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# The Suitability of Quantum Magnetometers for Defence Applications

UDT 2019 - 14th May 2019

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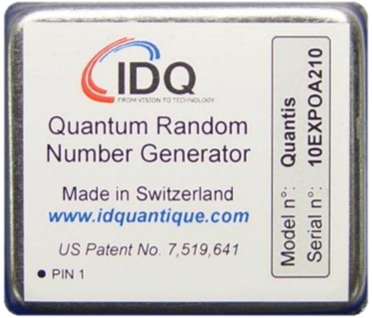
# Quantum Devices



## Quantum technologies are beginning to move out of laboratory environments and into industrial applications.

## Various devices now exploit quantum effects,

- Magnetometers
- Random number generation
- Accelerometers
- Gravimeters
- Clocks





www.idquantique.com

Imperial College

# Quantum Magnetometers

- **Recent funding announcements such as the EU Quantum Flagship and UK National Quantum Technologies Programme will only accelerate their adoption further.**

- **This paper has focused on two promising magnetometers developed by leading academic institutions, SMEs and Thales UK;**
  - Atomic Magnetometer for Magnetic Induction Tomography (AMMIT) – University College London
  - MagCell – University of Strathclyde, INEX Microtechnologies and Fraunhofer Centre for Advance Photonics

# Quantum Magnetometers

## Quantum devices

- increases in sensitivity by several orders of magnitude.

## Typical fluxgate

- resolve changes in magnetic fields below 1nT.
- noise floor of less than 6pTrms/√Hz.

## Quantum device

- aims for a resolution of a few pT or less.
- noise floor of fT/ √Hz.

http://www.cryogenic.co.uk/products/s700x-squid-magnetometer

## Ideally performance rivalling a Superconducting Quantum Interference Device (SQUID) magnetometer but cryogenic cooling and a smaller form factor.







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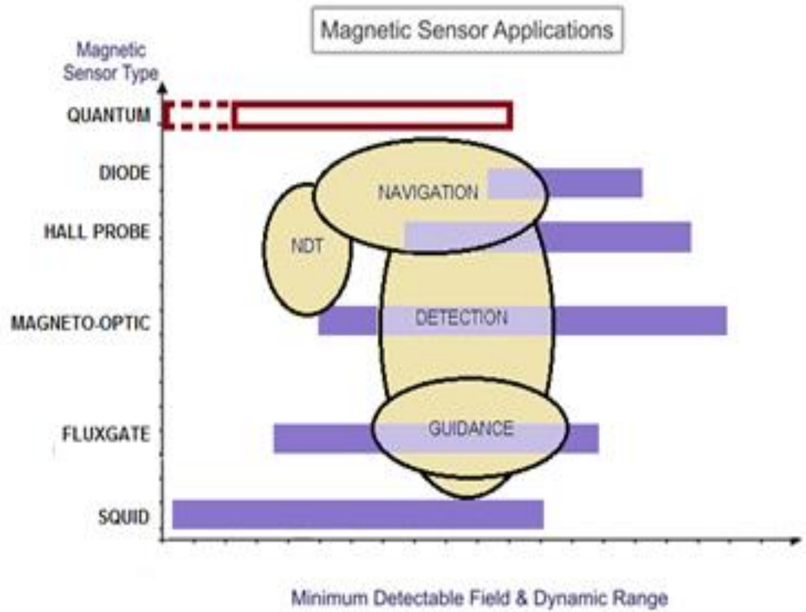
# Quantum Magnetometers - Uses

## Increased performance, so how can we use it?

- Remote detection
- Remote inspection
- Vessel protection
- Navigation




modified from doi:10.3390/s90402271

## Re-evaluate use cases where magnetics has benefits but in the past has been surpassed by other technologies.







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# Quantum Magnetometers - Uses

## Remote Detection

https://en.wikipedia.org/wiki/Magnetic_anomaly_detector

https://www.cae.com/media/media-center/documents/datasheet.MAD-XR.pdf

- CAE MAD-XR
- 1200m range
- Can this be improved upon?

# Quantum Magnetometers – Remote Detection

## Remote detection of targets requires;

- a highly sensitive device
- low self-noise
- bandwidth from DC to several kHz
- Form factor and power requirement?

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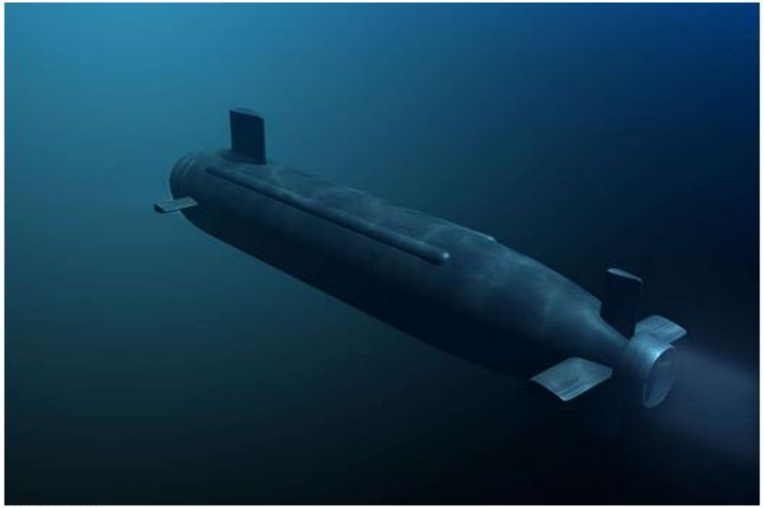

Tailed by a SQUID
Snaprender/Alamy Stock Photo

New Scientist

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# Quantum Magnetometers – Remote Detection

- Magnetometers could be used for detection of low signature mines
- Acoustic solutions are ineffective in cluttered, shallow waters or the surf-zone
- Sensor fusion may be the only viable solution
- LIDAR could be an alternative

www.liberaldictionary.com







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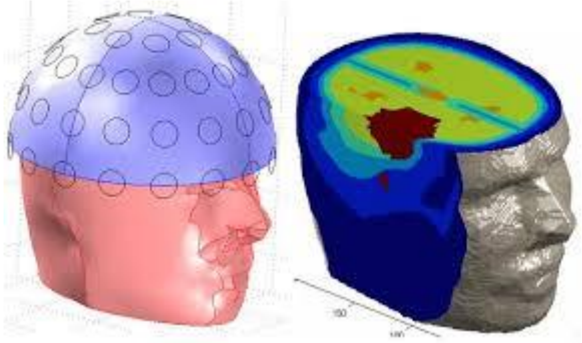
# Quantum Magnetometers – Remote Inspection



## Thales UK and UCL have recently conducted a research task to develop magnetometers under Innovate UK project 131885

## The main technique researched was Magnetic Induction Tomography (MIT),

- tomography is an imaging technique that produces slices, or sectional, images of the object under inspection.
- Commonly used in;
  - Medicine,
  - Geophysics,
  - Non-Destructive Testing



http://sine.ni.com/cs/app/doc/p/id/cs-13088#

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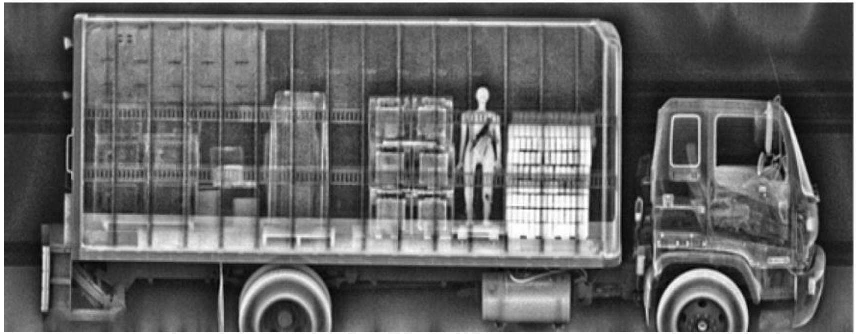
# Quantum Magnetometers – Remote Inspection



## MIT has been shown to image metallic objects even through screening materials.

- Applications in;
  - border security
  - Parcel scanning
  - Container inspections
  - Investigating the insides of buildings



https://kaes.com.sa/solution/turnstiles/

- For fast screening of parcels or containers the key requirements for a device would be sensitivity and noise floor. The form factor and power requirements can be offset if the technology provides a viable solution.





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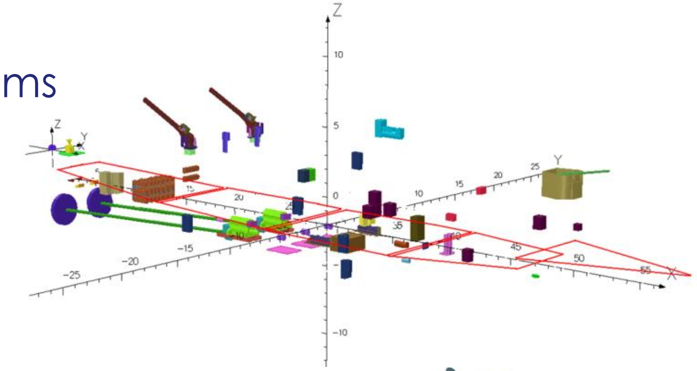
# Quantum Magnetometers – Vessel Protection

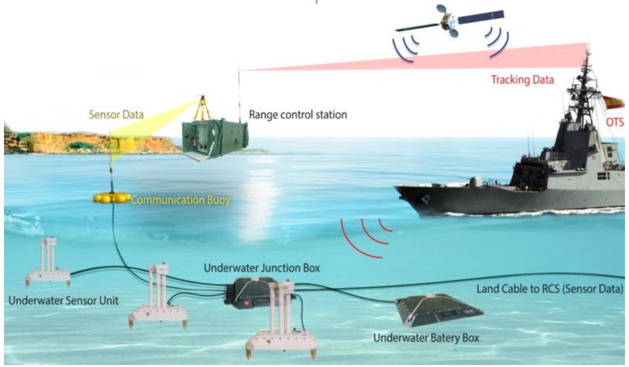
## Degaussing Systems

- Fluxgates are commonly used for degaussing systems
- Small, low power
- Have sufficient sensitivity



## Signature Ranging

- Multi-Influence ranges
- Conflicting requirements which increased sensitivity of magnetometers could overcome




https://electronica-submarina.com/underwater-measurement-category/mirs-signatures-measurement-for-ships-and-submarines/







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# Quantum Magnetometers – Navigation



**As well as increased sensitivity another benefit of quantum magnetometers is that they do not required calibration.**

**A magnetometer based navigation device works by detecting ripples in the Earth's field and detecting previously mapped anomalies.**

- Could be used in GPS-denied environments as part of a navigation system.
  - Combined with quantum accelerometer and quantum roll sensors.
  - A quantum inertial navigation system (INS).





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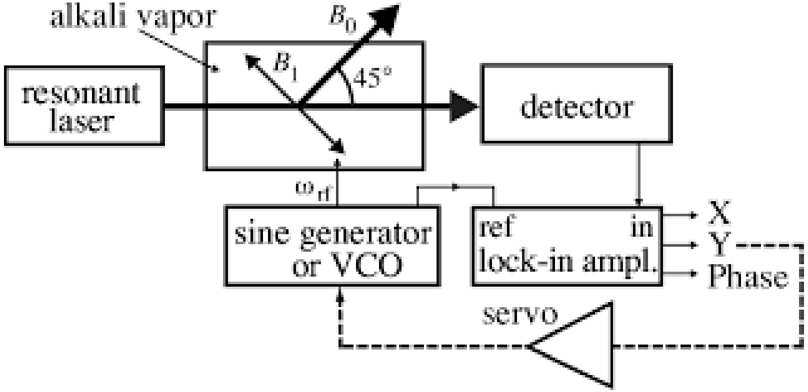
# Quantum Magnetometers – Theory of Operation



- The devices considered have similar principles of operation and components.
- Both types consist of a laser, a vapour cell and a photo-detector.
- Different measurement techniques can employ lock-in amplifiers and secondary magnetic field generation.




Fenici, "Comparison of magnetocardiographic mapping with SQUID-based and laser-pumped magnetometers in normal subjects"





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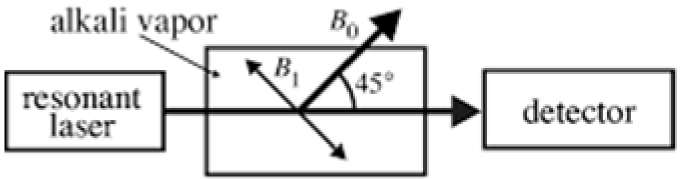
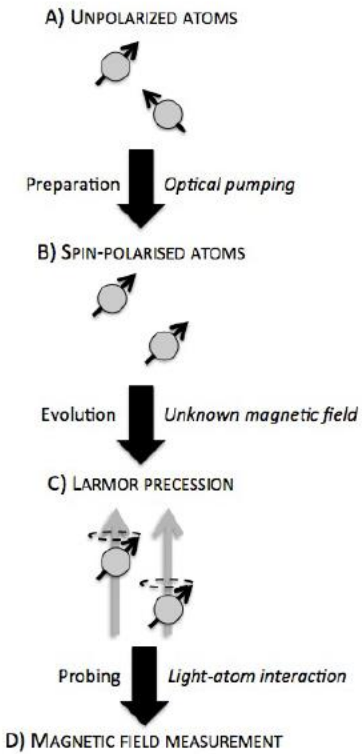
# Quantum Magnetometers – Theory of Operation




- Step A) - The atoms in the vapour cell are un-polarised.
- Step B) - The laser optically pumps the cell and aligns the spin of the atoms (typically Caesium, Rubidium, Helium or Potassium). The spin of the electrons in the atom to process at a known frequency.
- Step C) - An external magnetic field (such as from a target) causes a shift in the rate of procession known as the Larmor frequency.
- Step D) - The Larmor frequency is proportional to the external magnetic field and can be measured.




doi: 10.1117/12.2195482







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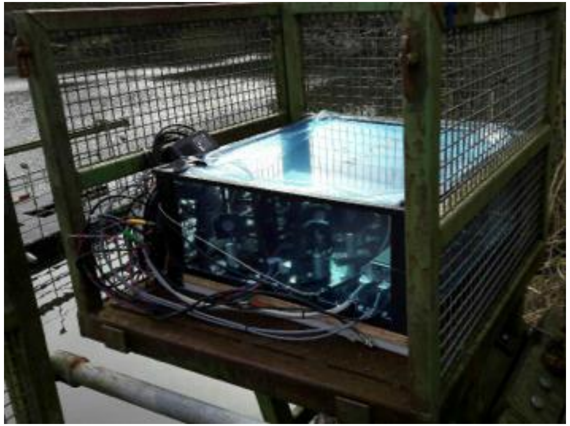
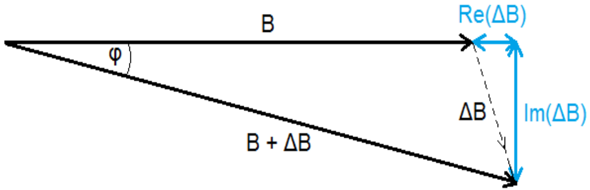
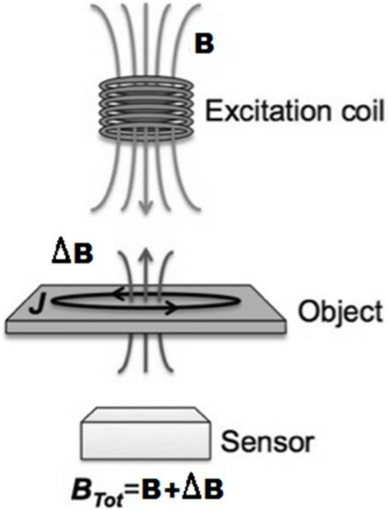
# Quantum Magnetometers – AMMIT

- Atomic Magnetometer for Magnetic Induction Tomography (AMMIT) – University College London.
- Could be considered an 'active' device.
- Stimulates eddy currents in a conductive target.
- Eddy currents generate a measurable secondary magnetic field.
- Target must be conductive but not necessarily magnetic.

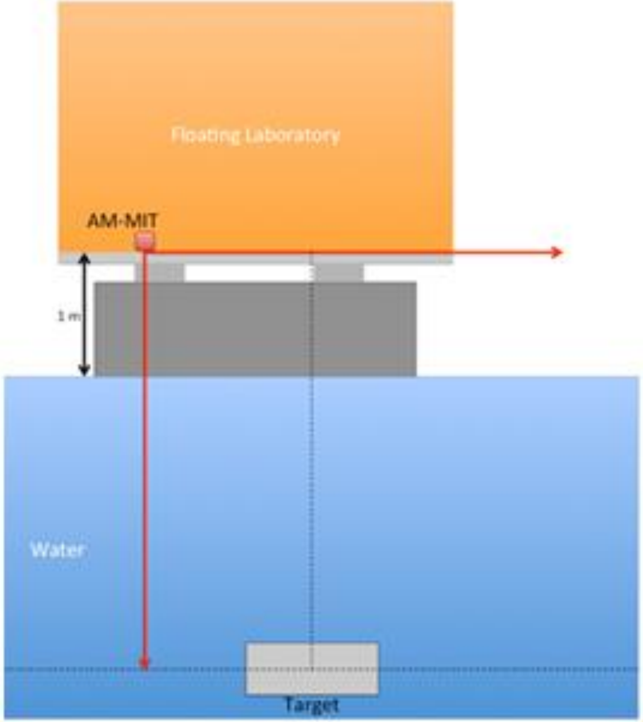




# Quantum Magnetometers – AMMIT

## Experimental setup





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# Quantum Magnetometers – AMMIT

- AMMIT Waterlip Quarry experiment demonstrated target detection at useful ranges.

- UCL have also demonstrated detection and localisation of underwater targets in a laboratory environment and have reported a reported noise floor of 130fT/√Hz.







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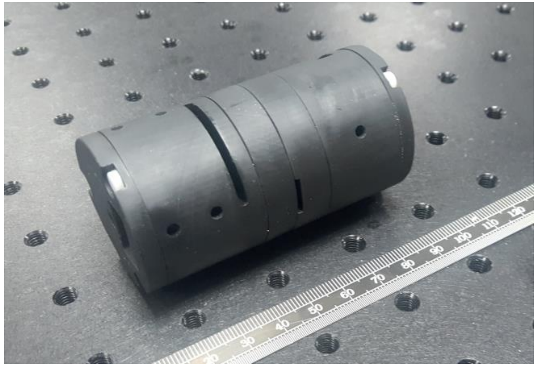
# Quantum Magnetometers – MagCell



- **MagCell – Field Demonstration of Atomic Vapour Cell Magnetometry – Innovate UK Grant 103999.**
  - Thales UK, University of Strathclyde, INEX Microtechnologies and Fraunhofer Centre for Advanced Photonics.
- **Could be considered an 'passive' device.**
- **Scalar Magnetometer**
- **The double resonance technique results in a versatile sensor capable of measuring both static and alternating magnetic fields to a high degree of accuracy.**





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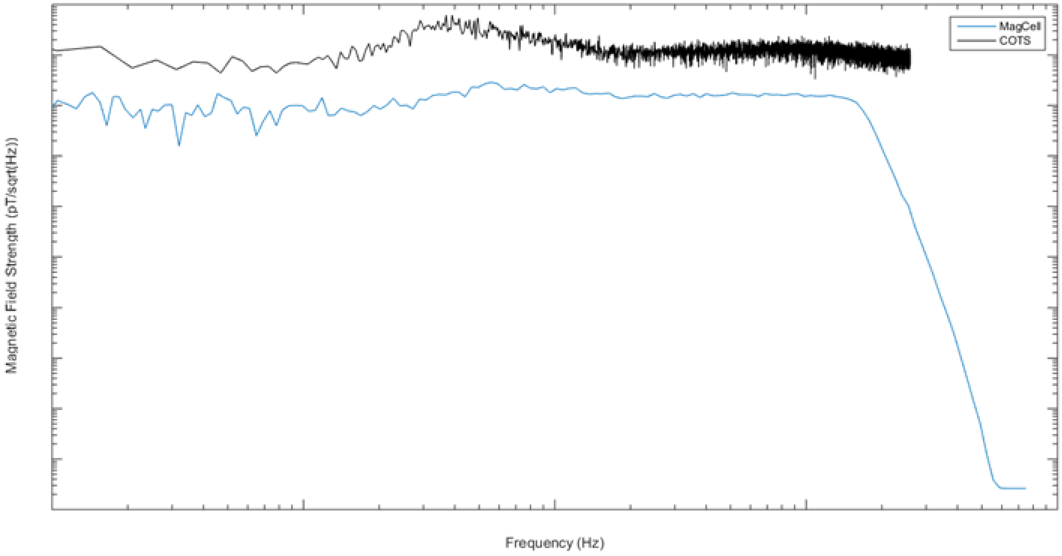
# Quantum Magnetometers – MagCell

- **Noise floor compared to COTS device.**
- **Measured at Underwood Quarry as 3.4pT/√Hz initially but subsequently improved to approximately 1pT/√Hz in further quarry tests.**







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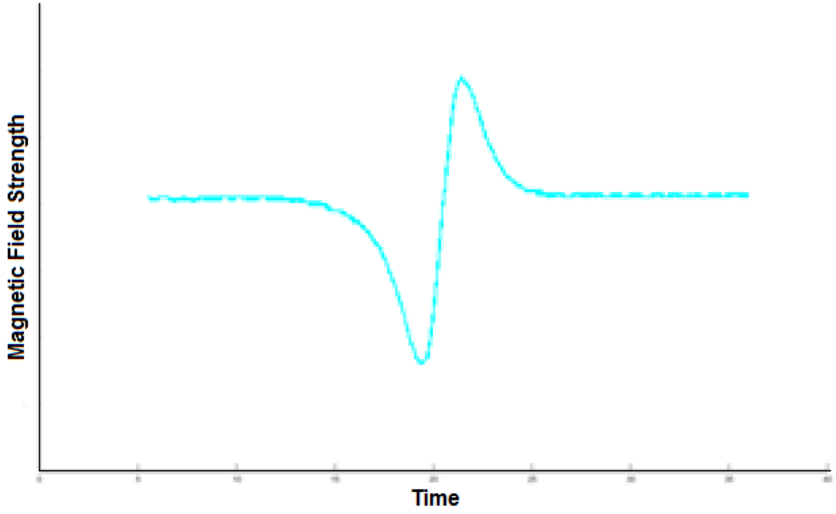
# Quantum Magnetometers – MagCell

## Tests against representative ferromagnetic targets and controllable electromagnets designed for the experiment.

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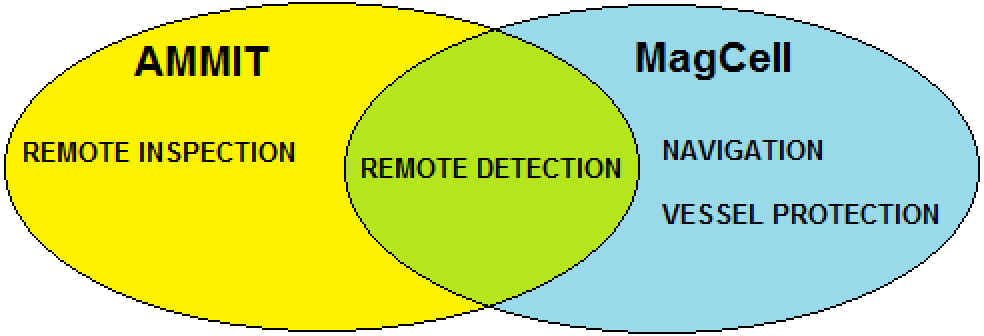
# Conclusions

## Two promising devices have been developed;

- One active device (AMMIT) – target does not need to be magnetic,
- One passive device (MagCell).




## Experimental evidence for both magnetometers provides useful detection ranges – offering benefits over acoustic technologies in noisy environments

## MagCell 'SWAP' potentially easier to exploit at this time.







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# Thank you for your attention

# Any questions?

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