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Verification and validation of consequence models

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Verification and validation of consequence models

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- Introduction
- Discharge
- Dispersion
- Flammable effects

Continuous release with rainout

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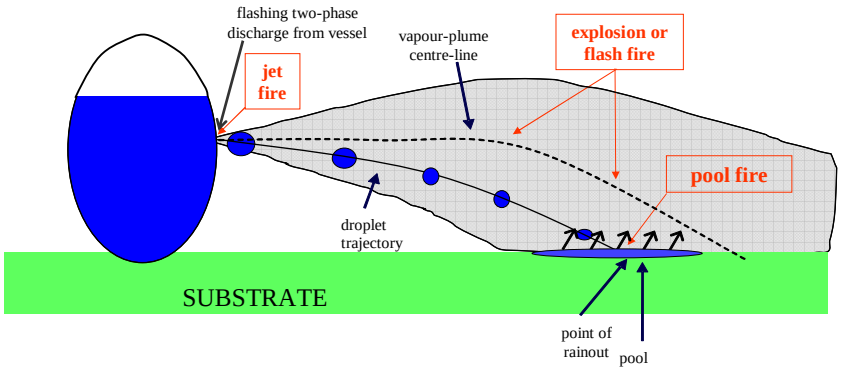

Quality procedure for model development

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- Define model
  - Literature review
  - Formulate physical and mathematical model
  - Solution method and algorithm
- Design (preliminary, detailed) and coding
- Model testing
- Documentation
- Review
- Model integration into overall product

Model testing

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- Verification - code solves correctly mathematical model
  - Against analytical solution
  - Against parallel 'verification' Excel spreadsheet
  - Against other model
- Validation against experimental data – justify model assumptions
  - Small-scale experiments (isolating phenomenon)
  - Large-scale experiments
- Sensitivity analysis – overall robustness and effect parameters
  - Base case
  - Parameter variations (single or multiple parameters)

Key references for consequence and risk modelling

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- Dutch Yellow Book (1997)
- Loss Prevention Process Industries
  - Lees (1996)
  - Updated Mannan (2005)
- Perry Chemicals Engineering Handbook (1999)
- CCPS guidelines
  - Dispersion (1996)
  - Flammable effects (1994)
  - QRA (2000)

Discharge model

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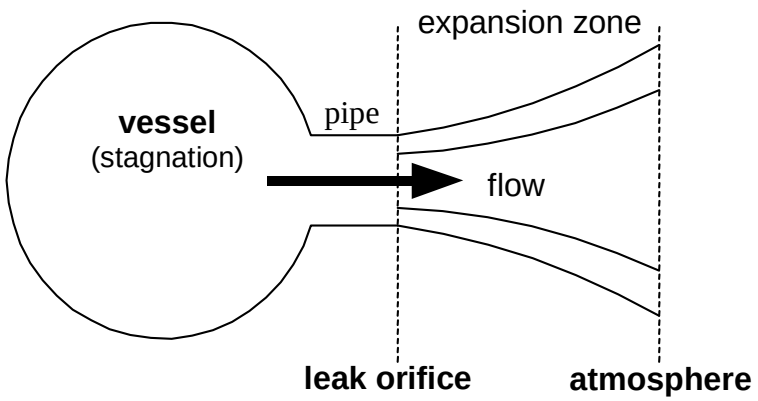

Discharge model

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- Range of scenarios
  - Leak from vessel, short or long pipes, instantaneous, relief systems, …
  - Sub-cooled liquid, flashing liquid, or gas release
- Data
  - Flow rate, velocity and liquid fraction (both orifice and post-expansion data)
  - Droplet size
- Literature survey
  - Numerous discharge models
  - No up-to-date overview of experiments (benchmark tests)
  - No published established systematic model evaluation
- Literature review to establish experimental dataset
- Application to Phast discharge models

Discharge model verification and validation

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- Verification
  - Analytical flow-rate equations
    - incompressible liquid (Bernoulli)
    - ideal gas (choked and un-choked)
  - Process simulators
  - Worked-out examples in literature (e.g. CCPS publications)
- Validation
  - Subcooled and saturated water jets
    - Sozzi and Sutherland (varying pipe length)
    - Uchida and Narai (varying pipe length and stagnation pressure)
    - Many other experiments
  - Hydrocarbon releases
    - Full-bore and orifice releases of liquid propane (Shell)
    - Orifice releases of butane (Shell)
    - Long pipe - validation against Isle of Grain (full-bore and partial leaks – LPG)

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Discharge model validation for sub-cooled water release

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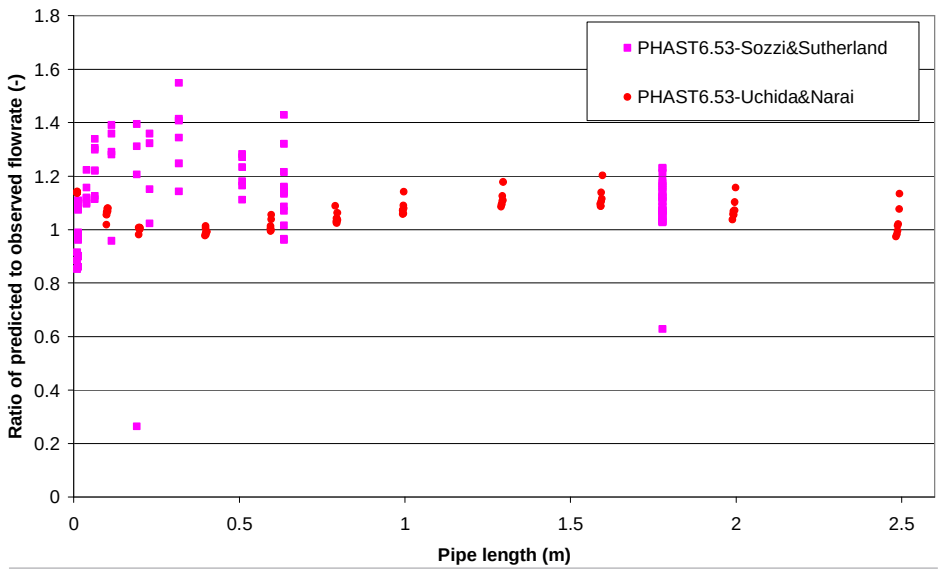

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Validation against P66: mass expelled against time (45.3% breach)

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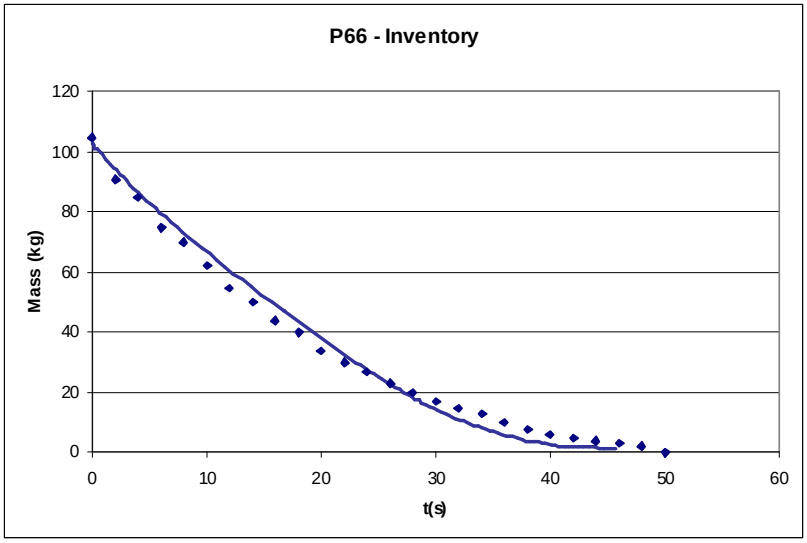

Dispersion (example PHAST Unified Dispersion Model UDM - continuous dispersion)

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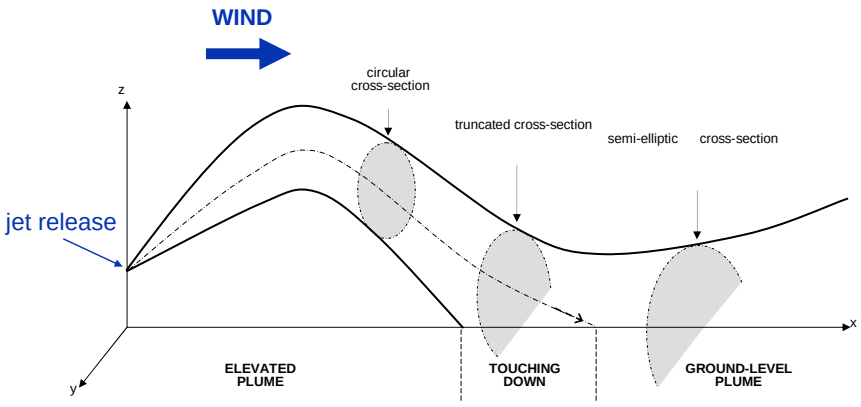

- Elevation phases: elevated, touching down, ground-level, lift-off, elevated, mixing layer
- Dispersion phases: jet, heavy, passive

Dispersion module verification and validation

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- Near-field elevated/jet dispersion
  - Verification: analytical solution (horizontal jet), vertical jet correlations
- Heavy dispersion
  - Verification: analytical solution (2D), HEGADAS (3D)
  - Validation: McQuaid (2D isothermal), HTAG (3D isothermal)
- Passive dispersion
  - Verification: analytical solution, TNO Gaussian concentration profile
- Finite duration
  - Verification: SLAB/HGSYSTEM [finite-duration correction model – FDC]
  - Validation: Kit Fox [quasi-instaneneous model (QI) and FDC]

Dispersion module verification and validation (continued)

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- Thermodynamics
  - Verification: analytical, HEGADAS (pure component, mixture, HF)
  - Validation: Schotte experiment (HF)
- Pool spreading/evaporation
  - Verification: GASP
  - Validation: spills on water/land, wide range of chemicals (LNG, propane, …)
    - spreading (non-volatile chemicals)
    - evaporation (confined pools)
    - simultaneous spreading and evaporation

Dispersion – Validation against large scale experiments

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- Continuous passive dispersion
  - Prairie Grass
- Continuous elevated two-phase jet
  - Ammonia (Desert Tortoise and FLADIS)
  - Propane (EEC)
  - HF (Goldfish)
- Continuous dispersion from pool
  - LNG (Maplin Sands, Burro, Coyoto)
  - LPG (Maplin Sands)
- Un-pressurised instantaneous
  - Freon-12 (Thorney Island)
- Continuous and finite-duration dispersion from area source
  - CO_2 (Kit Fox)

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Dispersion – Validation for Kit Fox experiment

(20 second release of CO_2, experiment KF0706)

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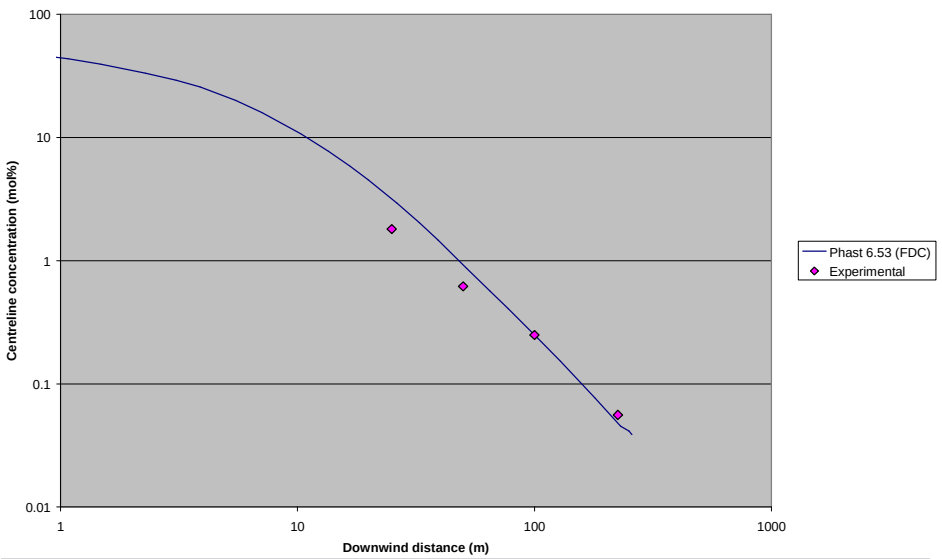

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Fireballs, jet fires and pool fires

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- Mathematical model
  - Empirical correlations for fire geometry and surface emissive power
    - Fireball (sphere)
    - Pool fire (tilted cylinder)
    - Jet fire (cone)
  - Radiation at given location by means of integration along fire surface
- Verification
  - Simple hand calculations and/or spreadsheet
  - Comparison against other models
- Validation
  - Pool fire:
    - LNG (Montoir, Johnson)
    - Hexane (Lois and Swithenbank)
  - Jet fire:
    - Vertical natural gas (Chamberlain)
    - Horizontal natural gas (Johnson, Bennett et al.)
    - Two-phase LPG (Bennett et al.)
    - Horizontal liquid crude oil (Selby and Burgan)

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Pool fire model (Phast model POLF)

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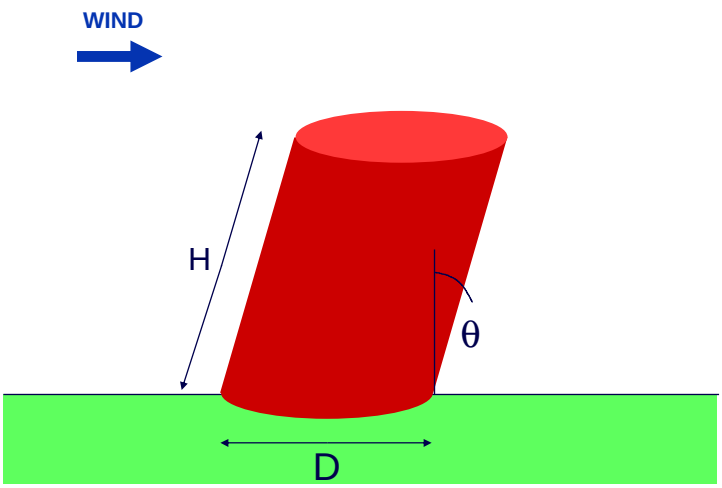

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Validation against Johnson LNG pool fire experiments

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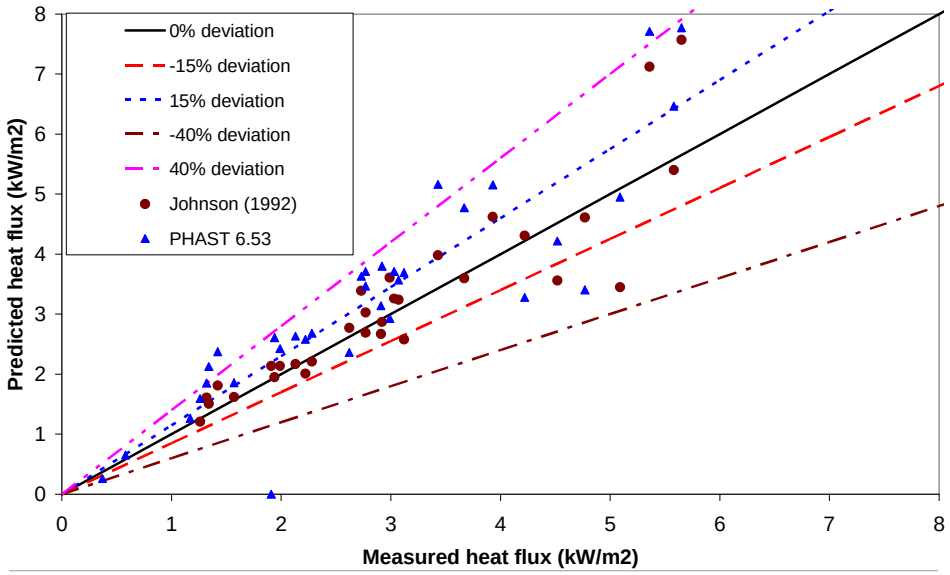

Jet fire - Chamberlain pure-vapour model (no crosswind)

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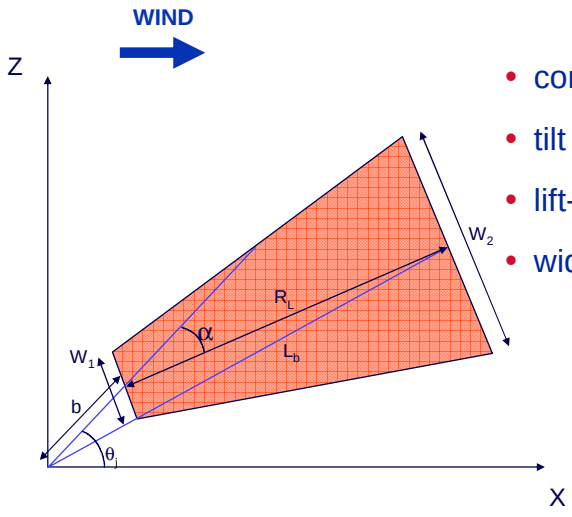

- cone
- tilt by wind
- lift-off distance
- widths, length

Validation against Johnson LNG jet fire experiments

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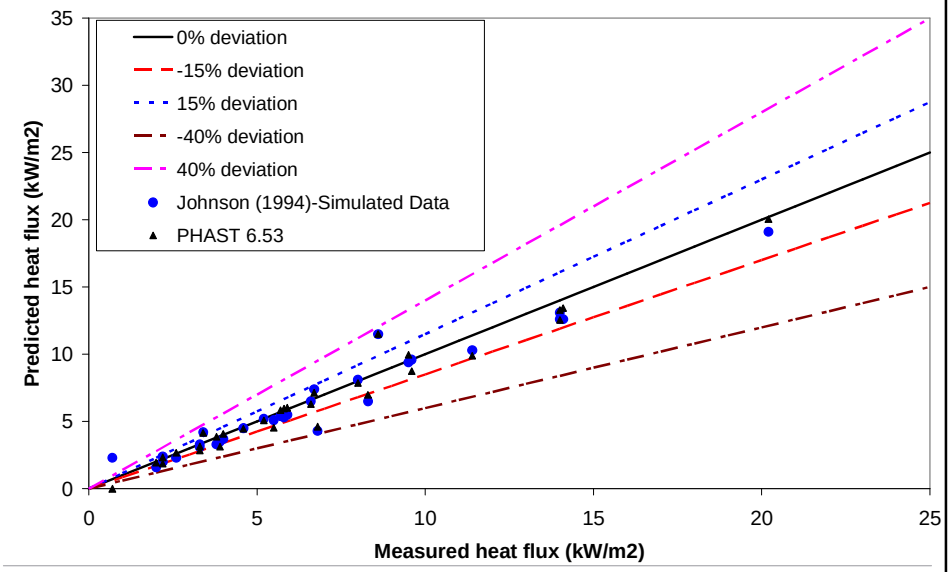

Explosion modelling

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- Comparative study by Fitzgerald
  - Key models:
    - TNO Multi energy (MULT)
    - Baker Strehlow (BSEX)
    - Shell Congestion Assessment Model (CAM)
  - Validation:
    - LNG, LPG (EMERGE - TNO)
    - LNG (BFETS -SCI)

Explosion - Validation against EMERGE 6 experiment

(LPG, medium scale)

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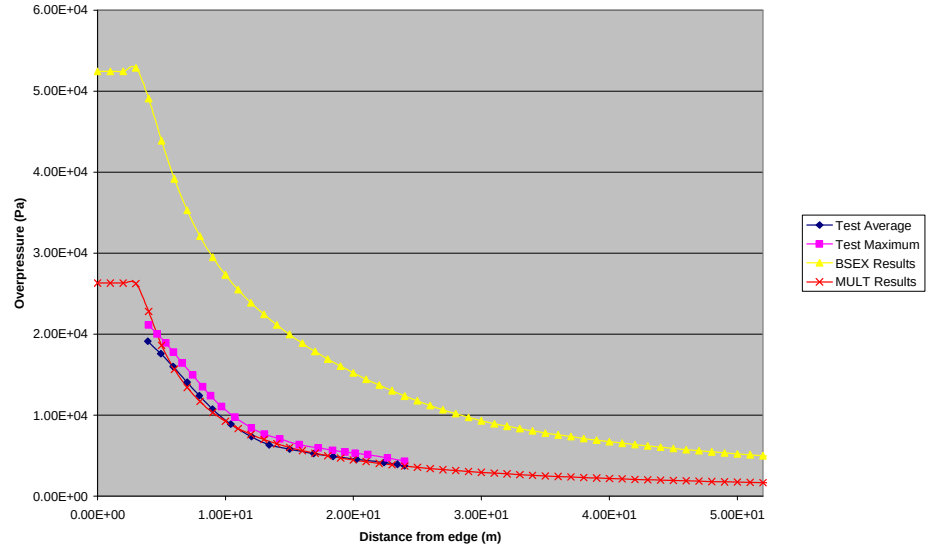

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