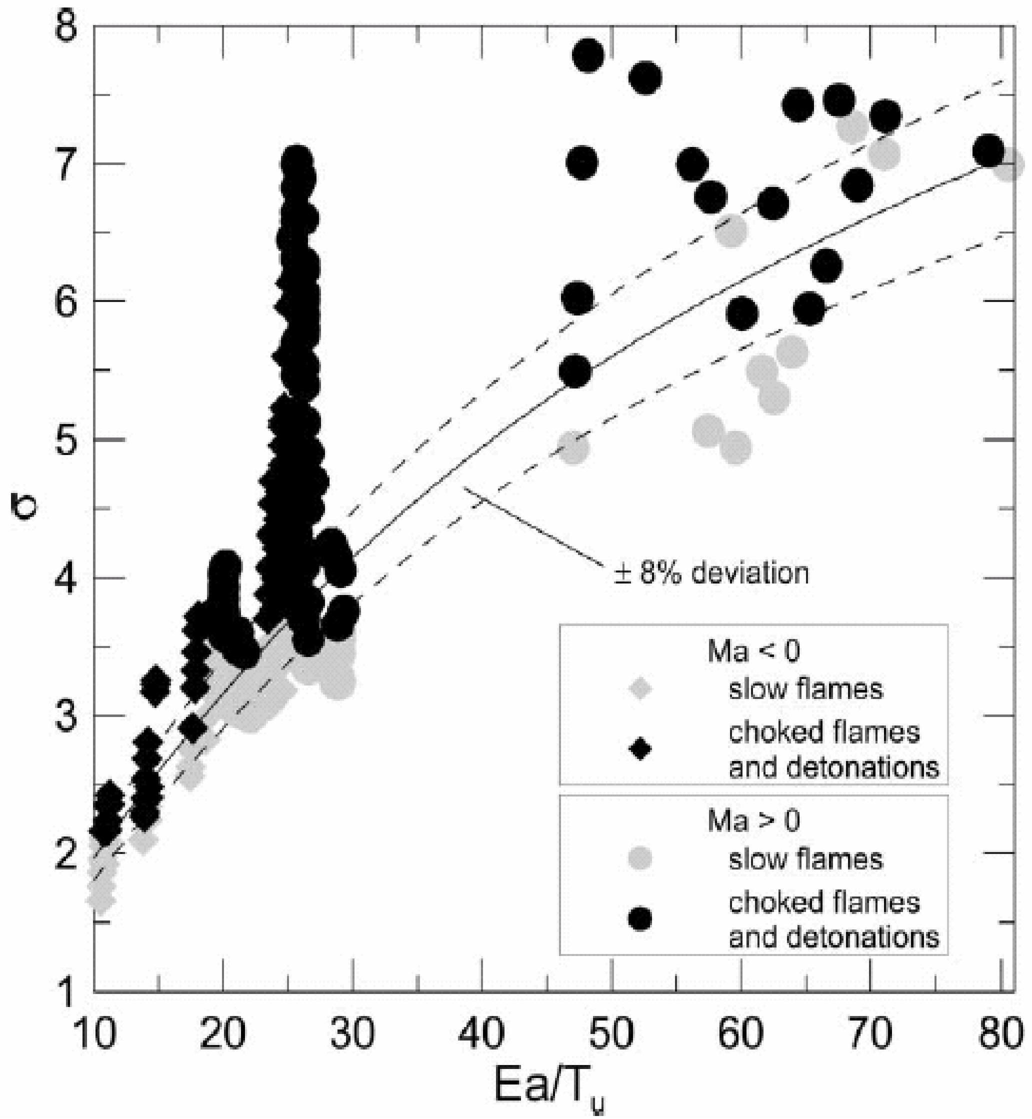
- Definition of index for FA.

$$i_{\sigma} = \frac{\sigma}{\sigma^{*}}$$

- Quantification of index for FA

$$i_{\sigma} = \frac{\sigma}{\sigma^{*}} \geq 0.92$$

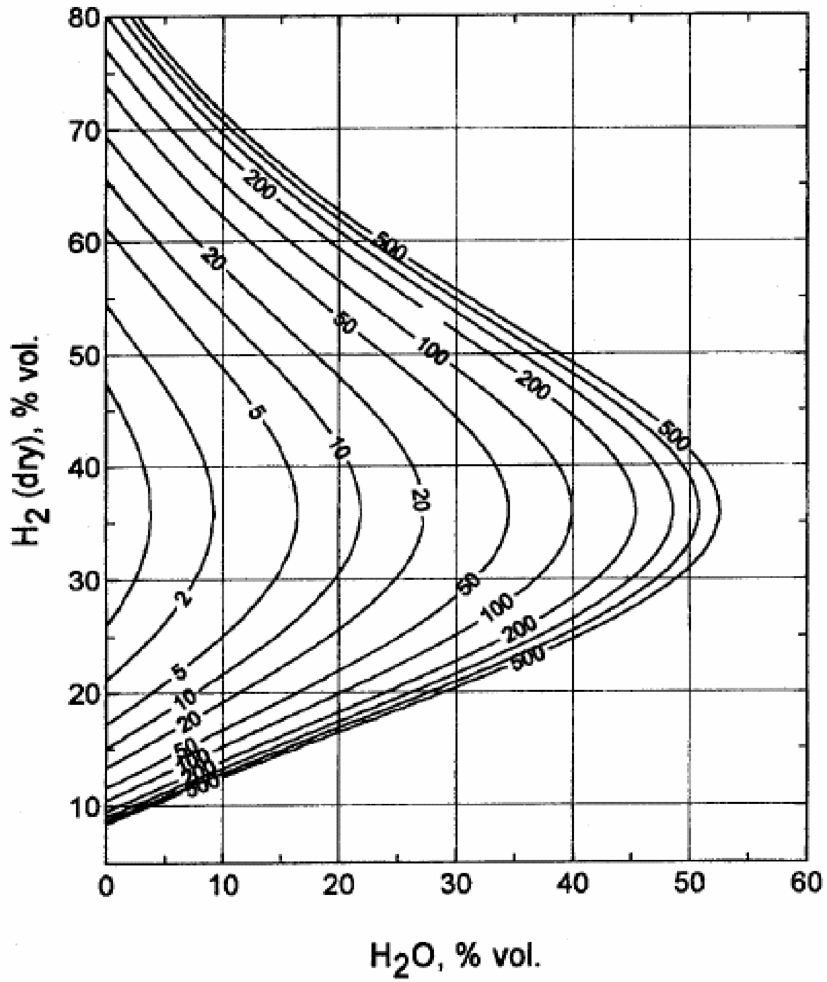
Flame Acceleration Criterion. Dorofeev (2001)



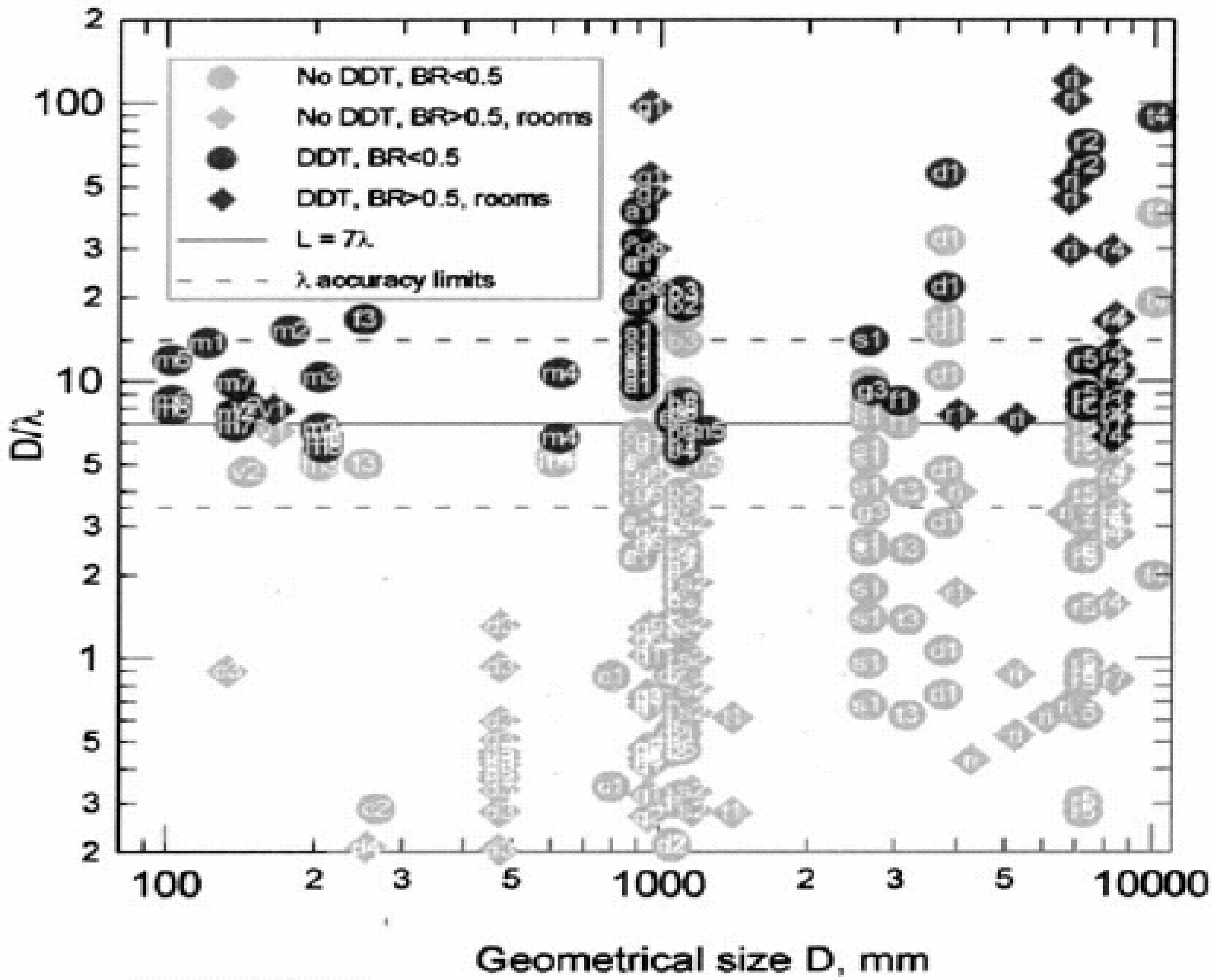
DDT Criterion

- Definition of DDT index $$i_\lambda = \frac{D}{7\lambda}$$
- D geometric value $$D = V^{1/3}$$
- λ: detonation cell size $$\log_{10}(\lambda) = f(X_{H2,dry}, X_{H2O}, T, p)$$
- Quantification of DDT index $$i_\lambda = \frac{D}{7\lambda} \geq 0.57$$

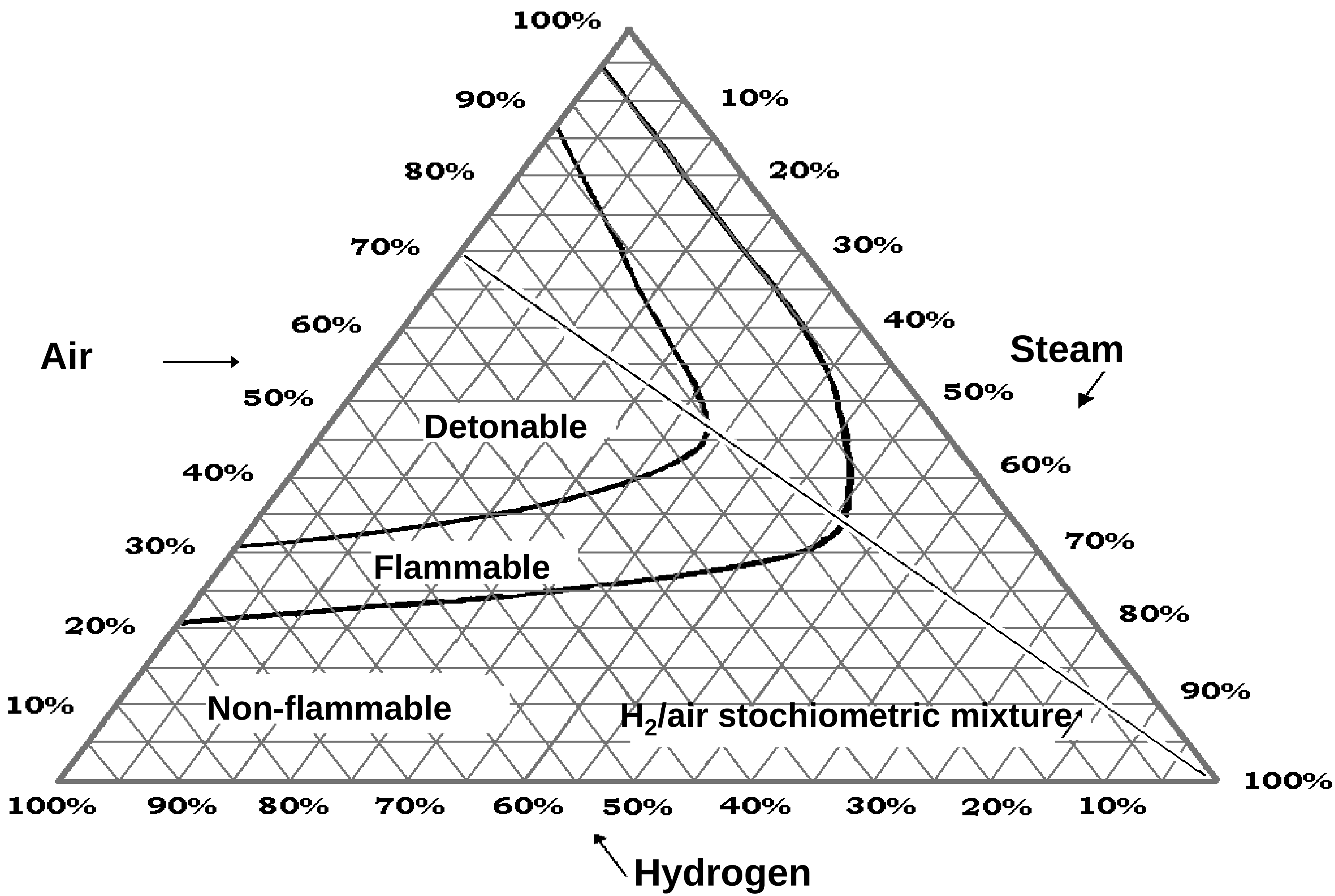
DDT Criterion (CSNI SOAR, 2000).



DDT Criterion (Breitung, 2000).



Direct Detonation Criterion



Pressure Rise Calculation: Slow Deflagrations

$$\sum_A \left(n_A c_{v,A}\right)_b T_b^{AICC} = \sum_A \left(n_A c_{v,A}\right)_u T_u + n_{H2,q} q_{H2} + n_{CO,q} q_{CO}$$

$$c_{vA} = \left(A_A + B_A T + C_A T^2 + D_A T^3\right)\frac{R}{PM_A} - R$$

$$p_b^{AICC} = p_u \left(\frac{T_b^{AICC}}{T_u}\right)\left(\frac{n_b}{n_u}\right)$$

Pressure Rise Calculation: General Case

$$y'' + (2\pi f)^2 y = \frac{p_i(t)}{m}$$

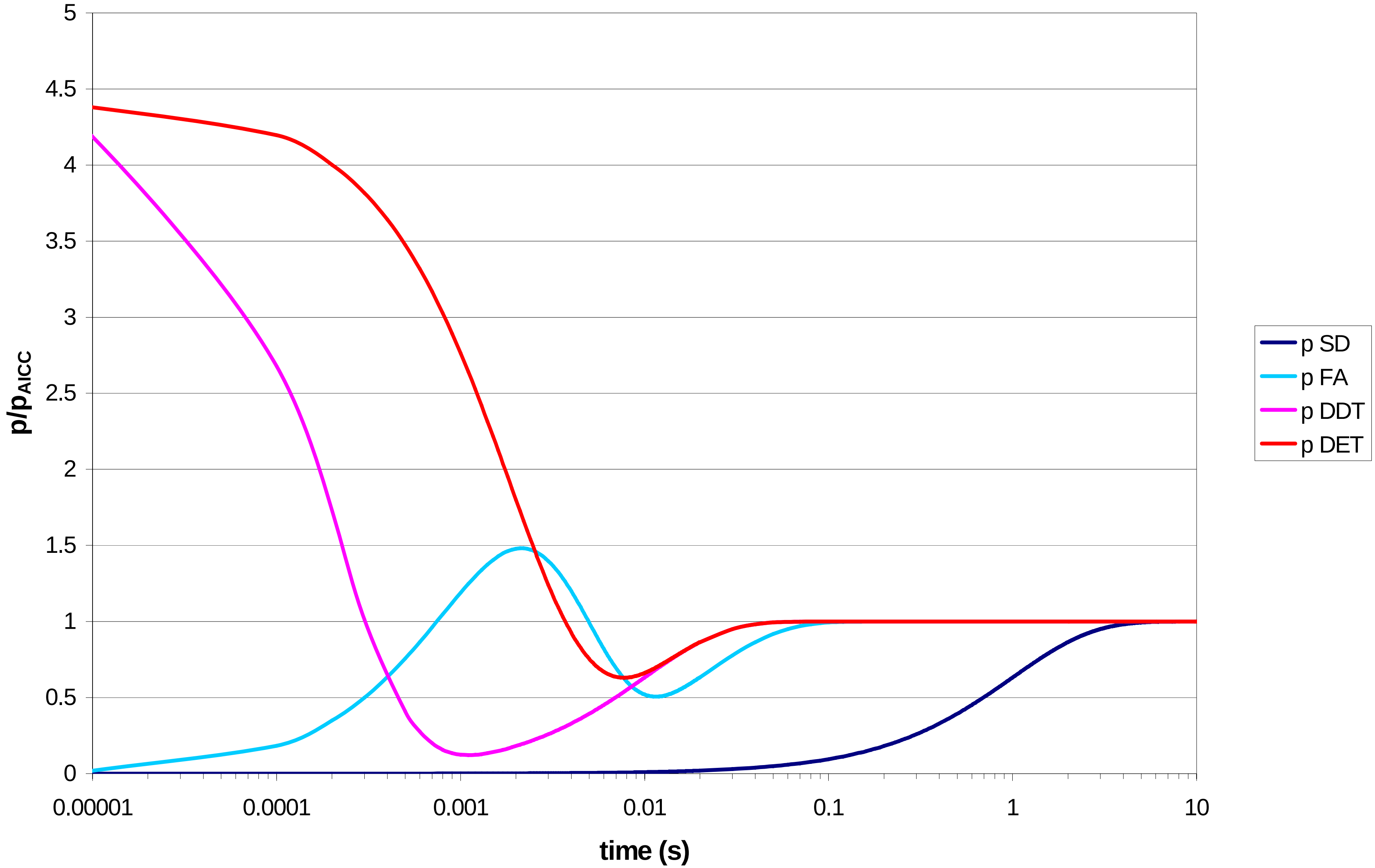
Frequency: input data. 5 to 500 Hz as indicated by Breitung and Redlinger (1995b)

Pressure Rise Calculation: General Case.

- Pi(t) obtained from typical shape of pressure loads at the different combustion regimes (Breitung and Redlinger (1995b).

- Upper bound values:
  - $P_{\mathbf{CJ}} = 1.8\ (+0.08)\ P_{AICC}$
  - $P_{\mathbf{CJ-R}} = 4.1\ (+\ 0.3)\ P_{AICC}$

Pressure Rise Calculation: General case.



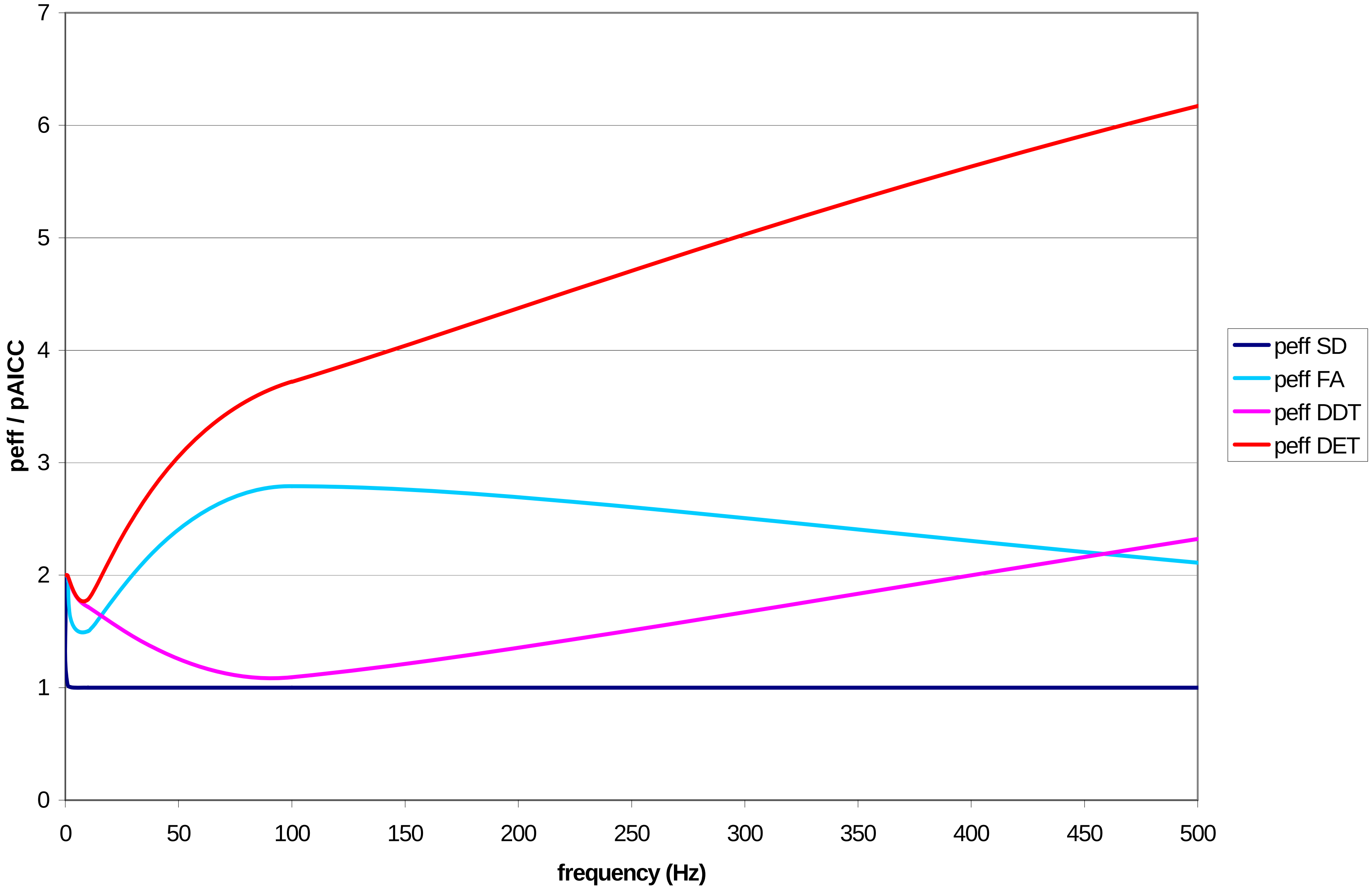
Pressure Rise Calculation: General case.

- Calculation of the effective static pressure:

$$y'' + (2\pi f)^2 y = \frac{p_i(t)}{m}$$

$$p_{eff} = (2\pi f)^2 m \, y_{\max}$$

Pressure Rise Calculation: General Case.



Validation & Verification

- Comparison with MELCOR calculations to verify that CPPC provides an upper bound.
- CPPC code uses combustion completeness = 1.
- T0: scenarios with CHR activation coincident with vessel failure.
- T1: scenarios with CHR activation coincident with the maximum of the σ parameter.
- ESF: Spray + Fan-cooling units.
- FCL: Fan-cooling units. Full capacity.
- SPR: Spray system: full capacity. Full capacity.

Validation & Verification

	MELCOR			CPPC	
Scenario	Duration (s)	H2 (CO) mass burnt (kg)	Pmax (bar)	PAICC (bar)	Regime
dryT0-ESF	70	51 (229)	1.69	4.110	SD
dryT0-FCL	58	80 (331)	1.96	4.106	SD
dryT0-SPR	31	120 (1175)	2.23	3.996	SD
wetT0-ESF	57	424 (3145)	5.11	6.483	FA
wetT0-FCL	57	424 (3149)	5.11	6.495	FA
wetT0-SPR	17	374 (1914)	4.45	5.175	SD

Validation & Verification

	MELCOR			CPPC	
Scenario	Duration (s)	H2 (CO) mass burnt (kg)	Pmax (bar)	P_{AICC} (bar)	Regime
dryT1-ESF	46	364 (2848)	4.53	5.322	FA
dryT1-FCL	58	361 (2644)	4.46	5.332	FA
dryT1-SPR	44	360 (2635)	4.46	5.378	FA
wetT1-ESF	88	420 (3138)	5.07	6.374	FA
wetT1-FCL	86	422 (3155)	5.07	6.375	FA
wetT1-SPR	89	419 (3129)	4.92	6.453	SD

Validation & Verification

- CPPC results compared with those obtained with other code for AICC calculations in case of slow deflagrations.
- Satisfactory results, differences in the pressure increase range in the 1%.

Validation & Verification.
Breitung calculations.

XH2 (% vol)	XH2O (% vol)	Tu (*) (K)	Pu (*) (bar)	P_{AICC} Breitung (bar)	P_{AICC} CPPC (bar)	Deviation (%)
15	30	362	2.26	9.953	10.03	-0.8
20	40	380	3.26	14.48	14.4	0.6
20	0	366	2.58	13.29	13.5	-1.5
15	15	335	1.62	7.487	7.95	-1.3
20	0	293	1.27	8.618	8.82	-2.3
29.5	0	293	1.44	11.87	12.77	-7.5
30	15	342	2.12	13.31	13.36	-0.3
25	30	368	2.84	14.28	14.24	0.3

Validation & Verification.
Breitung calculations.

- Relative errors lie around 1% in wet mixtures.
- Less than 10% in dry mixtures.
- Results are considered as acceptable.

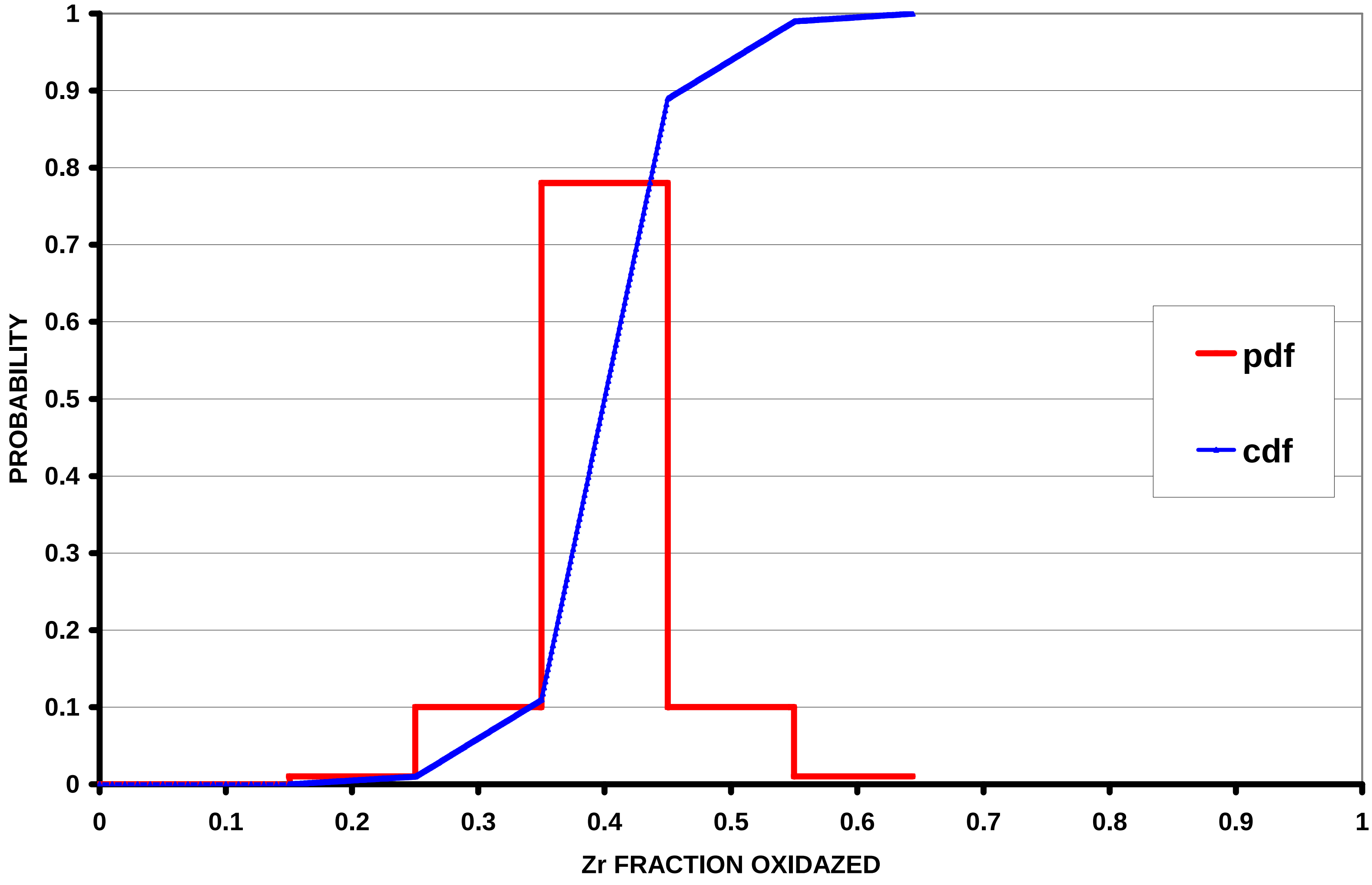
Plant Applications

CSN methodology to calculate the containment failure probability due to hydrogen combustion during the in-vessel phase

Plant Applications

- Obtain containment pressure prior to H_2 combustion. MELCOR calculations.
- Obtain H_2 mass in the containment. H_2 well mixed.
- Calculate the containment pressurization. CPPC useful in this step.
- Overlap the containment pressure distribution with containment fragility curve to obtain containment failure probability.
- Reflooding considered: 20% additional hydrogen generation (Kuan, 1994).

Plant Applications

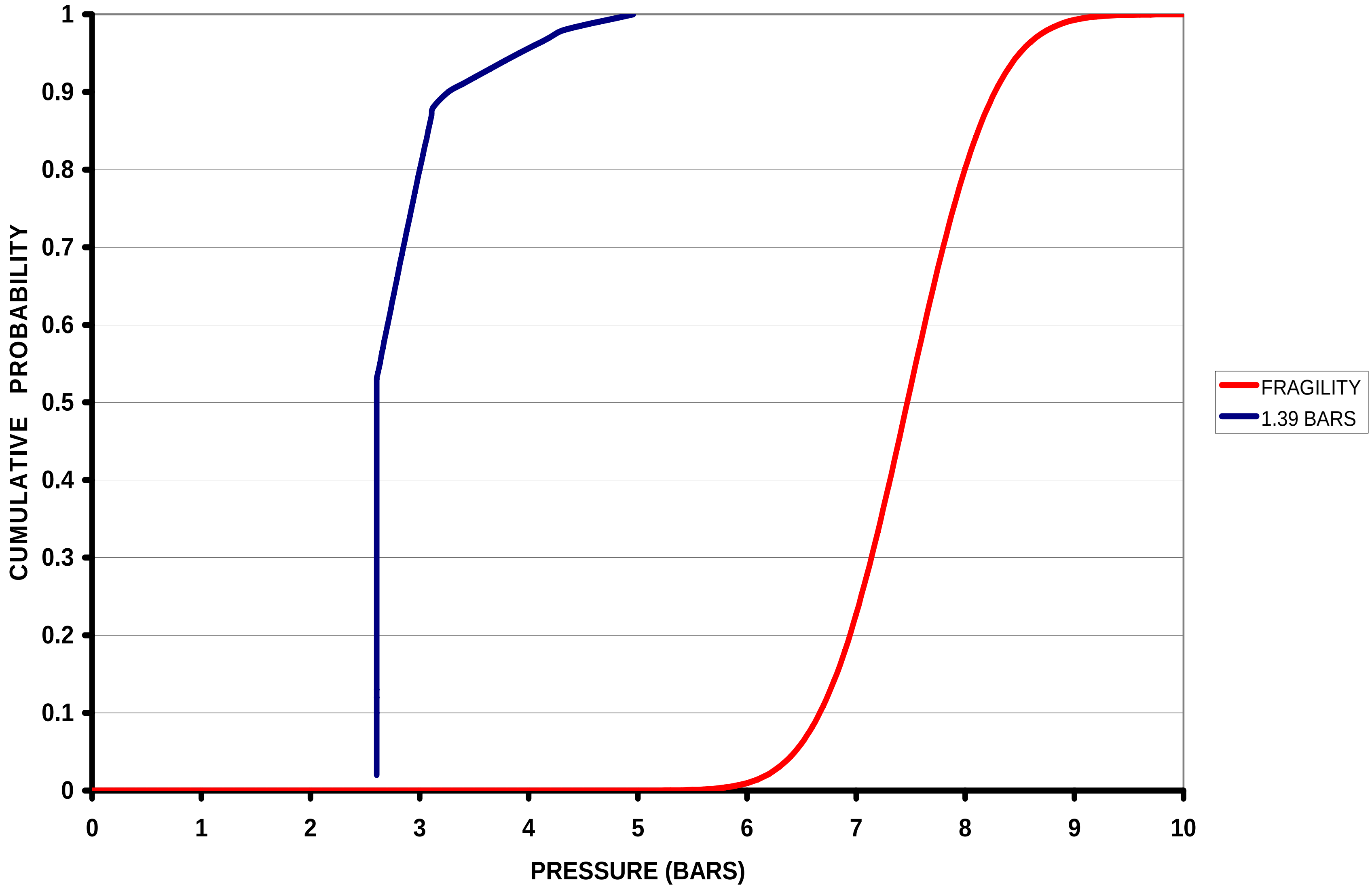


Plant Applications

Results obtained

- No reflooding scenarios: negligible probability.
- Reflooding scenarios: significant increase in the containment failure probability and potential for flame acceleration.
- Safety significance of these results under study.

Plant Applications: No reflooding case



Plant Applications

- Future applications are planned:
  - Continuation of the verification process.
  - Calculation of the containment failure probability for the ex-vessel phase.
  - Analyses of local hydrogen accumulations.