Approaches to Natech risk assessment

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Natech risk:

- Natural-hazard triggered technological accidents (Natechs) can have serious impacts on the population, environment, and economy.

- For Natech accident prevention and consequence mitigation, targeted prevention, preparedness and response are needed:
  - Natech-prone areas should be identified.
  - Natech risks must be assessed in a systematic way.

- Natech risk maps are considered a high priority need.

- Hardly any Natech risk maps exist in the EU/OECD.
Studies show that 5% of accidents in industrial accident databases were caused by natural hazards

AND

There is a bias towards high-consequence accidents in databases, so the actual number of Natech accidents is probably higher

“Well he certainly does a very thorough risk analysis.”
(Natech) risk assessment

Main questions to address:

**WHAT can go wrong?**

**HOW likely is it?**

**WHICH consequences are expected?**
Qualitative versus quantitative

**Qualitative:** requires little effort and no specific RA expertise → understand which hazards need to be prioritized to reach pre-defined risk reduction targets

**Quantitative (QRA):** powerful technique but application is complex, time-consuming and requires skilled resources → well-accepted Framework for QRA exists, allows identification of system weaknesses and the prioritization of safety measures

**Natech RA:** regardless of approach chosen, extensions to both qualitative and quantitative RA need to be made to fully consider Natech characteristics
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Step 1 Characterization of the natural hazard

1) Identify and describe the natural hazard in terms of severity and frequency

2) Identify the areas on-site a hazardous installations potentially affected by a natural hazard
A hazard missed is a hazard uncontrolled

Remind me again why the hazard was dismissed...

Er, well, because it has never happened here – until now, that is.
ad 1) **Identify and describe the natural hazard in terms of severity and frequency**

Is my installation located in a natural-hazard prone area, e.g. in an earthquake or flood zone?

- Natural-hazard maps (e.g. from authorities)
- Reports or anecdotal information from past events

**Which are possible natural-hazard sources, e.g. for floods:**

- High groundwater during long periods of rainfall
- River floods
- Flash floods
Surface elevations in Houston Ship Channel

Hurricane surge tide projected at 6-7.5m for a 100-yr storm

*From Blackburn & Bedient, Learning the lessons of Hurricane Ike, 2010*
ad 1) Identify and describe the natural hazard in terms of severity and frequency

Every natural hazard has its own specific severity parameters:

- **Earthquakes**: Peak ground acceleration (PGA), peak ground velocity (PGV), ground displacement
- **Floods**: Water height and speed, flood duration

There are methods to estimate the occurrence frequency of natural hazards with a given intensity at a specific location:

- e.g. Probabilistic Seismic Hazard Analysis (PSHA) for earthquakes
ad 2) **Identify the areas in a hazardous installation potentially affected by a natural hazard**

**Given a certain hazard severity, which areas in my installation will be hit by the natural hazard I identified as relevant?**

- Need to know site topography and location of structures and equipment

- Criteria on which assessment is based usually determined by the regulator (e.g. 100-yr flood, 475-yr earthquake). Operator can decide to go above minimum requirements

- **Climate change is a game changer!** Affected operators recommend using worst-case scenarios for the on-site hazard identification
Illustration of storage tank vulnerability to a major surge event.

Graphic courtesy of Dr. Hanadi Rifai of the University of Houston and the SSPEED Center at Rice University.
Step 2 Identification of critical equipment

Prioritize the most dangerous equipment likely affected by a natural hazard. Selection criteria are:

- Type and quantity of hazardous substances processed or stored
- Equipment operating conditions (temperature, pressure)
- Severity of potential accident scenarios
- Involvement in past Natech accidents (e.g. from accident database analyses)

For flood/rain/tsunami-related Natech accidents consider also the potential reactivity of releases with the water
<table>
<thead>
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<th>Critical equipment categories</th>
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<tbody>
<tr>
<td><strong>Storage</strong></td>
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<tr>
<td><strong>Processing</strong></td>
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<tr>
<td><strong>Auxiliary</strong></td>
</tr>
<tr>
<td><strong>Pipelines</strong></td>
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</tbody>
</table>
Step 3 Identification of damage severity and accident scenarios

Which natural-hazard intensity causes how much equipment damage? Answers can come from:

- Natech accident analyses
- Numerical modelling (structural engineering)

Detailed damage models are available for some natural hazards (e.g. earthquakes) and some types of equipment:

- BUT: use not practicable for risk assessment of a whole chemical complex
- INSTEAD: Possibility to define discrete damage states (e.g. as in HAZUS)
<table>
<thead>
<tr>
<th>Damage state</th>
<th>Damage category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS1</td>
<td>None</td>
<td>None or insignificant structural damage</td>
</tr>
<tr>
<td>DS2</td>
<td>Light</td>
<td>Slight movement of tank from support</td>
</tr>
<tr>
<td>DS3</td>
<td>Moderate</td>
<td>Failure of some connected piping; repairable damage to the tank support system; moderate likelihood of release of tank contents</td>
</tr>
<tr>
<td>DS4</td>
<td>Severe</td>
<td>Failure of most piping connections; tank support system completely failed; almost certain release of tank contents</td>
</tr>
<tr>
<td>DS5</td>
<td>Total</td>
<td>Failure of all piping connections; tank support system completely failed; tank itself damaged (possible buckling); contents of tank released</td>
</tr>
</tbody>
</table>

*From Seligson, Eguchi, Tierney, Richmond, Chemical hazard, mitigation and preparedness in areas of high seismic risk, 1996*
If equipment damage occurs due to a natural hazard, will there be a loss of containment of hazardous materials and if yes, how extensive will it be?

→ Define accident scenarios
What are the accident scenarios related to the damage?

**Depends on the extent of the release and the substance hazard**

- Releases from pressurized equipment could have different consequences than releases from vessels kept at atmospheric pressure.

Once release severity is known, the accident scenarios can be identified (e.g. pool fire, jet fire, toxic dispersion)

- Event trees can be applied to identify the scenarios.

- Natech-specific event trees should be used (available for some natural hazards from accident analysis).
Release of complete tank content during floods, toxic substance, atmospheric storage

From Cozzani, Campedel, Renni, Krausmann, Industrial accidents triggered by flood events: Analysis of past accidents, 2010
Step 4 Estimation of damage likelihood/probability of critical equipment

Equipment damage models link the damage intensity to the associated damage likelihood

- Qualitative estimates
- Fragility curves
- Probit functions (for QRA)

The lack of equipment damage models for natural-hazard impact is currently one of the main limitations in Natech risk assessment
Step 5 Consequence evaluation of accident scenario

The consequences of a loss of containment event caused by natural hazard can be assessed using conventional consequence models

- Source models
- Dispersion models
- Fire and explosion models
- Effects models (impact of overpressure, heat radiation, toxic effects on population)
Steps 6-8 Identification of event combinations, their likelihood and their consequences

For some natural hazards (e.g. earthquakes, floods) it is possible that there will be releases from more than one process or storage unit at the same time

- Rarely considered in risk assessment
- Requires likelihood estimates for all possible event combinations

Overall consequences of combined scenarios are obtained by summing up the results for e.g. human health impact from each single scenario
Step 9 Risk integration

In the last step the Natech risk from the identified accident scenarios is estimated. Depending on the assessment approach chosen (qualitative, quantitative) the outcome can be visualized in different ways:

- Risk matrix
- Individual risk, Societal risk (F-N curves) → need information on risk receptors
- Impact zones

BE AWARE OF UNCERTAINTIES!
Risk matrix

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Very Low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
</tr>
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<tbody>
<tr>
<td>Very High</td>
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<tr>
<td>Low</td>
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<td>Very Low</td>
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Impact zones

Individual Risk curves

F-N curves
**Side note**

In principle, the existence of protection measures (prevention, mitigation) should also be considered in the risk assessment.

**BUT:** also protection measures are vulnerable to natural-hazard impact or they can be overcome

- e.g. earthquake damage to catch basis or retaining walls
- e.g. containment dikes inundated during floods
- Active safety barriers require water or power

**THEREFORE:** for Natech risk assessment a worst-case scenario should be assumed in which no protection measures are available
Methods and Tools for Natech risk assessment

- Salzano et al. (2010) Hazard and vulnerability ranking
- Cruz et al. (2008): Preliminary assessment of Natech risk in urban areas
- Busini et al. (2011): Qualitative screening tool for seismic Natech risk using multi-criteria decision analysis

- **ARIPAR**: QRA for chemical facilities; includes module for earthquake impacts on single sites

- **RAPID-N**: Semi-quantitative general framework for Natech risk assessment and mapping
RAPID-N: Web-based decision-support tool for Natech risk assessment and mapping

RAPID-N unites natural-hazard assessment, damage estimation, and consequence assessment in one tool!

Where are natural-hazard prone areas and which chemical facilities are at risk there?
Maybe instead of buying giant gauges, we should have spent the money on relief valves.
1. The development of Natech risk assessment and mapping tools are a high priority need to understand where Natech risk zones are.

2. Natech risk assessment requires additional assessment steps and models as compared to conventional industrial risk assessment.

3. Knowledge gaps have hindered the development of Natech risk assessment methodologies such as lack of Natech scenarios and equipment vulnerability models.

4. The JRC has developed the RAPID-N framework for rapid Natech risk assessment and mapping which can be used to quickly identify Natech risk hotspots.