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A Review of the Aqaba Bay Chlorine Incident

Presenter: Justin Phillips

Senior Director

Phillips.j.tx@iomosaic.com

Authors: Neil Prophet & Hamed Al Nahawi

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Justin Phillips – Senior Director

- B.S. Chemical Engineering, Texas A&M University
- 14+ years of process & pressure relief systems engineering
- Technical Experience
  - Refinery relief systems revalidations and design correction
  - Offshore production platform relief systems revalidations
  - Gas fractionation plants relief systems revalidations and design correction
  - Inland terminal facility relief systems revalidations and design corrections
  - Flare hydraulic evaluations ranging from simple converging networks to complex looped refinery networks, including time-based transient analyses
- Contact Information: phillips.j.tx@ioMosaic.com

This presentation discusses a catastrophic release of chlorine in the port facilities of Aqaba, Jordan

- Port of Aqaba background
- Chlorine Industrial Usage
- Chlorine Toxicology
- Incident Video
- Consequence Modeling
- Incident Investigation Results
- Root Causes and Lessons Learned
- Recommendations / Conclusions

The Port of Aqaba is an Important Facility to the Country of Jordan

- Jordan's only port facility
- Passenger ferry routes
- Industrial cargo (20 million tons per year)
- Relocated to new port facilities in 2014

Source: Google Earth. Used for educational purposes only. Do not copy, share or distribute.

Source: ioMosaic Stock Image

On 27th June, 2022 a release of chlorine caused the death of 13 people in the port facilities in Aqaba, Jordan

- 25-ton ISO container full of chlorine being loaded to the ship Forest 6
- During loading a winching cable snapped
- Resulted in catastrophic failure of the ISO container
- Rapid vaporization and dispersions of the liquefied chlorine
- 13 fatalities and 250 injured

Source: Roya News. Used for educational purposes only. Do not copy, share or distribute.

Chlorine is among the ten highest volume chemicals manufactured in the world

- Widespread usage:
  - Water treatment
  - Food processing
  - Paper mills
  - Water cooling systems
  - Production of ethylene dichloride, polyvinyl chloride (PVC) resins and chlorofluorocarbons
- It is used in over half of all industrial chemical processes, including:
  - 90 per cent of pharmaceuticals
  - 96 per cent of crop protection chemicals

Source: Wikipedia. Used for educational purposes only. Do not copy, share or distribute.

Pressurized chlorine gas is distributed in large containers such as tank cars, trucks and various sizes of cylinders

- Chlorine is commonly transported in ISO tank containers
- Consistent construction based on ISO Standards
- Low alloy steel
- Multiple protective layers / frame
- 21,000 - 40,000 liters volume
- Design pressure around 250 psig
- Should only be handled by trained, experienced personnel, familiar with the hazards of chlorine

Source: Wikipedia. Used for educational purposes only. Do not copy, share or distribute.

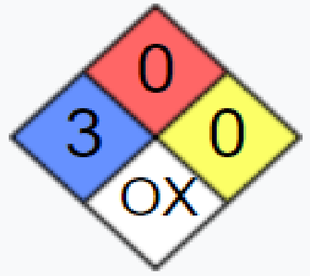
ISO tank containers have a number of advantages, which reflects their widespread use

- Reliable, cost-effective and typically safe, way of transporting bulk liquids
- Designed to meet specific criteria according to the substance they will be carrying
- Very reliable and can withstand extreme pressure and damage
- Unlikely to leak and do not require additional packaging materials for cargo
- Can maintain a specific temperature for temperature-sensitive cargo and can be transported by land or ocean

Source: Wikipedia. Used for educational purposes only. Do not copy, share or distribute.

Chlorine Toxicology

- A yellow-green gas at room temperature
- Pungent, irritating odor similar to bleach that is detectable at low concentrations
- Approximately 2.5 times denser than air
- Not flammable, but is a strong oxidizer and may react explosively or form explosive compounds
- Slightly water soluble and reacts with moisture to form hypochlorous acid (HClO) and hydrochloric acid (HCl)
- Commonly pressurized and cooled for storage and shipment as an amber-colored liquid
- No antidote in the event of exposure

Hazards	
GHS labelling:[107]	
Pictograms	
Signal word	**Danger**
Hazard statements	H270, H315, H319, H330, H335, H400
Precautionary statements	P220, P233, P244, P261, P304, P312, P340, P403, P410
NFPA 704 (fire diamond)	[108] 

Source: Wikipedia. Used for educational purposes only. Do not copy, share or distribute.

Chlorine Toxicology

- Acute Exposure Guideline Levels

Exposure Period	AEGL-1	AEGL-2	AEGL-3
10 minutes	0.5 ppm	2.8 ppm	50 ppm
30 minutes	0.5 ppm	2.8 ppm	28 ppm
60 minutes	0.5 ppm	2.0 ppm	20 ppm
4 hours	0.5 ppm	1.0 ppm	10 ppm
8 hours	0.5 ppm	0.71 ppm	7.1 ppm

- Based on various exposure times
  - Level 1 - Notable discomfort, irritation, or certain asymptomatic non-sensory effects
  - Level 2 - Irreversible or other serious, long-lasting adverse health effects
  - Level 3 - Life-threatening health effects or death

Video of incident (one second after impact)

- Videos of the incident were posted many times on social media
- As one ISO container tank is being winched from a truck, many other trucks are waiting in line. The ISO container tank is seen to fall from the crane winch and then impact the ship deck, rupturing instantly
- As the ISO container tank loses its chlorine contents, a bright yellow chlorine cloud can be seen rapidly spreading, with the yellow cloud visible up to a radius of at least 180 meters

Source: Roya News. Used for educational purposes only. Do not copy, share or distribute.

Video of incident (four seconds after impact)

- Cloud is seen to spread very quickly
- Workers can be seen desperately fleeing from the cloud on foot and in vehicles

Source: Roya News. Used for educational purposes only. Do not copy, share or distribute.

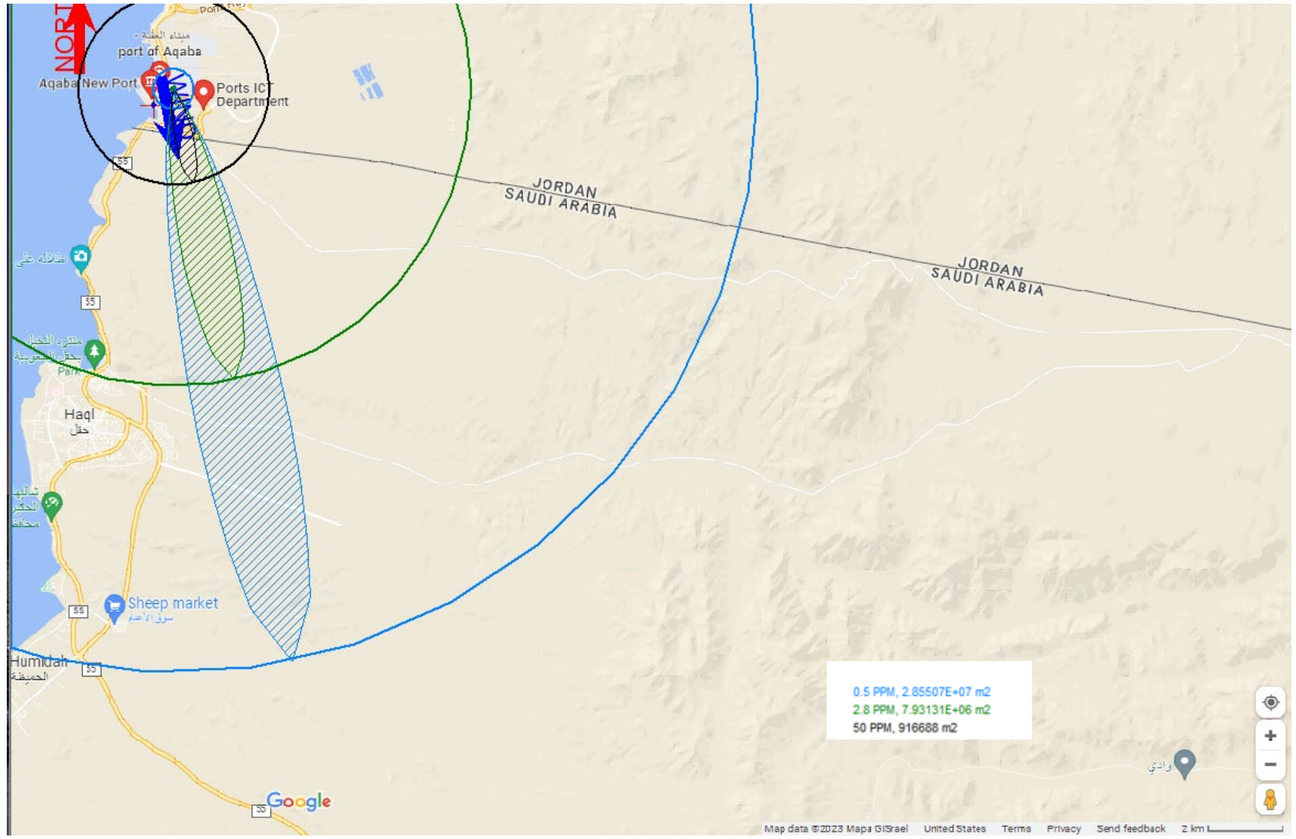
Video of incident (six seconds after impact)

- Cloud continues to spread very quickly in all directions
- The cloud remains close to the ground, heavier than air
- Harmful effects of the release would have been felt much further beyond the visible extent of the yellow cloud

Source: Roya News. Used for educational purposes only. Do not copy, share or distribute.

Consequence Modeling

- It is always useful to recreate an incident
- Helps to better understand what events took place prior, during and after the incident
- Can shed light on some of the potential consequences that might have taken place had some of the conditions been different
- Consequence modeling can also provide a technical basis for incident investigation efforts, and can set foundations for planning, prevention and protection against similar future events

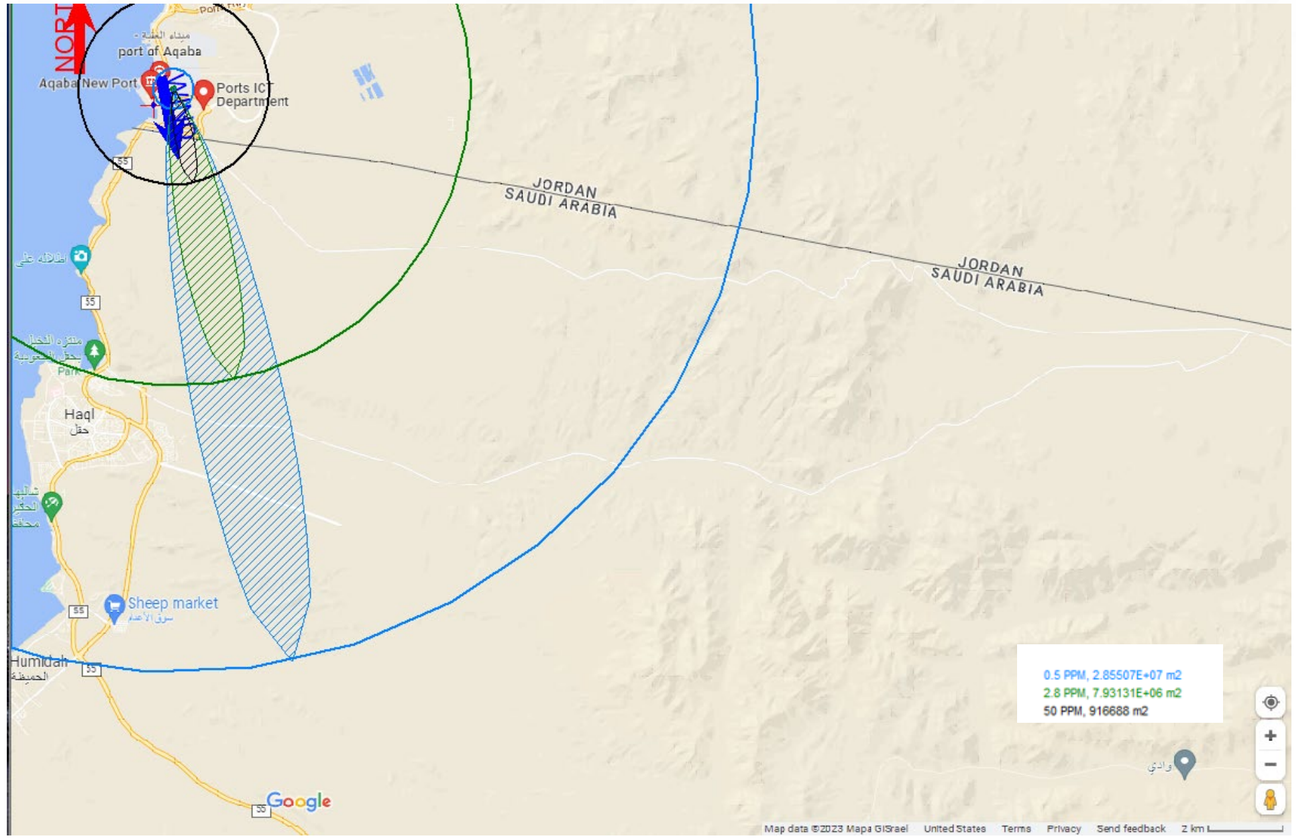


Source: Google Earth. Used for educational purposes only. Do not copy, share or distribute.

Consequence Modeling

- Meteorological conditions were based on measured data

Parameter	Value
Temperature	33º C
Pressure	1006 hPa
Windspeed	5 m/s
Wind Direction	From 347º
Humidity	21%
Surface Roughness	1 (Industrial Site) - by author
Atmospheric Stability[10]	C - by author



Source: National Oceanic and Atmospheric Association (NOAA). Used for educational purposes only. Do not copy, share or distribute.

Consequence Modeling - inputs

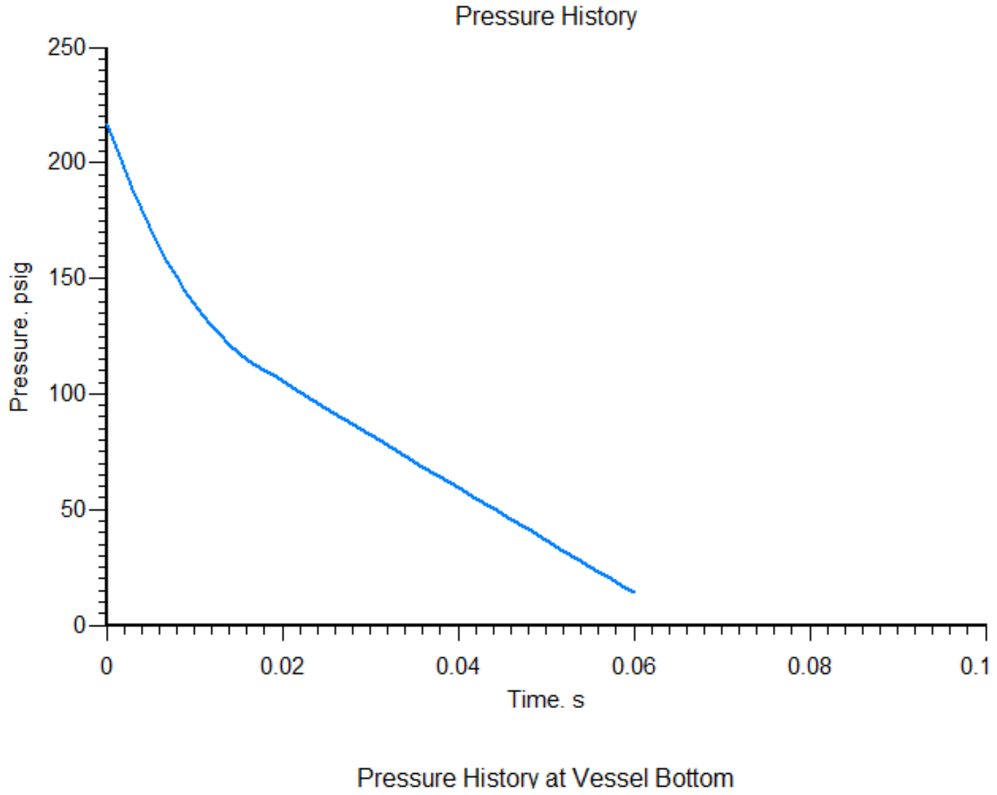
- Release conditions

Parameter	Value
Release Pressure	217 psig
Release Temperature	91 °F
Inventory	50,000 lb
Estimated Hole Size	225 in^2

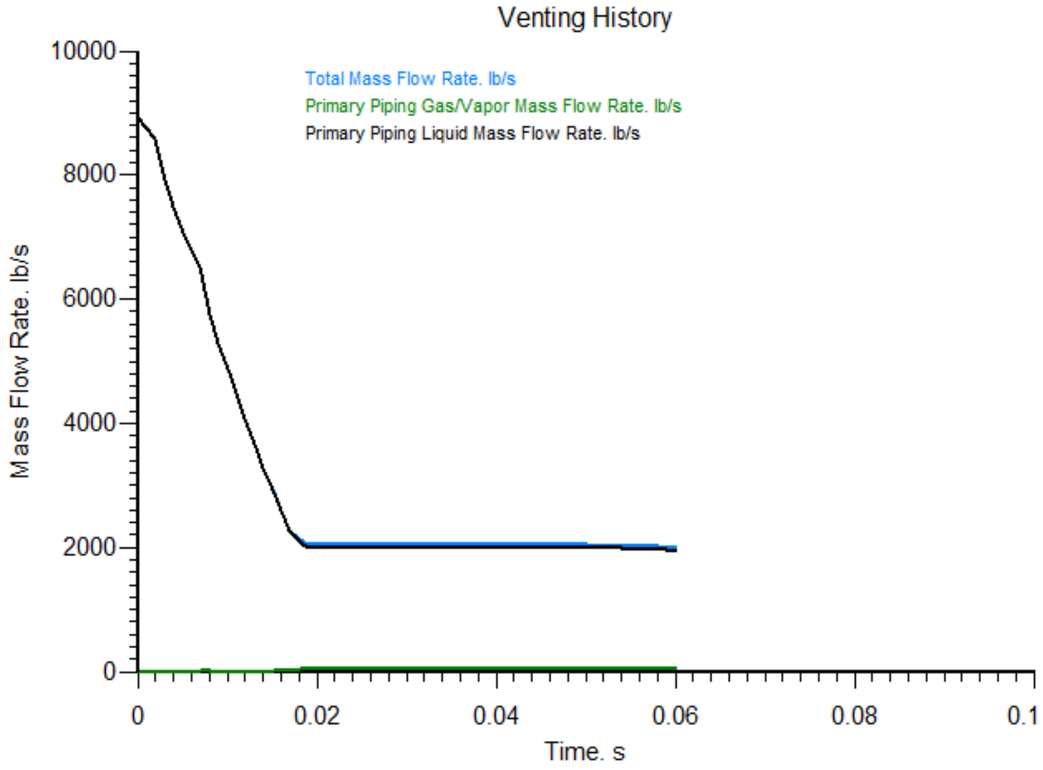
Source: Al Mamlaka News. Used for educational purposes only. Do not copy, share or distribute.

Consequence Modeling - outputs

- A very rapid depressurization was calculated



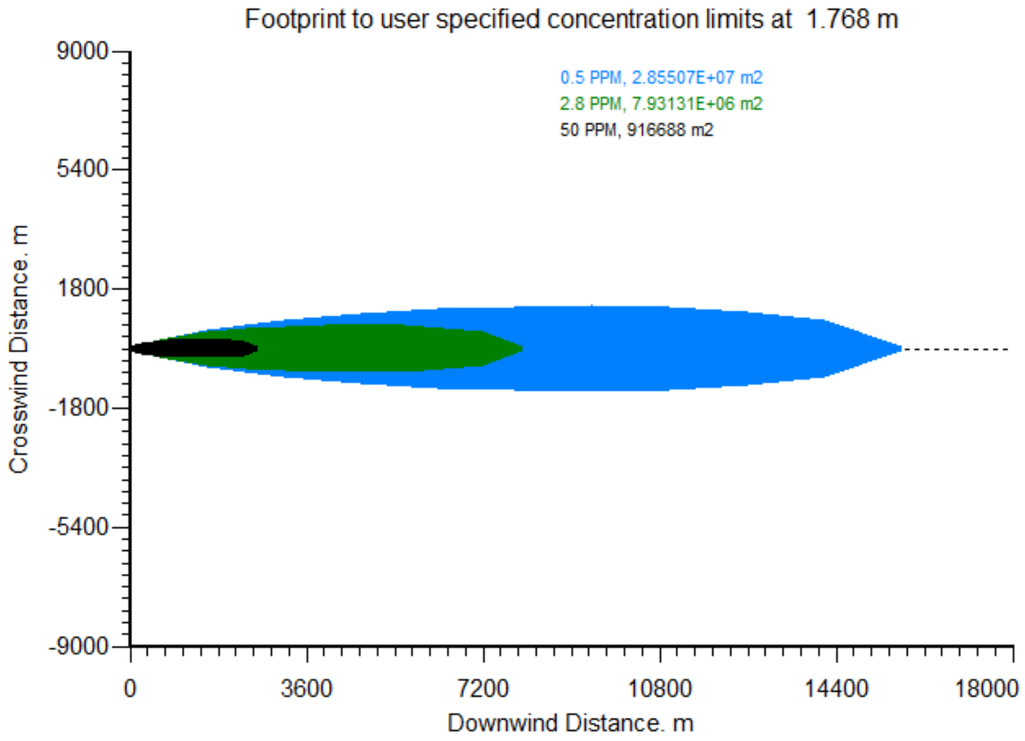
Pressure History at Vessel Bottom

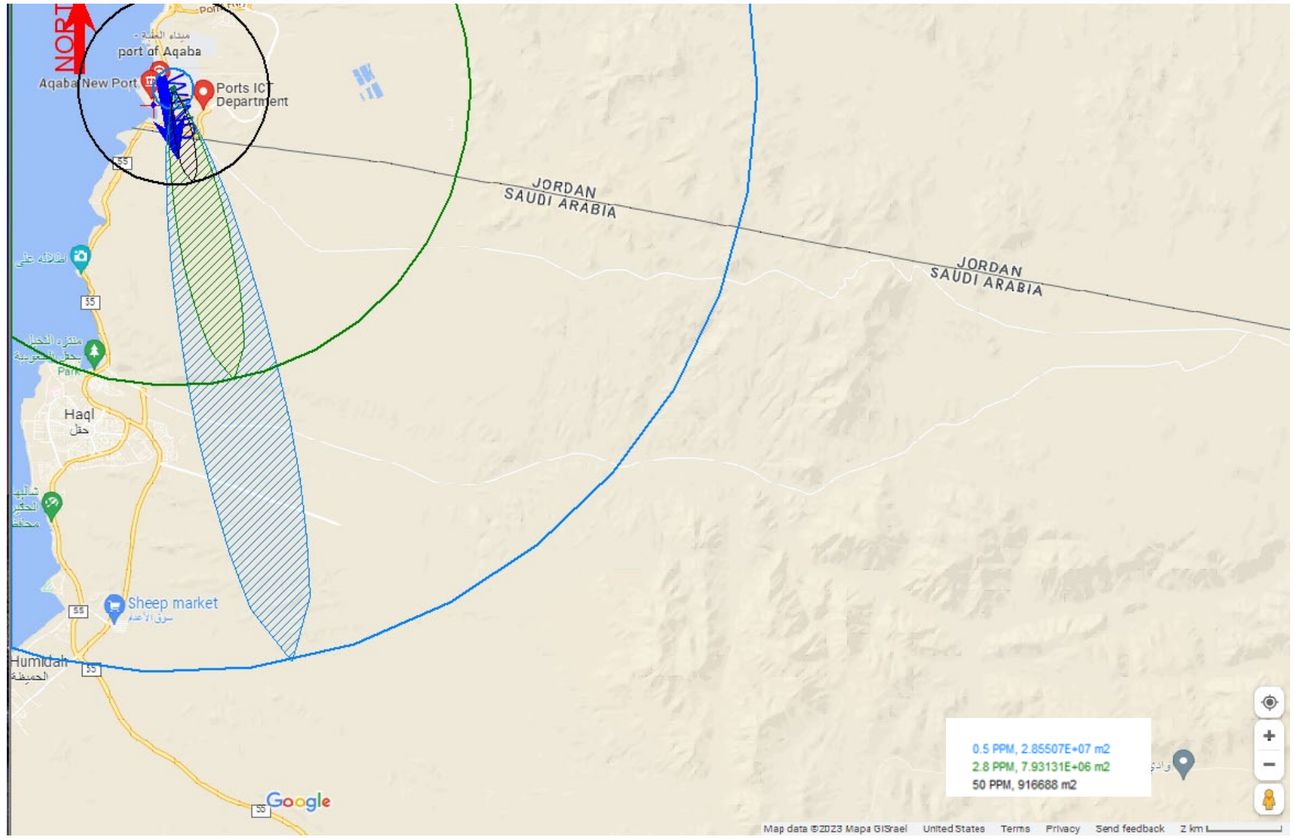


Source: Process Safety Office®, SuperChems™, ioMosaic Corporation.

Consequence Modeling - outputs

- The cloud was calculated to drift a long distance

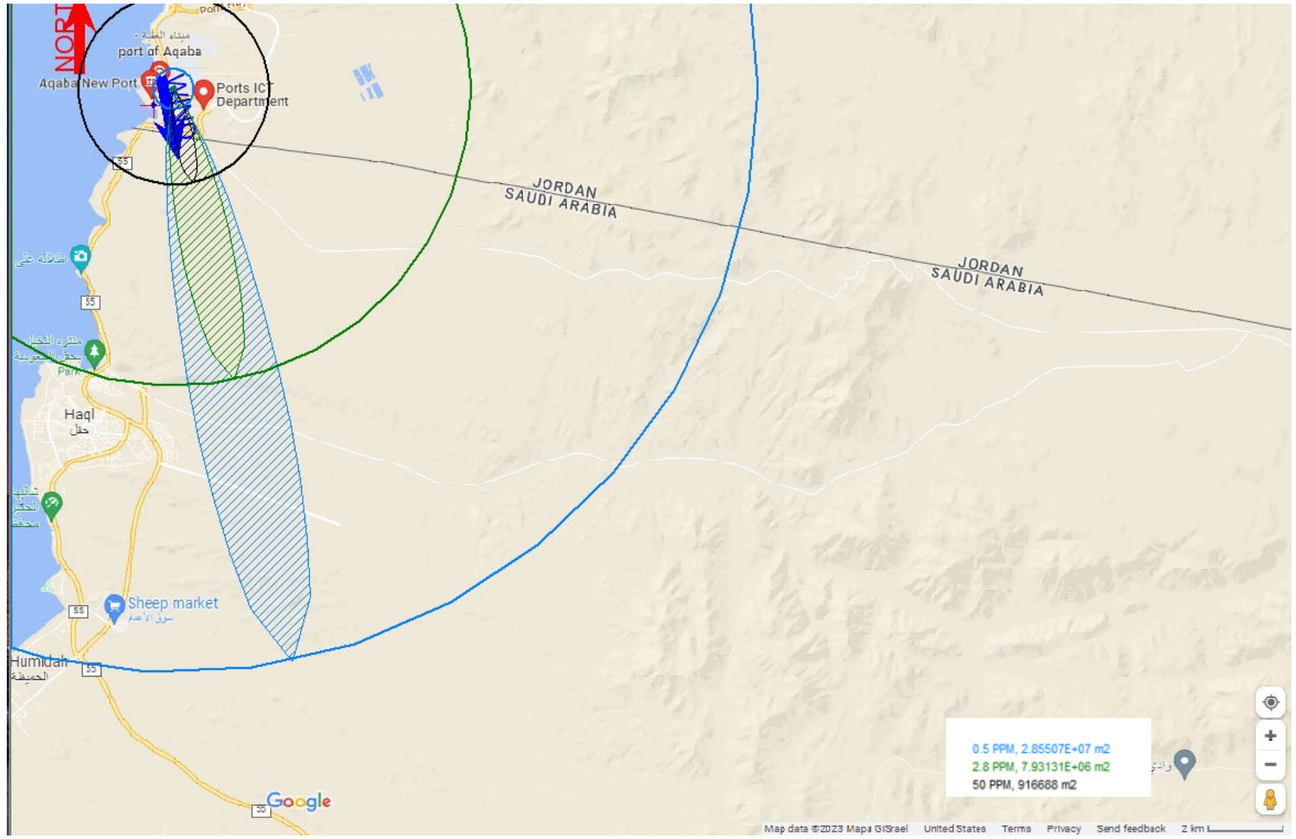




Source: Process Safety Office®, SuperChems™, ioMosaic Corporation.

Consequence Modeling - outputs

- Some mitigating factors helped to limit the consequences
- Warm, windy summer conditions, which helped to break up the cloud due to turbulence in the atmosphere
- The port facilities are in a fairly isolated location
- Northerly wind, which blew the release away from more populated areas of Aqaba, and into uninhabited desert areas



Source: Process Safety Office®, SuperChems™, ioMosaic Corporation.

Incident Investigation Results

- The incident generated huge media coverage
- The Jordanian Minster of Interior commenced investigation efforts immediately once the port facility was safe to enter
- Within one week the committee announced its preliminary findings
  - Primary cause was the use of improper lifting equipment
  - The lifting slings were designed for a maximum load of 8.6 tons, almost 3 times less than the 28.9 tons load that was being lifted

Source: Roya News. Used for educational purposes only. Do not copy, share or distribute.

Root Causes and Lessons Learned (1)

- Further investigations revealed
  - This was only the second time hazardous chemicals were handled in the specific port lane where the incident took place
  - Port staff were unfamiliar with hazards specific to chlorine and this type of operation
  - The failed cable was “worn out, rusted, and lacking technical specifications” according to the preliminary investigation reports
- There was non-compliance with safety procedures in the port
  - Employees had no specific training for the handling of such chemicals
  - There were very poor hazard communication procedures
- Some of the concerned personnel were not aware of the contents nor the weight of the lifted tanks, while others were under the impression, they were loading empty ISO container tanks

Root Causes and Lessons Learned (2)

- Further investigations revealed
  - There were no supervisors or safety officers on site during the tank lifting operations.
  - There was no regular reporting of daily operations and maintenance activities, no distinct leadership, and vague distribution of responsibilities
- Only two months prior to the incident, the Jordanian Social Security Corporation had issued a report highlighting safety concerns, especially with lifting equipment which were evidently non-conforming and in need of maintenance
- **Lack of safety culture was identified as a major root cause**

Recommendations and Conclusions (1)

- Understand the risks associated with any process or operation
- Ensure appropriate training of personnel
- Hazardous materials should only handled by competent trained staff in well controlled environments. Use of permitting can control such work activities
- Use of a management of change process is crucial for ensuring that new risks are identified, and suitable procedures are employed
- Accordingly, safety culture in any work environment should be instilled in all levels of an organization

Recommendations and Conclusions (2)

- Even though a port facility may not be considered a Process Safety Management covered process, the quantities of highly hazardous chemicals being transported exceed the threshold quantities defined in the OSHA PSM standard
- The fourteen elements required in the PSM standard all play their part in managing risk and controlling hazards
- The application of these process safety elements in any hazardous activity would be beneficial to the responsible party

For More Information Contact Us At

1.844.ioMosaic
www.ioMosaic.com
sales@ioMosaic.com

About ioMosaic Corporation

Through innovation and dedication to continual improvement, ioMosaic has become a leading provider of integrated process safety and risk management solutions. ioMosaic has expertise in a wide variety of areas, including pressure relief systems design, process safety management, expert litigation support, laboratory services, training, and software development.

ioMosaic offers integrated process safety and risk management services to help you manage and reduce episodic risk. Because when safety, efficiency, and compliance are improved, you can sleep better at night. Our extensive expertise allows us the flexibility, resources, and capabilities to determine what you need to reduce and manage episodic risk, maintain compliance, and prevent injuries and catastrophic incidents.

Our mission is to help you protect your people, plant, stakeholder value, and our planet.

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