



TBM excavation in contaminated ground - Innovation at the service of the Cityringen Metro

The logo for CMT, consisting of the letters 'CMT' in a bold, red, sans-serif font, enclosed within a white rectangular box.

George Kafantaris
Technical & Design Director

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Project Outline

Contract Data

Duration: January 2011 – July 2019

Type: Design & Build

Value: € 3.2 billion

Client: Metroselskabet I/S

Municipality of Copenhagen (50%)

Danish State (42%)

Municipality of Frederiksberg (8%)

CWC Contractor:

CMT

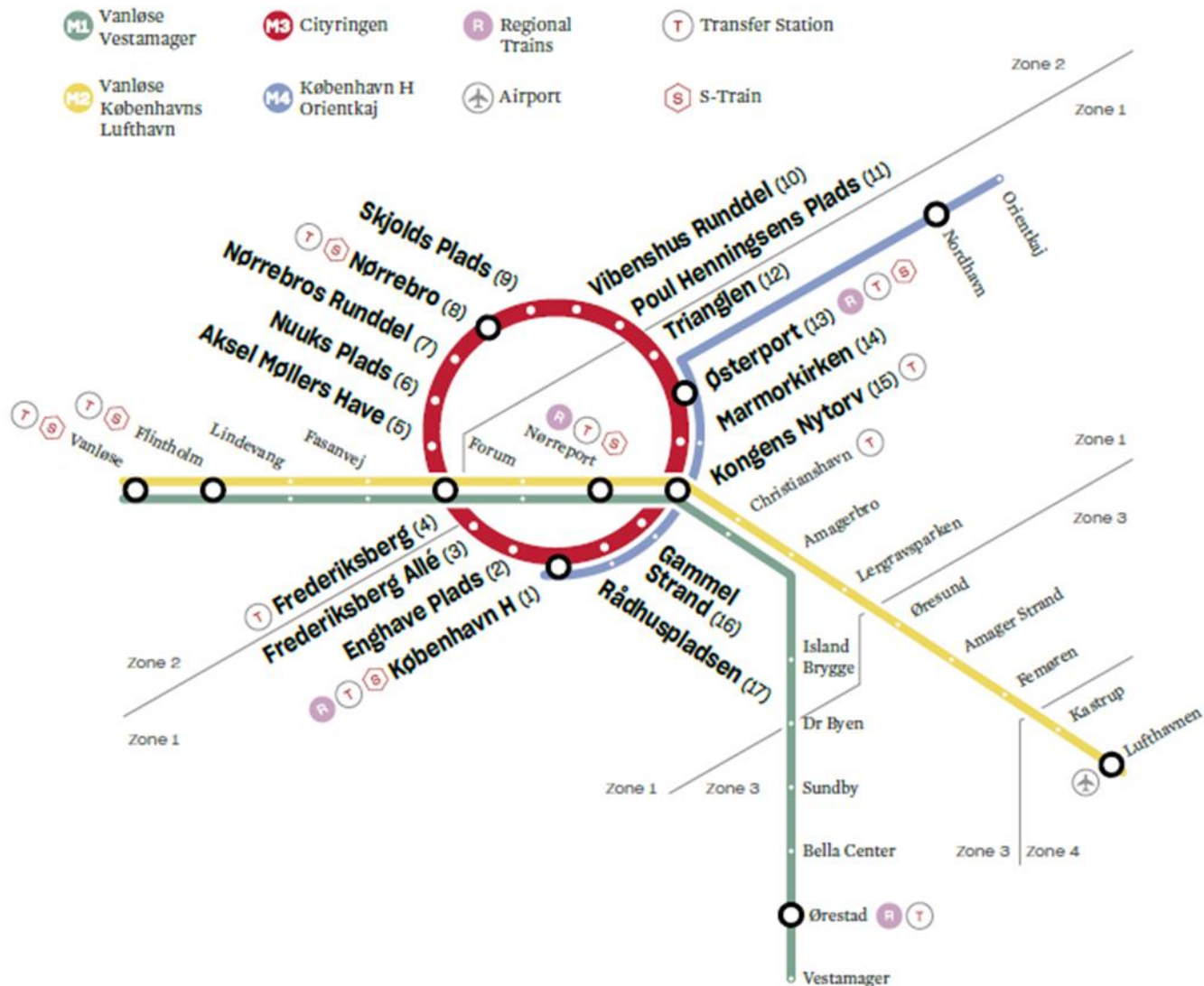
salini
impregilo

Tecnimont
Civil Construction

SELI denmark

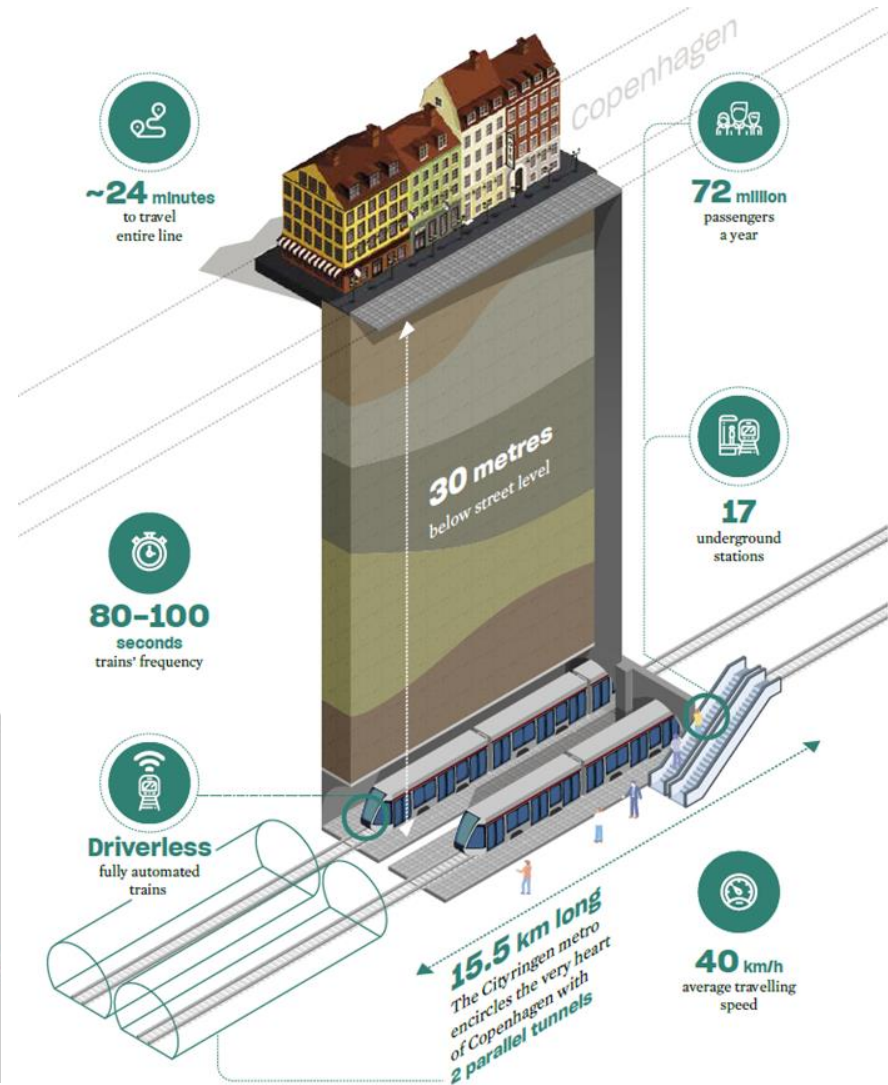
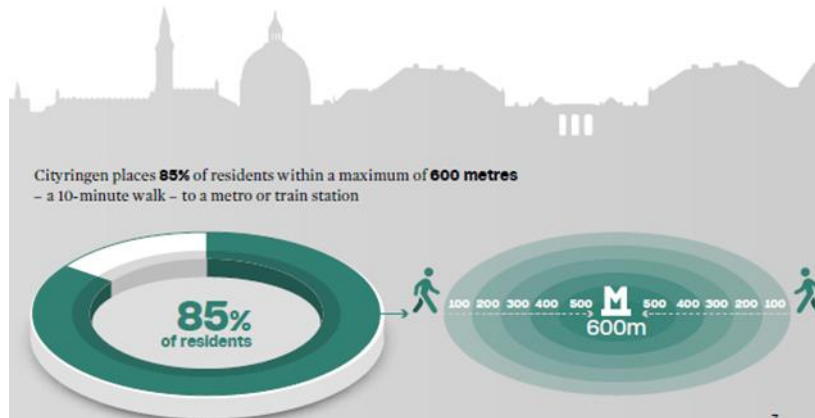


Project Outline



Project Outline

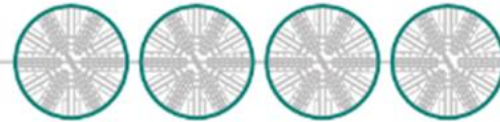
The Cityringen metro line is among the most innovative sustainable mobility projects in the world. Forming a ring around the historic city center with its 17 new underground stations, it stands to support the city's ambition of becoming the world's first carbon-neutral capital by 2030. The new stations are interconnected by driverless, fully automated, trains passing every 80 to 100 seconds.



Project Outline



Tunnels were excavated using **4 TBMs**



Eva **Minerva** **Nora** **Tria**



The TBMs drilled a total of **31 kilometres**



Variable geotechnical context **glacial deposits & limestone**

The TBMs had an advance rate of **22 metres per day**



Project Highlights – Health & Safety

The Challenge:

Building a mega-project in 8 years, with an multinational workforce spread in 22 worksites while having to deal with great volumes of contaminated soil (e.g. benzene, etc).

The Achievement:

Managing to inculcate a strong safety culture in CMT's personnel and subcontractors, through safety awareness campaigns and training, with remarkable results (RoSPA Gold Award Winner for OHS performance in 2018).



~5,000 workers



24 nationalities



5,000 hours
for planning supervision
and reporting



25% women
in project's staff



50% local workforce



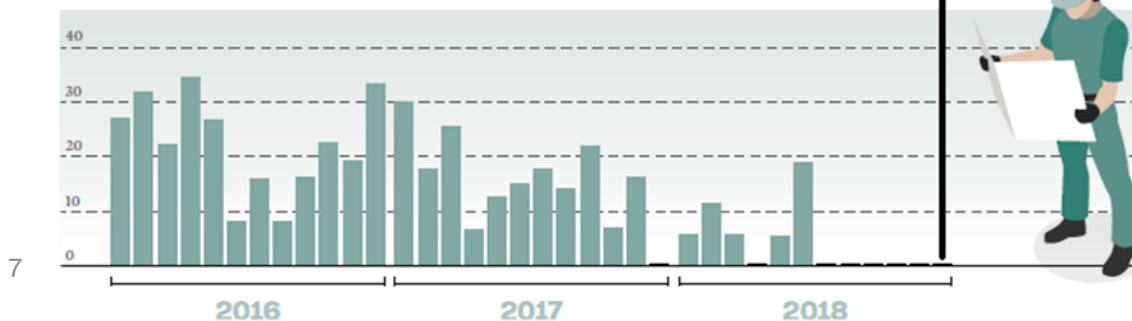
215,000 tonnes
of contaminated soil excavated, treated
and removed from stations and shafts



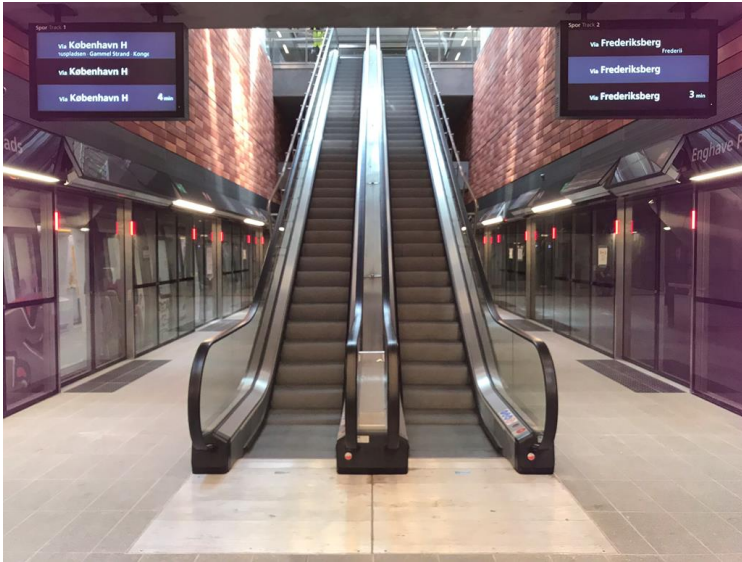
ROSPA
Gold Award

Lost Time Injury Frequency Rate (LTIFR)

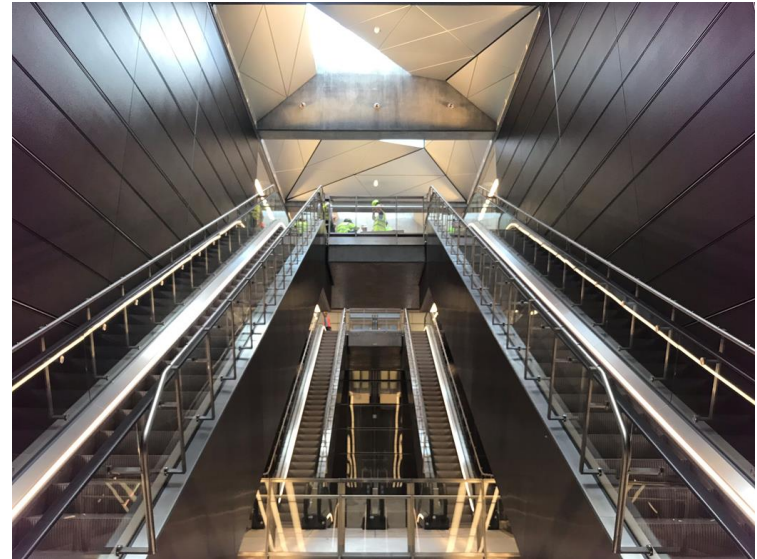
No Injuries



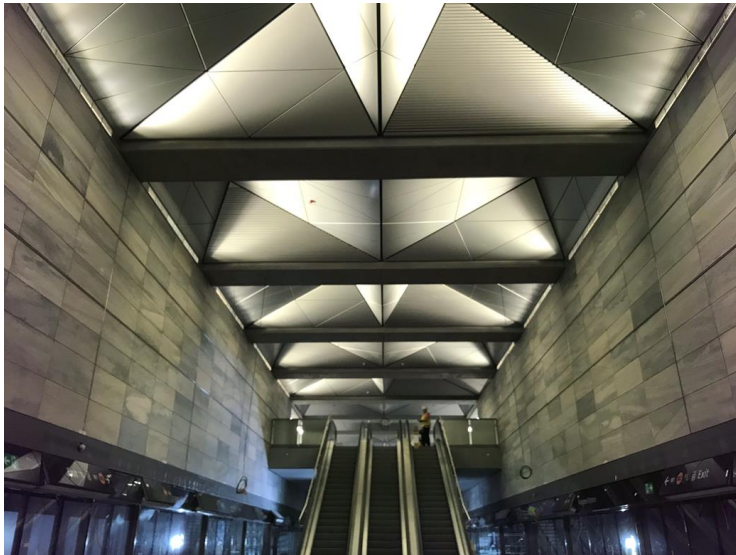
The New Stations



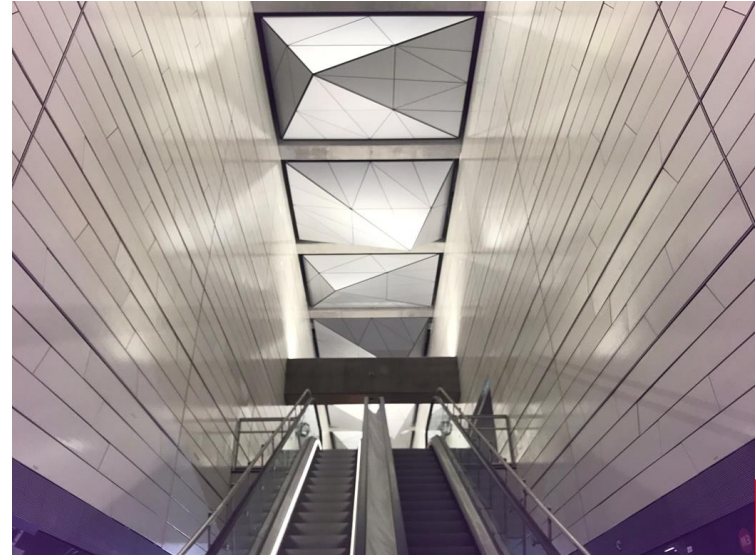
Enghave Plads



Radhuspladsen

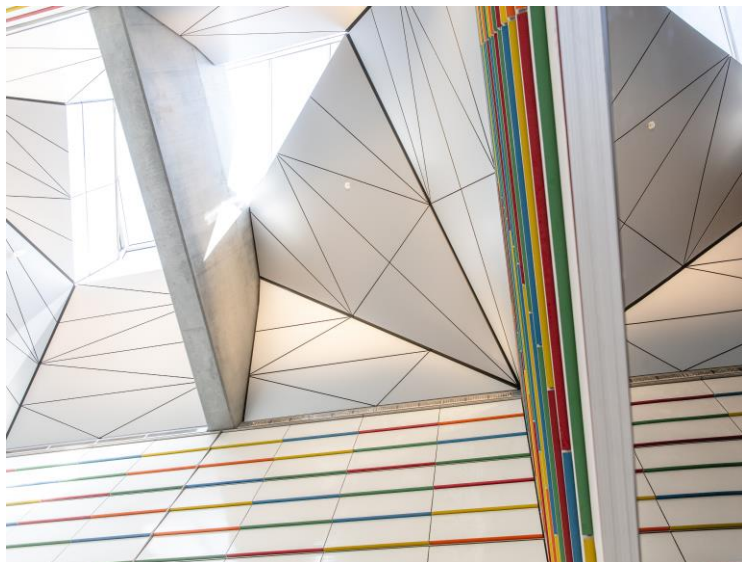


Kongens Nytorv

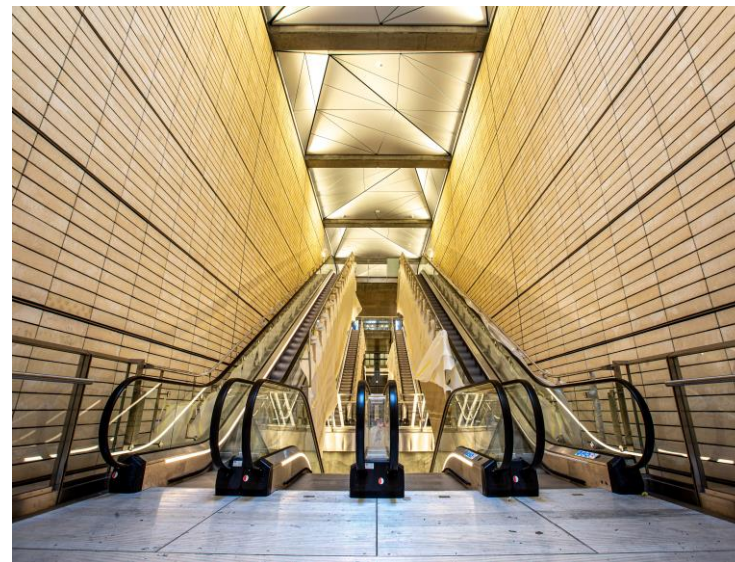


Gammel Strand

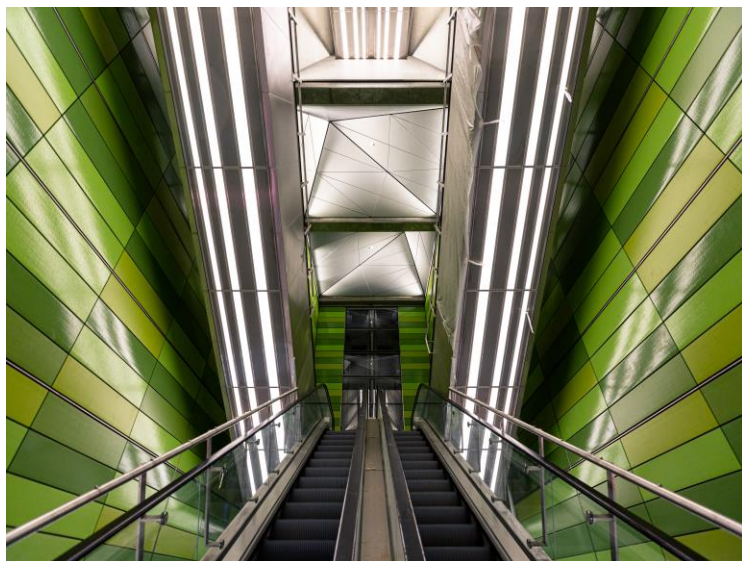
The New Stations



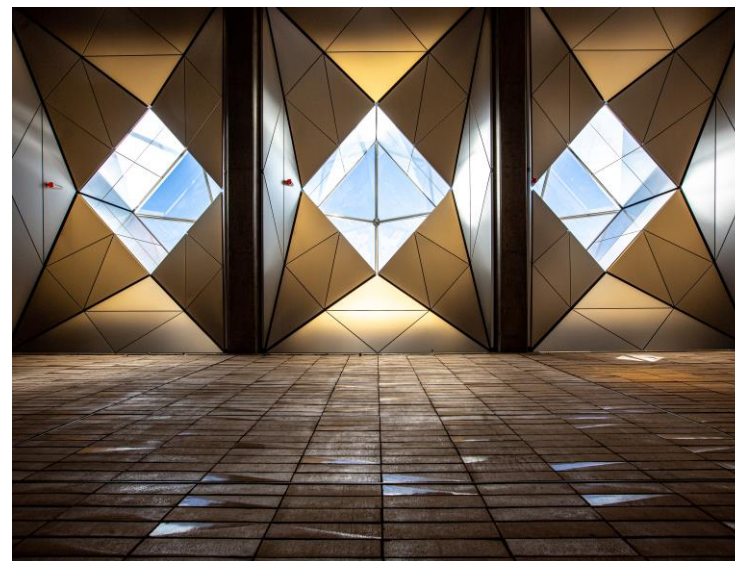
Vibenshus Runddel



Nørrebro Runddel



Frederiksberg Alle

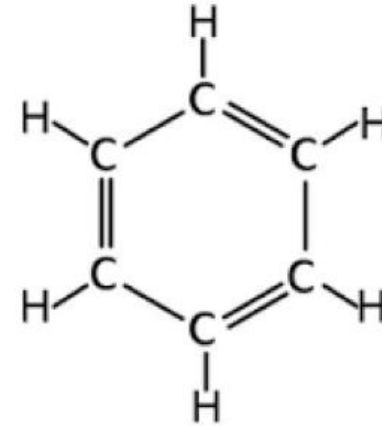


Aksel Møllers Have

Innovation in tunnel excavation – Case study

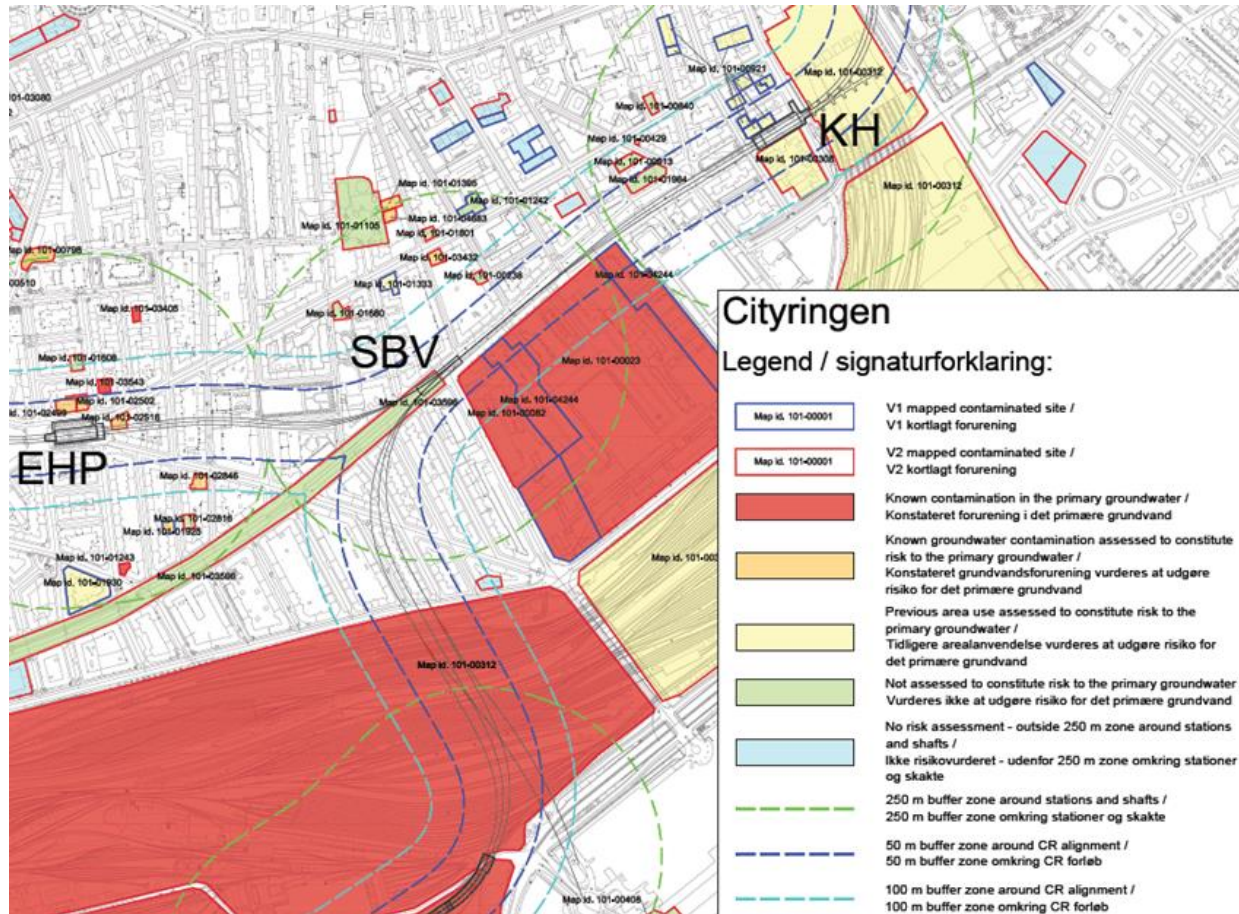
Benzene:

- clear, colorless, highly flammable and volatile, liquid aromatic hydrocarbon with a gasoline-like odor
- acknowledged by the smell when its concentration is over 10ppm
- if inhaled even in small concentration can be carcinogen; at higher concentration can induce dizziness, headaches
- very high concentration of benzene, higher than 500ppm, can be lethal in the short term



Innovation in tunnel excavation – Case study

Benzene concentrations up to 40mg/l in water samples, due to a former gas distribution plant, were detected along 300m of TBM alignment between Sønder Boulevard shaft and København H station.



Innovation in tunnel excavation – Case study

Risks...or challenges?

1. Health and safety

- TBM crew
- Other operative personnel in the tunnel
- Station/shaft workers
- TBM logistic personnel at portal

2. Environment

- Contaminated muck disposal and handling
- Polluted air and water

3. Project schedule

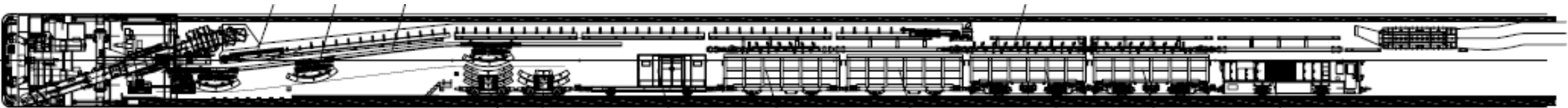
- Delays/stoppages
- Evacuation



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Areas of high risk for benzene release, from the excavation face and up to the portal:

- Excavation chamber
- Screw conveyor discharge
- Back-up belt conveyor
- Service train muck boxes



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Risk mitigation strategy

Collaboration between:

- Copenhagen Metro Team
- SELI Tunneling Denmark
- Webuild Head Office
- Employer (Metroselskabet)
- Local Authorities (WEA, Fire Brigade, Københavns Kommune)



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Risk mitigation strategy

Three clusters of preventative and mitigation measures.

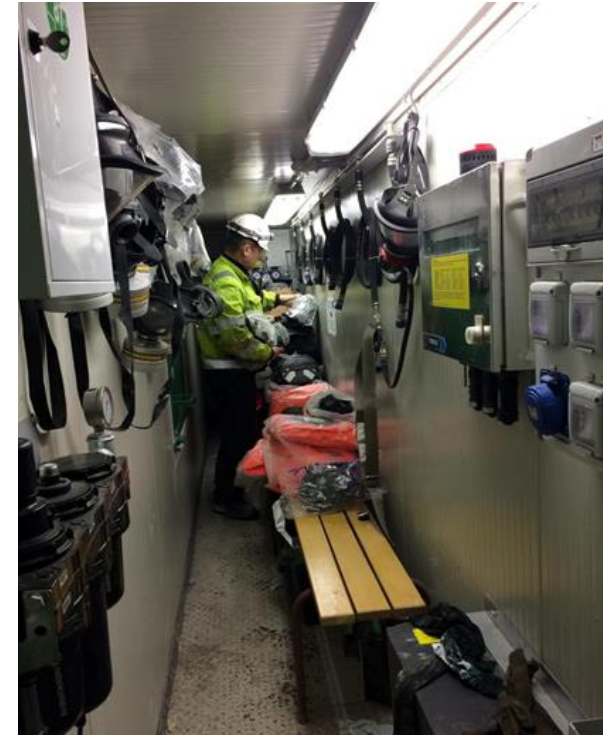
Technical/equipment



Monitoring



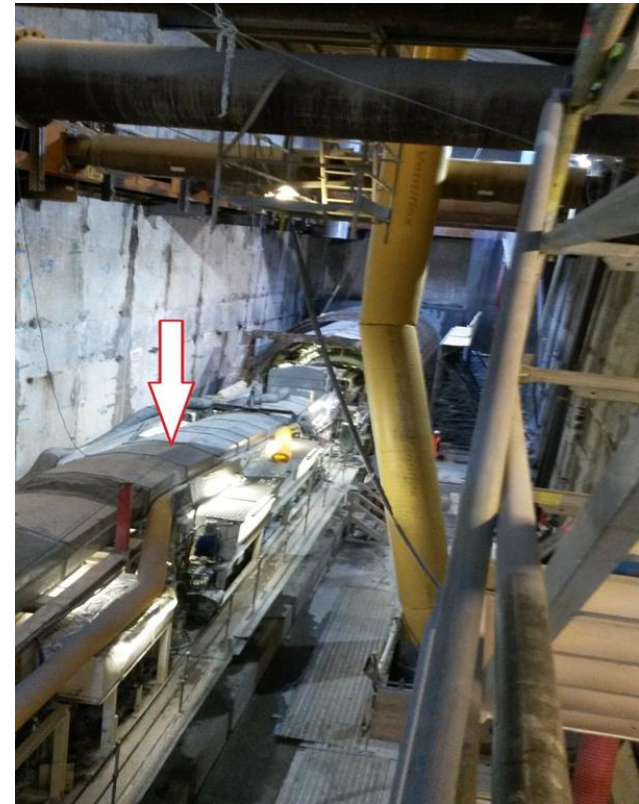
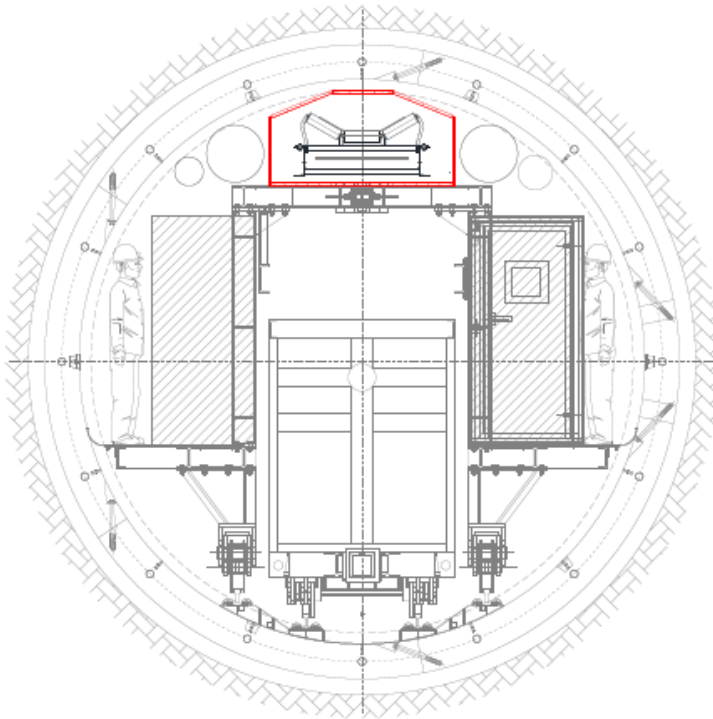
Training & PPE



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Technical solutions & equipment modifications

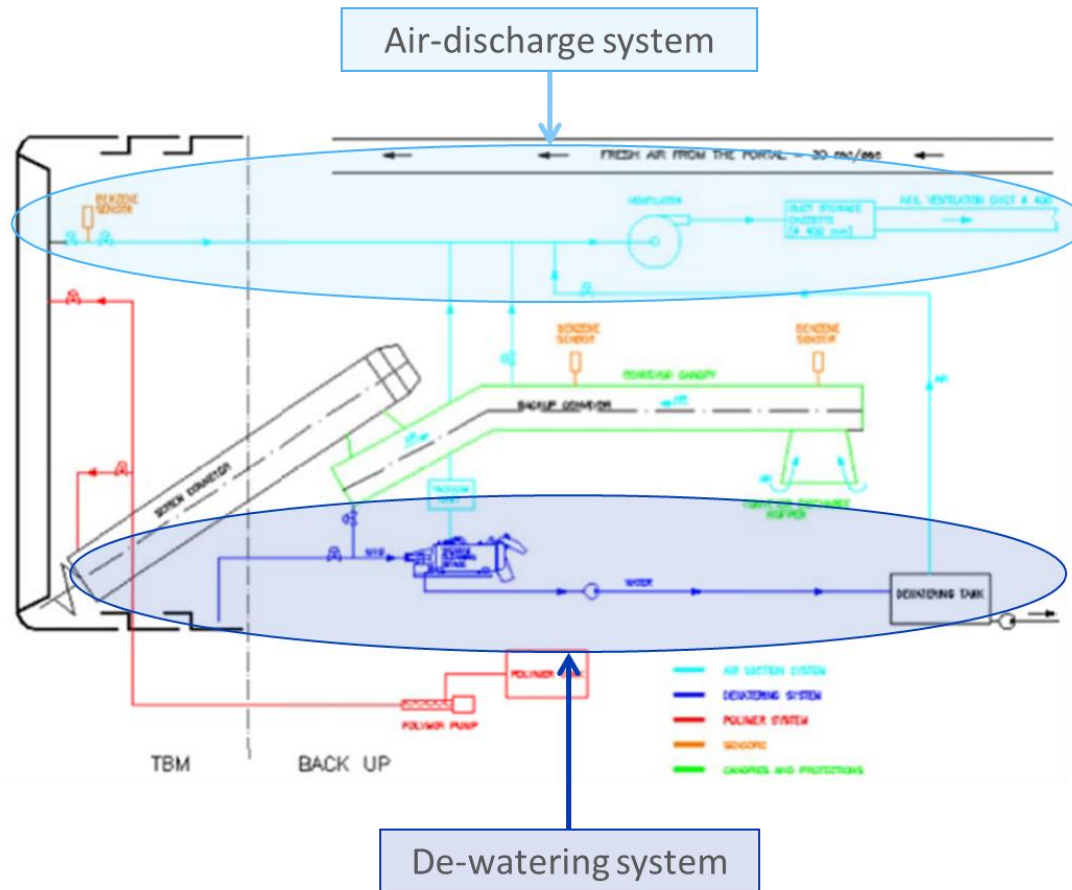
1. Sealed enclosure of the conveyor belt along the entire back-up



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Technical solutions & equipment modifications

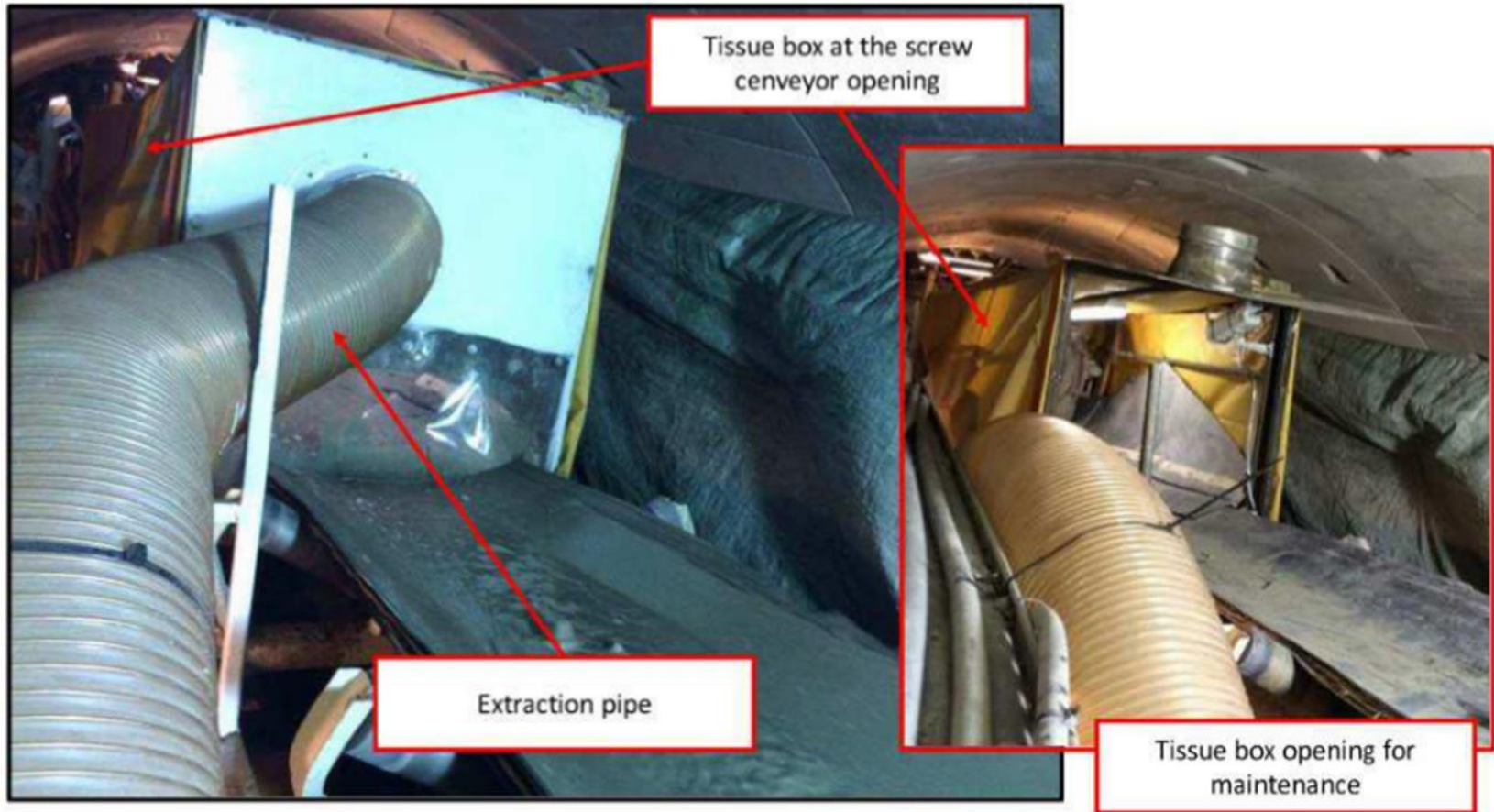
2. Direction of excavation chamber air discharge to the muck conveyor sealed enclosure



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Technical solutions & equipment modifications

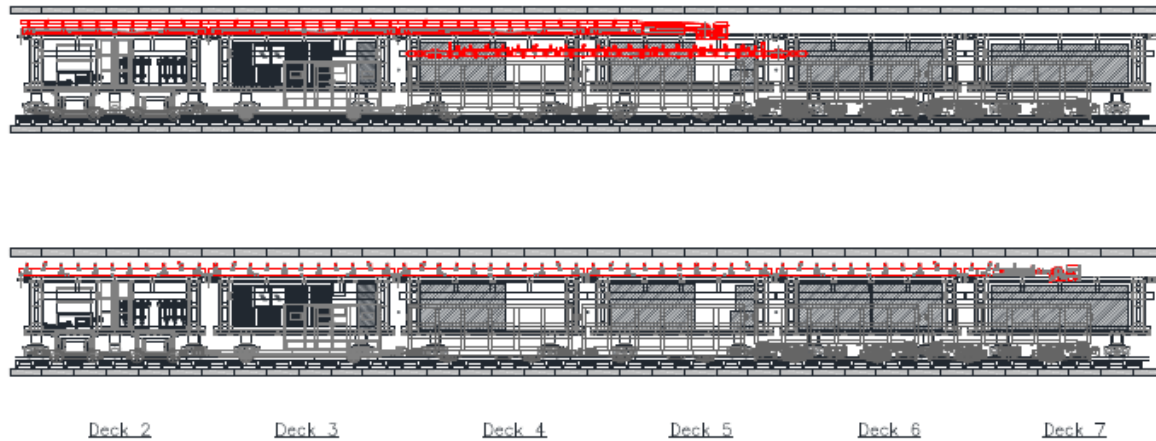
3. Fume extraction at the screw conveyor discharge point as well as the erector



Innovation in tunnel excavation – Case study

Technical solutions & equipment modifications

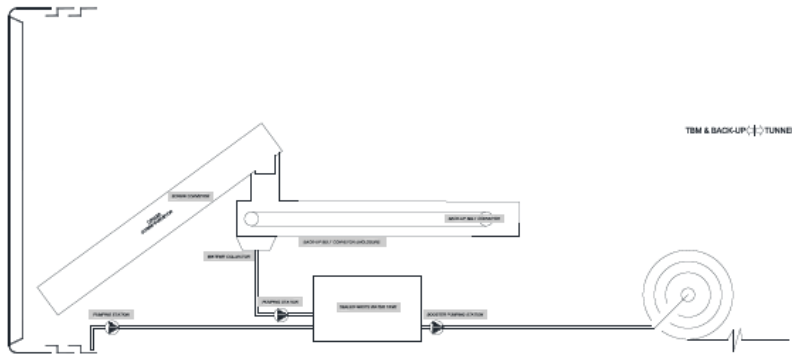
4. Extension of belt conveyor to eliminate mobile/reversible parts



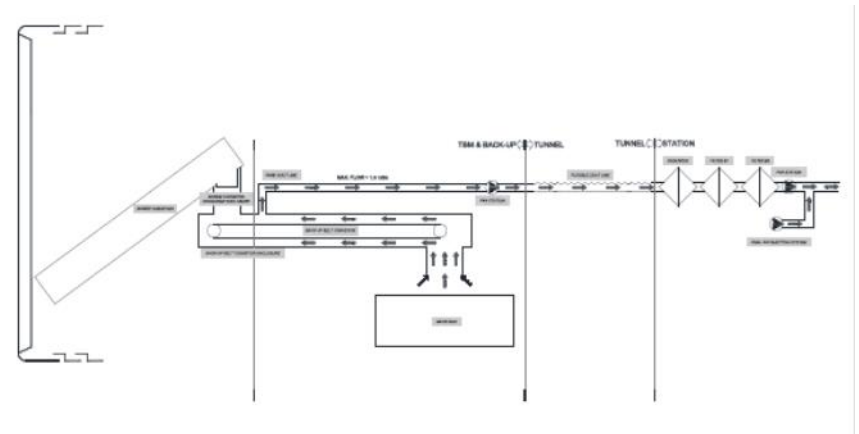
Innovation in tunnel excavation – Case study

Technical solutions & equipment modifications

5. Water collector at the conveyor belt sealed enclosure connected with sealed tank



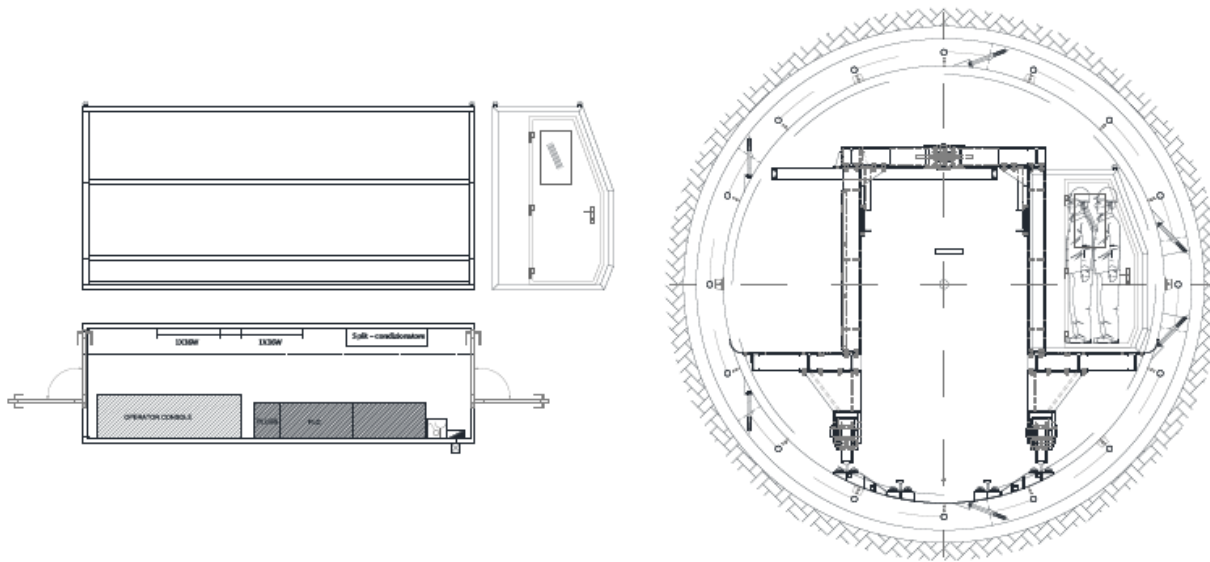
6. Forced air extraction along the covered/sealed conveyor belt



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Technical solutions & equipment modifications

7. Sealed TBM control cabin



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Technical solutions & equipment modifications

8. Fire retardant and foam sprinkler system on top of the muck boxes



9. Muck box covering system immediately after loading

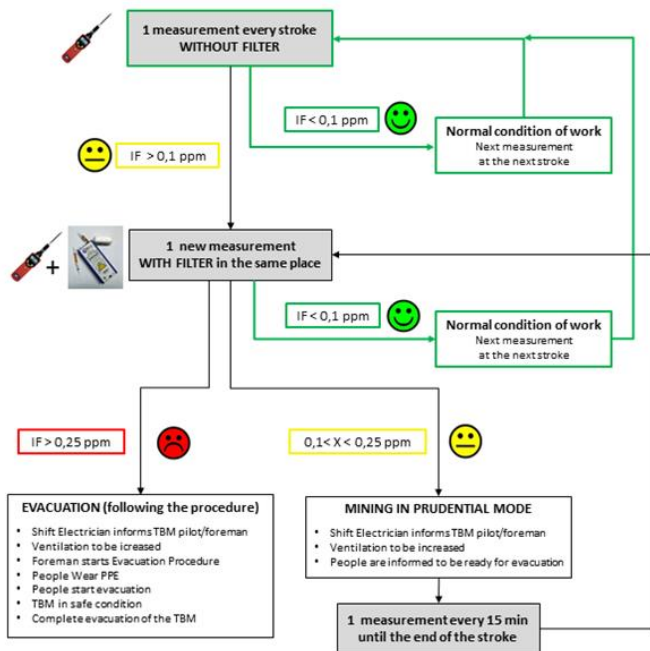


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Monitoring plan and emergency procedure

MONITORING PLAN FOR BENZENE (STRETCH SBV – KH)

Benzene detected concentration	Frequency of measurement
$x < 0,1$ ppm	1 reading every stroke (that means every 1.4m of excavation)
$0,1 \text{ ppm} < x < 0,25$ ppm	1 reading every 15 min (until the end of the subjected stroke)
$x > 0,25$ ppm	EVACUATION



BENZENE READINGS ON TBM 4 SBV to SBV

DATE	TIME	ERECTOR	DISCHARGE POINT	BACK OF TBM	NAME OF PERSON READING
12/12/14	12:30	0,00	0,00	0,00	Paul Evans
12/12	14:30	0,00	05,53	5,10	PAUL EVANS
12/12	15:00	0,00	0,00	0,00	PAUL EVANS
12/12	15:00	0,00	0,00	0,00	PAUL EVANS
12/12/14	15:15	0,00	0,00	0,00	FRANCESCO CURATO
12/12/14	15:30	0,00	0,00	0,00	FRANCESCO CURATO
12/12/14	17:15	0,00	0,00 L 0,00 R	0,05	FRANCESCO CURATO
12/12/14	17:15	0,00	0,00	0,05	FRANCESCO CURATO
12/12/14	19:00	0,00	0,00	0,00	FRANCESCO CURATO
12/12/14	19:50	0,65	2,60	1,20	FRANCESCO CURATO
12/12/14	20:30	0,00	0,00	0,00	FRANCESCO CURATO
12/12/14	21:00	0,00	0,00	0,00	FRANCESCO CURATO

* ~~EVACUATED~~ TBM. IN THE STATION SBV
 ** THE TBM WAS SAFE TO BE E.



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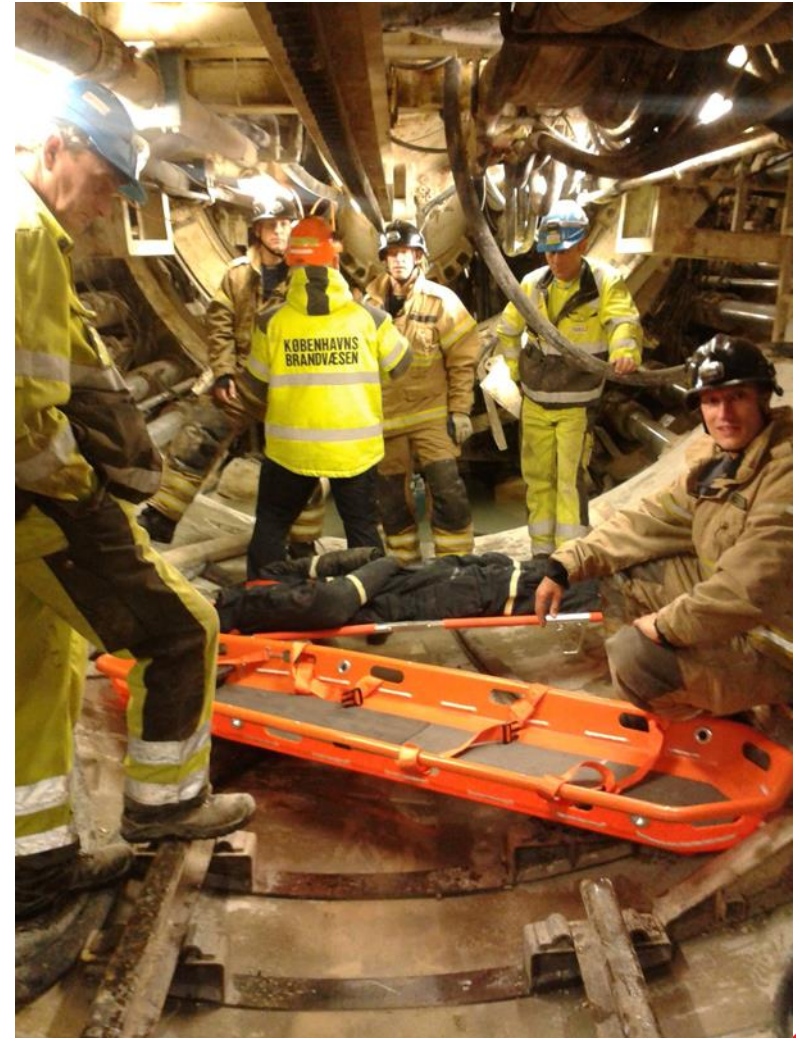
Training & PPE

Special PPE available on the TBM:

- Full face masks with filter
- Fully sealed protective suits

Dedicated training for all crew members

Emergency drills



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Results

- ✓ Zero accidents due to contaminants propagation
- ✓ TBM excavation completed within time schedule
- ✓ No authority notifications regarding OHS and/or environmental issues
- ✓ Effectiveness of innovative mitigation measures confirmed



Innovation in tunnel excavation – Case study

Lessons learnt

- ✓ Hope for the best, plan for the worst
- ✓ Timely and detailed risk assessment leads to the most useful inputs
- ✓ Engagement of all stakeholders at an early stage always pays back
- ✓ Challenges and innovation in engineering go hand in hand



Questions?

