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Table 1: MIC Storage System Hazard Analysis

Initiating Event [IE] or Safeguard [SAF] Description	CREDIT (probability of failure, in years) Available	Taken	Explanation
[IE] E-213 MRS Condenser cooling water leak into MIC Storage Tank	1/100	1/10	Conservative credit (1/10) taken: History of leaks in existing process
[IE] MIC Circulation Pump Failure (multiple failures per year)	1/10	1 (no credit)	11 °C high temperature alarm stays active until the pump is repaired
[SAF] Refrigeration Unit	1/10	1 (no credit)	No IPL: Common Mode Failure - requires a working Circulation Pump
[SAF] High MIC Temperature Alarm + Procedure to isolate tank	1/10	1 (no credit)	No IPL: Circulation Pump, alarm integrity, and operator dependencies
[SAF] High MIC Temperature Alarm + MIC Unit transfer (reprocessing)	1/10	1 (no credit)	No IPL: Circulation Pump, alarm integrity, and operator dependencies
[SAF] High MIC Temperature Alarm + E-611 transfer (quench)	1/10	1 (no credit)	No IPL: Circulation Pump, alarm integrity, and operator dependencies
[SAF] High MIC Temperature Alarm + E-619 transfer (more cooling)	1/10	1 (no credit)	No IPL: Circulation Pump, alarm integrity, and operator dependencies
[SAF] High MIC Temperature Alarm + VGS transfer (destruction)	1/10	1 (no credit)	No IPL: Circulation Pump, alarm integrity, and operator dependencies
[SAF] High MIC Temperature Alarm + Solvent quench	1/10	1 (no credit)	No IPL: Alarm already active ("Common Trouble" when pump fails)
[SAF] Independent control room temperature gauge + Solvent quench	1/10	1 (no credit)	Undetectable ("Common Trouble" when pump fails - see **Figure 3**)
[SAF] Vent Valve automatically opens (Basic Process Control System)	1/10	1 (no credit)	Choked vapor flow through vent during a thermal runaway reaction
[SAF] Safety valve opens when tank pressure reaches 40 PSIG	1/100	1 (no credit)	Take credit only after VGS/Flare load calculations confirm capacity
Frequency of Consequence:	1×10^{-14}	1×10^{-1}	

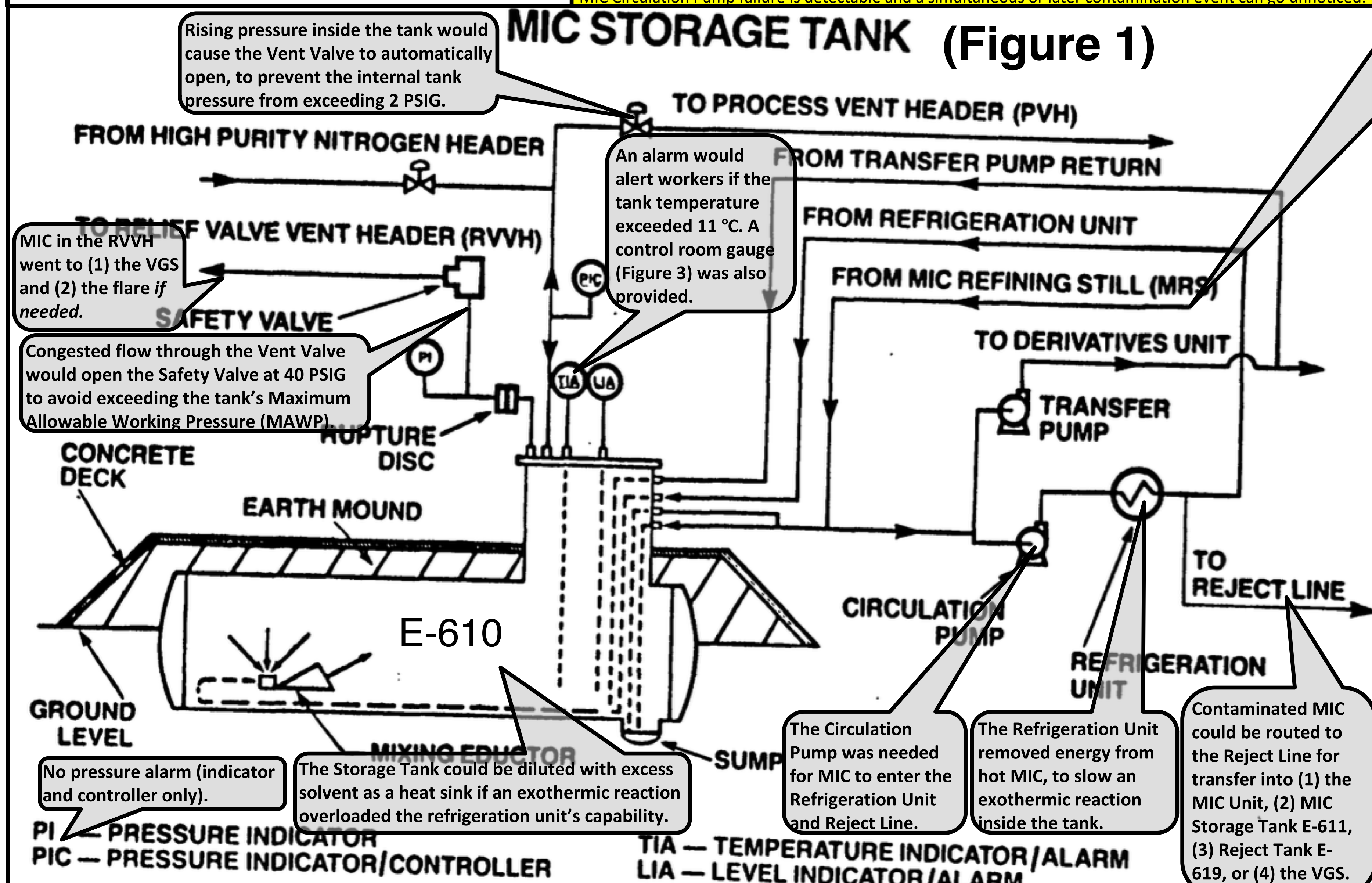
Credit taken after applying the LOPA "*Independent* Protective Layer" (IPL) rule.

Taking credit only for safeguards that conform with LOPA rules exposes a credible scenario that is also highly-probable.

Designing a system with multiple safeguards may give the impression that an incident is not realistically possible.

Double Jeopardy? Due to design dependencies a MIC Circulation Pump failure would defeat seven safeguards. However, the pump failure is independent from a contamination event that could initiate a thermal runaway reaction. Therefore, this situation may represent a highly-improbable "double jeopardy" scenario. That is not true in this scenario since only one failure is detectable. Without an independent high *pressure* alarm, only the MIC Circulation Pump failure is detectable and a simultaneous or later contamination event can go unnoticed.

MIC STORAGE TANK (Figure 1)



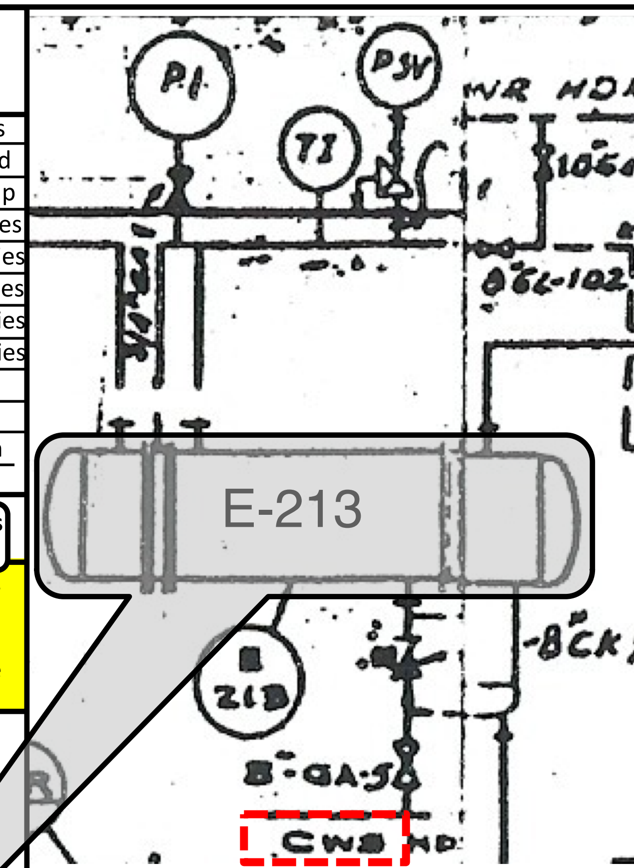


Figure 2 (above): The E-213 MRS Condenser used cooling water (CWS) to liquify MIC vapor by removing thermal energy from product exiting the MIC Refining Still (MRS). The September 1984 Institute MIC II Unit Operational Safety / Health Survey noted that ". . . a leaking MRS Condenser. . . could allow a situation to proceed to the point where it is not controllable."

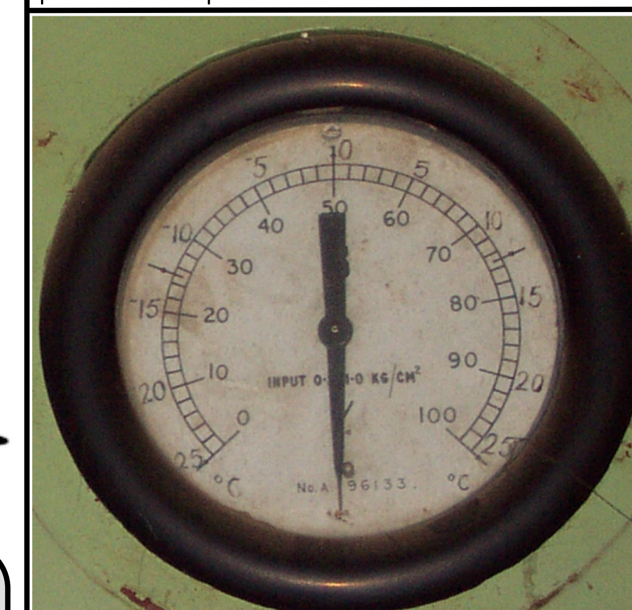


Figure 3 (above): The MIC Storage Tank temperature gauge was scaled to 25 °C maximum. Note that it was common for the gauge needle to operate above maximum range when the MIC Circulation Pump failed. Since a high pressure alarm was not provided, this would make a contamination incident undetectable.

NOTES

Purpose: Use a modern, accepted industry practice to assess the ability for the MIC Storage System in Bhopal India (**Figure 1**) to operate safely.

Step 1: Establish Risk Tolerance
Risk = Frequency x Consequence. Since 0 risk is unattainable for any industrial process, the goal is to achieve as close to 0 risk as possible. This is done by using system design to minimize the frequency of an event. For a toxic chemical (MIC) release that can produce multiple fatalities, a frequency of 1 event in 10,000,000 years (1×10^{-7}) might be acceptable and achievable. If design allows the frequency of this event to be higher than 1×10^{-7} years, then the system does not meet safety requirements and must be redesigned.

Step 2: Define a credible scenario
The E-213 MRS Condenser (**Figure 2**) leaks cooling water into the MIC rundown line, resulting in a thermal runaway reaction inside the MIC storage tank. Tank pressure increases above MAWP (40 PSIG) as the MIC starts to boil, causing the tank to burst; releasing MIC into the atmosphere resulting in multiple inhalation injuries and fatalities.

Step 3: Calculate the "Frequency of Consequence"
Multiplying all allowable credits results in a 1×10^{-1} Frequency of Consequence (see **Table 1**.)

Step 4: Compare the "Frequency of Consequence" with Risk Tolerance
The Frequency of Consequence (1×10^{-1}) is higher than the Risk Tolerance (1×10^{-7}) so a redesign is required.

MIC Storage System Design Drawing obtained from:
https://tinyurl.com/y3m7w3y5

UCIL Bhopal India	MIC Storage System	*Layer of Protection Analysis (LOPA)		The Bhopal Medical Appeal