

Analysing the risks of chemical accidents including those caused by natural hazards (NATECH)

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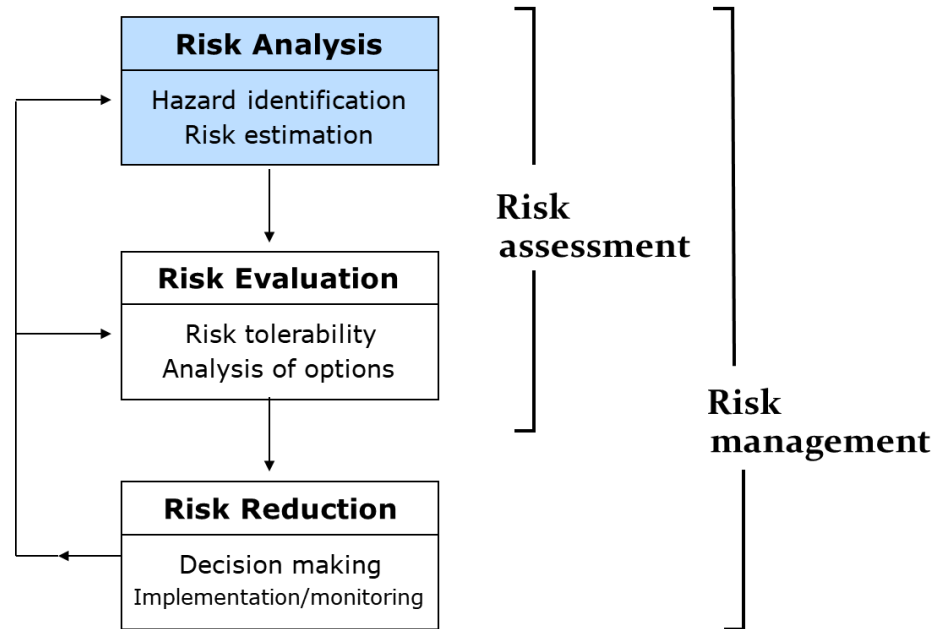
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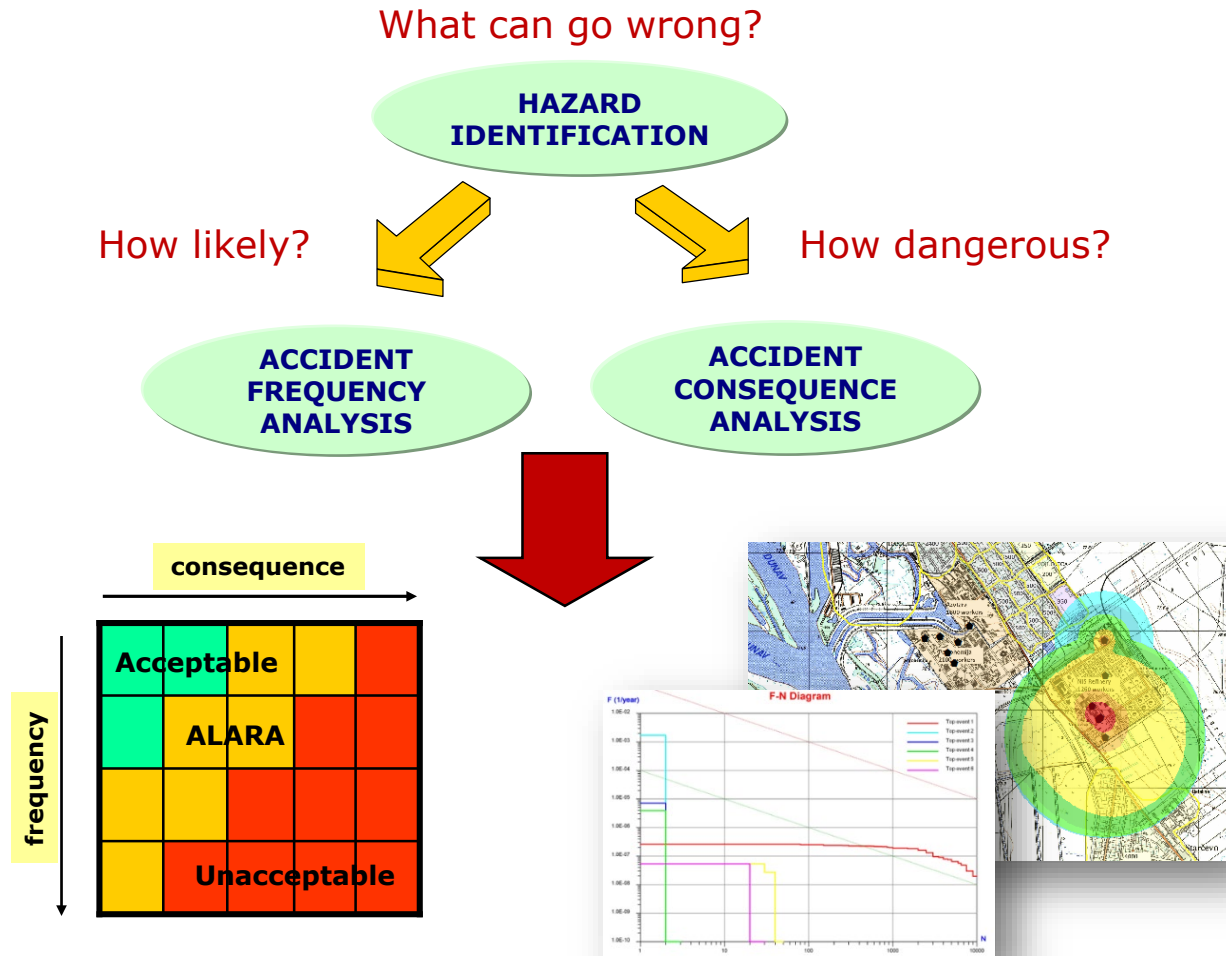
Chemical Accident Risk Analysis

- **Risk analysis** is a prerequisite for understanding likelihood and severity of possible **chemical accidents** originating from hazardous industrial activities.
- The analysis allows:
 - **Identification** of critical equipment.
 - Evaluation of **effectiveness** of prevention and mitigation measures.
 - **Prioritization** of safety measures needed to reduce the risk.
 - **Better** decision making process.

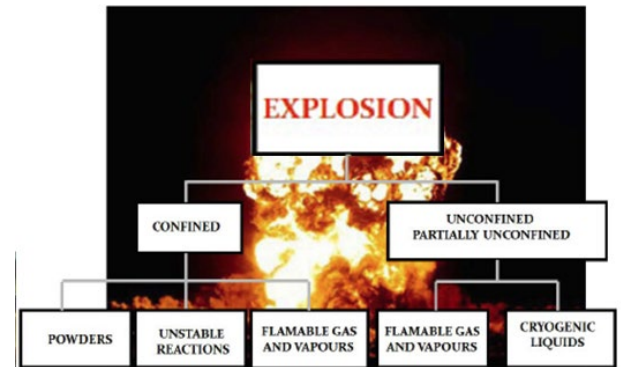
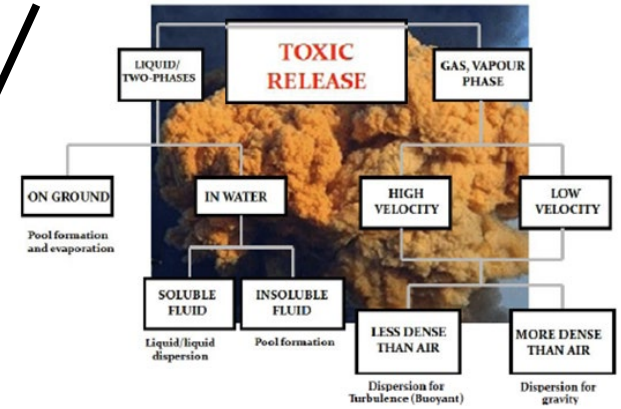
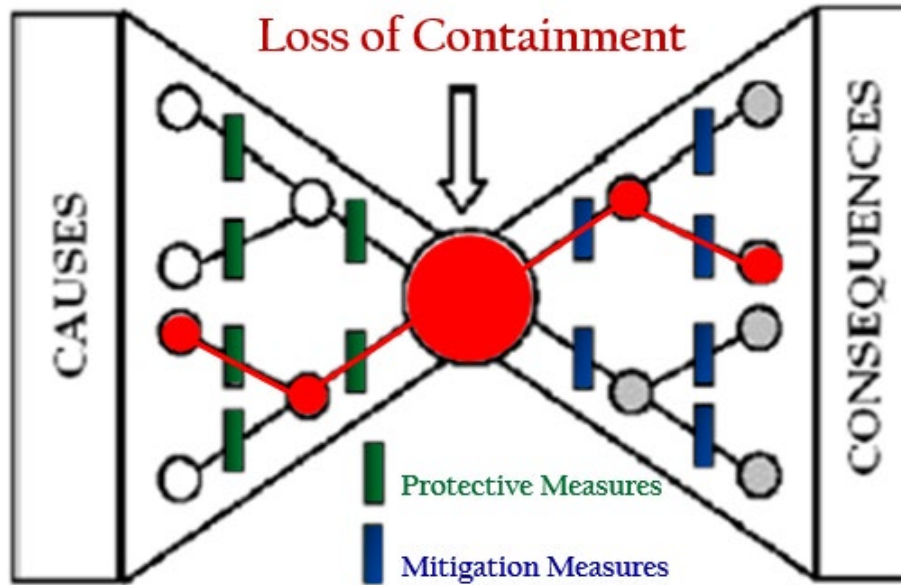


IEC 300-3-9 (1995)
IEC Guide 73 (2002)

Risk Analysis Process



Accident Scenarios

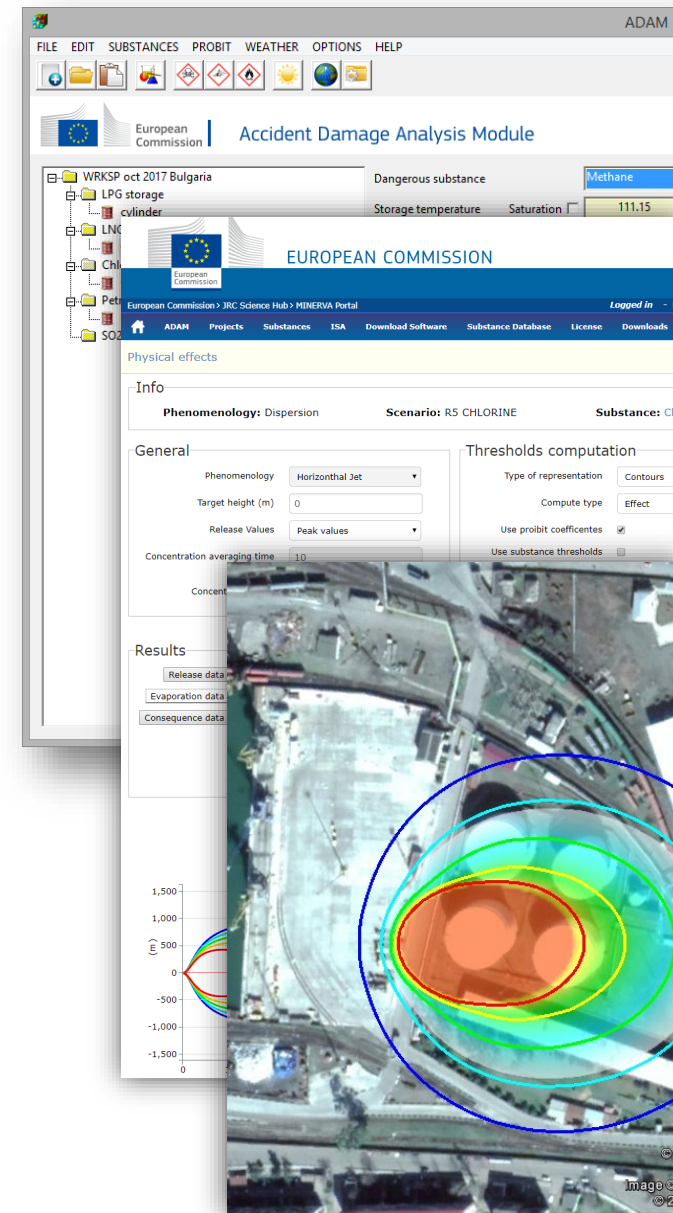


Prerequisites of Chemical Accident Risk Analysis

- Understanding of the **fundamentals** of risk analysis
- Knowledge on industrial units and processes
- Knowledge on accident scenarios
- Knowledge on hazardous consequences
- **Natech:** Knowledge on natural hazard impacts
- **Natech:** Knowledge on Natech accident scenarios
- Methods and models
- **Tools**

Accident Damage Analysis Module

- **ADAM** is a software **specifically developed** to assist the **Competent Authorities** of the EU Member States and Neighbouring Countries in **quickly** assessing the **potential consequences** of a chemical accident.
- It calculates the **physical effects** of an accident in terms of thermal radiation, overpressure or toxic concentration that may result from the loss of containment of a **flammable or toxic** substance.
- **Desktop** and **online** versions are available for governmental and research organisations by request.



ADAM: Methodology

INPUT DATA

Substance Amount
Operating Conditions
Failure mode



Database on
Substances

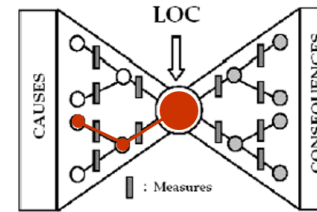
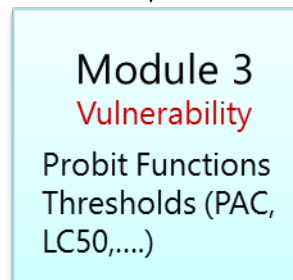
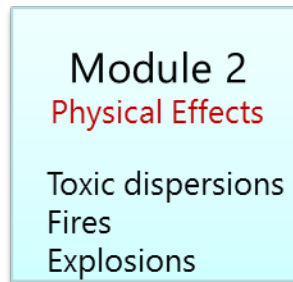
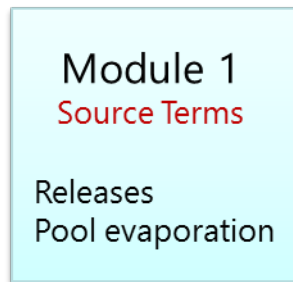


Environment
Conditions



Model
Assumptions

CALCULUS MODULES



State

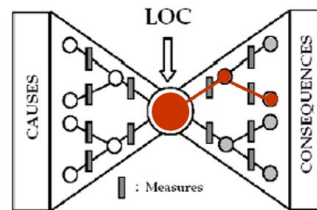
- Compressed Gas
- Non-boiling Liquid
- Pressurised Gas

From

- Vessel
- Pipe
- Pipeline

Type

- Catastrophic release
- Continuous release



Dispersion

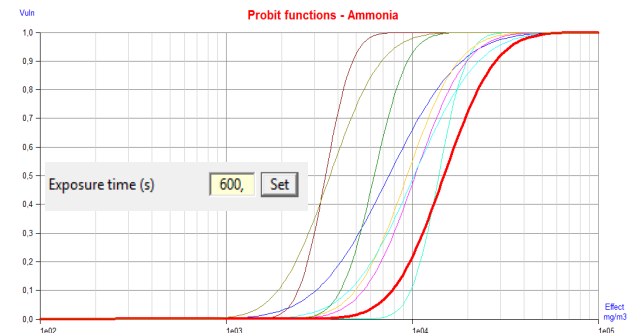
- Toxic clouds
- Flammable clouds

Fire

- Pool fires
- Jet Fires
- Fireball
- Flash Fires

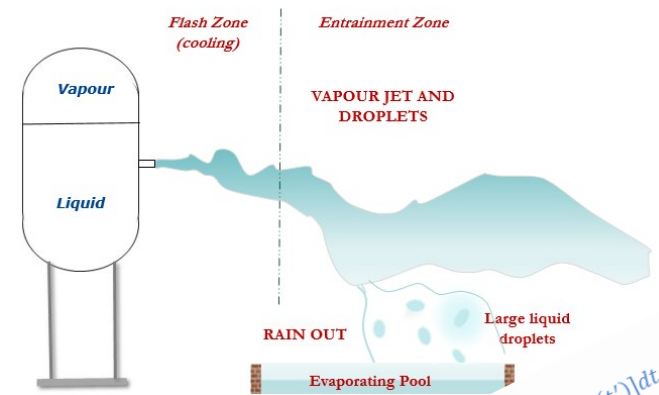
Expl.

- Vapour Cloud Explosion



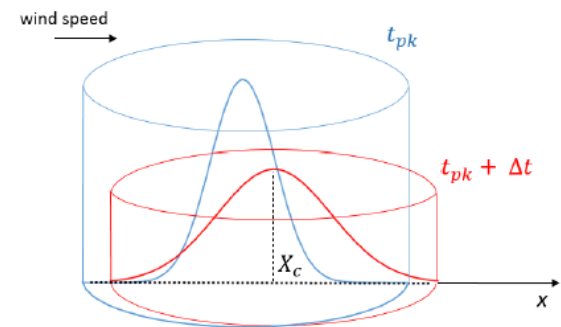
ADAM: Features

- Numerous source and consequence models
 - Instantaneous & finite duration releases
 - Pool formation & evaporation
 - Pool fire (Modified TNO; Shokri & Beyler; Mudan)
 - Jet fire (Chamberlain; Johnson; Cook)
 - Fireball
 - VCE (Equivalent TNT; TNO multienergy; BTS)
 - Toxic dispersion (SLAB, time-dependent, w/rainout)
- Fast analysis
 - Fine-tuned
 - Optimised
- Advanced visualization



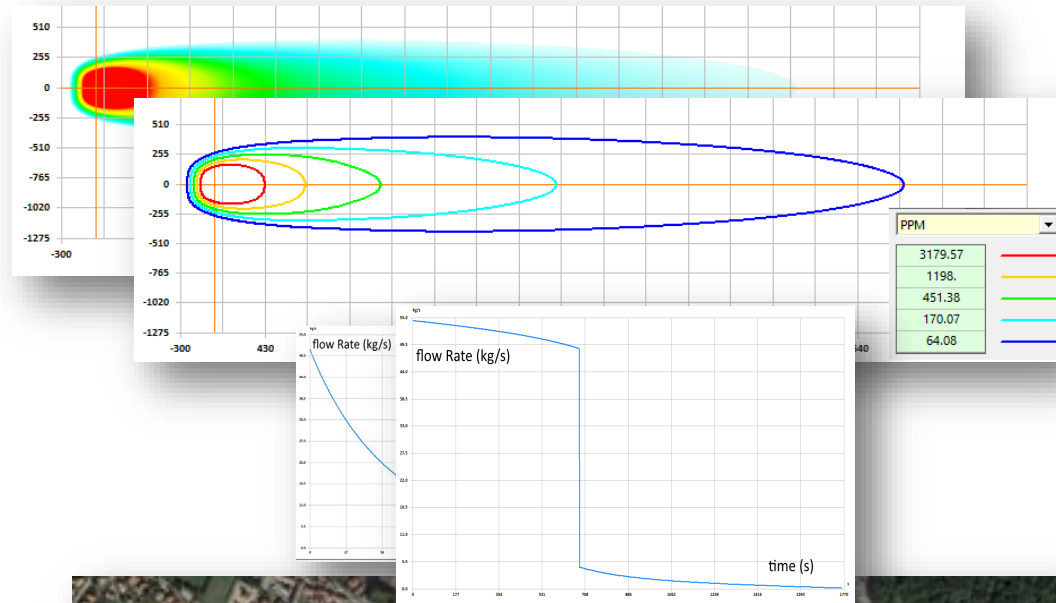
$$H_c = -\lambda \frac{\Phi(t)}{\sqrt{\pi a t}} - \frac{\kappa}{A(t)\sqrt{4\pi a}} \int_0^t (t-t')^{\frac{3}{2}} [\Phi(t)A(t) - \Phi(t')A(t')] dt$$

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



ADAM: Output

- Source term graphs
- Iso-effect contours
- Consequence maps
- Lethality curves / maps
- GIS data
- Tabular data



Contours data

	A	B	C	D	E	F	G	H	I	J	K
1											
2	iso value (ppm)	Max dist. (m)	Area (m ²)								
3											
4	1256.540000										
5	591.785730										
6	278.710069	103.558067	16.836743								
7	131.262548	211.856842	2194.725995								
8	61.820000	337.538330	6766.130179								
9											
10											
11	Downwind dist	Centerline at targ	Centerline height	Maximum center		iso (ppm)	278:				
12		Concentration p				X (m)	Y (m)				
13											
14	41.792015	61.757648	9.342219	1123.431253		96.099075	0.914				
15	46.792015	92.623831	9.260913	961.382705		95.629944	0.908				
16	51.792015	124.697092	9.229857	833.144268		95.424919	0.899				
17	56.792015	155.298036	9.148551	729.895103		95.209946	0.888				
18	61.792015	182.655827	9.048051	645.601913		95.189728	0.880				
19	66.792015	205.851957	8.960744	575.970937		94.781303	0.841				
20	71.792015	224.141450	8.866244	520.010345		94.339241	0.811				
21	76.792015	245.924125	8.753882	467.352057		94.236931	0.800				
22	81.792015	263.407457	8.572076	420.414896		93.878433	0.793				
23	86.792015	274.394740	8.359214	381.935353		93.481499	0.792				
24	91.792015	280.090807	8.014795	350.412845		93.260294	0.619				
25	96.330000	281.627974	7.658514	326.833901		92.962013	0.627				
26	101.330000	280.253242	7.031789	309.540329		92.638254	0.571				
27	106.330000	276.454812	6.211396	288.429845		92.254494	0.507				
28	111.330000	270.912535	5.019528	274.924006		92.027069	0.429				

Input data Results





Natech Risk Analysis

- Characteristics that differ from ordinary chemical accidents
 - **Simultaneous** releases from **multiple sources** over wide areas
 - **Extreme** environmental conditions
 - **Malfunctioning** of accident prevention measures
 - **Unavailability of lifelines** needed for accident mitigation
 - **Competition** for scarce response resources
 - **Hazardous** releases hampering emergency response activities
 - **Non-functional** or **inappropriate** standard civil protection measures
- Necessary additional risk analysis steps
 - **Characterization** of natural hazard severity
 - **Identification** of vulnerable critical equipment
 - **Estimation** of severity and likelihood of **natural-hazard damage**
 - **Estimation** of potential Natech accident scenarios
 - **Analysis** of consequences considering simultaneity and abnormality

Rapid Natech Risk Analysis and Mapping System

- **RAPID-N** is a web-based, publicly available decision-support system for Natech risk analysis and mapping.
- **Unites** natural-hazard impact assessment, Natech scenario development and consequence analysis in **one tool**.
- Features a **modular, extensible** and **collaborative** architecture facilitating data entry and **quick** analysis.
- Users are from **> 120** institutions globally.

Name: HAZUS, On-ground anchored steel tank
Process Unit Type: Storage Tank
Damage Classification: HAZUS (Water Storage Tanks)
Hazard Parameter: Peak ground acceleration (PGA)

Unit:
Type:
Functional Form:

Conditions
Base Type:
Base Support Type:
Construction Material:

Data
No. Damage States:
1. \geq DS2
2. \geq DS3
3. \geq DS4
4. = DS5

Properties
Storage Condition:
Shape:
Roof Type:
Construction Material:
Volume:
Height:
Diameter:
H/D Ratio:
Fill Level:

Substances
No. Substance:
1. Naphtha (C)

References
No Reference:
1. U.S. EPA, "HAZUS"

Fragility Curve
Probability (%) vs. PGA (cm/s²)

Hazard Information
Hazard: 9.9962 %g
Hazard Map: ShakeMap (XML, Gzipped), 2003/10/10 10:18:04

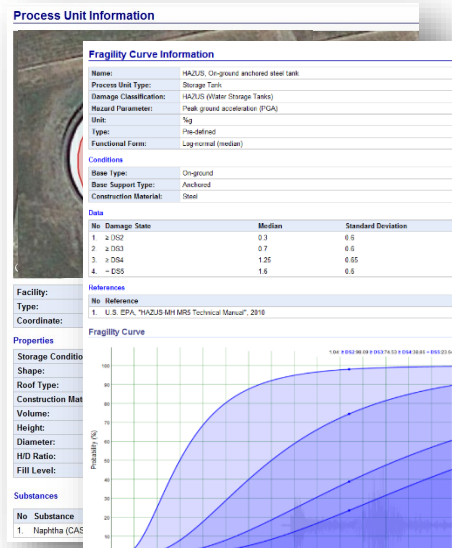
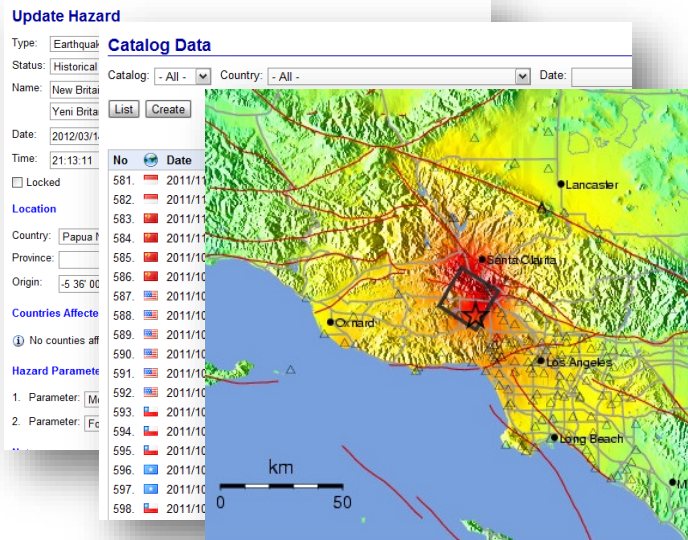
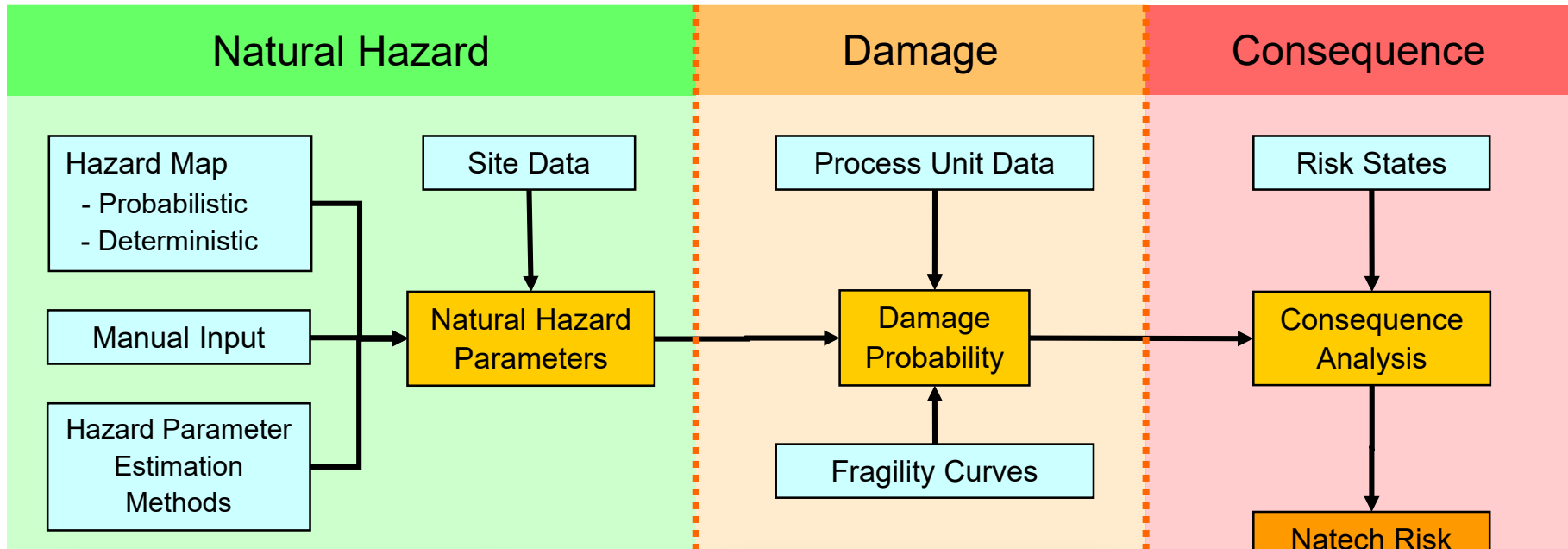
Industrial Plant Information
Industrial Plant: Raffineria di Mezzogiorno S.p.A. - Mezzogiorno Raffineria, Italy
Plant Unit: Storage Tank, 96, Propane (74-98-6)

Damage Estimation
Damage Classification: Auto
Flexible fragility curve selection: No

Industrial Plants
1. Raffineria di Mezzogiorno S.p.A. - Mezzogiorno Raffineria, Italy

No.	Plant Unit	Hazard Parameters	Fragility Curve	Damage Estimate
1.	Storage Tank (96) Propane, Q _{stored} : 878456 kg; V: 1767.1 m ³ ; Shape: Spherical; d: 15 m; r: 7.5 m; ϕ _{hg} : 1 m/m; d _g : 7.5 m; Base Type: Above Ground; V _{storage} : 1767.1 m ³ ; Q _{storage} : 1033478 kg; Storage Condition: Pressure; T _{storage} : 25°C; Storage State: Liquid; Fill Percent: 85 %; H _{fill} : 11.334 m; V _{storage} : 1502.1 m ³ ; f _{m, passive} : 1; f _{m, active} : 1	PGA: 9.9962 %g; d _c : 23.384 km; MM: Rather Strong; MSK: Fairly strong; EMS: Strong; MMI: 5.4687; PGA _n : 41.418 cm/s ² ; PGV: 6.3253 cm/s	OS00-F50-G	\geq DS2: 0.1896% \geq DS3: 1.6883-10 ⁻⁶ %

RAPID-N: Methodology



RAPID-N: Features

- Quick local and regional analysis
 - Multiple units
 - Multiple facilities
- Dynamic model building
 - Scalable
- Extensible modeling platform
 - User-defined estimators
- Data estimation
- Global data coverage
 - > 22,000 earthquakes
 - > 5,500 industrial facilities
 - > 64,500 plant units

Update Property Estimator

Property: Peak Ground Acceleration

Type: Function Exact Estimate

Function: `if ([NEHRP] == 'B') $$ = 0;
if ([NEHRP] == 'C') $$ = 1;
if ([NEHRP] == 'D') $$ = 2;
return exp(4.16 + 0.69 * [Mw] + 1`

Unit: cm/s2 *

Properties	
Storage Condition:	Atmospheric
Shape:	Cylindrical Vertical
Roof Type:	Floating Roof
Construction Material:	Steel
Volume:	22285 m ³ *
Height:	14.00 m*
Diameter:	147.64 ft (45.00 m)
H/D Ratio:	0.3114 m/m*
Fill Level:	85 %v*

Conditions

- Property: Moment Magnitude Value: 4.5 - 7.0 f*
- Property: Epicentral Distance
- Property: Faulting Mechanism

Regions

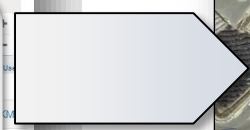
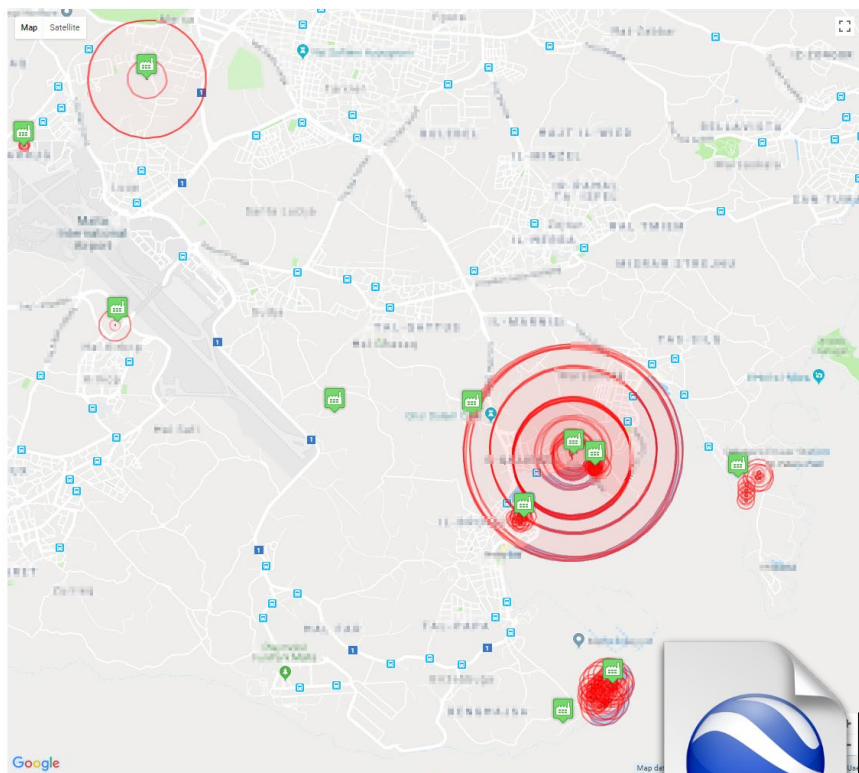
- Greece, Flinn-Engdahl Region
- Southern Greece, Flinn-Engdahl Reg
- Dodecanese Islands, Greece, Flinn-E
- Crete, Greece, Flinn-Engdahl Region

References

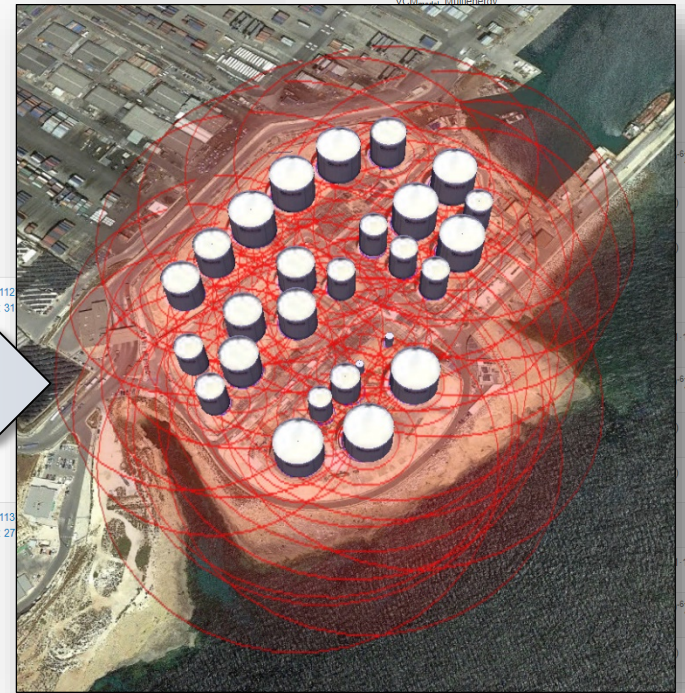
- Margaris, B.; Papazachos, C.; Papaioannou, C.; Theodulidis, N.; Kalogeras, I.; Skarlatoud attenuation relations for shallow earthquakes in Greece", 2002



RAPID-N: Output



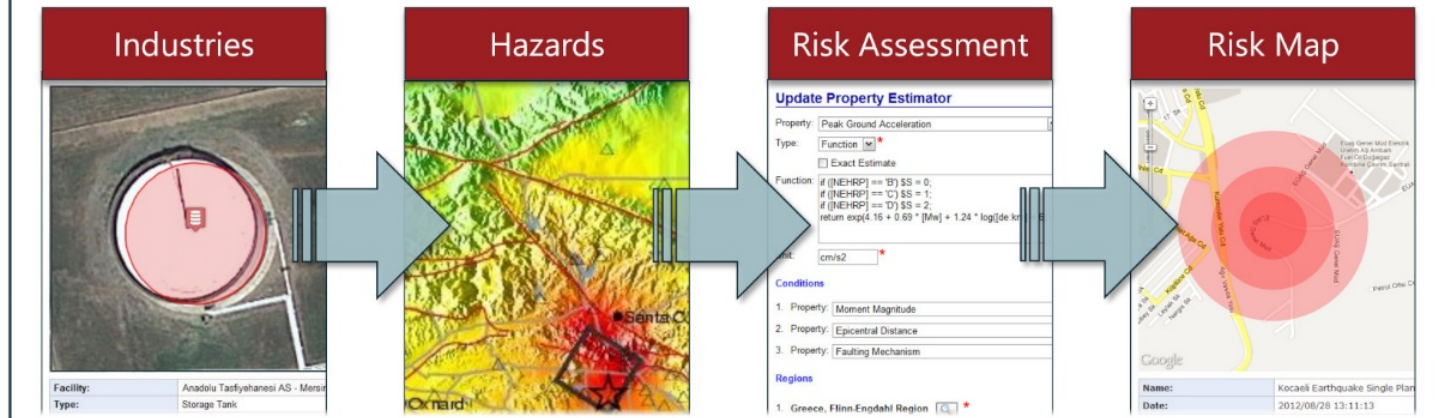
No	Plant Unit	Hazard Parameters	Fragility Curve	Damage Estimate	Scenario Parameters	End-point Distance
1.	Storage Tank (T-111) Gasoline, Q _{stored} : 31850000 kg, V: 34636 m ³ , Shape: Cylindrical Vertical, h: 25 m, d: 42 m, r: 21 m, ϕ _{hd} : 0.5952 mm; d ₀ : 21 m, Obstruction Class: Obstructed, Status: Operational, A _{roof} : 1385.4 m ² , Roof Type: Internal Floating Roof, A _{base} : 1385.4 m ² , Base Type: On-ground, Base Support Type: Anchored, Construction Material: Steel, h _{storage} : 29.721 m, V _{storage} : 41176 m ³ , Q _{storage} : 37470588 kg, Storage Condition: Atmospheric, T _{storage} : 25°C, P _{storage} : 1 atm, P _g : 0 atm, Storage State: Liquid, Fill Percent: 85 %v, h _{lg} : 25.263 m, V _{lost, eq} : 35000 m ³ , D _{dike} : 159.58 m, h _{dike, eq} : 141.42 m, Enclosure: Dike, h _{dike} : 3325 mm, A _{dike} : 20000 m ² , A _{pool} : 20000 m ² , V _{dike} : 51907 m ³ , V _{pool} : 866500 m ³ , f _{m, passive} : 1, f _{m, active} : 1	PGA: 15.11 %g, d _g : 24.651 km	ALA- GSOA	DS1: P(0.9735) DS2: P(0.02621)	Fire/Explosion Event: No Fire, Q _{released} : 0 kg > Fire/Explosion Event: Pool Fire, Q _{released} : 763.06 kg, h _{pool} : 0 m, h _{hole} : 10 mm, A _{hole} : 0.7854 cm ² , C _g : 0.8, h _{fl, hole} : 25.263 m, V _{lost, hole} : 35000 m ³ , Q _{released, hole} : 31850000 kg, P _{damage} : 0.02621, d _{pool} : 10.333 m, LOC State: Minor, L _{pool} : 9.1571 m, V _{g, released} : 0.002396%, V _{l, released} : 0.002396 %v, h _{pool, min} : 1 cm, P _{release} : 0.7862%, h _{release, max} : 6 h, P _{z, release} : 30%, Release State: Liquid, Q _{release} : 168.23 lb/min, h _{release} : 10 min, T _{release} : 25°C, V _{released} : 0.8385 m ³ , A _{pool} : 83.853 m ² , h _{pool} : 0.01 m, F _{max} : 0.2298, h _{name} : 15.895 m, SEP: 83.494 kW/m ² , SEP _{max} : 135.73 kW/m ² , Shape: Cylindrical, VCM: Multienergy	No Consequence 28.67 m, P(7.8621·10 ⁻⁶)
2.	Storage Tank (T-112) Gasoline, Q _{stored} : 31					
3.	Storage Tank (T-113) Gasoline, Q _{stored} : 27					



Name	Matla Case Study Site to 50 km (South-Oriental)
Date	2017/04/15 12:00:00
Hazard	2017/04/15 12:00:00
Hazard Map	ShakeMap (XML, Gzipped), 2017/04/07 16:53:00
Damage Classification	Auto
Flexible fragility curve selection	No
Use private property estimators	No
Vapor Cloud Explosion Model	Multienergy
Pool Fire Model	Solid Surface
Access	Private

RAPID-N in Action: Side Event

SIDE EVENT: Natech Risk Assessment and Mapping with RAPID-N



Natural hazard impacts on hazardous industrial activities can result in **severe cascading industrial accidents (NATECHS)** which may also have **cross-boundary consequences**.

RAPID-N is a unique, publicly available tool that allows the **rapid analysis of NATECH risk**.

Please join us for this side event hosted by **EC Joint Research Centre**, which will introduce the basics of **NATECH risk assessment** and **demonstrate** the capabilities of RAPID-N with case-studies.

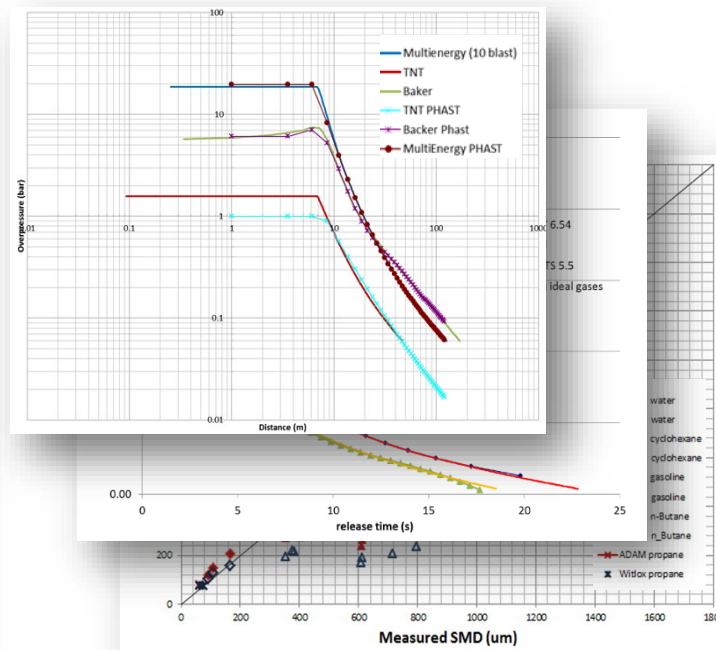
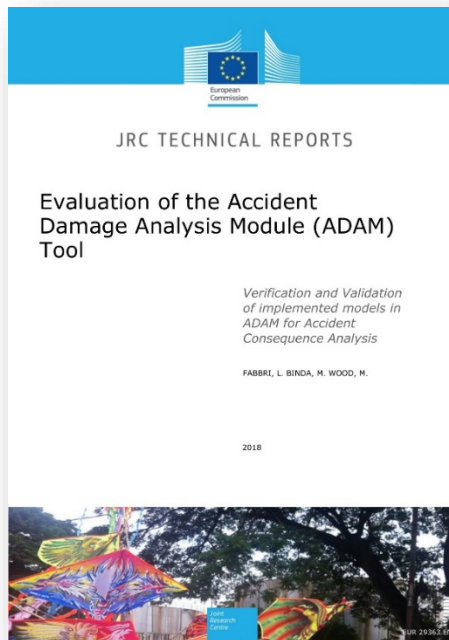


Tuesday, December 4th

14:15 - 15:00, Room VII

Usability: Quality Control

- Benchmarking with other existing software tools
- Comparing the results with experimental data
- Comparing the results with reference data

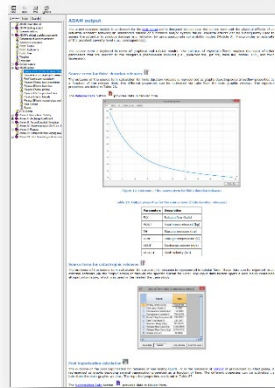


Unit	g
Exact Estimate	No
Validity Conditions	Moment Magnitude: 3.3-
Precedence	Auto
Disabled	No
References	Boatwright, J.; Bundock, magnitude inferred from
Notes	See Douglas (2004), pag Validation: M = 5.0, d = 10 km, NEH M = 6.0, d = 10 km, NEH M = 5.0, d = 100 km, NE
Access	Public

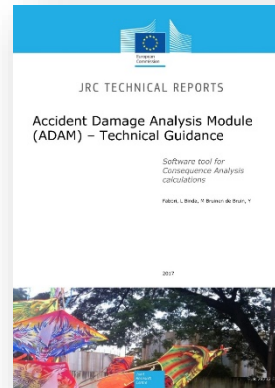
[EUR 29363 EN](#)

Usability: Resources

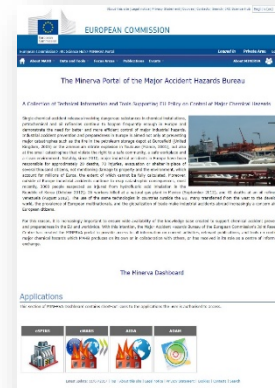
- ADAM



User Manual (Help)

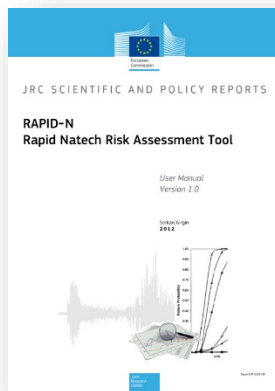


Technical Guidance

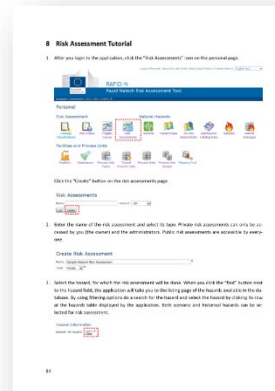


Minerva Portal

- RAPID-N



User Manual



Training Manual*



Case Studies

Potential Users and Applications

- Risk analysis specialists
- Public authorities
- Inspectors
- Emergency managers
- Emergency responders
- Risk management
- Land-use planning
- Emergency planning
- Early warning
- Preliminary damage assessment
- Preliminary consequence analysis



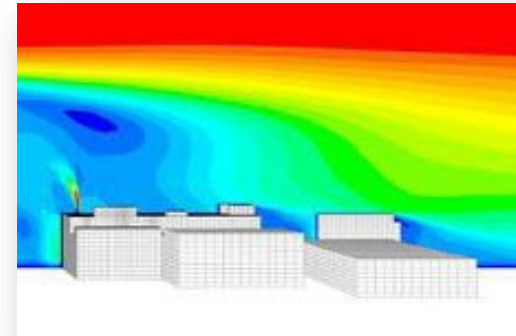
Support and Capacity Building

- Hands-on trainings
 - EU Member States
 - EU E&IA countries
 - EU Candidate and Neighbour countries
 - Safety experts (e.g. MoE, Bulgaria)
 - Research organisations (e.g. INERIS, France)
- Emergency management support
 - [EU RICHTER Caraibes 2017](#)
 - EDREX
- Technical support
 - Regional risk analysis (e.g. [Marsaxlokk, Malta](#))
 - User support (E-mail, not 24/7)



On-going R&D and Outlook

- ADAM
 - Software distribution to the interested stakeholders
 - Systematic sensitivity studies
 - Module on pipelines
 - Module on physical blast of vessels
 - Module on CFD for atmospheric dispersion
- RAPID-N
 - Enhanced scientific computation framework
 - Industrial data set
 - Early warning and alerting
 - Offline version
 - **ADAM / RAPID-N integration**



Stay in touch



ADAM: <http://adam.jrc.ec.europa.eu>



RAPID-N: <http://rapidn.jrc.ec.europa.eu>



EU Science Hub: ec.europa.eu/jrc



Twitter: [@EU_ScienceHub](https://twitter.com/EU_ScienceHub)



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LinkedIn: [Joint Research Centre](https://www.linkedin.com/company/joint-research-centre)



YouTube: [EU Science Hub](https://www.youtube.com/EU_Science_Hub)

References

- Fabbri, L., Binda, M., and Bruinen de Bruin, Y. (2017) Accident Damage Analysis Module (ADAM) – Technical Guidance, EUR 28732 EN, [doi:10.2760/523638](https://doi.org/10.2760/523638)
- Fabbri, L., Binda, M., and Wood, M. (2018) Evaluation of the Accident Damage Analysis Module (ADAM) Tool, EUR 29363 EN, [doi:10.2760/582513](https://doi.org/10.2760/582513)
- Girgin, S. (2012) RAPID-N: Rapid Natech Risk Assessment Tool - User Manual, EUR 25164 EN, [doi:10.2788/54044](https://doi.org/10.2788/54044)
- Girgin, S. and Krausmann, E. (2013) RAPID-N: Rapid Natech risk assessment and mapping framework, Journal of Loss Prevention in the Process Industries, [doi:10.1016/j.jlp.2013.10.004](https://doi.org/10.1016/j.jlp.2013.10.004)
- Girgin, S. and Krausmann, E. (2017) Case-study Application I: RAPID-N, in “Natech Risk Assessment and Management”, Krausmann et al. (eds.), Elsevier, [doi:10.1016/B978-0-12-803807-9.00010-3](https://doi.org/10.1016/B978-0-12-803807-9.00010-3)
- ADAM: <http://adam.jrc.ec.europa.eu>
- RAPID-N: <http://rapidn.jrc.ec.europa.eu>