Training on the Accident Damage Assessment Module (ADAM)

Chemical Accident Risks Seminar
Ispra, 14-15 June 2017

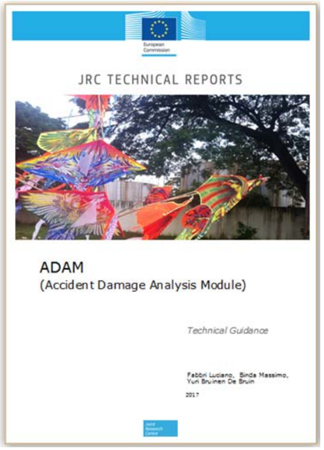
Luciano Fabbri
E02-Major Accident Hazards Bureau

Joint Research Centre
the European Commission's
in-house science service

European Commission

Joint Research Centre

Training Agenda

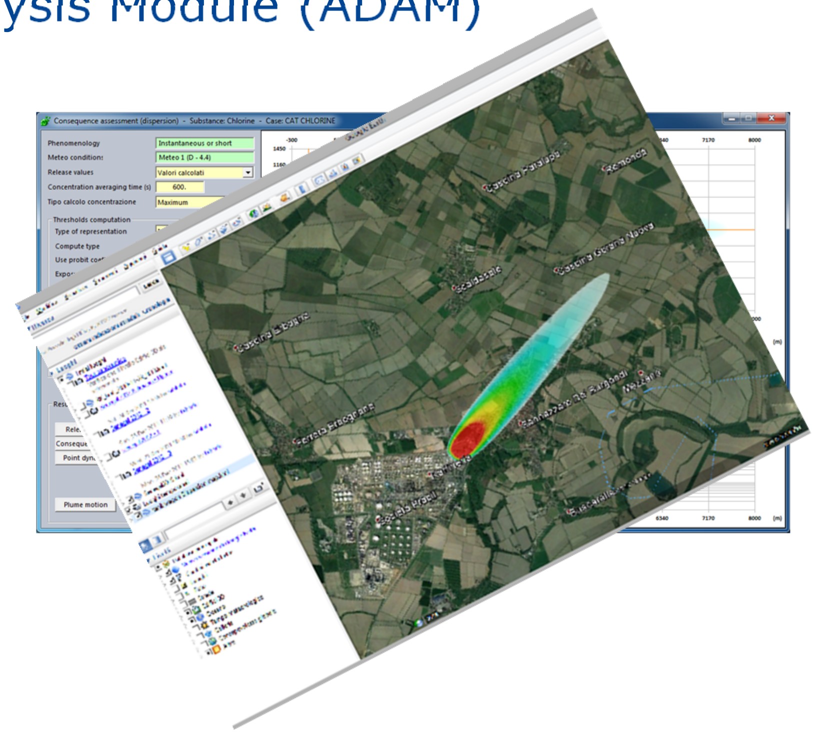


PART 1

- Brief reminder on Consequence Analysis
- Overview on the Accident Damage Analysis Module (ADAM)
- Verification and Validation of ADAM

PART 2

- Case study 1: toxic substance
- Case study 2/3: flammable substance



Trainee profile

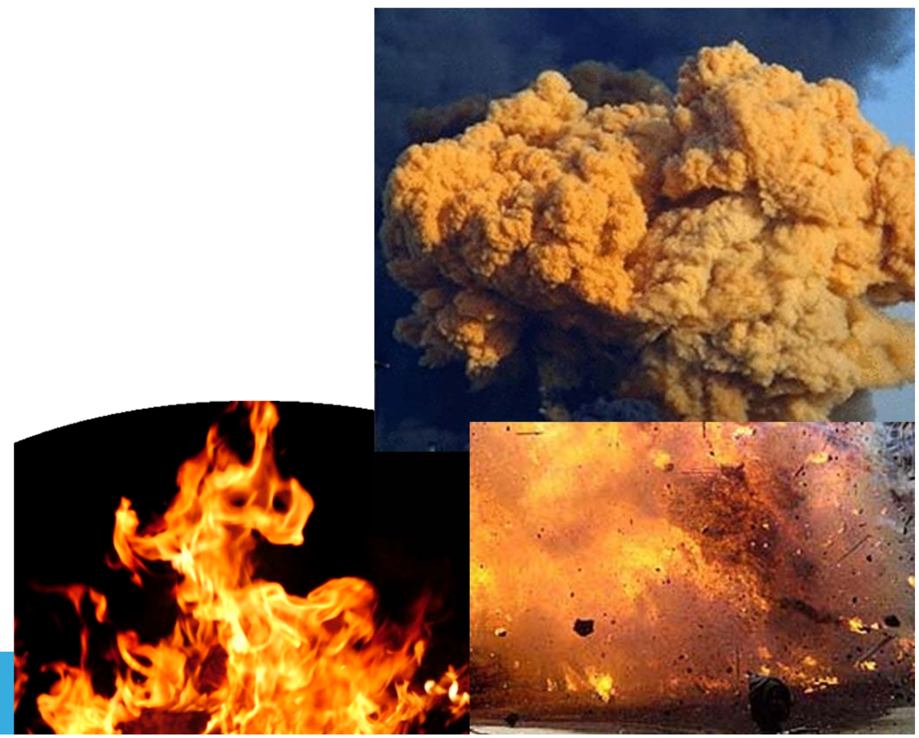
- Competent authorities responsible for the evaluation of Safety Reports
- Some knowledge on Industrial Safety and Accident prevention

Use of ADAM

- Requires specialised knowledge about the object being assessed (e.g., chemical process safety)
- Requires understanding of the fundamentals of risk assessment

European Commission

PART 1: Introduction to Consequence Analysis



Joint Research Centre

Risk Analysis

What may be wrong?

HAZARD IDENTIFICATION

How dangerous is it?

ACCIDENT CONSEQUENCE ANALYSIS

How frequent is it?

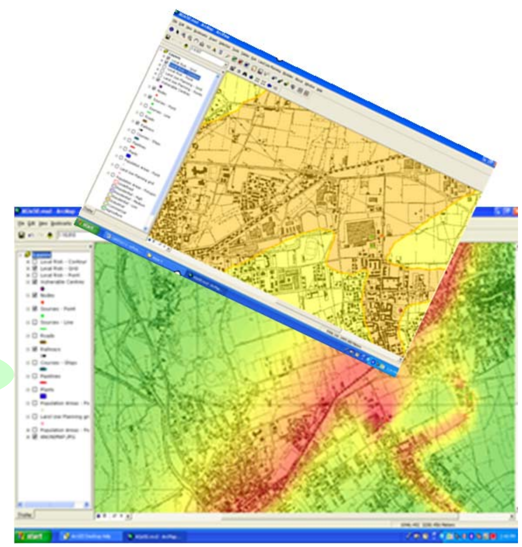
ACCIDENT FREQUENCY ANALYSIS

RISK CALCULATION & REPRESENTATION

RISK MANAGEMENT & LUP

EMERGENCY PLANNING

DECISION-MAKING



Scope

- Chemical process plants
- Refineries and oil depots
- Storage units
- Power plants
- Offshore oil and gas facilities
- Transport of hazardous substances (road, rail, pipelines)

Consequence Analysis

ACCIDENT CONSEQUENCE ANALYSIS

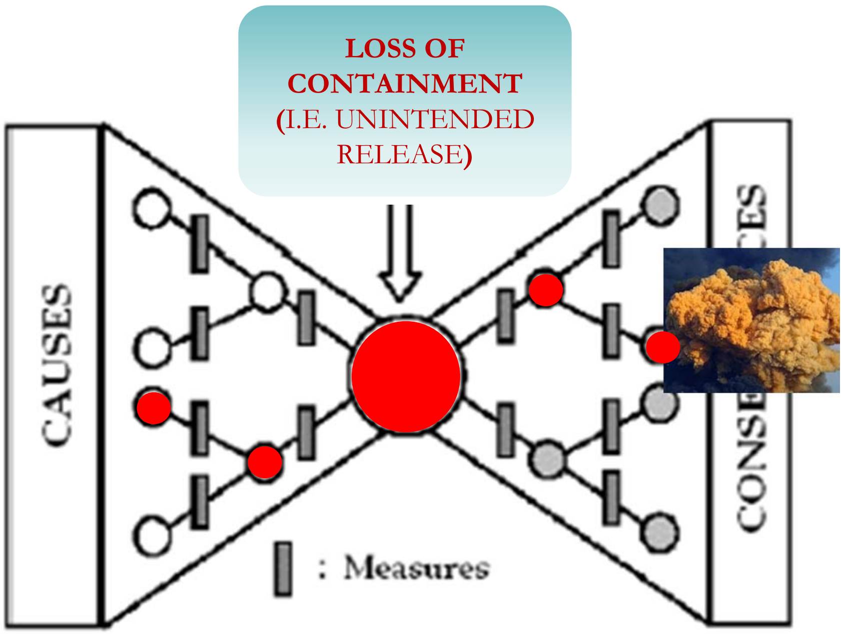
- Studies the Effects of an industrial accident due to the development on an unintended loss of containment
- Allows to determine the Damage to: people, environment, assets
- Identify Distances associated with different damage levels

Rigorous and Systematic

Highly technical process

Consequence Analysis

ACCIDENT CONSEQUENCE ANALYSIS



Accident Scenario

TOP EVENT

Toxic Dispersion
Fire
Explosion

↓

PHYSICAL EFFECTS

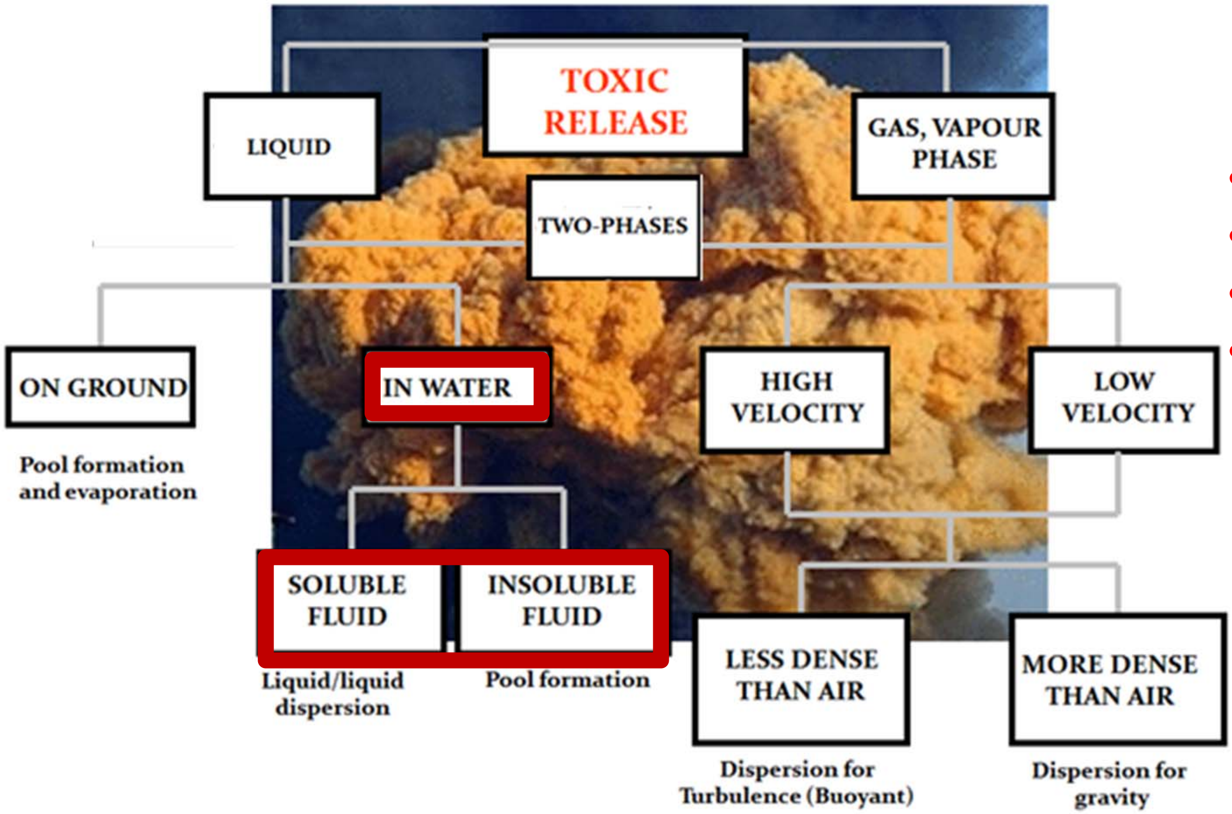
Toxic Concentration
Thermal Radiation
Overpressure

↓

DAMAGE

Humans
Environment
Assets
Domino

Toxics Releases



- **Simple Asphyxiants**
- **Chemical Irritants**
- **Chemical Asphyxiants**
- **Cyanide Poisoning**

WIND

ATHMOSPHERE

1. Marx J, Hockberger R, Walls R: Rosen's Emergency Medicine: Concepts and Clinical Practice. Mosby: St. Louis, Mo. 2010.
2. Tintinalli J, Kelen G, Stapczynski J: Tintinalli's Emergency Medicine: A Comprehensive Study Guide. McGraw-Hill: New York. 2010.

Fires

PIPER ALPHA (1988)
flame lenght: 100m
platform destroyed
167 deaths
TORONTO BLEVE (2008)
Sunrise Propane acc.

WIND

Vapour Cloud Explosions

- Release of a large amount of flammable vapor (i.e. highly volatile pool or rupture of a pressure vessel)
- Presence of Confinement and ignition

Type	*VBR*	*Geometry*	*Description*
Low	<10%		Easy to walk through, there are only 1-2 layers of obstacles
Medium	Between 10% and 40%;		Cumbersome to walk through. Often necessary to take indirect paths, 2-3- layers of obstacles
High	> 40%		Not possible to walk through, as there is insufficient space to pass between obstacles. 3 or more closely spaced obstacles

Table 15: Level of Congestion vs the volume blockage ratio (VBR)

DISPERSION

↓

IGNITION

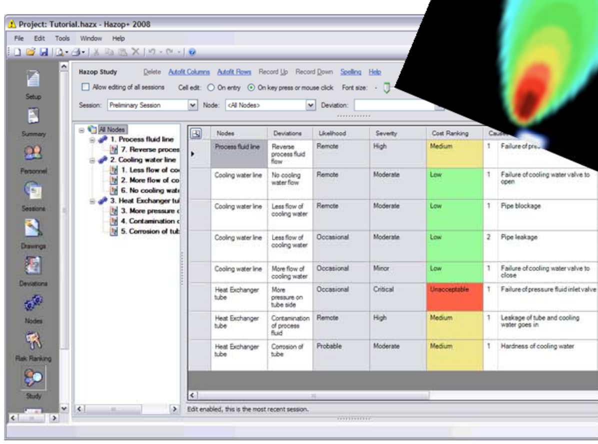
↓

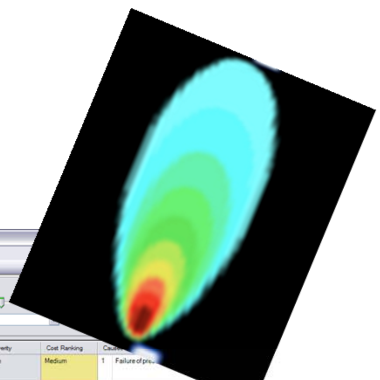
EXPLOSION

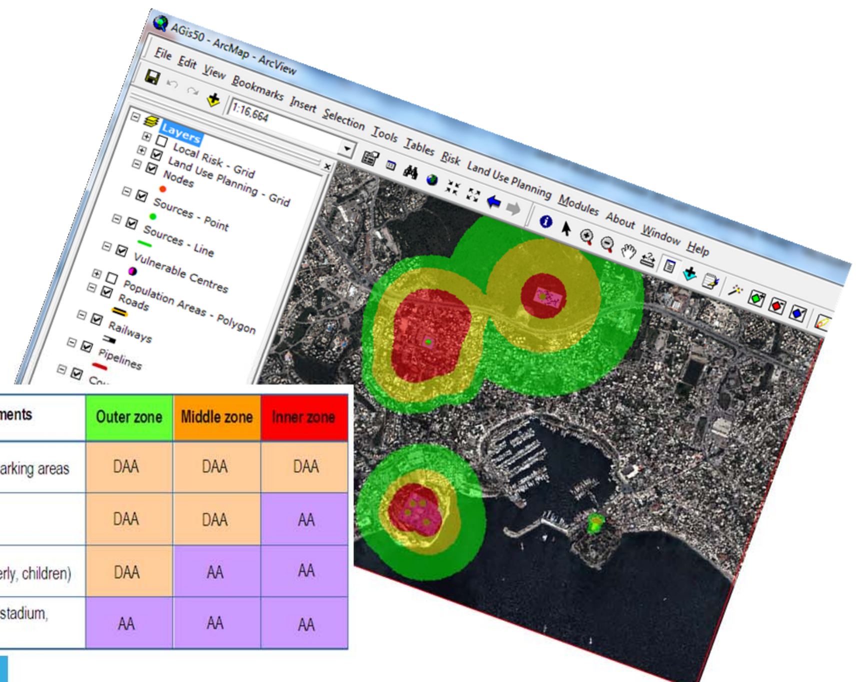
European Commission

Applications

- Design of new establishments/installations
- Risk analysis for safety reports related applications
- Estimate of impact distances for LUP and emergency planning applications



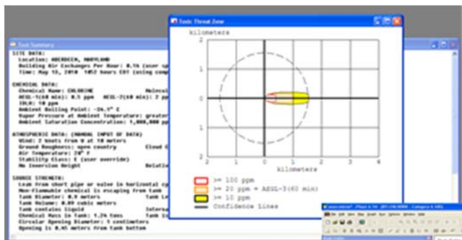




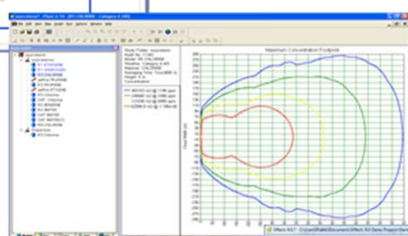
		Example of developments	Outer zone	Middle zone	Inner zone
Sensitivity level	1	Industrial establishments, parking areas	DAA	DAA	DAA
	2	Residential areas	DAA	DAA	AA
	3	Vulnerable population (elderly, children)	DAA	AA	AA
	4	Highly vulnerable facilities (stadium, hospital)	AA	AA	AA

Research Centre

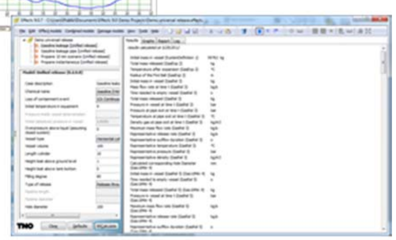
Existing Tools for CA (based in integral models)



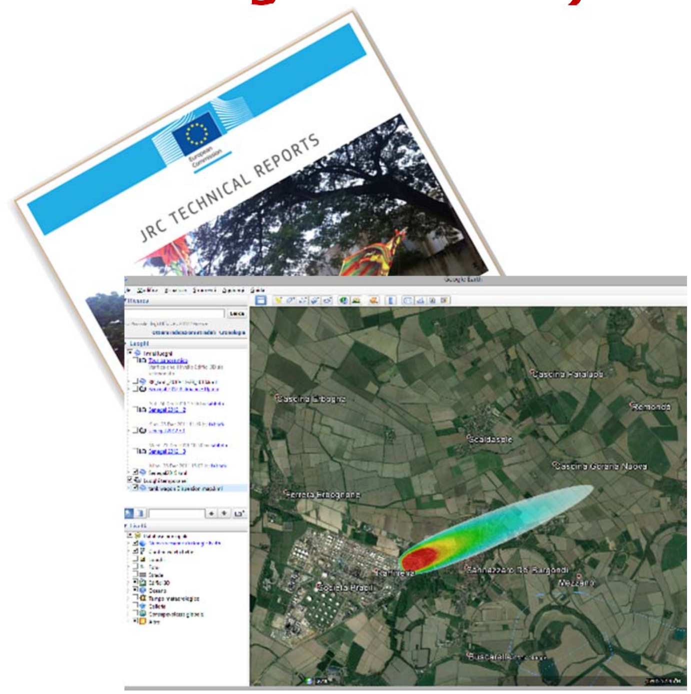
ALOHA
EPA



PHAST
DNV



EFFECTS
TNO



ADAM

Purpose of ADAM

- This software is specifically intended to assist the EU Competent Authorities, who are responsible for the implementation of the Seveso Directive in their countries, in **quickly assessing the potential consequences of an industrial accident**.
- ADAM will be incorporated as a calculus module within the next version of the GIS **Area Risk Assessment** tool and **Land Use Planning**

European Commission

ADAM in short

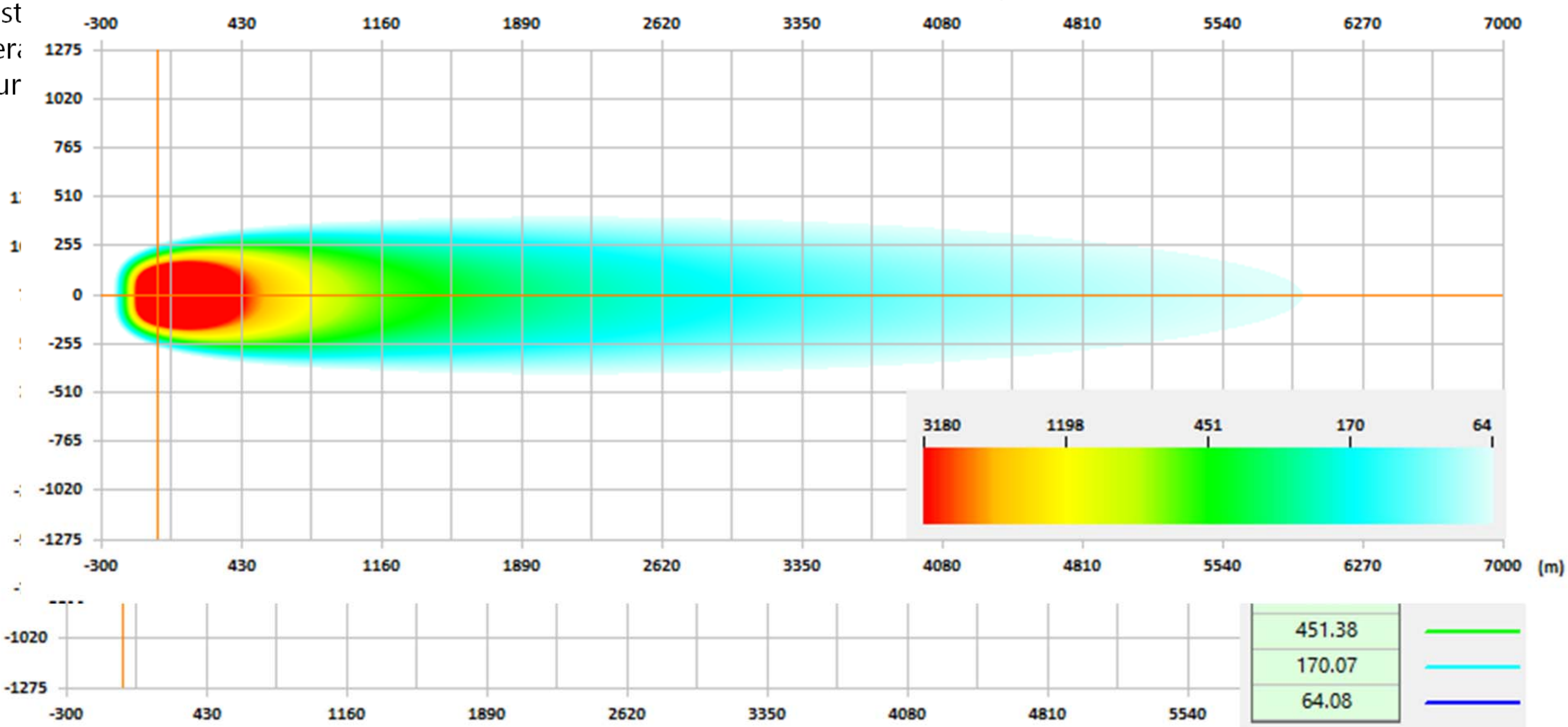
ACCIDENT CONSEQUENCE ANALYSIS

INPUT DATA

Subst
Opera
Failur

En
C

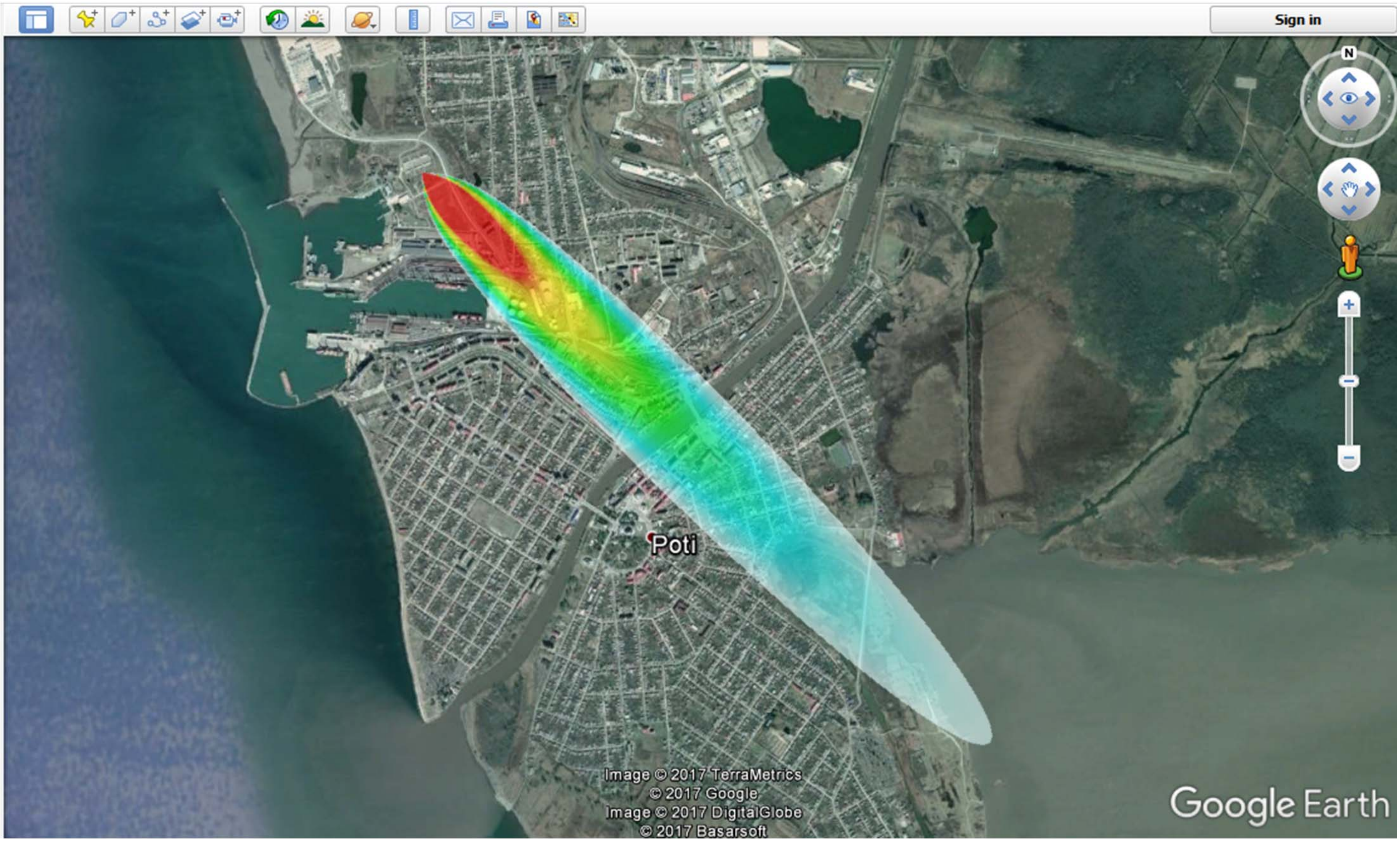
As



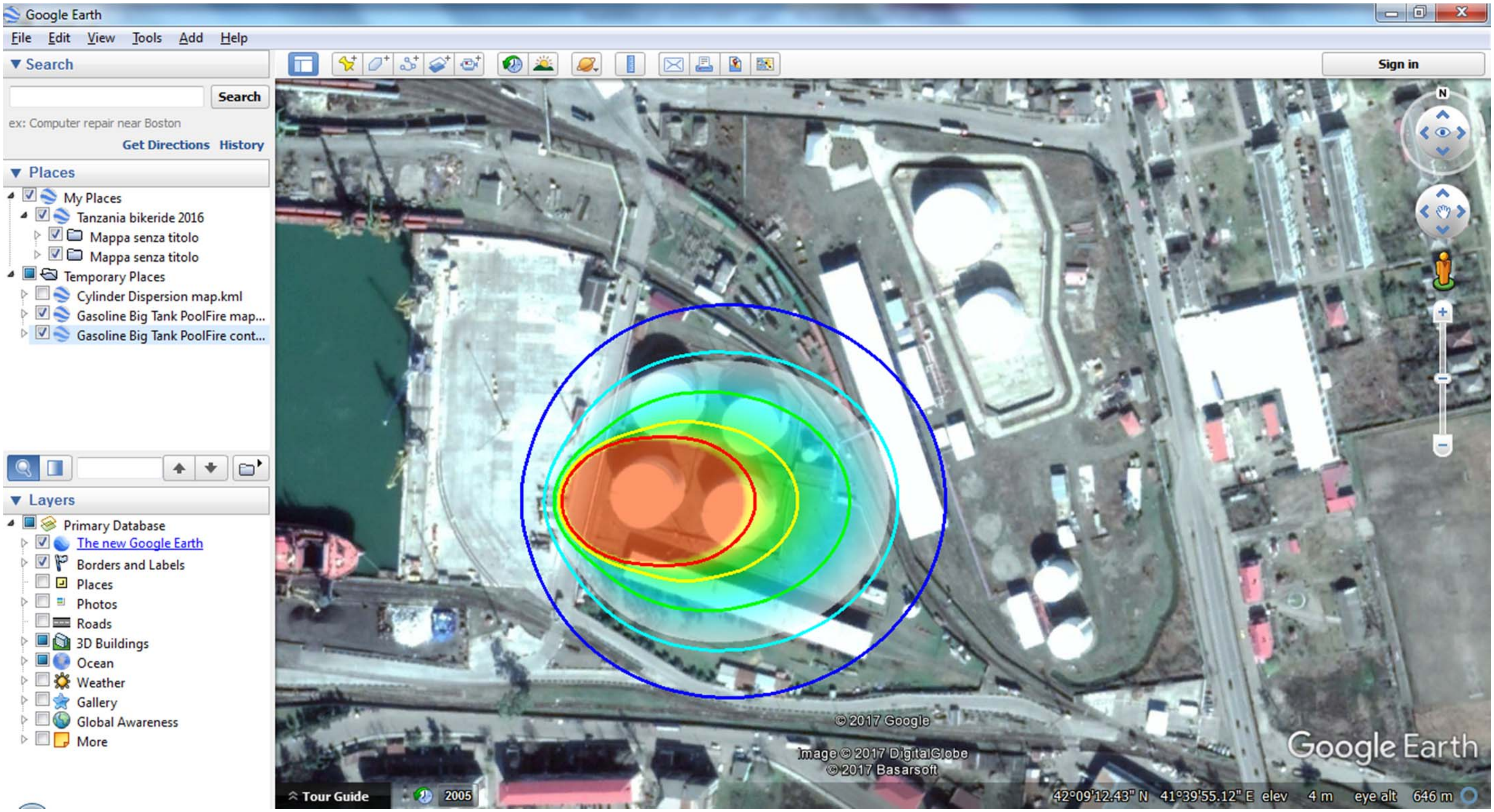
Database on Substances

Joint Research Centre

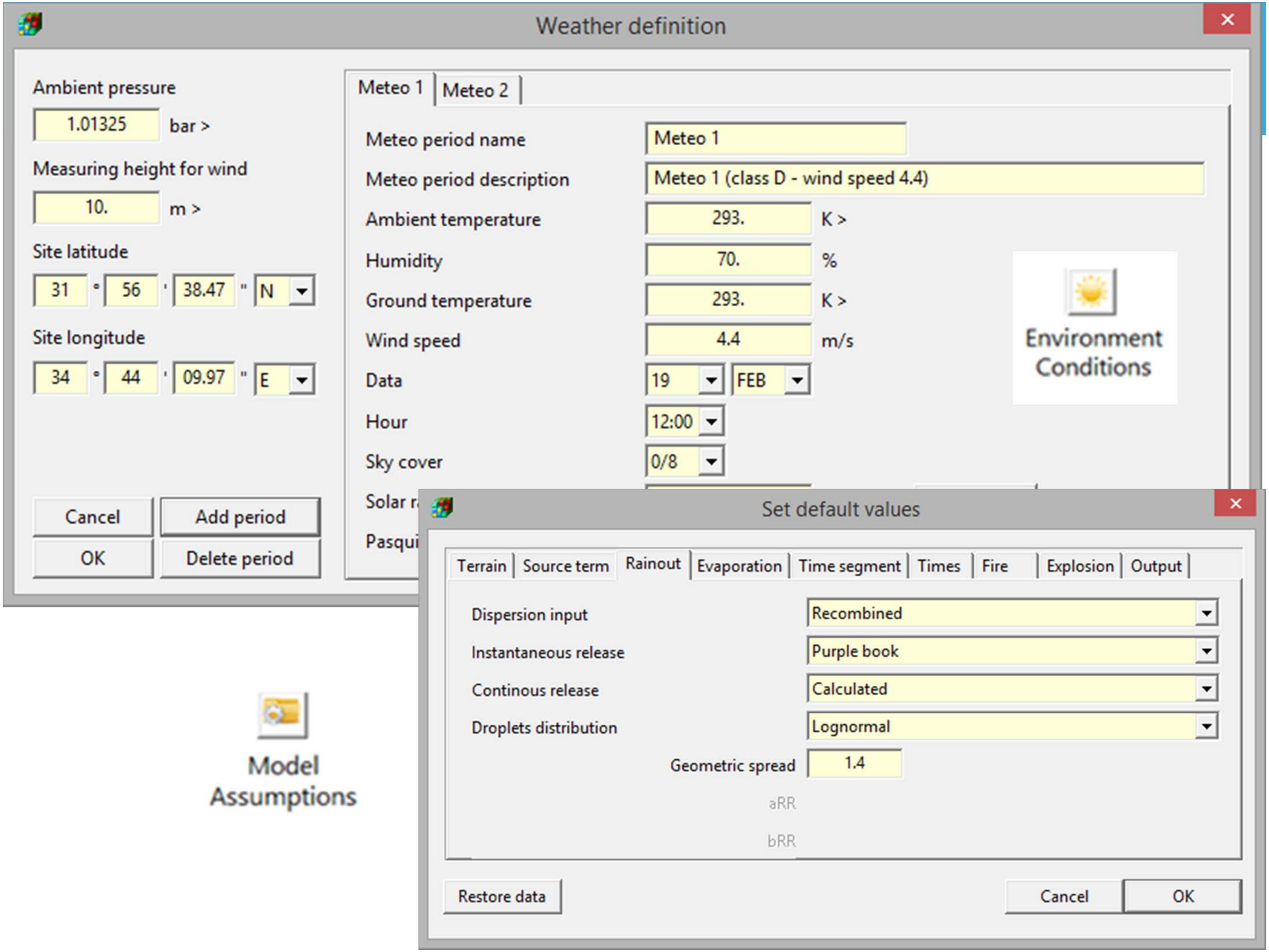
European
Commission

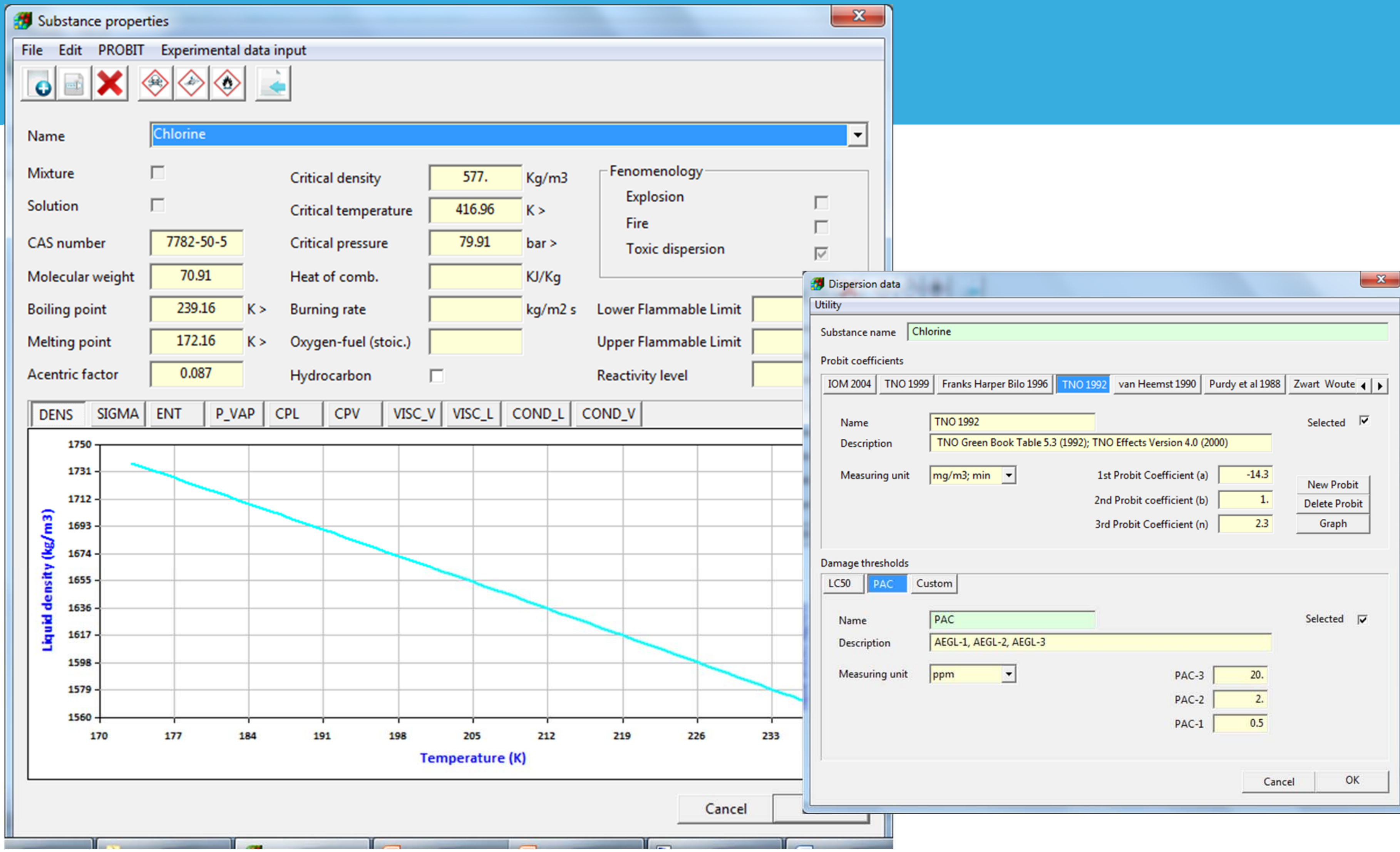


European Commission



Joint Research Centre


Weather definition
Ambient pressure
1.01325 bar >
Measuring height for wind
10. m >
Site latitude
31 ° 56 ' 38.47 " N
Site longitude
34 ° 44 ' 09.97 " E
Cancel
Add period
OK
Delete period
Meteo 1
Meteo 2
Meteo period name
Meteo 1
Meteo period description
Meteo 1 (class D - wind speed 4.4)
Ambient temperature
293. K >
Humidity
70. %
Ground temperature
293. K >
Wind speed
4.4 m/s
Data
19 FEB
Hour
12:00
Sky cover
0/8
Environment Conditions
Set default values
Terrain
Source term
Rainout
Evaporation
Time segment
Times
Fire
Explosion
Output
Dispersion input
Recombined
Instantaneous release
Purple book
Continous release
Calculated
Droplets distribution
Lognormal
Geometric spread
1.4
aRR
bRR
Restore data
Cancel
OK
Model Assumptions

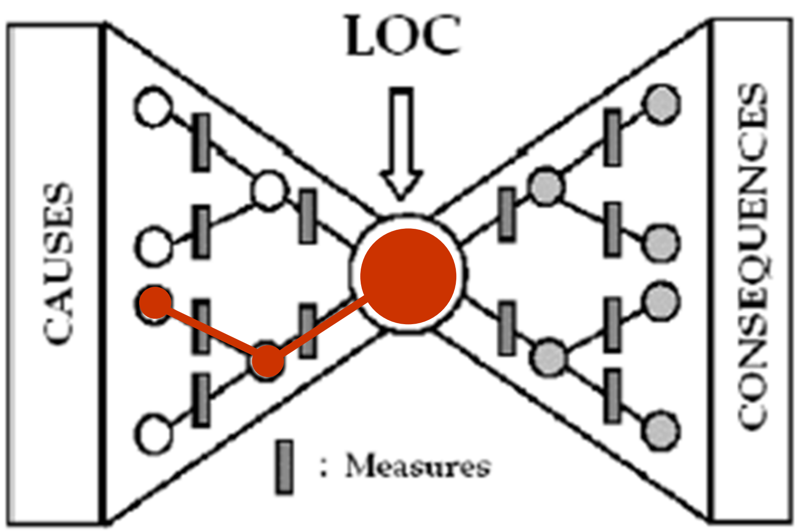


Physical Properties of the substances included in the **ADAM database,** were taken from: **2010 VDI Heat Atlas, Editors VDI e. V. @Springer-Verlag Berlin Heidelberg 2010**, *With permission of Springer]*

Joint Research Centre

European Commission

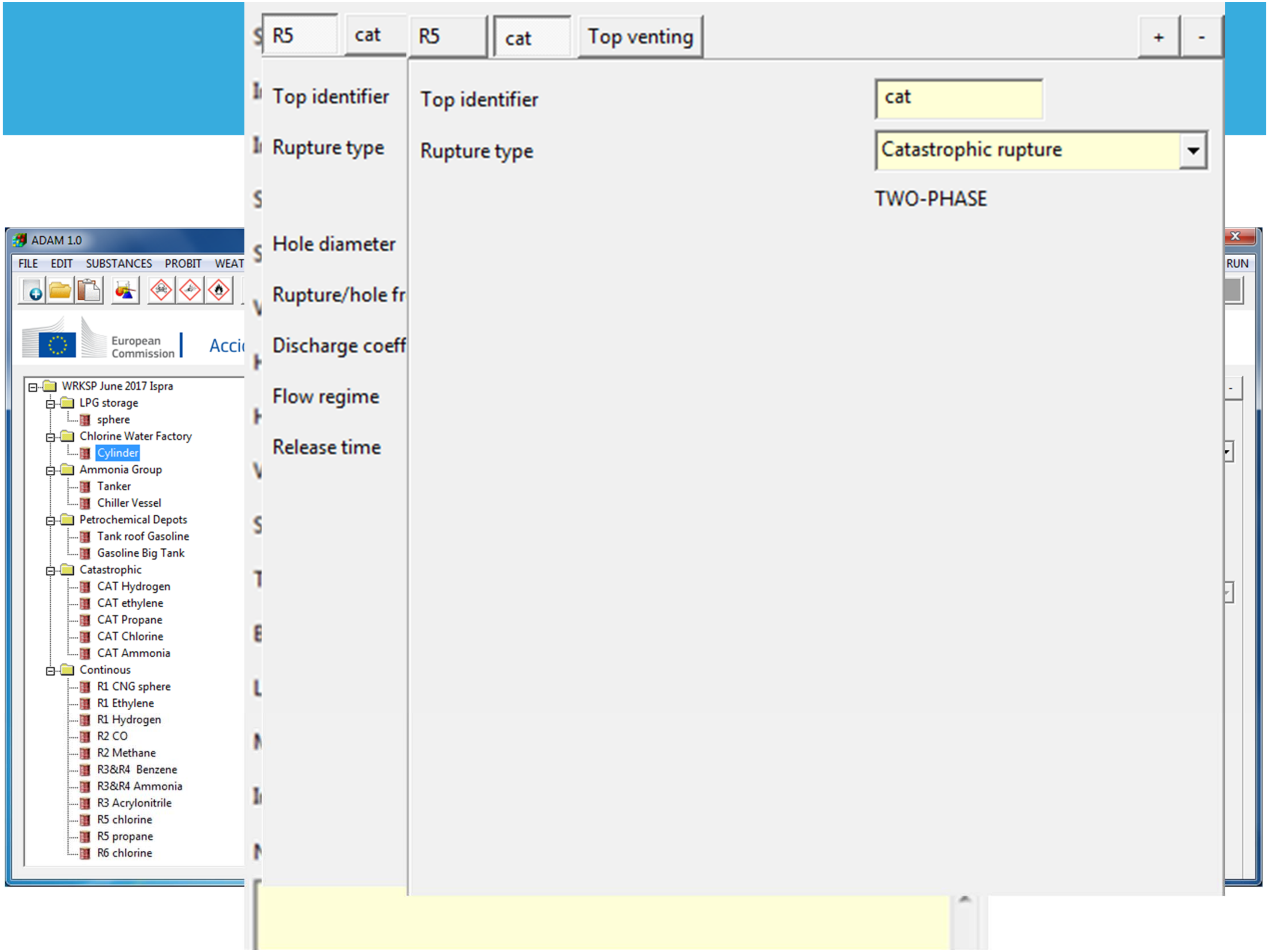
Module 1: Source Terms



State
- Compressed Gas
- Non-boiling Liquid
- Pressurised Gas

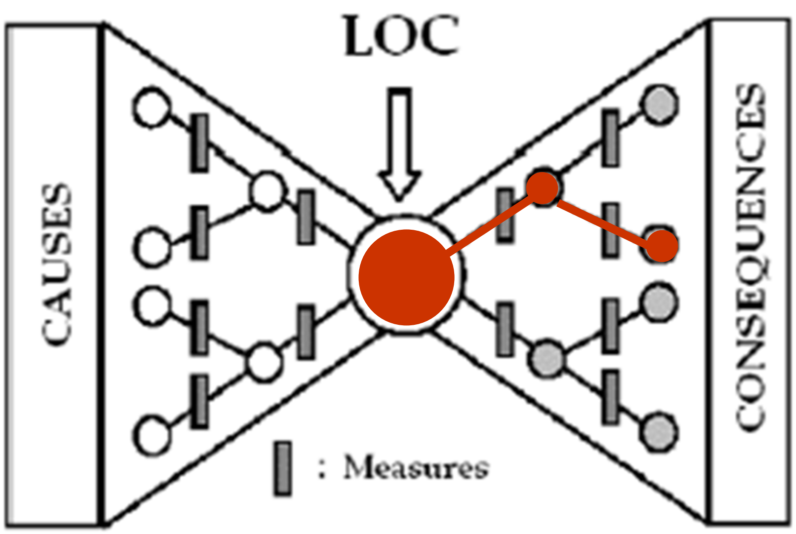
From
- Vessel
- Pipe
- Pipeline

Type
- Catastrophic release
- Continuous release


R5
cat
R5
cat
Top venting
+
-
Top identifier
Rupture type
Hole diameter
Rupture/hole fr
Discharge coeff
Flow regime
Release time
Top identifier
cat
Rupture type
Catastrophic rupture
TWO-PHASE
ADAM 1.0
FILE
EDIT
SUBSTANCES
PROBIT
WEAT
RUN
European Commission
Acci
WRKSP June 2017 Ispra
LPG storage
sphere
Chlorine Water Factory
Cylinder
Ammonia Group
Tanker
Chiller Vessel
Petrochemical Depots
Tank roof Gasoline
Gasoline Big Tank
Catastrophic
CAT Hydrogen
CAT ethylene
CAT Propane
CAT Chlorine
CAT Ammonia
Continous
R1 CNG sphere
R1 Ethylene
R1 Hydrogen
R2 CO
R2 Methane
R3&R4 Benzene
R3&R4 Ammonia
R3 Acrylonitrile
R5 chlorine
R5 propane
R6 chlorine

European Commission

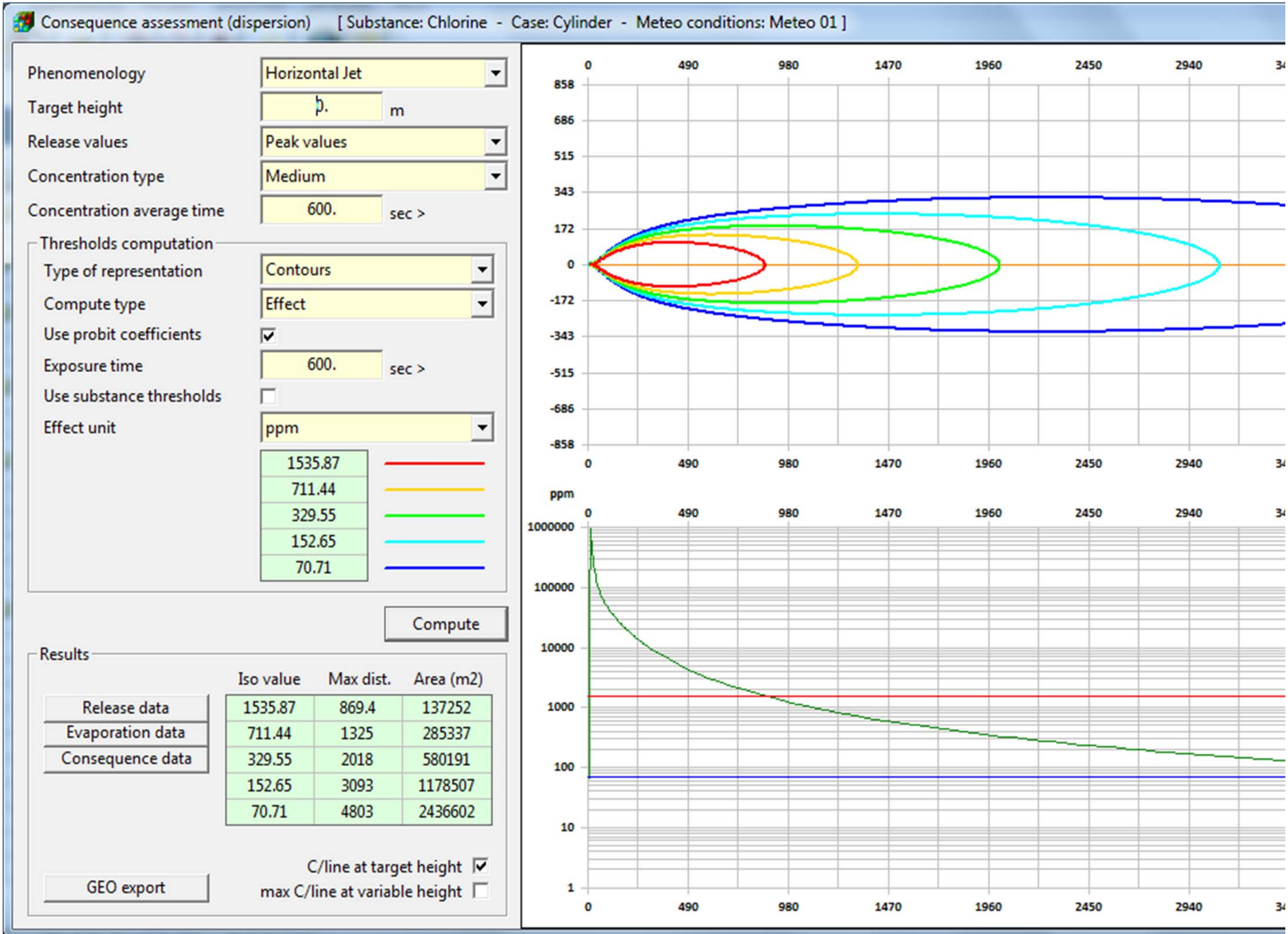
Module 2: Physical Effects



Dispersion
- Toxic clouds
- Flammable clouds

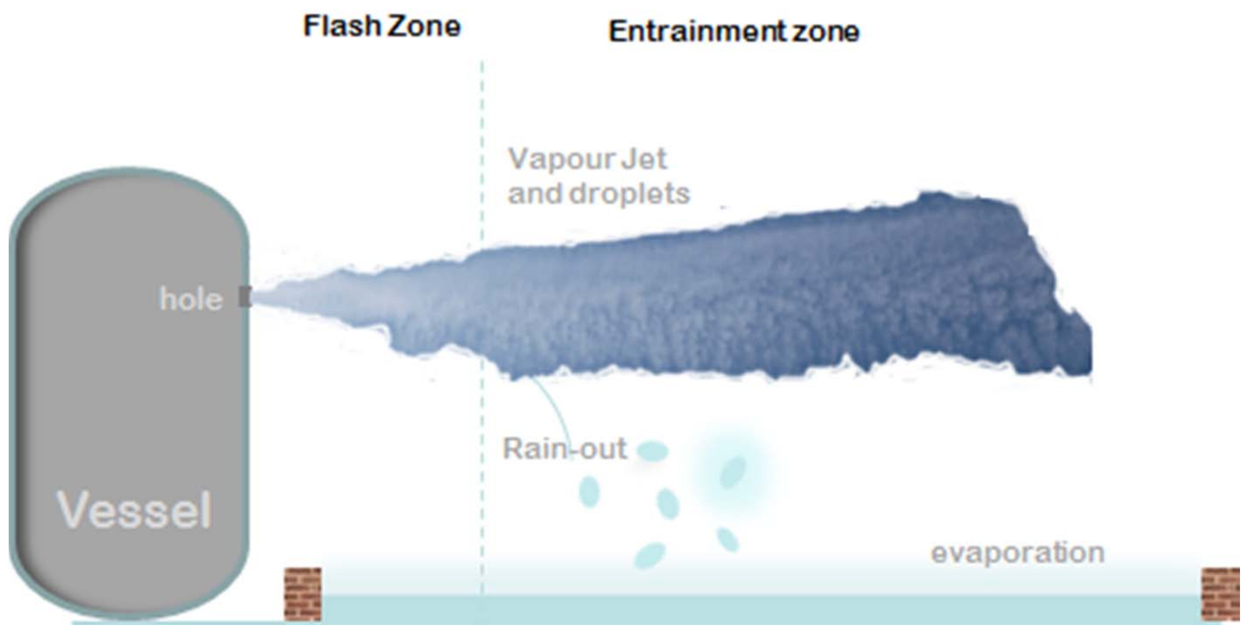
Fire
- Pool fires
- Jet Fires
- Fireball

Expl.
- VCE



Consequence assessment (dispersion) [Substance: Chlorine - Case: Cylinder - Meteo conditions: Meteo 01]
Phenomenology
Horizontal Jet
Target height
0.
m
Release values
Peak values
Concentration type
Medium
Concentration average time
600.
sec >
Thresholds computation
Type of representation
Contours
Compute type
Effect
Use probit coefficients
Exposure time
600.
sec >
Use substance thresholds
Effect unit
ppm
1535.87
711.44
329.55
152.65
70.71
Compute
Results
Iso value
Max dist.
Area (m2)
Release data
Evaporation data
Consequence data
1535.87 869.4 137252
711.44 1325 285337
329.55 2018 580191
152.65 3093 1178507
70.71 4803 2436602
GEO export
C/line at target height
max C/line at variable height
0 490 980 1470 1960 2450 2940
858 686 515 343 172 0 -172 -343 -515 -686 -858
ppm
1000000 100000 10000 1000 100 10 1

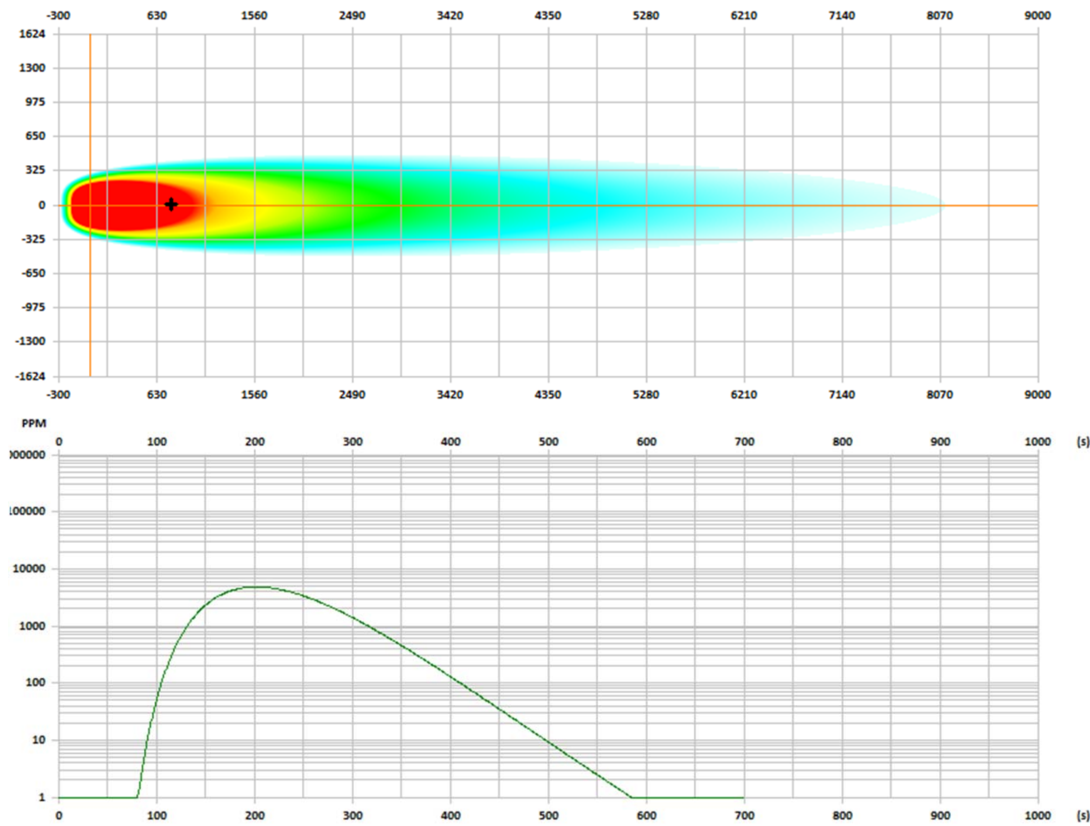
Centre



- in-house modified version of the **SLAB model** (Zeman, 1982 – Ermak, 1990).
- **Integral method** (i.e. Solution of *spatially-averaged* conservation equations yields the spatially-averaged cloud properties

ADAM-SLAB

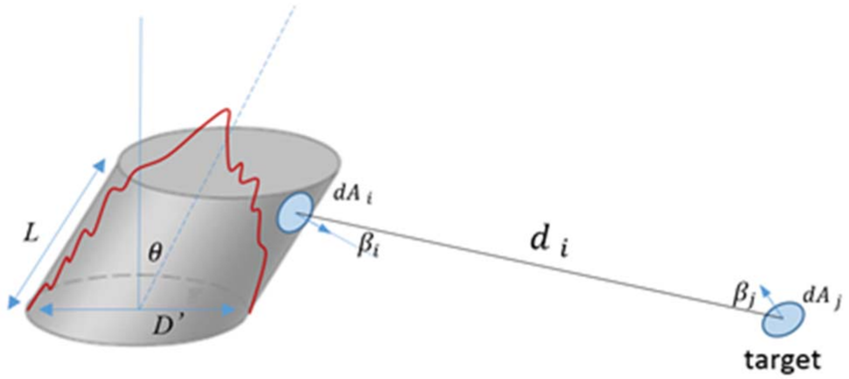
- Designed to model time-dependent releases.
- Incorporates rainout effects and combines the contribution to the cloud formation from jet vapour release and evaporation.
- Corrected and inherent error for instantaneous releases by performing the right calculation on the average concentration



Pool and Roof Fires

CODE	MODEL	DESCRIPTION	REF
1	MODIFIED TNO	Originates from the TNO procedure but with diverse correlations describing the flame .	Engelhard, 2005 Pritchard, 1992
2	SHOKRI and BEYLER	Based on Heskestad's correlation for the flame length. There is no flame tilt and drag. It does not account of atmosphere transmissivity.	Shokri, 1989
3	MUDAN	Based on Thomas' correlation for the flame length and AGA correlation for flame tilt.	Mudan, 1988

Table 6: Poof fires. Empirical methods implemented in ADAM.



$$F_{view} = \iint_{A_i} \frac{\cos(\beta_i)\ \cos(\beta_j)}{\pi d^2} dA_i$$

Jet Fires

$$P_s = P_0 + d\ \widehat{n_F} + r(d)[\widehat{s_1}\cos\varphi + \widehat{s_2}\sin\varphi]$$

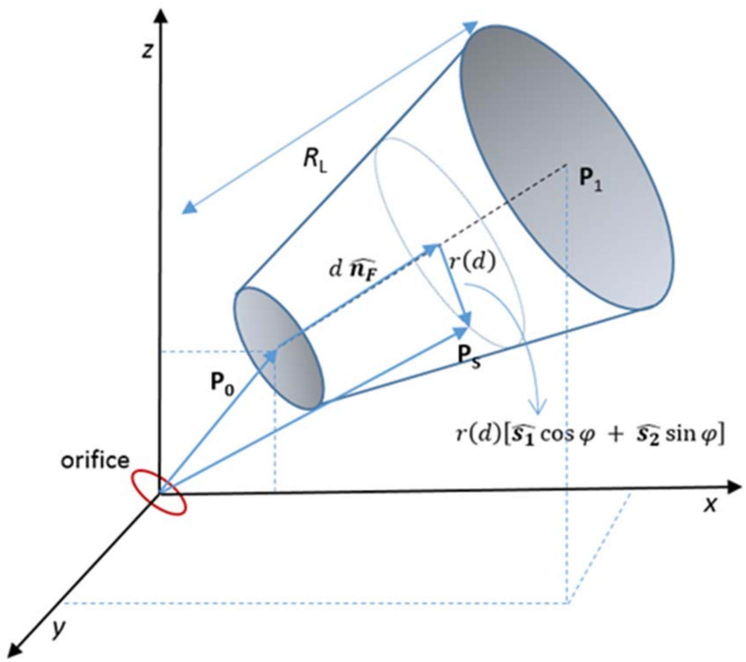


Figure 10: Frustum: main vectors

$$F_{view} = \iint_{A_i} \frac{\cos(\beta_i)\ \cos(\beta_j)}{\pi d^2} dA_i$$

- Chamberlain (vertical fires)
- Johnson (horizontal fires)
- Cook correction (two phase releases)

Flash Fire

- In order to identify the flame contour, size and position of the flammable cloud has to be determined (dispersion modelling).
- ADAM calculates the iso-contours of the cloud at the time in which ignition is supposed to take place, by determining the level of cloud concentration equal to LFL.

Fireball

$$D_{max} = C_1\, M^{C_2}$$

$$t_d = C_3\, M^{C_4}$$

	n-BUTANE	PROPANE	n-PENTANE	HYDR.CARB. (other)
C_1	5.72	5.88	5.25	5.8
C_2	0.303	1/3	0.314	1/3
C_3	0.45	1.09	1.07	0.45
C_4	1/3	0.167	0.181	1/3
Ref.	Lihou and Maund (1982)	Williamson and Mann (1981)	Hasegawa and Sato (1977)	Roberts (1982)

Table 9: Coefficients used in eq. 183 and 184 and related references.

Vapour Cloud Explosion

ADAM estimates the amount of explosive mass using dispersion models together with the values of the flammability limits of the substance under study

$$M_{ex} = \iiint_{V_{LFL}} c(r, t_{ig})\, dV$$

CODE	MODEL	DESCRIPTION	REF
1	Equivalent TNT	It assumes that all VCE are detonations and is based on a scaled curve where the explosive flammable equates an equivalent mass of TNT (i.e. tri-nitrotoluene).	Lees, 2005
2	TNO MultiEnergy	Based on 10 scaled curves for different strengths of explosion blast that depend on the layout where VCE takes place.	Van den Berg, 1985 Mercx,2005
3	Backer-Strehlow-Tang (BTS)	Based on a continuum of numerically determined scaled curves obtained for different flame propagation speeds. **Default Method in ADAM**	Baker, 1996-Baker, 1996 - Tang, 1999 - Tang, 2000 Pierorazio 2005

Table 10: VCE models used in ADAM

European Commission

Vulnerability

PHYSICAL EFFECTS

↓

DAMAGE

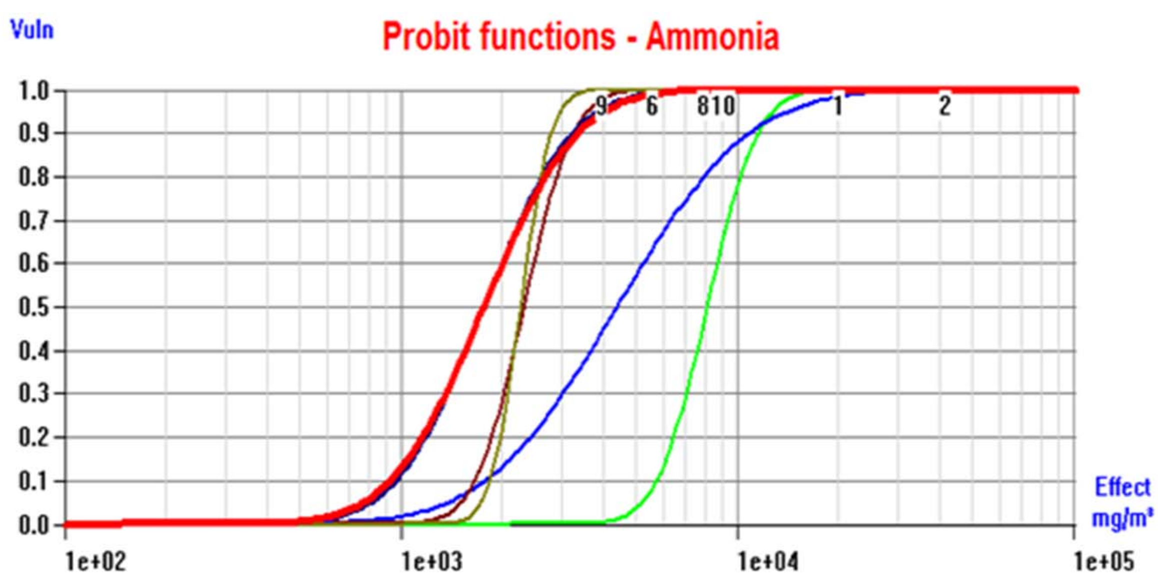
- Quantitative (**Probit Approach**)
- Qualitative endpoints (e.g. **Protective Action Criteria**)

e.g. from a radiation level of 12.5 kW/m2
to the lethality level

European Commission

Quantitative - Probit Approach

- **Probability** to produce the reference damage vs. the level of physical effect
- It depends on the **reference damage type** (injury, death, infrastructure damage)
- For **toxics** is strongly dependent on the substance



Qualitative endpoints

Toxics

Protective Action Criteria
Based on AEGL-EPA, ERPG-AIHA and TEEL-SCAPA
PAC-1, -2, and -3). Each successive associated with an increasingly severe effect

Fires

Radiation intensity (kW/m2)	Observed effect
37.5	Damage to process equipment
12.5	Minimum energy for igniting wood
4	Pain to personnel if unable to reach cover within 20 seconds
1.6	No discomfort for long

Explosions

Peak Overpressure (bar)	Observed effect
0.60	Lethality
0.35	Eardrum rupture
0.30	Structural failure
0.07	Serious injury
0.03	Glass breakage

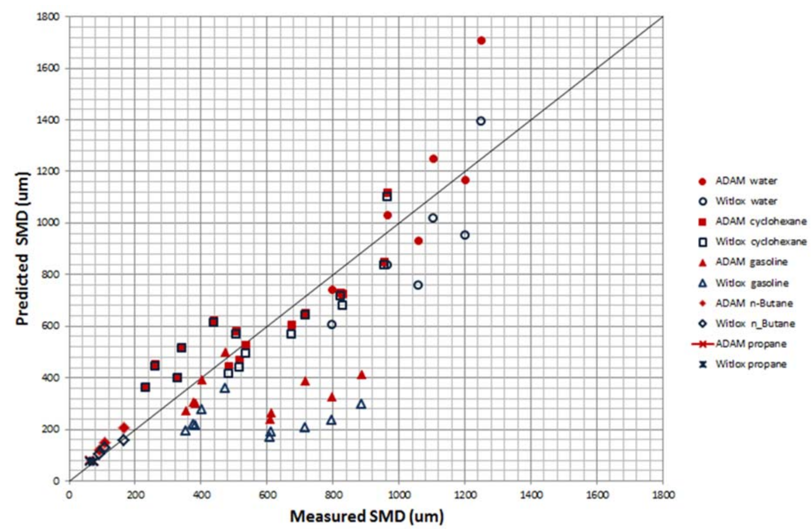
European Commission

Verification/Validation of ADAM

- **Benchmarking** with other existing tools
- Comparing the results with **experimental data**

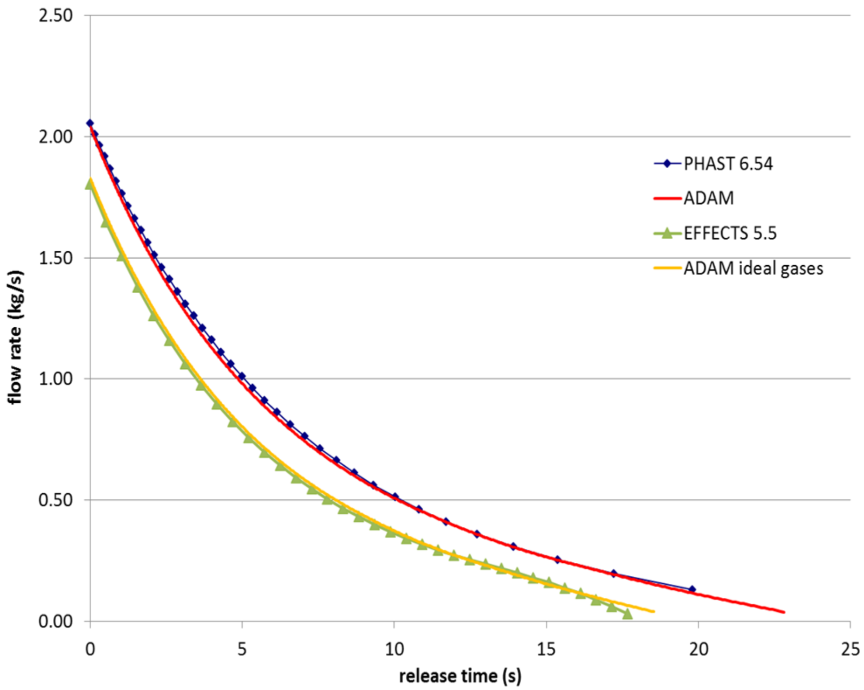
Table 1: Performance measures.

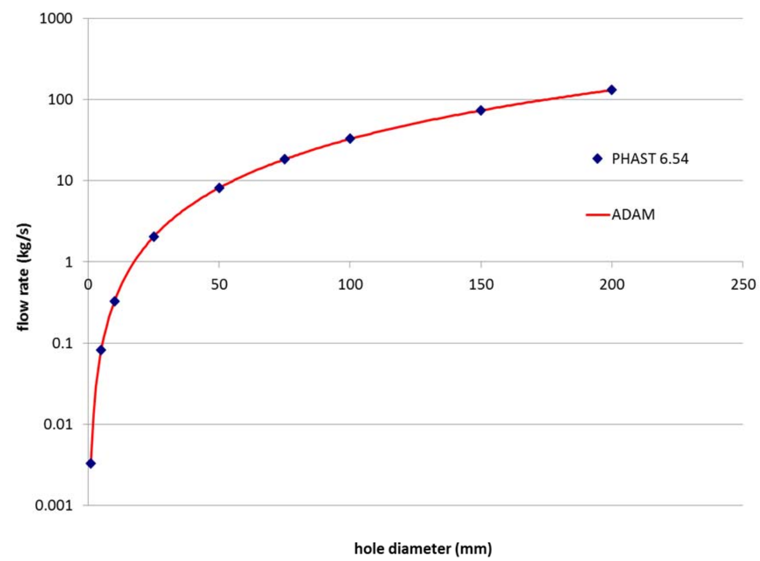
Performance measure	Formula	Description
Fractional Bias (FB)	$FB = \frac{\overline{C_o} - \overline{C_p}}{0.5\ (\overline{C_o} + \overline{C_p})}$	The Fractional Bias (FB) is a measure of mean bias and indicates systematic errors, which allows assessing whether the model underestimates or overestimates the measured values. FB is based on a linear scale and the systematic bias refers to the arithmetic difference between *Cp* and *Co*.
Geometrical mean Bias (MG)	$MG = \exp(\overline{\ln(C_o)} - \overline{\ln(C_p)})$	The Geometrical mean Bias (MG) is also a measure of mean bias and indicates systematic errors, but differently from FB that is based on a linear scale is based on a logarithmic scale. Its use is normally preferred in dispersion related applications because of the wide range of magnitudes involved.
Normalised Mean Square Error (MNSE)	$NMSE = \frac{\overline{(C_o - C_p)^2}}{\overline{C_o} \cdot \overline{C_p}}$	The normalized mean square error (NMSE) is a measure of the overall scatter about the true value and accounts of unpredictable fluctuations. It reflects both systematic and unsystematic (random) errors.
Geometric Variance (VG)	$VG = exp\left[\overline{(\ln(C_o) - \ln(C_p))^2}\right]$	The Geometrical Variance (VG) is, analogously to the NMSE, a measure of the overall scatter about the true value. It is based on a logarithmic scale and its use is normally preferred in dispersion related applications because of the wide range of magnitudes involved.
Correlation Coefficient (R)	$R = \frac{\overline{(C_o - \overline{C_o})(C_p - \overline{C_p})}}{\sigma_{C_o}\, \sigma_{C_p}}$	The correlation coefficient (R) reflects the linear relationship between two variables. It is insensitive to either an additive or a multiplicative factor. A perfect correlation coefficient is only a necessary, but not sufficient condition for accuracy.
Fraction of Predictions within a factor-of-two (FAC2)	FAC2 = fraction of data that satisfies $0.5 \le \frac{C_p}{C_o} \le 2$	The fraction of predictions within a factor of two of observations (FAC2) is the most robust measure, because it is not overly influenced by high and low outlier.



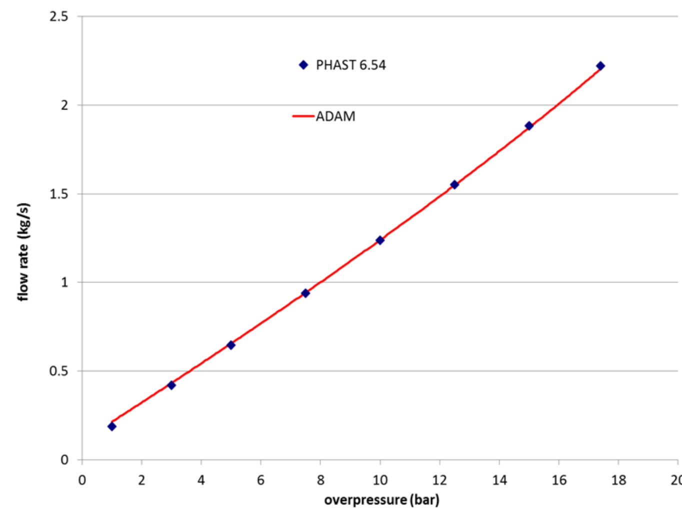
Performance measures as suggested by Chang and Hanna (Chang, 2004), which are normally applied for the validation of airborne dispersion modelling evaluation

Source Term Compressed Gas



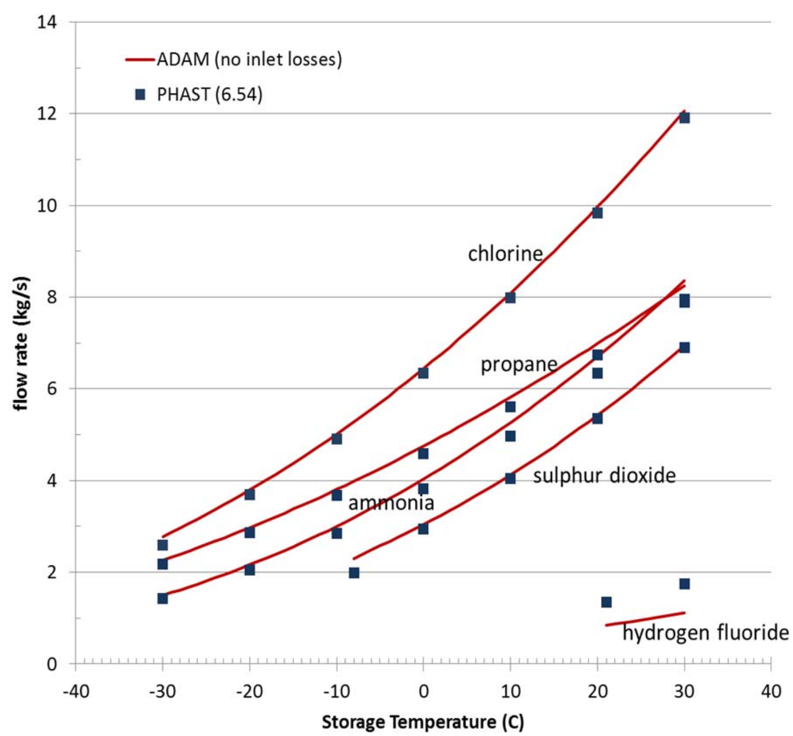


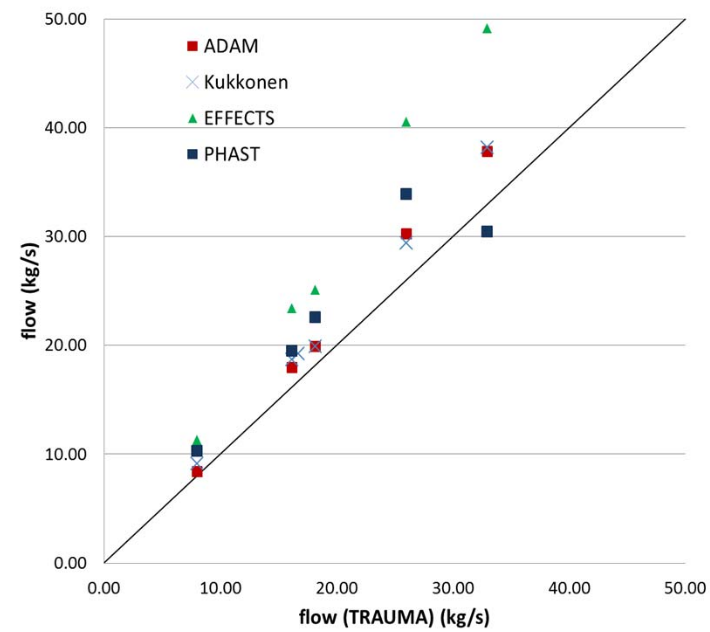
Input Parameter	Value
Substance	Ethylene
Storage temperature	-25 °F
Storage overpressure	250 psi
Vessel Volume	0.5 m³
Hole Diameter	25 mm
Discharge coefficient	Automatic (0.865 in EFFECTs)



Joint Research Centre

Source Term Pressurised Gas

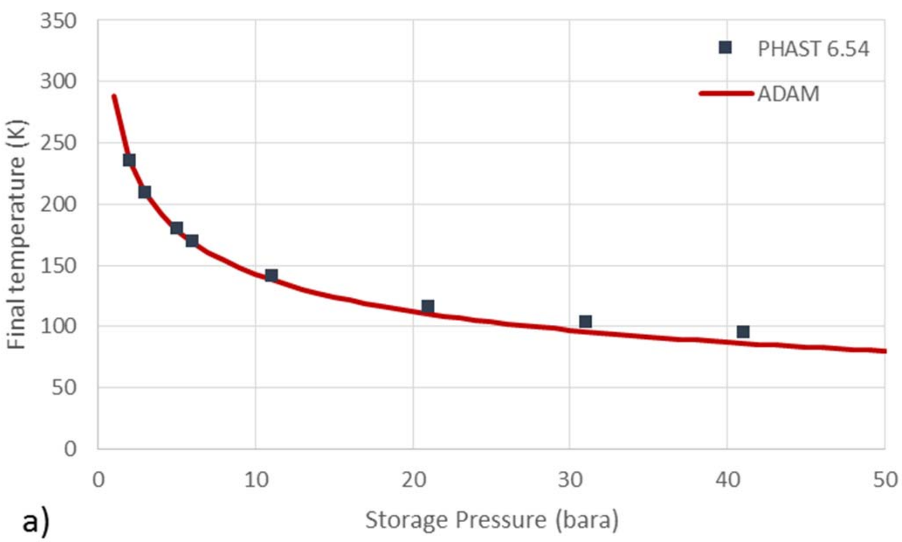




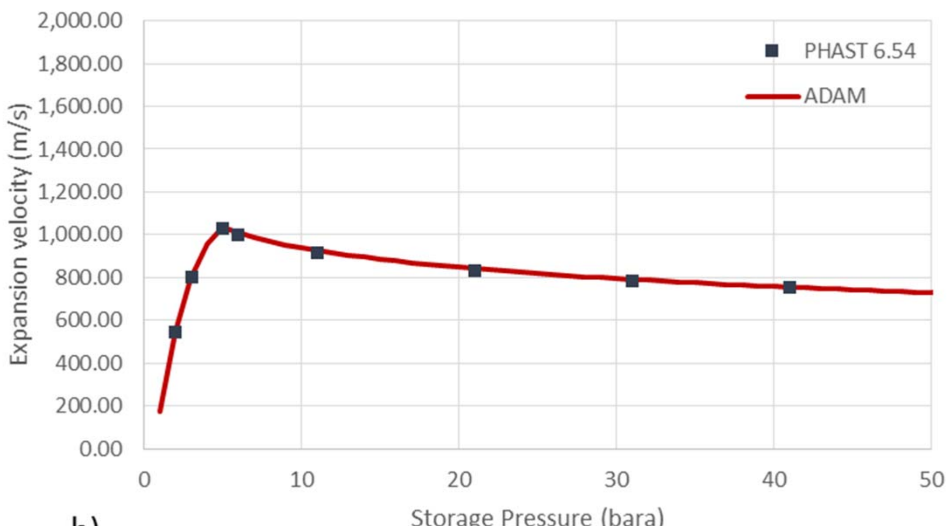
Pipe diameter D = 40mm, Pipe roughness ε = 0.05 mm, no losses in pipe, pipe length at rupture L = 2m

case	*Substance*	*Vessel*		*Pipe structure*	
		Storage T (C)	Storage P (bar)	L(m)	D(mm)
1	Ammonia	15	7.27	3.32	70
2	Ammonia	15	7.27	3.32	100
3	Chlorine	15	5.79	2.25	40
4	Sulphur Dioxide	15	2.76	2.50	100
5	Propane	15	7.26	1.72	70

Hydrogen



a)



b)

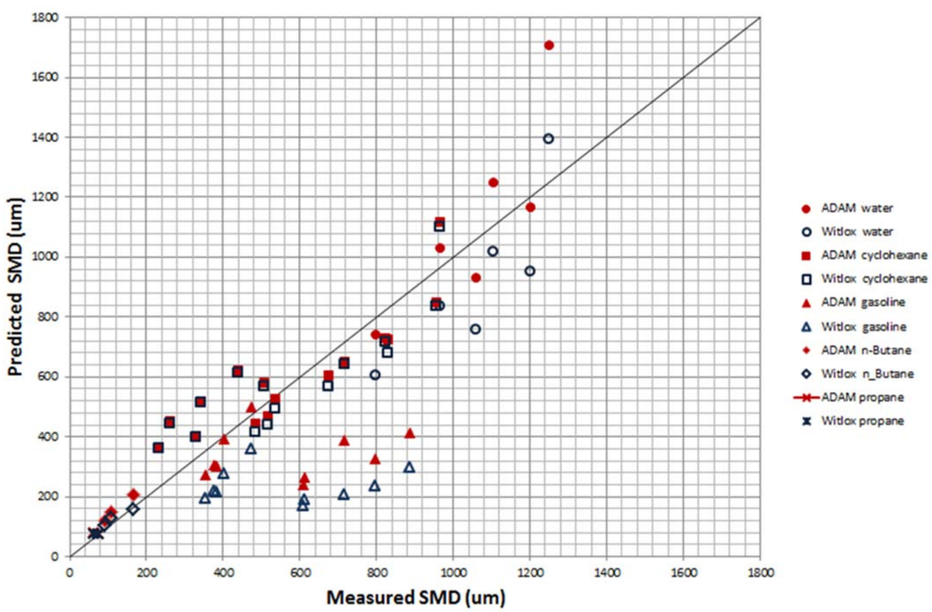
Post expansion parameters vs absolute storage pressure:
a) Flash Temperature,
b) Expansion velocity

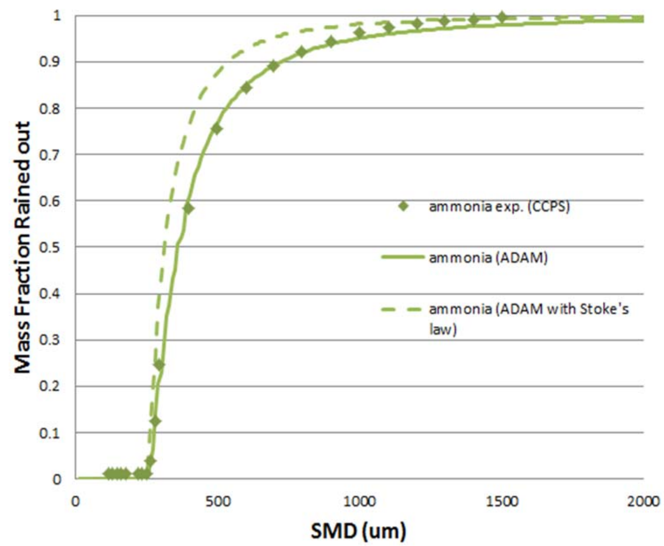
Input Parameter	
Substance	Hydrogen
Storage temperature	288.15
Storage absolute pressure	1.5-50 bara
Vessel Volume	1 m^3

European Commission

Two-phase flashing: rainout

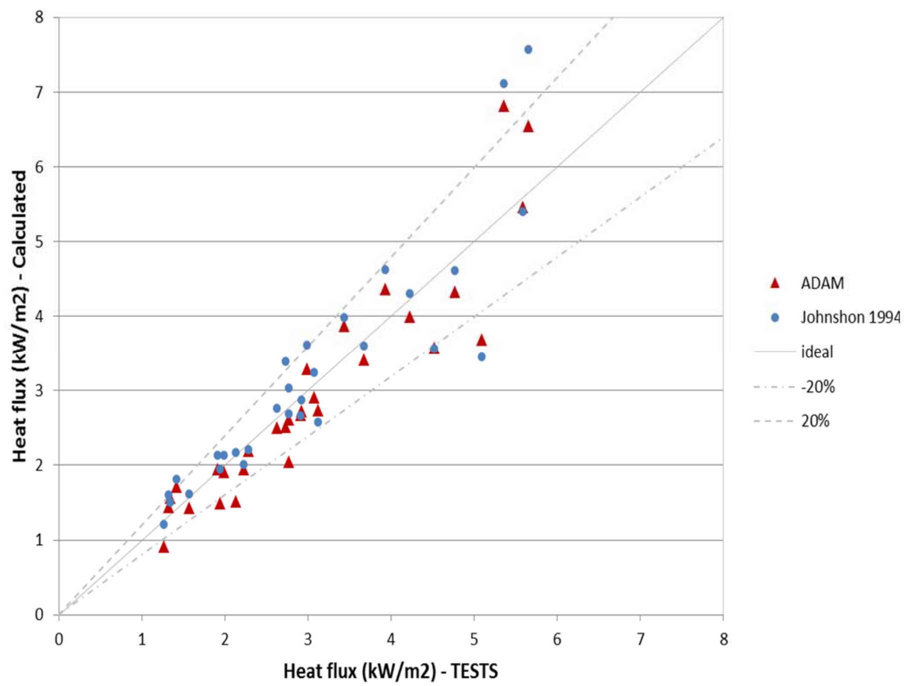
ADAM can use different correlations for the estimate of the Sauter mean diameter (SMD) of the droplet size:



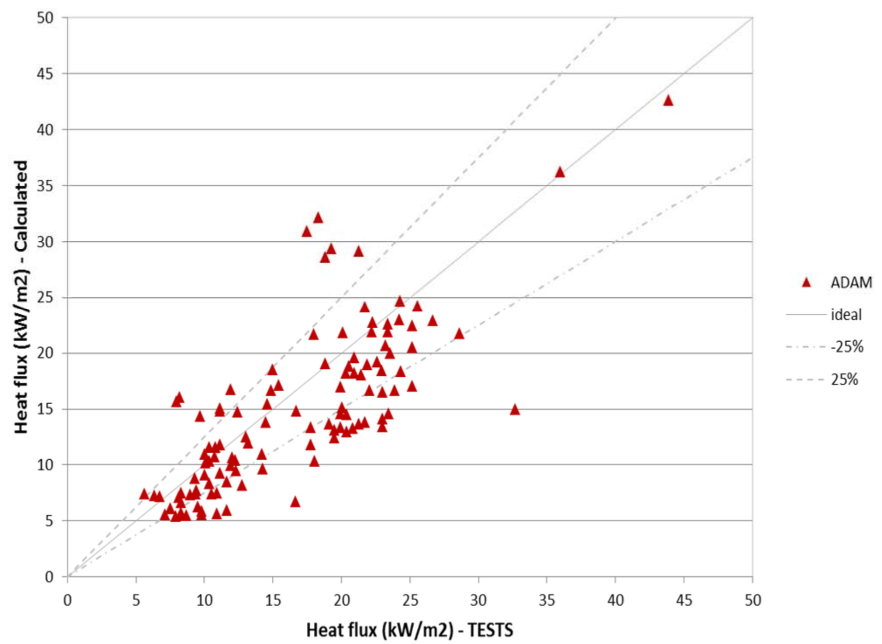


Ambient Temperature:	304K
Ambient Pressure:	90000 Pa
Release Elevation:	1.22 m

Physical Effects Pool Fires



LNG by Johnson, 1992

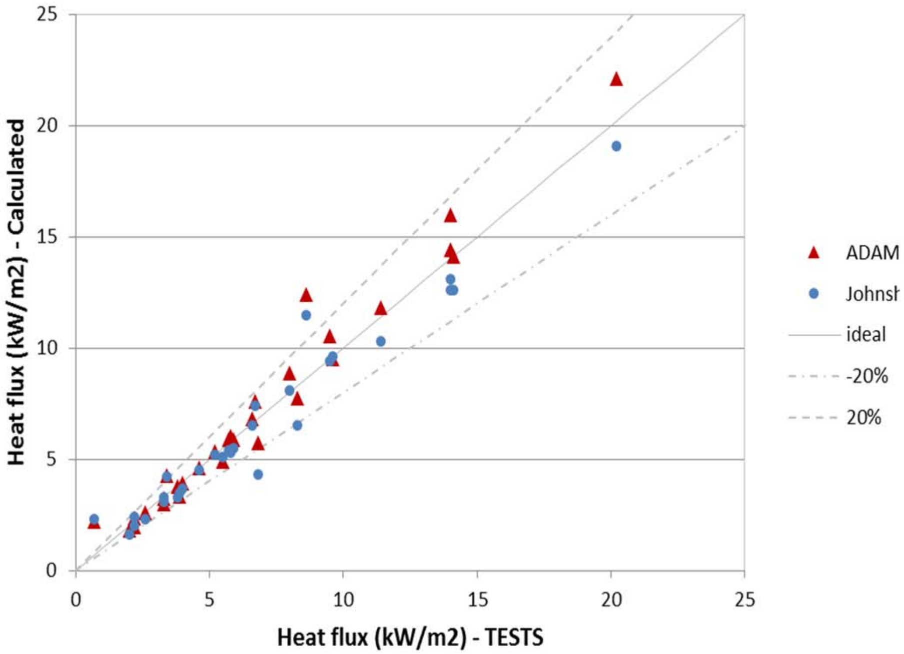


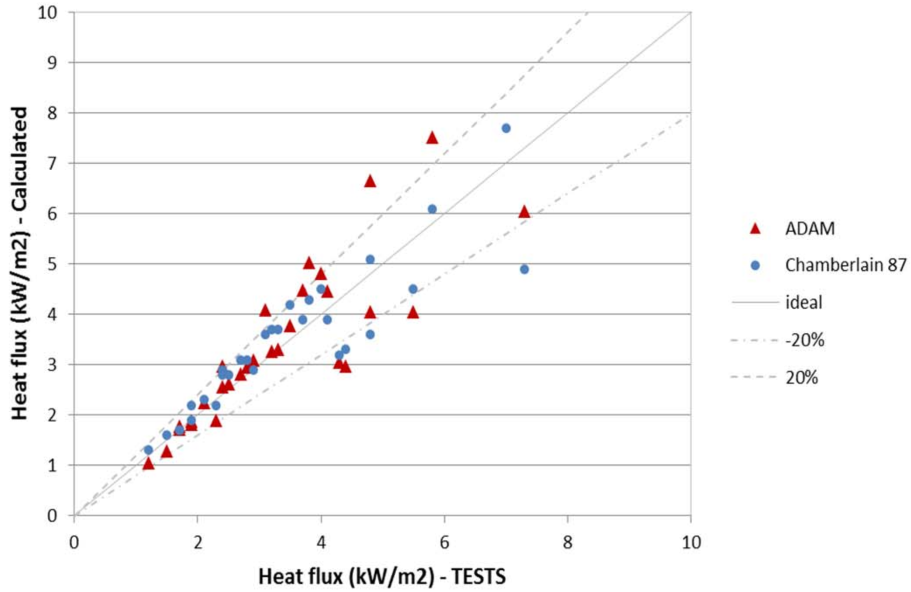
LPG by Welker and Cavin, 1982

Physical Effects

Jet Fires

European Commission





Horizontal Jet
by Johnson, 1994

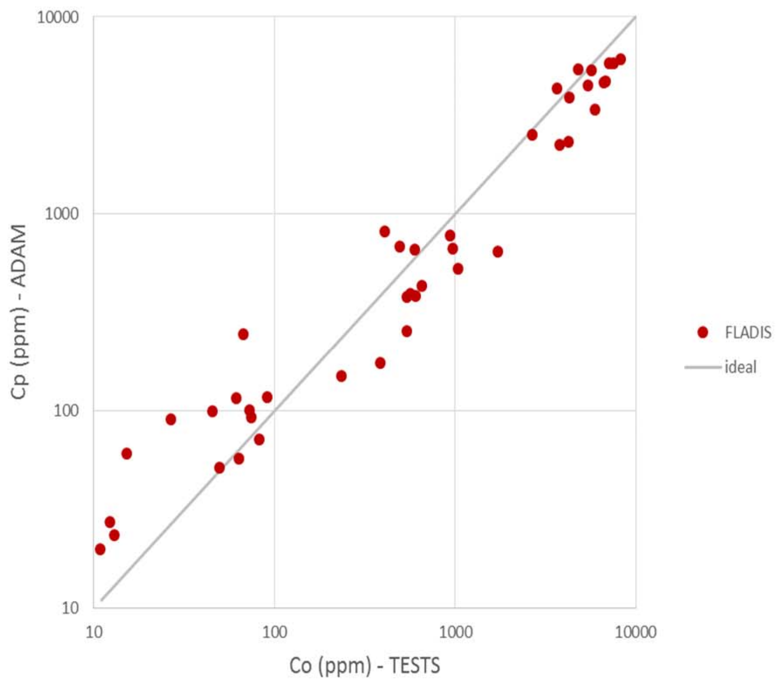
Vertical Jet
by Chamberlain, 1987

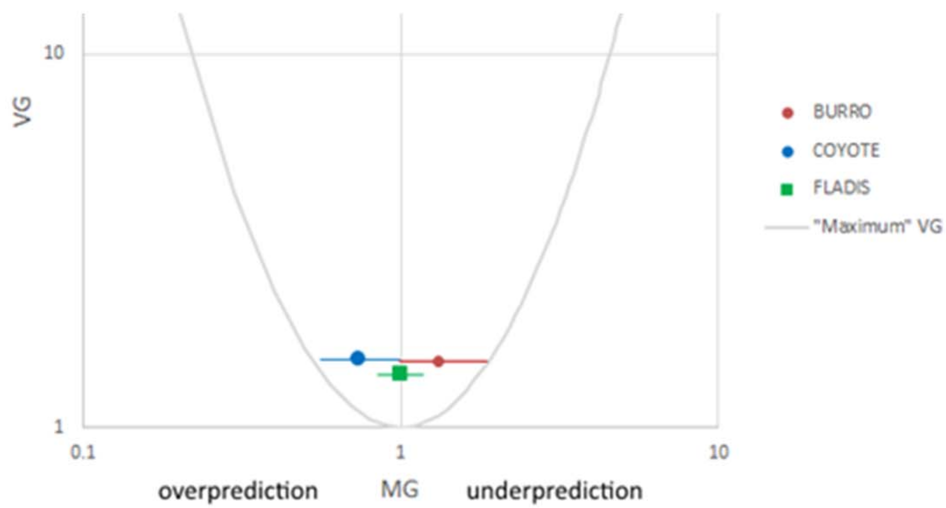
Joint Research Centre

Physical Effects Cloud Dispersion

European Commission

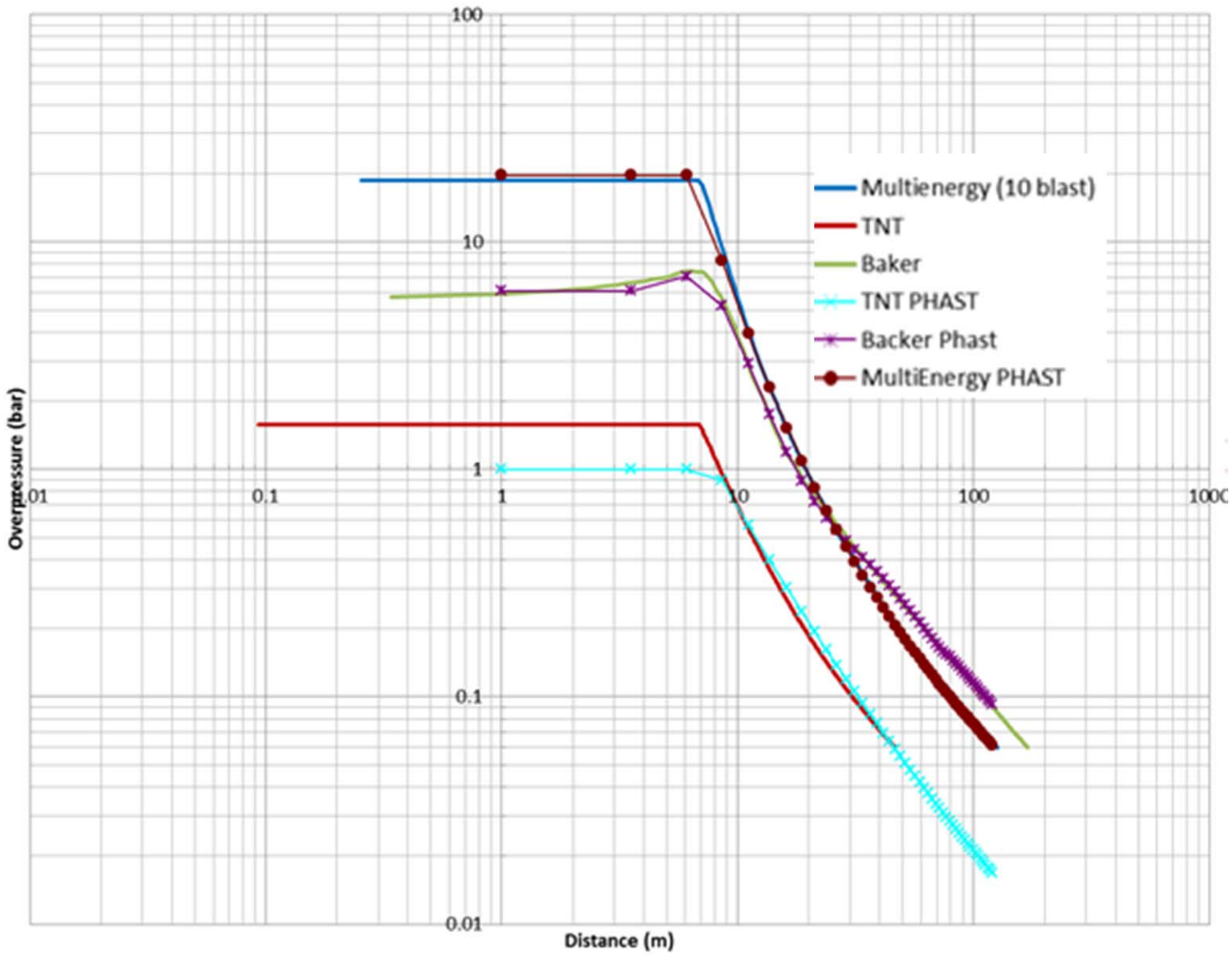
Field campaign	*substance*	*Release type*	*Reference*
Burro	LNG	Evaporating Pool	Koopman, 1982a 1982b
Coyote	LNG	Evaporating Pool	Goldwire, 1983
Desert Tortoise	Ammonia	Horiz. jet (2phases)	Goldwire, 1985
Goldfish	Hydrogen Fluoride	Horiz. jet (2phases)	Blewitt, 1987
Fladis	Ammonia	Horiz./Vert. jet (2phases)	Nielsen, 1994
Thorney Island	Freon12+N2	Instantaneous release	McQuaid, 1985





Physical Effects Explosion

European Commission

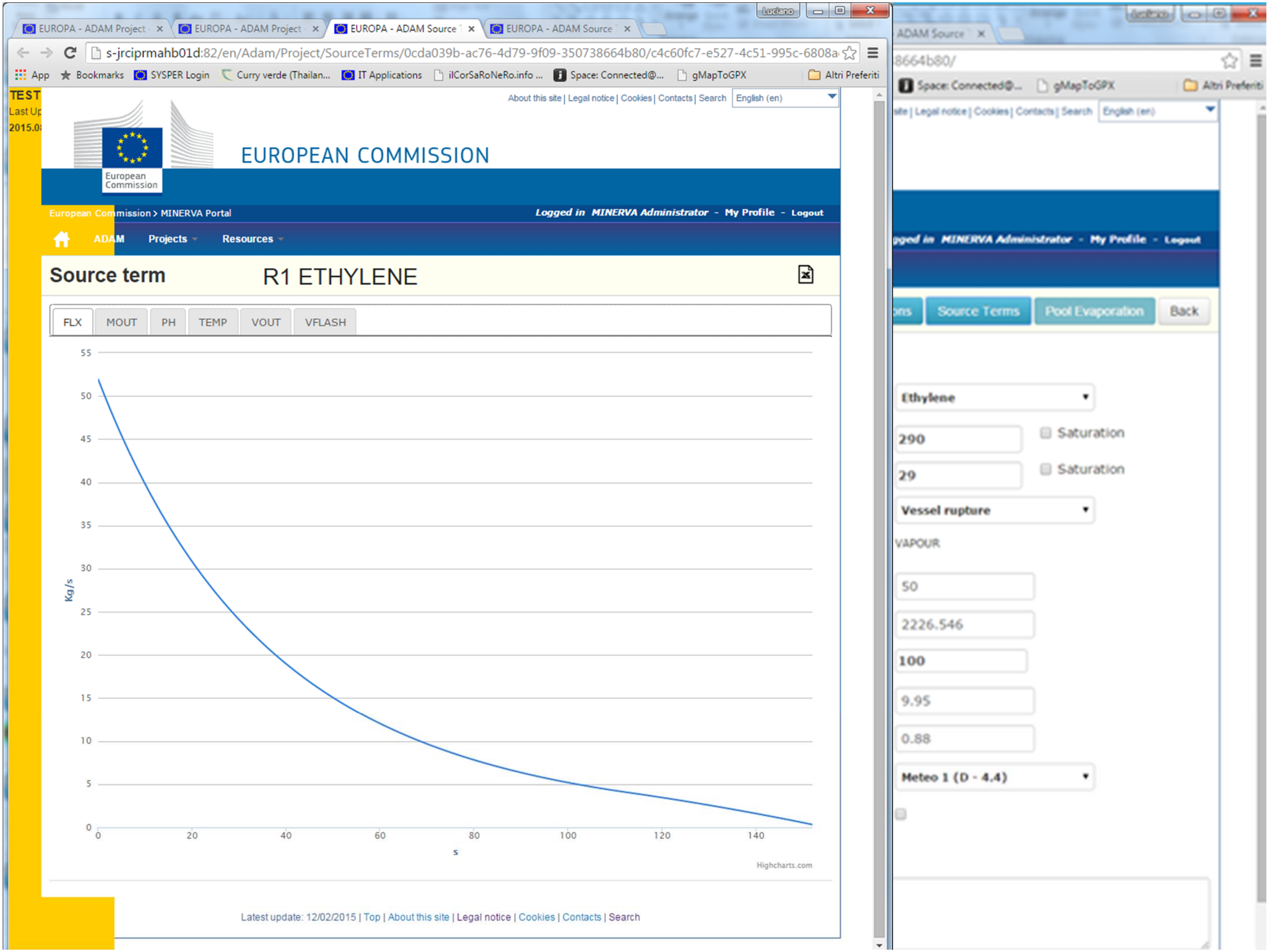


Methane

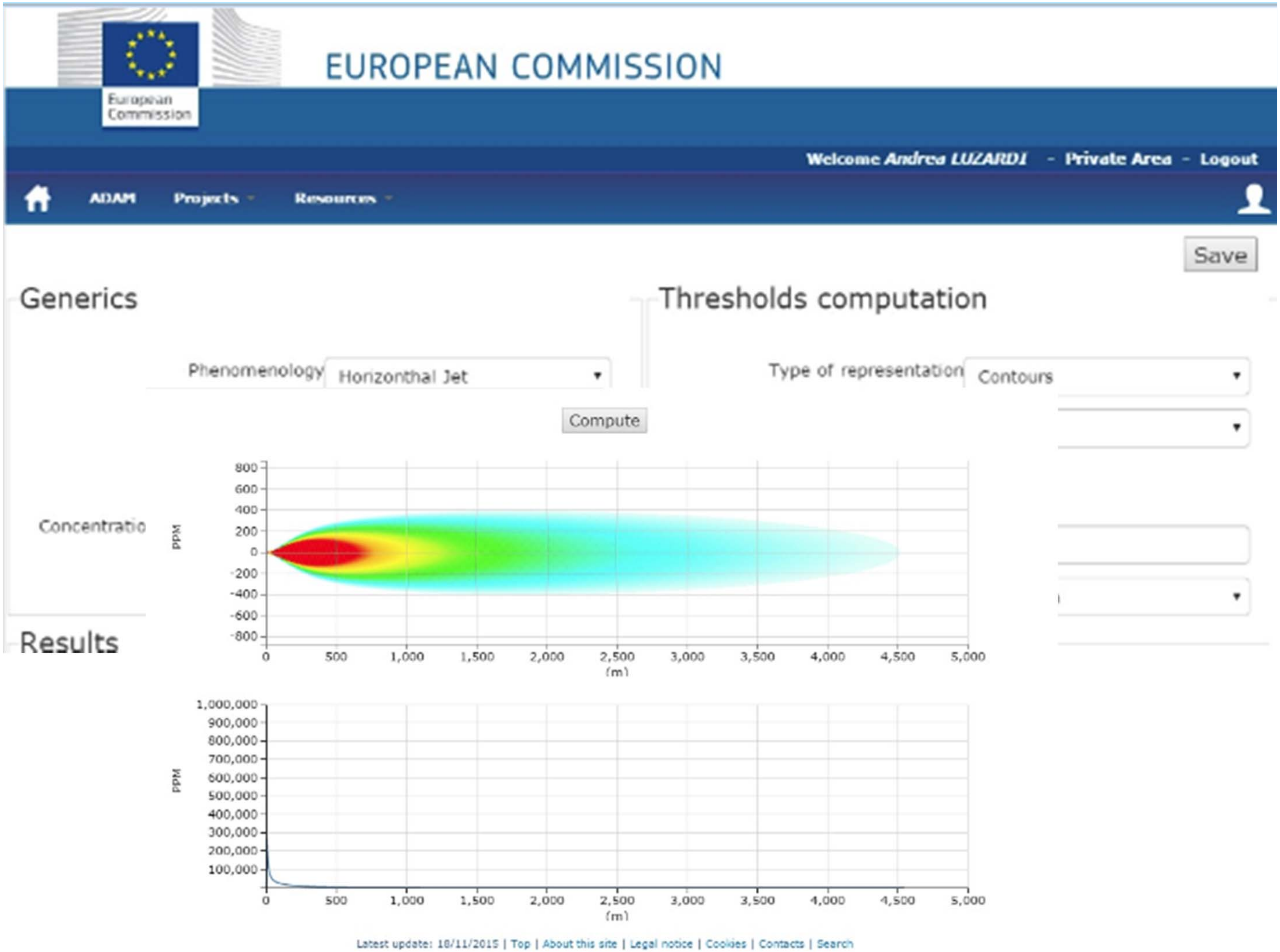
T = 288K
P = 10 bar (overpressure)

45Kg explosive mass, mixed in an air cloud with 538 m^3 volume

Centre



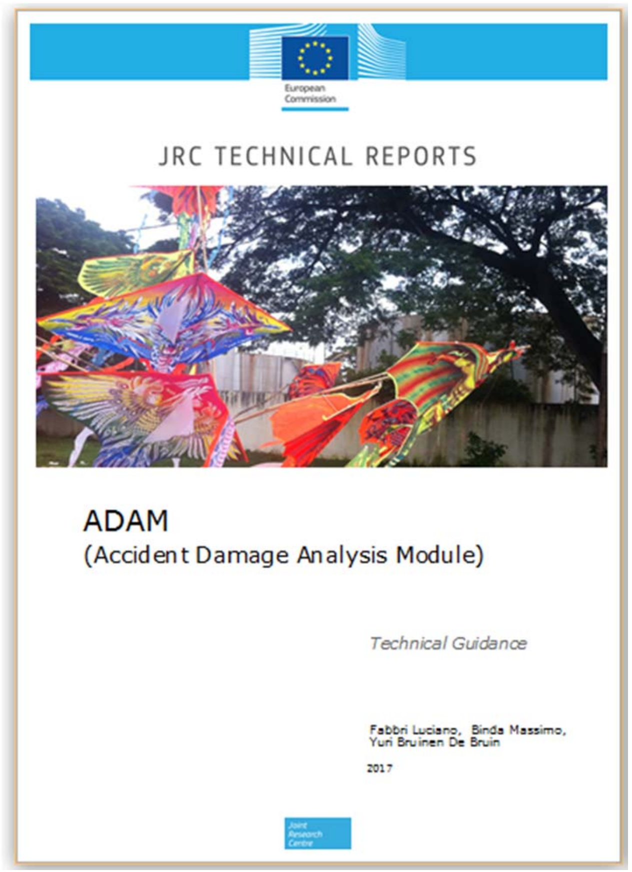
EUROPA - ADAM Project
EUROPA - ADAM Source
s-jrciprmahb01d:82/en/Adam/Project/SourceTerms/0cda039b-ac76-4d79-9f09-350738664b80/c4c60fc7-e527-4c51-995c-6808a
App Bookmarks SYSPER Login Curry verde (Thailan... IT Applications ilCorSaRoNeRo.info ... Space: Connected@... gMapToGPX Altri Preferiti
TEST
About this site | Legal notice | Cookies | Contacts | Search English (en)
EUROPEAN COMMISSION
European Commission
European Commission > MINERVA Portal
Logged in MINERVA Administrator - My Profile - Logout
ADAM Projects Resources
Source term
R1 ETHYLENE
FLX MOUT PH TEMP VOUT VFLASH
Kg/s
s
Highcharts.com
Latest update: 12/02/2015 | Top | About this site | Legal notice | Cookies | Contacts | Search
Source Terms Pool Evaporation Back
Ethylene
290 Saturation
29 Saturation
Vessel rupture
VAPOUR
50
2226.546
100
9.95
0.88
Meteo 1 (D - 4.4)


EUROPEAN COMMISSION
European Commission
Welcome Andrea LUZARDI - Private Area - Logout
ADAM
Projects
Resources
Save
Generics
Thresholds computation
Phenomenology
Horizonthal Jet
Type of representation
Contours
Compute
Concentratio
Results
PPM
(m)
Latest update: 18/11/2015 | Top | About this site | Legal notice | Cookies | Contacts | Search

ADAM Documents

1. Accident Damage Analysis Module (ADAM): Technical Guidance EUR document, 2017 (in Press)

2. Evaluation of the Accident Damage Analysis Module (ADAM) tool, EUR document, 2017 (in Press)



European Commission

JRC TECHNICAL REPORTS

ADAM
(Accident Damage Analysis Module)

Technical Guidance

Fabbri Luciano, Binda Massimo,
Yuri Bruinen De Bruin

2017

Joint Research Centre

European Commission

Future & on-going Developments

- Completion of the porting to the Minerva Web Platform
- Elaboration of a module on Pipelines
- Elaboration of a module on physical blast of vessels
- Software distribution to the interested stakeholders

Joint Research Centre