Two fatalities due to a toxic cloud

At 10:12 am in a chemical plant (during its annual closure), the tank of a titanium tetrachloride ($TiCl_4$) evaporator overflowed. The 7.5-tonne leak spread inside the building. Upon making contact with humidity in the air, the $TiCl_4$ decomposed into hydrochloric acid (HCl, a toxic gas) and titanium dioxide (TiO_2, an opacifier). A thick white toxic cloud formed, engulfing several floors of the facility. Three subcontractors, working on a footbridge outside the building, noticed that a wall fan was expelling a whitish smoke. They put on full face masks and abandoned their workstations via the building. Two of them, unable to find their way out of the cloud, died of intoxication. One plant employee and 2 first responders were injured during the rescue attempt. Traffic was suspended on roads around the installation. Neighbouring residents were asked to remain indoors. An adjoining plant was evacuated.

Disassembly of a level sensor responsible for triggering the discharge

As part of the schedule during this down period, maintenance technicians had been working on the evaporator when the accident occurred; part of their mission was to disassemble the level measurement sensor located on top of the tank. This task had been planned without first draining the tank. Fearing the formation of plugs due to solid impurities in the $TiCl_4$, the plant operator had decided not to empty the tank. For these same reasons, the evaporator's power supply circuit and recirculation pump had not been turned off either. The permit drawn up for these works indicated that workers would be protected by the ventilation system. Tank depressurisation was supposed to guard technicians against contact with $TiCl_4$ or the HCL vapours.

Once these works had been authorised to begin, maintenance personnel disconnected the sensor before removing its mounting flange on the tank. Noticing an abnormal presence of vapours inside the tank, they suspended the task. These vapours had emanated due to the tank still being filled. In reality, disconnecting the sensor interrupted the signal relayed by the sensor to the process control system. Given that the absence of a signal and the signal corresponding to an empty tank were identical, the control system proceeded to activate the level regulation procedure inside the tank. Not having locked out the $TiCl_4$ feed line beforehand, the tank naturally filled up. The high level detection alarm signal, which had remained active on the tank, sounded, but the supervisor simply acknowledged it in failing to proceed with any verification. The tank then overflowed.

Many organisational failures led to this accident

The event analysis exposed flaws in the plant operator's site organisation, namely:

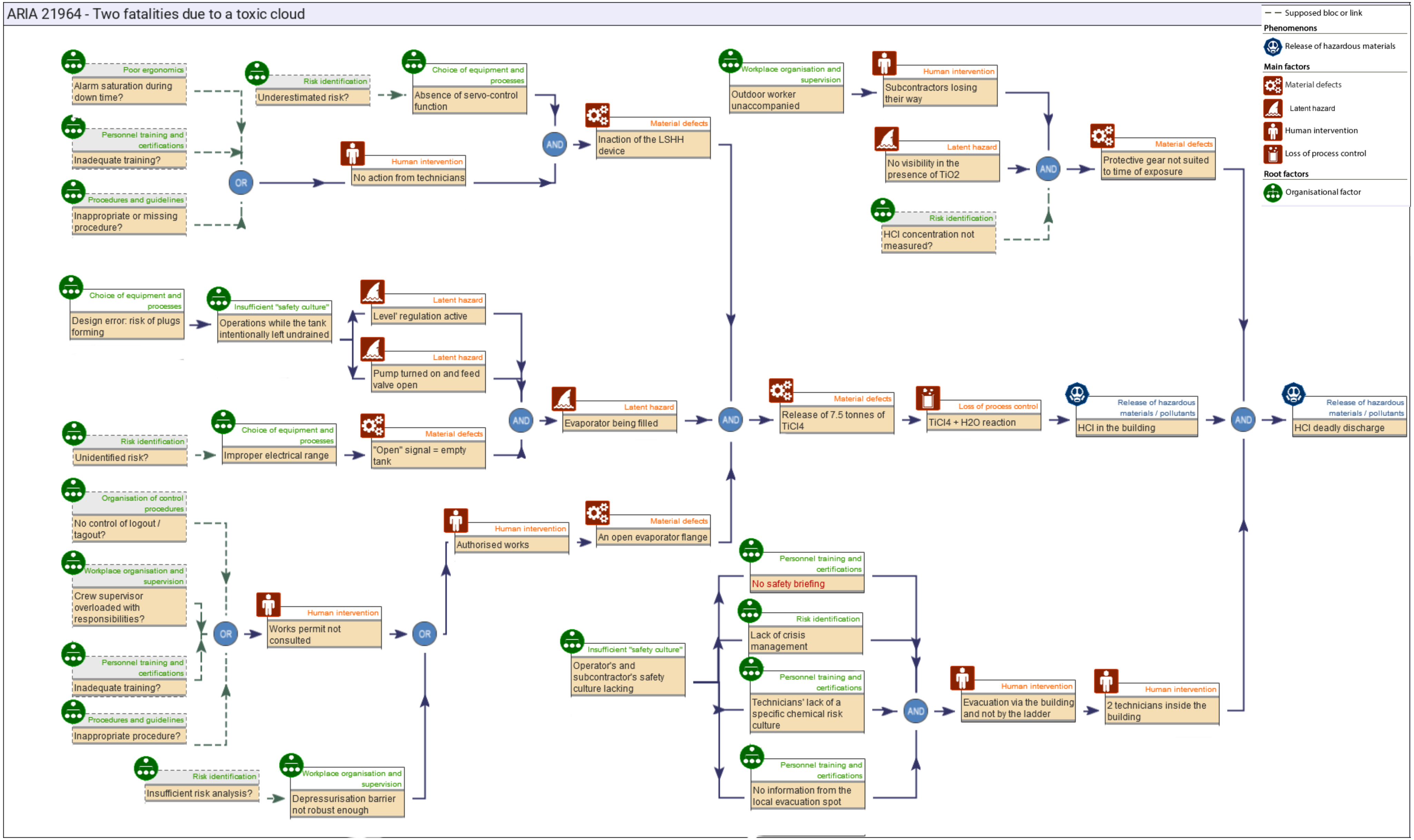
- Risk management deficiencies:
  - Errors in the choice of equipment and processes:
    - The installation design did not allow for complete drainage (risk of plugs forming);
    - The high level detection was not automatically servo-controlled to the tank inlet;
    - The signal indicating an empty tank was no different from the signal indicating ‘no signal’;
    - The individual protective gear supplied to subcontractors on the footbridge did not protect them from the toxic vapours they had experienced.

    - Insufficient identification of risks: decision to perform operations on a full tank with an unreliable safety countermeasure (ventilation), lack of instructions regarding the feed line.
    - Lack of crisis management: many employees evacuate to the control room, which adds to the work load of panel operators.
- Deficiencies related to technicians' working conditions:
    - Inadequate technician training and certification steps:
        - No verification by the supervisor of the veracity of the high level alarm triggered on the tank;
        - The work permit had not been consulted, and the crew supervisor had only issued a verbal agreement;
        - The subcontractors, who had arrived late, did not attend the safety briefing session before beginning their shift;
        - Appropriate evacuation routes from the footbridge had not been shown to the subcontractors;
        - The subcontractors, who were more accustomed to being in a workshop, were unaware of the potential hazards at a chemical installation site.

Not all the questions raised by this accident could be answered based on the information made available. In order to maximise the experience feedback from this event, it would be useful to know if:

- Any control room alarm management procedure was in effect and, if so, did this procedure adequately reflect actual operating conditions (even when the plant was down for maintenance)?
- The alarm supervision function had been adapted or if, on the other hand, the system was being inundated by alarms during idle periods?
- The works authorisation process had been strictly codified. If yes, would this process call for conducting verifications to ensure the installations were secure? Were technicians sufficiently trained and qualified to carry out such verifications? Were their work assignments from the shift manager compatible with such a codification?
- Similar events (incidents, near misses) occurred previously in the plant. If yes, have they been analysed and what were the corrective actions undertaken?
- Operations timeline played a role in the event. When did the maintenance operations start? Were these operations carried out during a single shift, at the beginning or the end of a shift, in parallel of other tasks, under pressure, etc.?
- This organisation that day was, from technicians point of view, the current practices in the facility at the time of the accident (e.g. was it usual to see a team performing operations without a work permit and without any safety briefing?)

Combined, these aspects highlight many flaws in plant operator's risk analyses and management, as well as a significant lack of personnel with sufficient hazards training and certification, ultimately demonstrating that efforts to instil a safety culture had met with little success.



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Supposed bloc or link
Phenomenons
Release of hazardous materials
Main factors
Material defects
Latent hazard
Human intervention
Loss of process control
Root factors
Organisational factor
Poor ergonomics
Alarm saturation during down time?
Personnel training and certifications
Inadequate training?
Procedures and guidelines
Inappropriate or missing procedure?
OR
Risk identification
Underestimated risk?
Choice of equipment and processes
Absence of servo-control function
Human intervention
No action from technicians
AND
Material defects
Inaction of the LSHH device
Workplace organisation and supervision
Outdoor worker unaccompanied
Human intervention
Subcontractors losing their way
Latent hazard
No visibility in the presence of TiO2
Risk identification
HCl concentration not measured?
AND
Material defects
Protective gear not suited to time of exposure
Choice of equipment and processes
Design error: risk of plugs forming
Insufficient "safety culture"
Operations while the tank intentionally left undrained
Latent hazard
Level' regulation active
Latent hazard
Pump turned on and feed valve open
Risk identification
Unidentified risk?
Choice of equipment and processes
Improper electrical range
Material defects
"Open" signal = empty tank
AND
Latent hazard
Evaporator being filled
AND
Material defects
Release of 7.5 tonnes of TiCl4
Loss of process control
TiCl4 + H2O reaction
Release of hazardous materials / pollutants
HCl in the building
AND
Release of hazardous materials / pollutants
HCl deadly discharge
Organisation of control procedures
No control of logout / tagout?
Workplace organisation and supervision
Crew supervisor overloaded with responsibilities?
Personnel training and certifications
Inadequate training?
Procedures and guidelines
Inappropriate procedure?
OR
Human intervention
Works permit not consulted
OR
Human intervention
Authorised works
Material defects
An open evaporator flange
Risk identification
Insufficient risk analysis?
Workplace organisation and supervision
Depressurisation barrier not robust enough
Insufficient "safety culture"
Operator's and subcontractor's safety culture lacking
Personnel training and certifications
No safety briefing
Risk identification
Lack of crisis management
Personnel training and certifications
Technicians' lack of a specific chemical risk culture
Personnel training and certifications
No information from the local evacuation spot
AND
Human intervention
Evacuation via the building and not by the ladder
Human intervention
2 technicians inside the building