Assessing the applicability of a trapped miner locator system in underground mines – a response to the proposed MHSA Chapter 16 Section 16.7 amendments

University of Pretoria

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SAIMM
MineSafe 2025
19 November 2025

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MINE HEALTH AND SAFETY CONFERENCE
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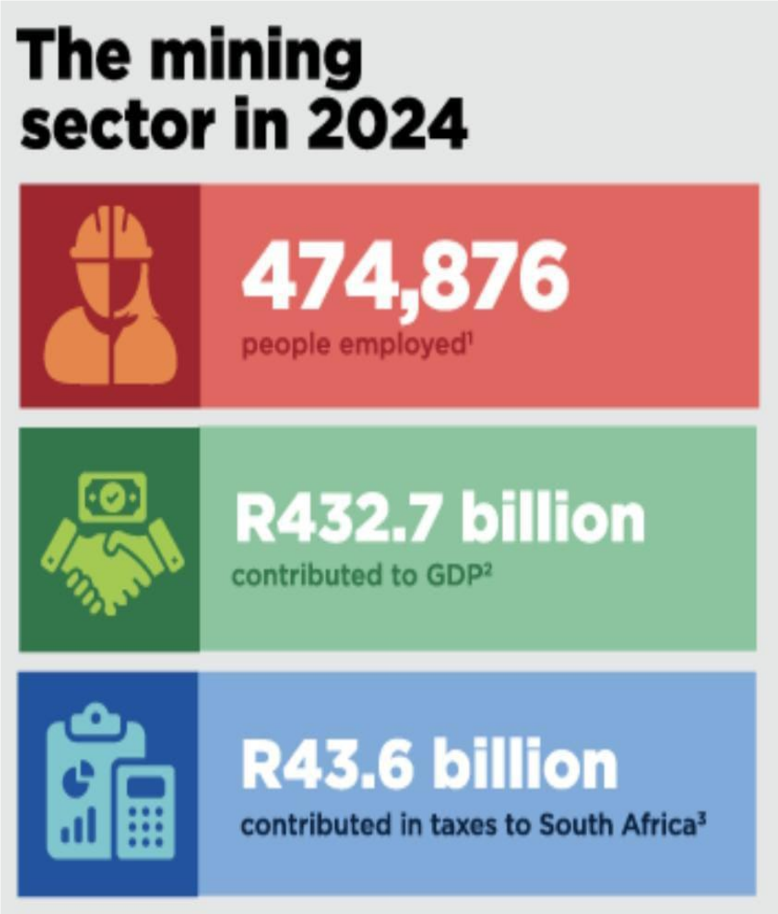
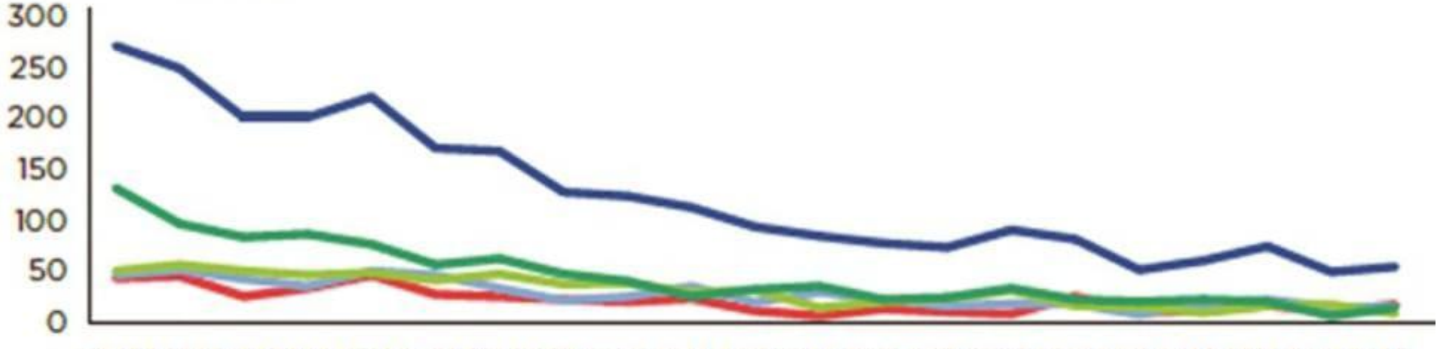
Presentation layout

- Project background
- Project goals
- Approach
- Results
- Conclusions and recommendations
- Acknowledgements

South-African mining industry



Fatalities per classification



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Falls of ground	131	96	83	86	76	56	62	47	40	25	32	35	22	24	33	22	20	22	20	6	15
Transportation and mining	50	56	50	46	48	41	47	37	38	29	31	14	20	23	31	16	15	9	16	17	8
General	46	51	42	35	50	46	33	21	25	35	19	29	22	16	18	18	7	18	22	15	15
Other	43	45	25	33	46	27	25	22	20	23	11	6	13	10	8	25	9	11	16	11	17
All	270	248	200	200	220	170	167	127	123	112	93	84	77	73	90	81	51	60	74	49	55

Minerals Council South Africa (2024)

Fatalities in 2024: 42

Rescue operations in underground mining accidents

Mine	Year	Incident	Number of trapped miners	Fatalities	Total time of entrapment	Time taken to make contact / locate
Beaconsfield Mine	2006	Rockfall	3	1	14 days	5 days
Impala Platinum Mine	2016	Rockfall	9	2	2 to 17 days	2 to 17 days
Sibanye Stillwater	2018	Rockfall	13	7	2 days	2 days
Sibanye Stillwater	2018	Poor visibility	5	5	3 days	3 days
Dugald River Mine	2023	Falling into a cavity	3	2	Over 24 hours	Over 24 hours


OCCUPATIONAL HEALTH & SAFETY INSIGHTS
DMRE – proposed new regulations on first aid, emergency response and missing person locator systems
WEBBER WENTZEL
in alliance with > Linklaters

Legislation

3rd April 2023: DMRE proposed amendments to the MHSA of 1996

Chapter 16 of the proposed amendments:

- It should be mandatory for all underground mines and surface mines with significant slope failure to equip workers with a fundamentally safe device capable of:
  - ❖ Locating them in case they go missing while working or during emergencies.
  - ❖ Have a power supply lasting at least 24 hours
  - ❖ Offer real-time tracking
  - ❖ Locate the missing person within 10 m in an unobstructed environment
  - ❖ Locate the missing person with 30 m through solid rock

Technology used to locate trapped miners

1930s

Through-the-wire (TTW)

- Dial-and-pager phones.
- Signal transmission through cables.
- Transmits signals over long distances (up to 70 km).
- Highly dependent on infrastructure.

2006

Through-the-air (TTA)

- Radio frequency identification systems (RFID) and Wi-Fi.
- Signal transmission through Ethernet/ leaky feeder (Coaxial cable).
- Two-way voice, text, and data transmission. Last known location.
- Highly dependent on infrastructure.

2014

Through-the-earth (TTE)

- Surface transmitter and underground receiver.
- Signal transmission through electromagnetic and seismic waves.
- Mine-wide location capability.
- Requires miner interaction.

Not yet implemented

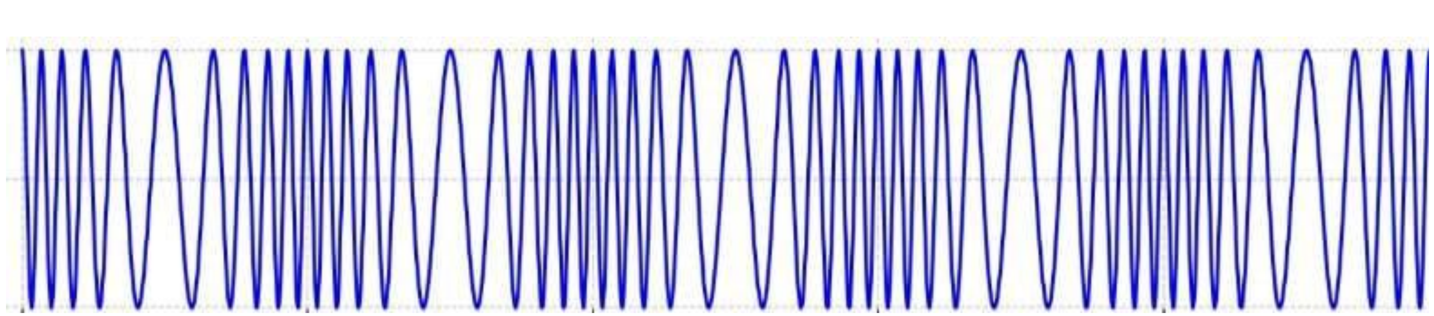
Through-the-rock (TTR)

- Transmitter attached to the miner's cap lamp, and receiver held by the rescue team.
- Short-range signal transmission through magnetic induction.
- Real-time location through 30 m of unobstructed areas and 60 m through solid rock.
- Functions without infrastructure or miner interaction.

TTR operating principles

RESCUE TEAM	SOLID ROCK AIR WATER	TRAPPED/MISSING MINER

Receiver

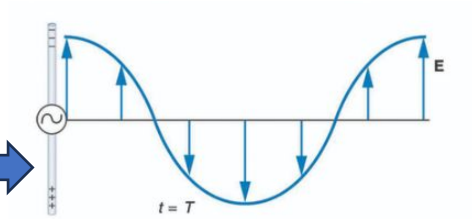


Signal transmission through a propagation medium

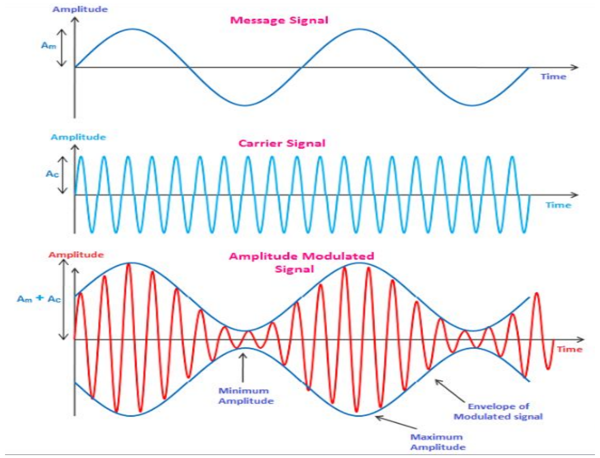
Transmitter

TTR Transmitter components

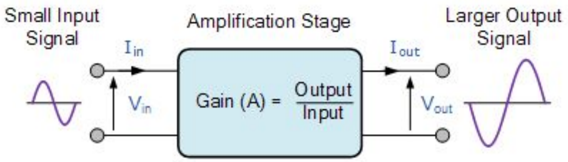
Power supply with direct current



Oscillator generates an alternating current to form a carrier wave with a certain frequency within the VLF band (3 – 30 kHz)

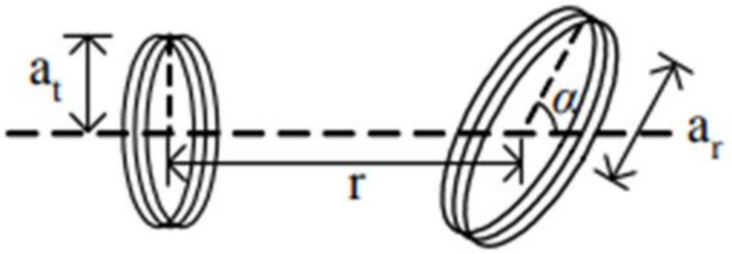


Modulator adds information to the carrier wave

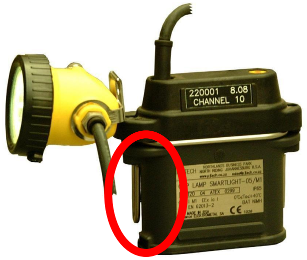


Amplifier boosts the signal to increase the transmission range

TTR Receiver components



Transmitter antenna **Receiver antenna**



Low noise amplifier (LNA) boosts the signal

Demodulator extracts the information-bearing signal from the carrier wave.

Analog-to-digital converter converts the waveform to digital data that can be displayed on screen.

Project goals

This study aims to establish a framework for the optimal implementation of TTR systems in underground mines by:

- Provide guidelines for an optimal TTR locator system.
- Compare the performance of TTR systems under different environmental and geological conditions.
- Determine how interference from electrical equipment and metal obstructions affects signal reception.

Approach

TTR system design

- **Select an optimal oscillator for the transmitter:** performance comparison of different linear harmonic oscillators.
- **Select an optimal antenna design:** determine the influence of antenna alignment on signal reception.
- **Calculate the minimum usable frequency:** determine the minimum data rates required for communication.
- **Select the optimal antenna size:** determine the influence of antenna size on signal transmission.

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System in its environment

- Find different host rock properties, specifically the electric conductivity and magnetic permeability.
- Calculate the transmission range through different geological settings at different frequencies.
- Compare the impact of electric and metallic interference on signal propagation.

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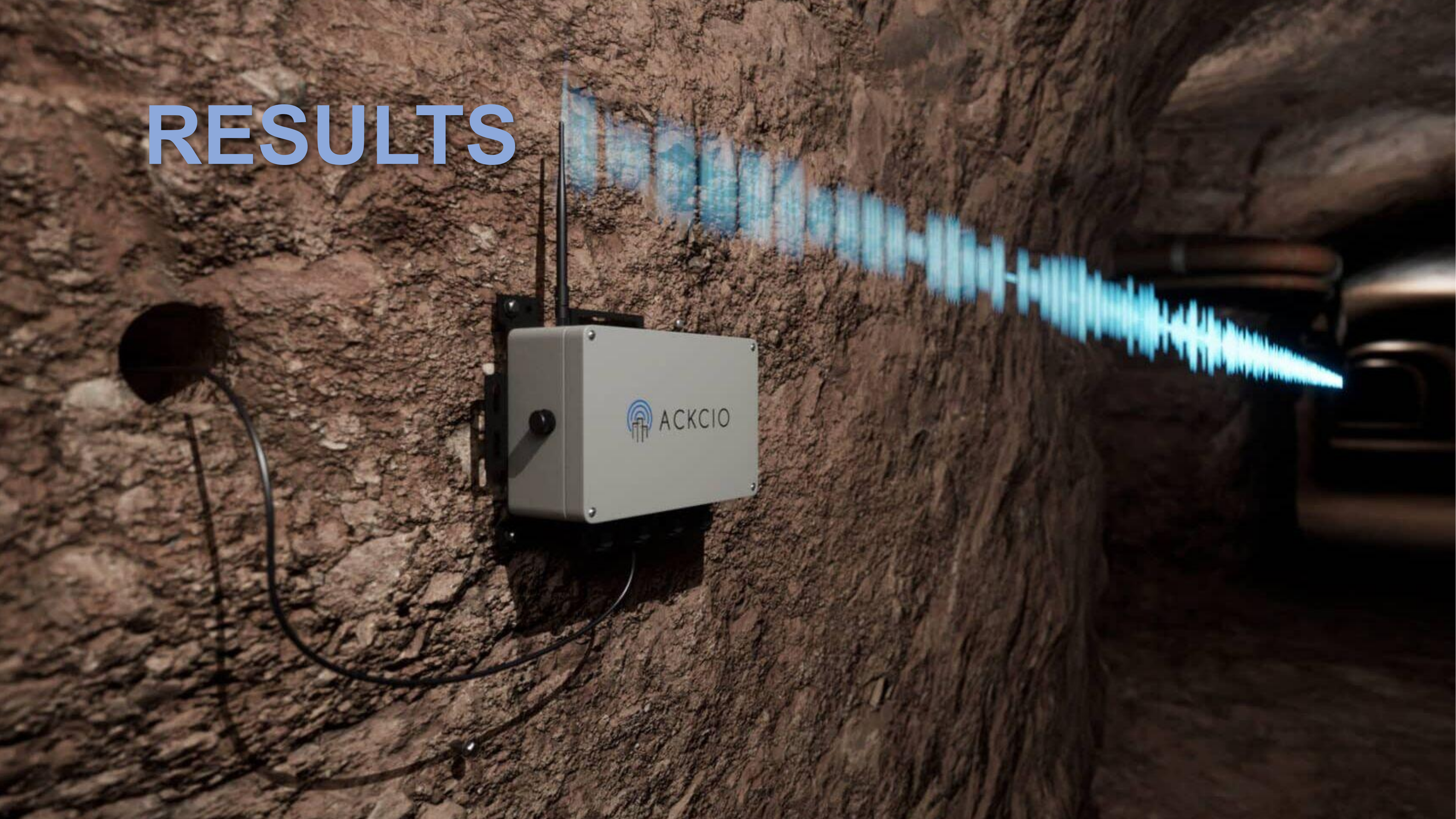
System in different scenarios

- Calculate the transmission range in different accident scenarios.

RESULTS



Oscillator selection

Oscillator	Linear harmonic signal generation	Very low frequency (VLF) compatibility	Accuracy	Environmental stability	Cost	Suitability
• Quartz • Resistor-capacitor(RC) • Inductor-capacitor(LC) • Silicone	Use resistors, capacitors, and inductors.	Yes	Low	Low	Low	Not suitable
Ceramic resonators	Use electric ceramics.	No	Medium	Medium	Low	Not suitable
Microelectromechanical (MEMS)	Use mechanic resonators on silicon chips.	Yes	Very high	High	High	Suitable
Crystal	Use quartz crystal resonator.	Yes	Very high	Very high	High	Best choice

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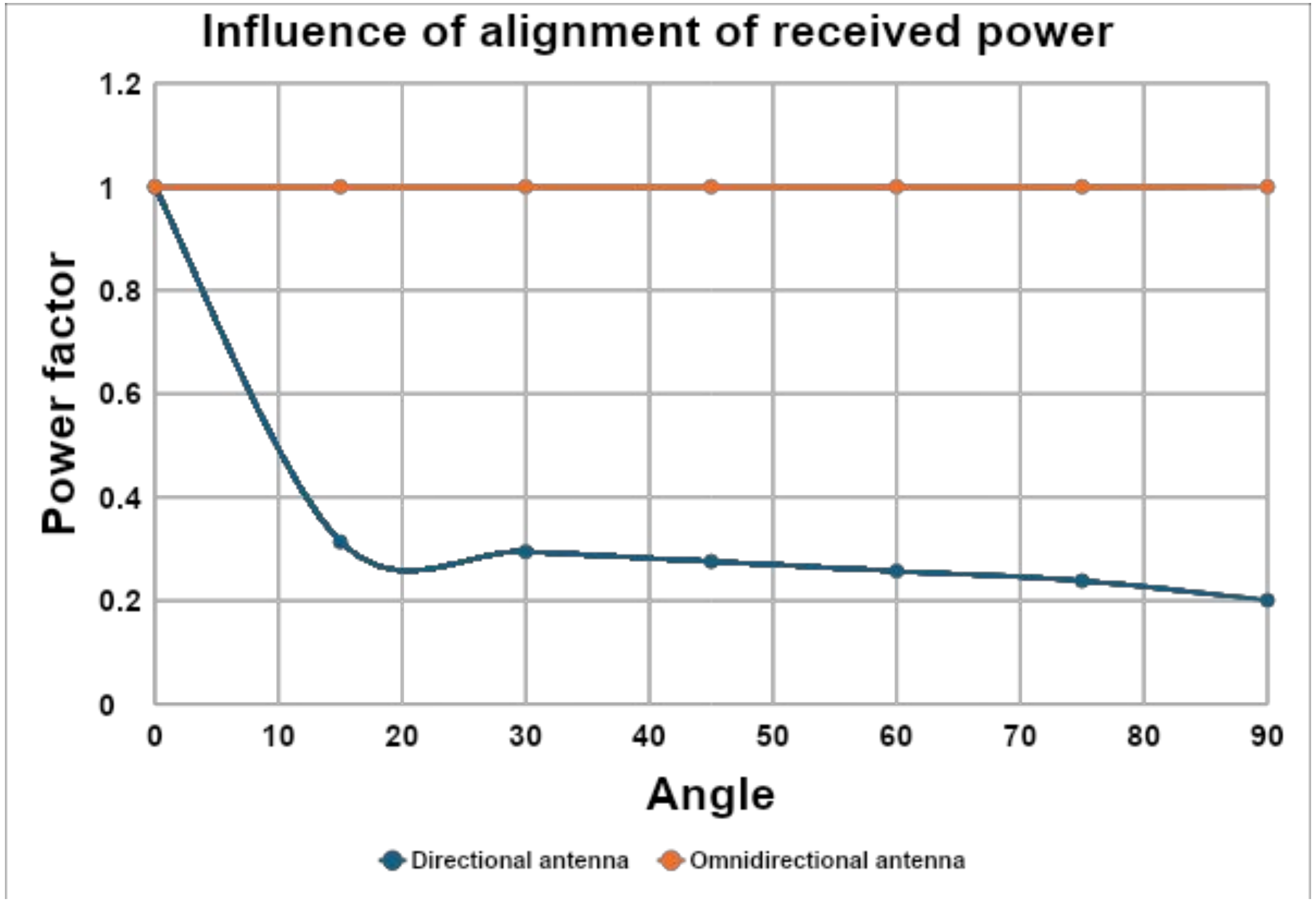
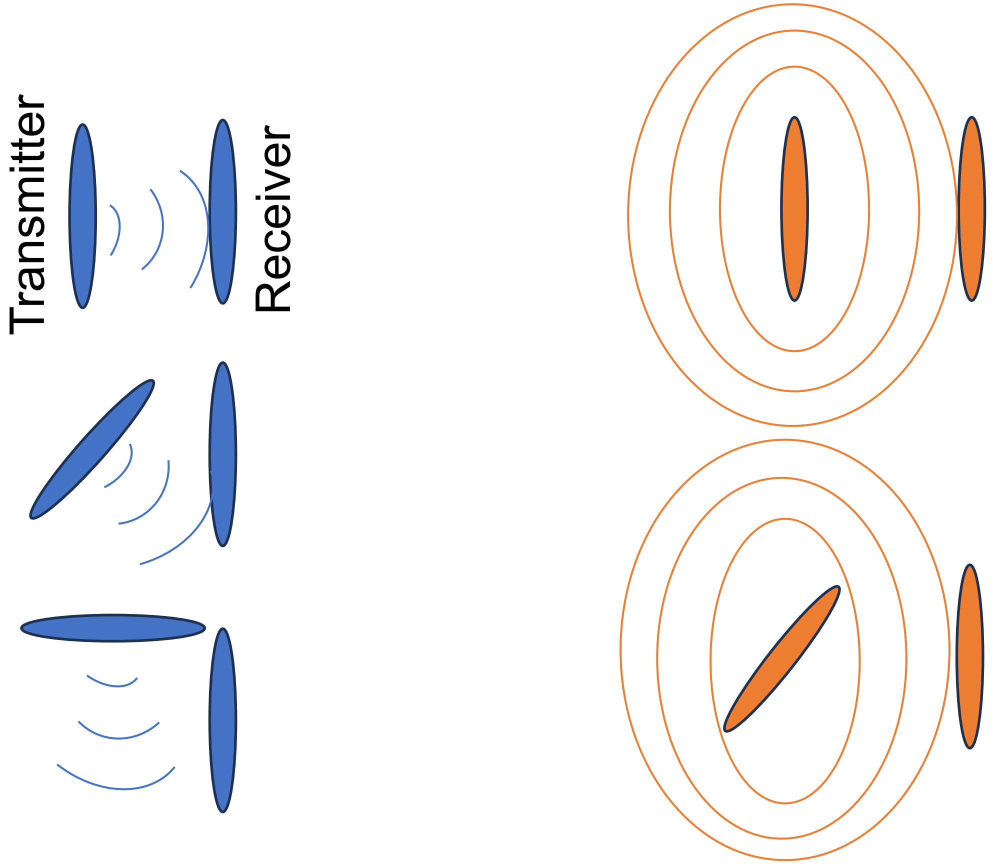
Antenna selection





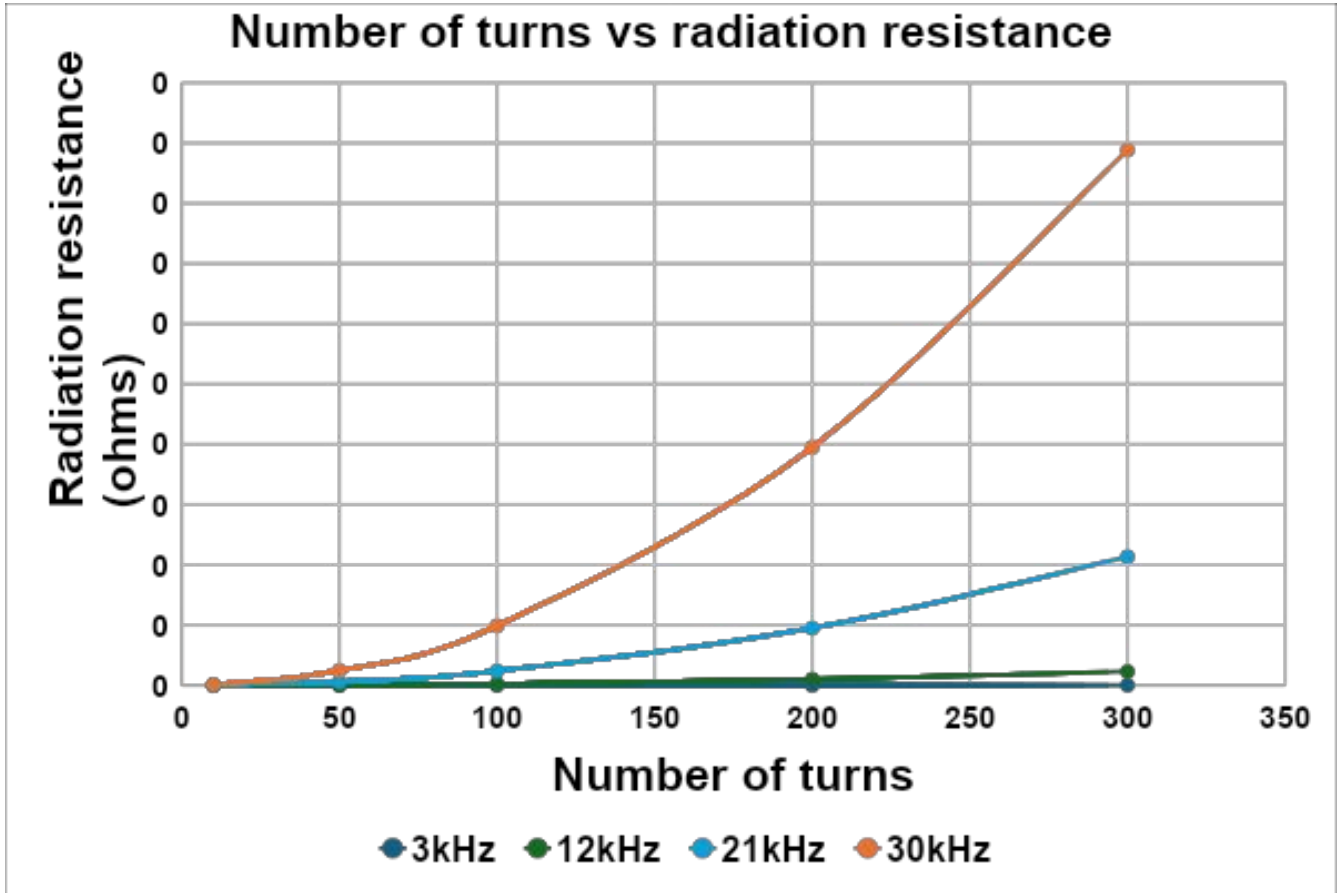
Directional antenna **Omnidirectional antenna**

Antenna size

Symbol	Name
	Frequency
	Speed of light
	Wavelength
	Radiation resistance
	Number of turns
	Area

$$v = c\lambda^{-1}$$

$$R = 320\pi^4(\frac{NA}{\lambda^2})^2$$



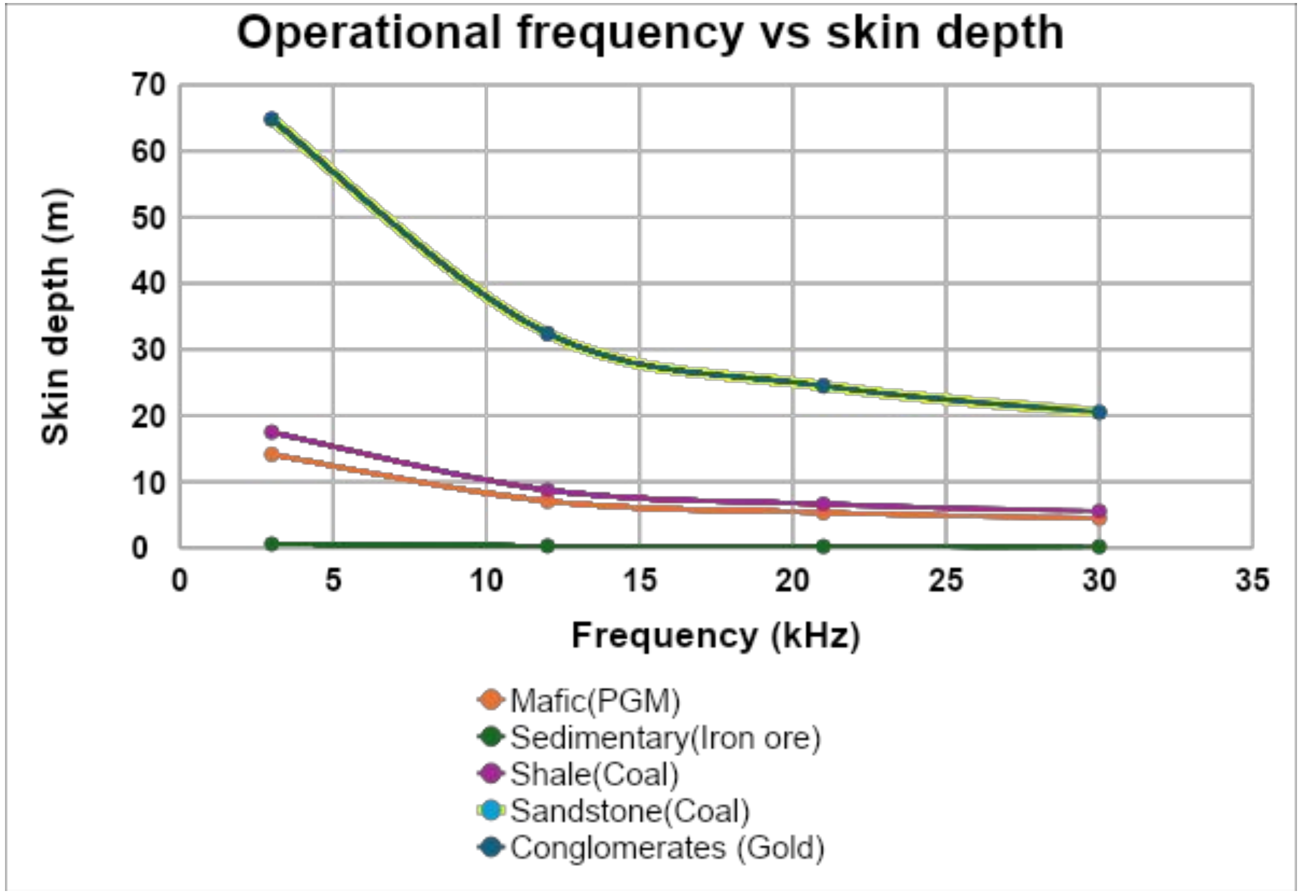
Optimal TTR system design

Component	Type
Oscillator	Crystal oscillator
Modulator	Frequency modulation
Amplifier	Power amplifiers Low noise amplifiers (LNA)
Antenna	Electrically small Omnidirectional

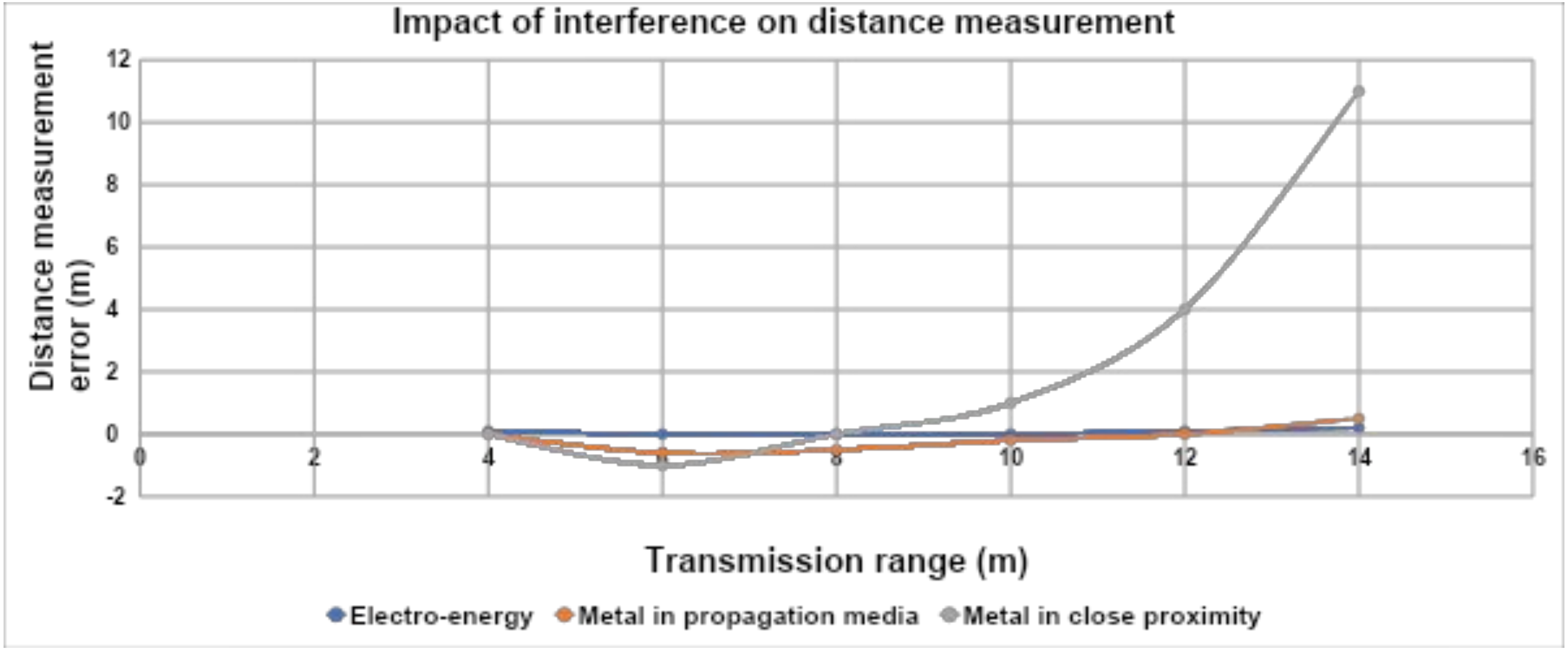
TTR performance in different geological conditions

Host rock		
Conglomerates	1.26E-6	20.05
Sand stone	1.26E-6	20.05
Shale	1.26E-6	275
Mafic	1.32E-6	402.5
Iron-bearing sedimentary	1.26E-3	250

$$\delta = \frac{1}{\sqrt{\pi \mu f \sigma}}$$



Impact of interference on signal reception



Key considerations for implementation

- High conductivity impacts signal transmission, therefore, mines with high-conductivity host rock may consider high-power transmitters. While increasing the power, the practicality of carrying heavier transmitters must be considered.

- As the presence of metals cause a distance measurement error, it is important for the rescue team to be cognisant of these error. However, the search area would have been significantly narrowed down even with the presence of the error

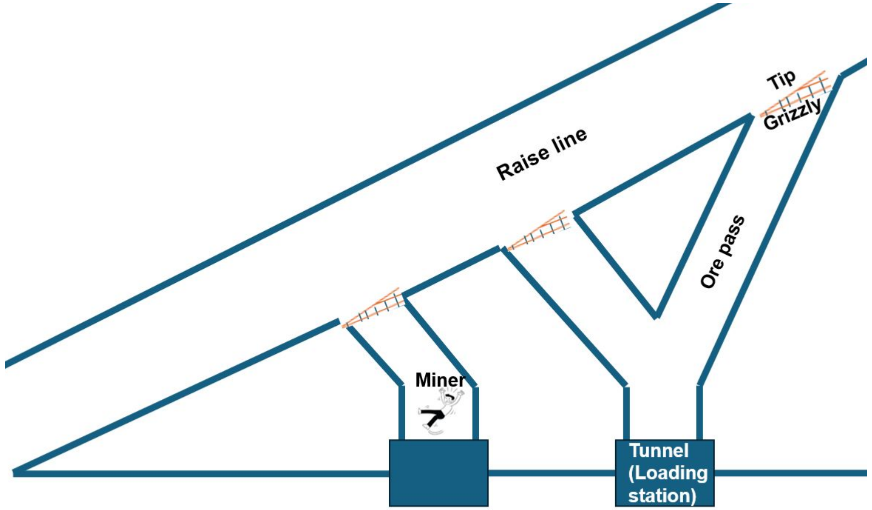
Scenarios where TTR can be used

- Localised incidents

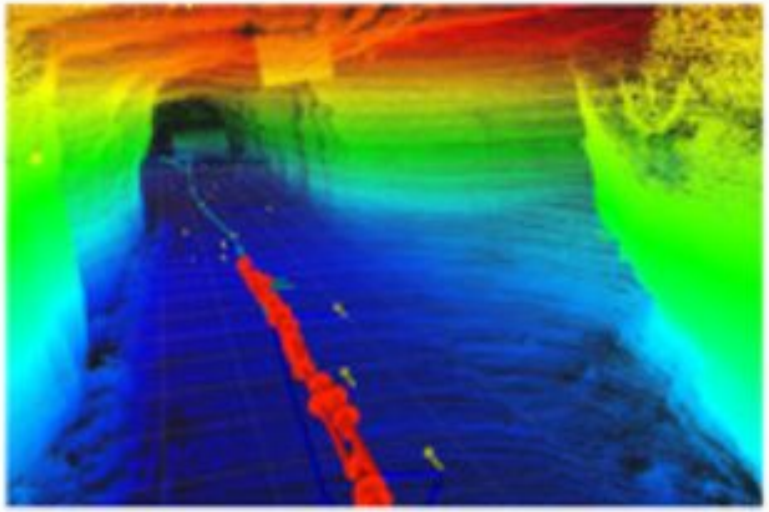
Rockfalls

CDC (2024)

Falling into a void



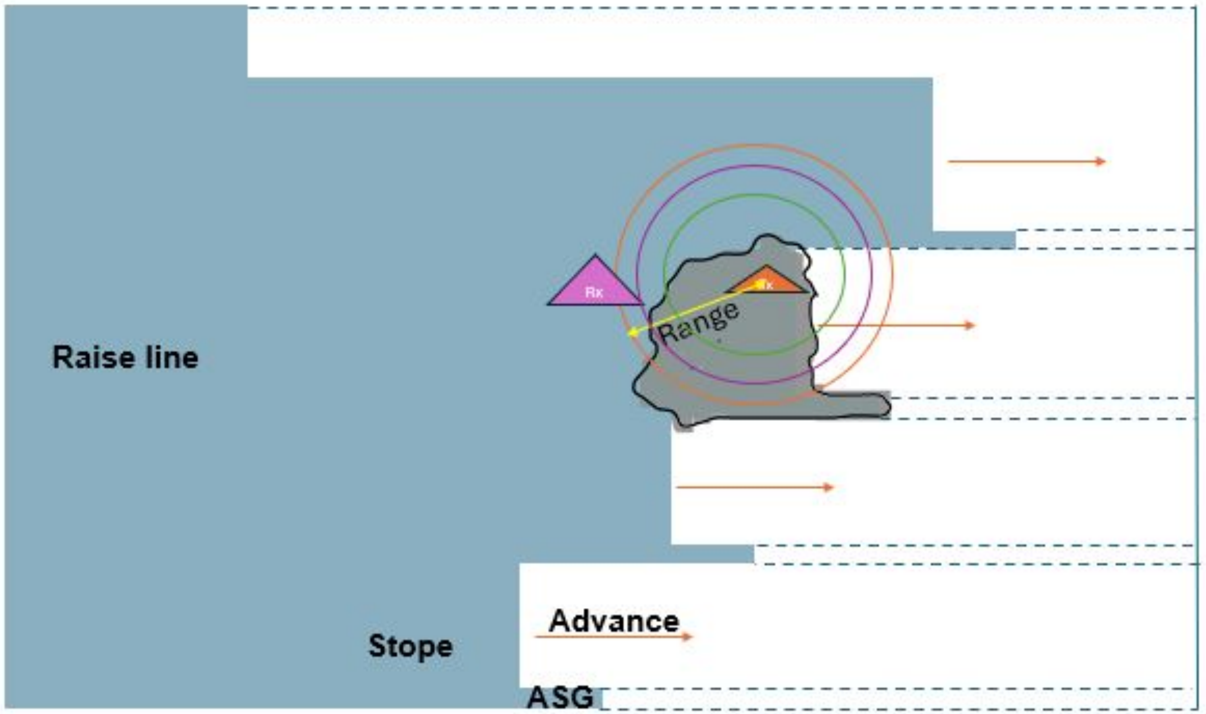
Poor visibility



Imam et al. (2023)

Stope rockfall scenario

- Kusasalethu Mine (25 August 2017)
- Seismic-induced stope rockfall
- 10 m fall of ground in one stope
- 5 miners trapped underground.
- The precise location of the trapped miners was unknown
- 2 miners located - 2 days after the accident
- 1 miner located - 4 days after the accident
- 2 miners located – 6 days after the accident



Tx Transmitter (attached to miner’s cap lamp)

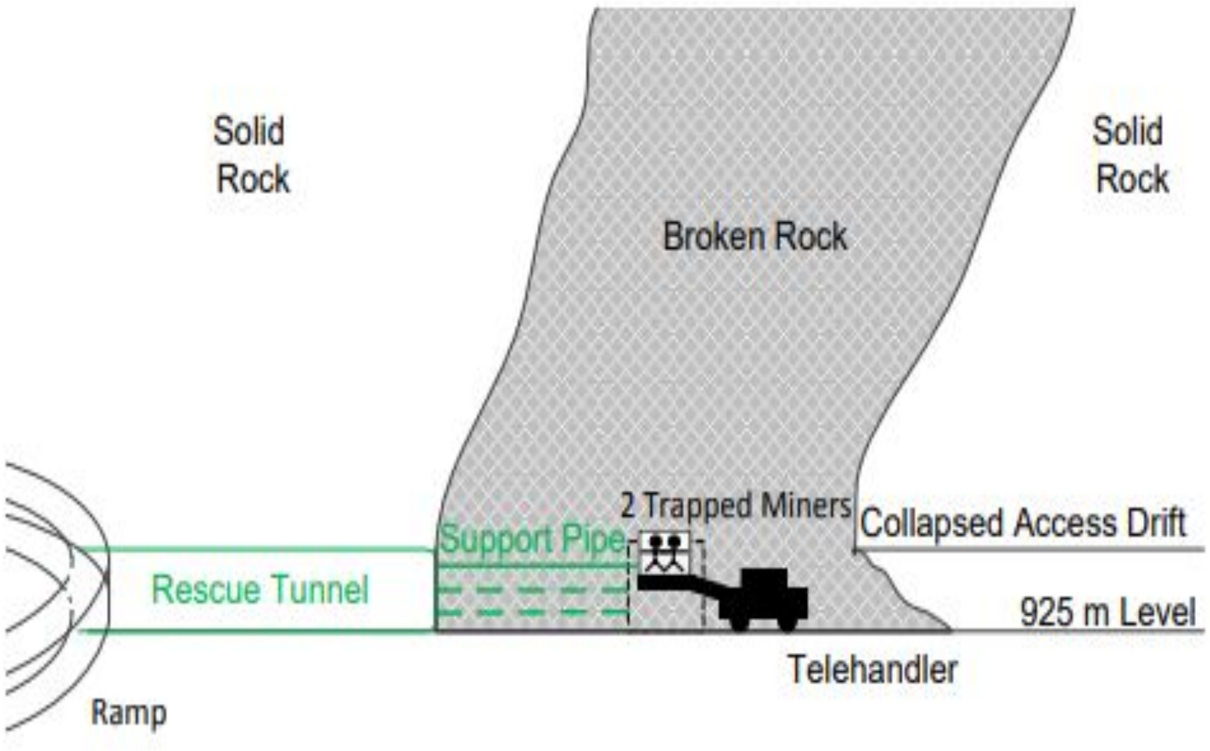
Rx Receiver (Hand-held by the rescue team)

Rockfall scenario

Mineral	Host rock	Permeability (H/m)	Conductivity (S/m)	Water content	Range at 3,3 kHz (m)	Range at 4 kHz (m)	Range at 6 kHz (m)
Gold	Conglomerates	1.26E-6	20.05	Dry	61.8	56.1	45.8
PGMs	Mafic	1.32E-6	402.5		13.5	12.2	10.0
Coal	Sandstone	1.26E-6	20.05		61.8	56.1	45.8
	Ground water	9.99991E-13	800	50% moisture content	19.3	17.6	14.3
					12.6	11.2	9.6
					19.3	17.6	14.3
				90% moisture content	14.6	13.2	10.8
					8.9	7.6	6.3
					14.6	13.2	10.8

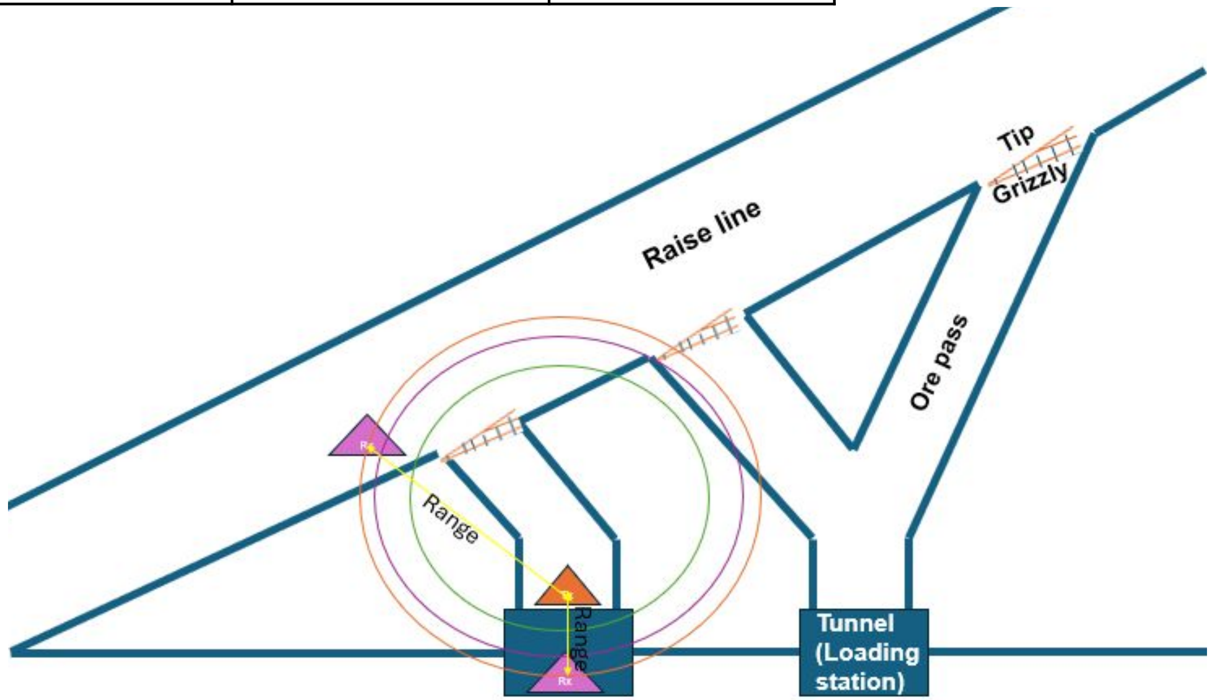
Rockfall scenario

- Beaconsfield mine rockfall (25 April 2006)
- Hangingwall shear slipped and caused a seismic event.
- 1 miner instantly killed by rockfall.
- 2 miners trapped in their telehandler basket.
- 5 days to find the miners' exact location.
- Total of 14 days to rescue.



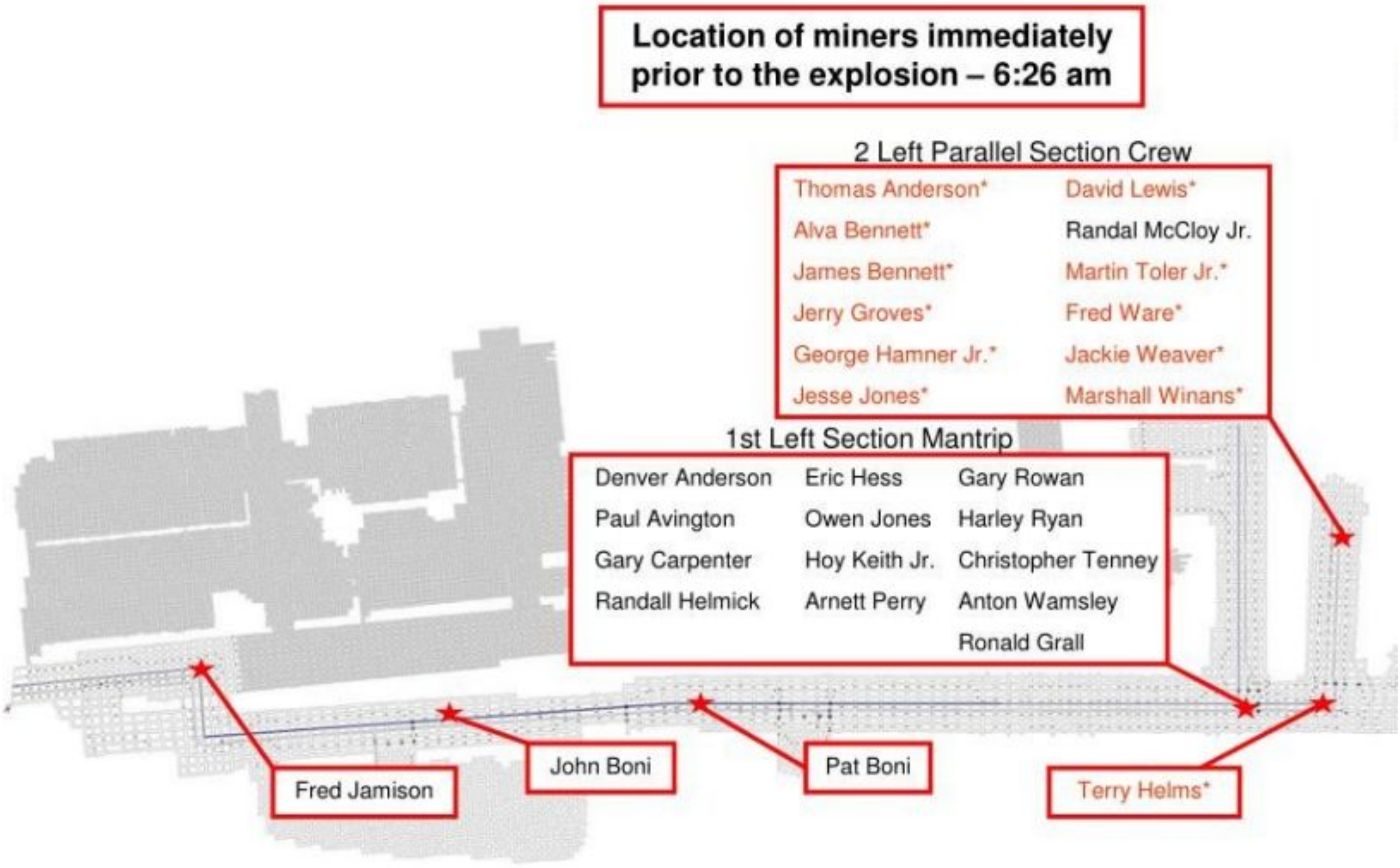
Falling into an ore pass scenario

Medium	Conductivity (S/m)	Range-3.3 kHz (m)	Range-4 kHz (m)	Range-6 kHz (m)
Conglomerates	20.05	123.6	112.2	91.7
Mafic	402.5	26.9	24.5	20.0
Sandstone	20.5	123.6	112.2	91.7
Air	1E-12			



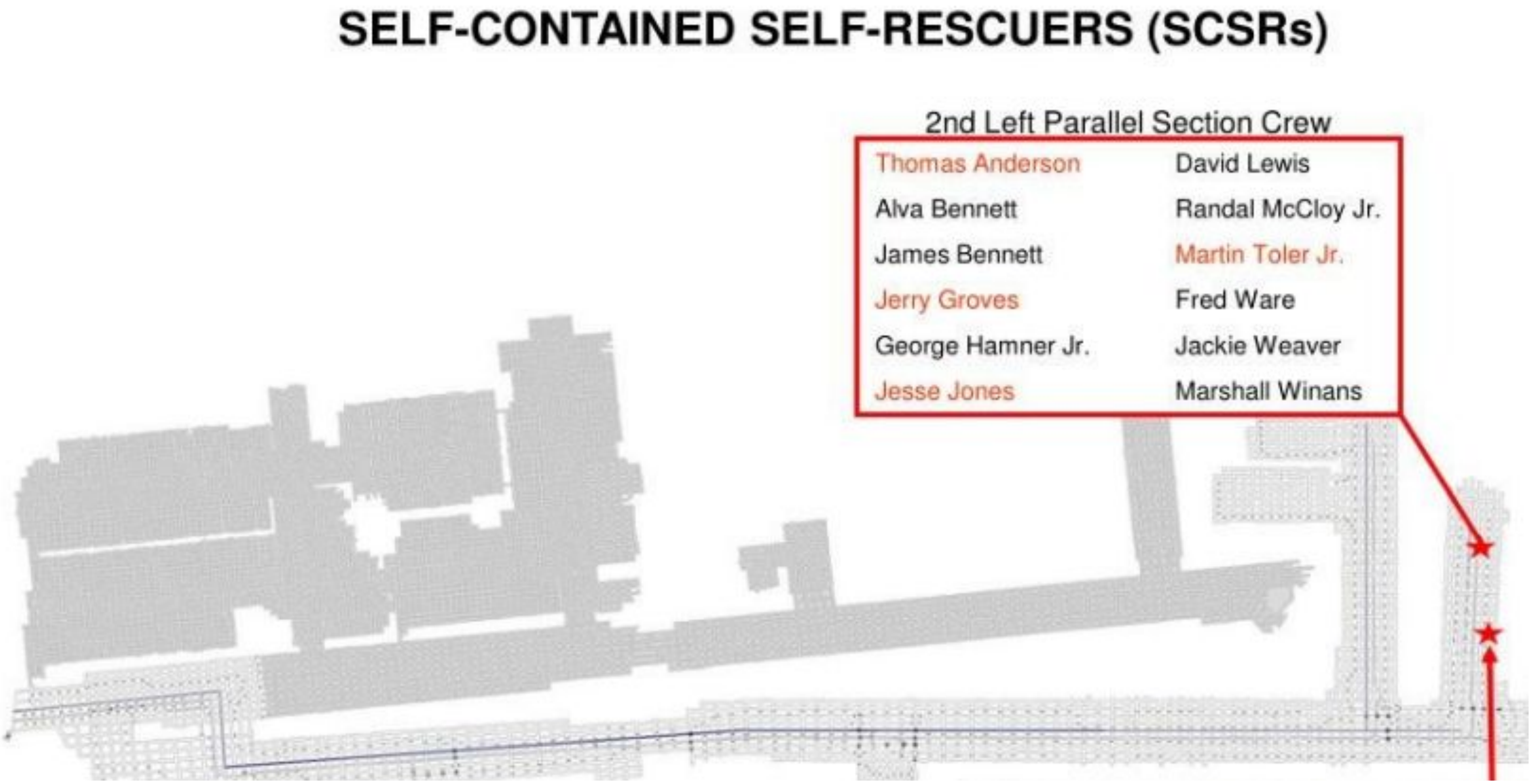
Poor visibility scenario

- Sago Mine disaster (2 January 2006)
- Methane gas explosion
- Instantly killing one miner



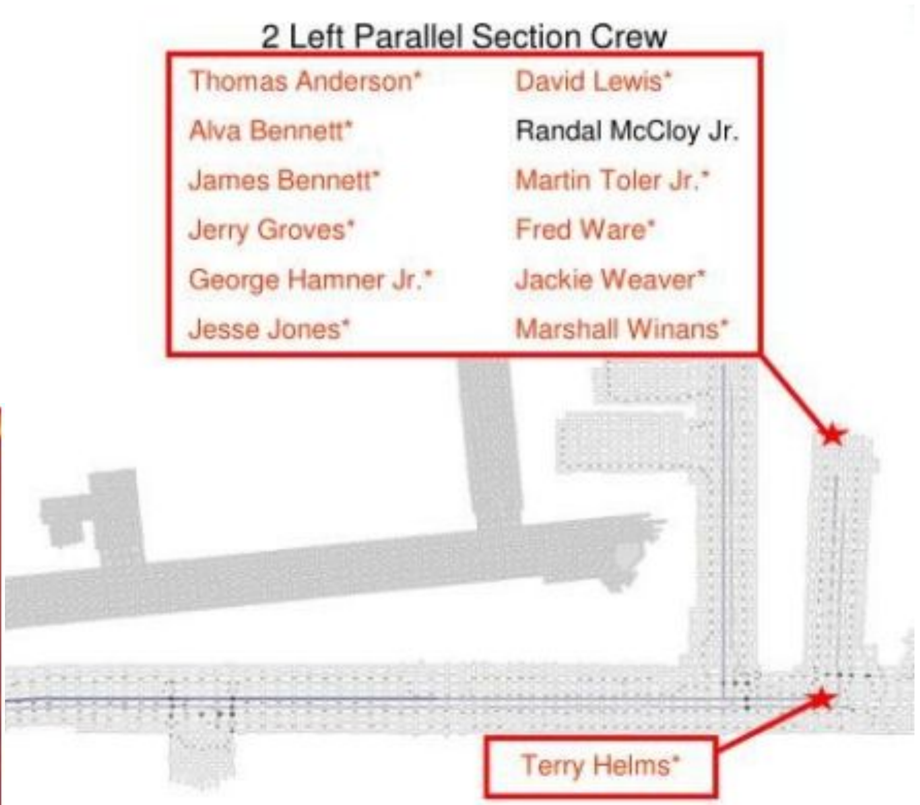
Poor visibility scenario

- 12 survived the initial blast
- Heavy smoke
- Dust
- Severely limited visibility



Poor visibility scenario

- 2 days to locate the barricaded crew.
- 11 died from carbon monoxide poisoning



Poor visibility scenario

Bigger pillars

Mineral	Medium	Permeability (H/m)	Conductivity (S/m)	Range at 3.3 kHz (m)	Range at 4 kHz (m)	Range at 6 kHz (m)
Gold	Conglomerates	1.26E-6	20.05	104.4	94.9	77.5
PGMs	Mafic	1.32E-6	402.5	22.8	20.7	16.9
Coal	Sandstone	1.26E-6	20.05	104.4	94.9	77.5
	30% Air	1.26E-6	1E-12			

Smaller pillars

Mineral	Medium	Permeability (H/m)	Conductivity (S/m)	Range at 3.3 kHz (m)	Range at 4 kHz (m)	Range at 6 kHz (m)
Gold	Conglomerates	1.26E-6	20.05	123.6	112.2	91.7
PGMs	Mafic	1.32E-6	402.5	26.9	24.5	20.0
Coal	Sandstone	1.26E-6	20.05	123.6	112.2	91.7
	50% Air	1.26E-6	1E-12			

Conclusion

- An optimal system should use a crystal oscillator and an electrically small omnidirectional antenna.
- The system's performance is influenced by the mining environment it is used. Properties that have a big impact on the system's operation are the conductivity and magnetic permeability of the transmission medium.
- Electric equipment has no impact on the signal transmission, while metals highly impact the signal transmission.
- The system would greatly speed up rescue missions in various underground scenarios, including rockfalls, ore pass falls, and poor visibility conditions.
- TTA (real-time tracking) and TTR can work in conjunction with each other to enhance rescue.

Recommendations and future studies

- A key finding is the significant variability in the performance of TTR systems under different geological conditions, particularly in iron-bearing host rocks.

- Therefore, it is recommended that the design and application of TTR systems account for this significant variability in performance observed under different geological conditions.

- The limitations of the system, such as the sensitivity to metallic interference, show the need for further research into signal processing methods.

Acknowledgements

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SAIMM and the organising committee

Thank you