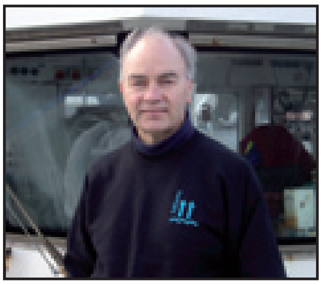

A new dimension in subsea monitoring

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Concerns at the United Kingdom Atomic Energy Authority's plant at Dounreay over the discovery of radiological particles in the open — both off and on-site — in the last 15 years have led to a series of investigations in the immediate waters off Dounreay. This charts some of these investigations.

IT was during a long oceanographic study at Dounreay in 1997 that the UK Atomic Energy Authority asked whether Fathoms could develop suitable methodologies for a subsea particle search. Apart from the provision of the detector, which had been adapted for underwater use, the project was put in our hands.

Three weeks later, a team of divers and surveyors started the search for particles. Within three days, several particles had been located and recovered to the surface. With the system proven in principle, further work was undertaken several months later when 34 particles were recovered in a four week period. The radioactive particles found in the local environment at Dounreay are fragments of irradiated nuclear fuel elements, which were released accidentally into the environment from the Dounreay site in the late 1960s and early 1970s. These are all the size of a grain of sand and lie on and mainly under the seabed, buried to a depth of up to 1m.

Subsea surveys

With the concept and principles proven, UKAEA let out a contract in 1998 for a major offshore radiological study that required the:

- Development of suitable underwater gamma probes.
- Assessment of the specific characteristics of the area.
- Selection of equipment appropriate to the terrain and depth of working.
- Selection of the most suitable survey regime.
- Development of methods for the suitable capture and recovery of particles detected on the seabed.
- Recovery of sediments samples.

UKAEA therefore required the contractor to propose suitable equipment and methodology to fulfil this contract. Apart from the selection of a suitable detector, the main decisions concerned the methodology. We considered various options; including the use of conventional remotely operated vehicles (ROV), tracked ROVs, towed systems and divers. The whole area covered some 1,970,000m^2, of which 5% had to be surveyed and studied.

The nature of the seabed also played a large part in determining the best method. Much of the offshore area consisted of fairly smooth sand whilst the majority of the inshore area consisted of rocks. As a result, we determined that the optimum methods would be a combination of a towed system for deeper areas that consisted of a sandy seabed, and divers for the inshore waters with rocks, stones and a generally less regular seabed. The matching of the methodology to the terrain was a crucial factor in the success of the operations.

The integrated tow system (FITS) was designed and built in-house and fitted into the combined systems. Mounted on the towed body were one detector and a video camera. Data from the detector was logged on board the vessel and integrated into a logging and processing system. The video was seen on board and provided the operators with a real time picture of the seabed. The software logged all radiological data, position, time and any other parameters required.

We selected a small trial area of about 50m x 50m. This was searched twice. The first time with the FITS and the second by divers. Examination of the results from the divers' search showed that the FITS had found every particle that had lain within its path. Some of these were also outwith the specification parameters for the search — indicating that the detectors were working very well. Furthermore, where the FITS indicated that there were no particles, the divers confirmed this; providing extra evidence of the reliability and consistency of the detectors and methodology.

Armed with these results, we continued the FITS search wherever we could, recognising that the system in this configuration would only be suitable for relatively large and open sandy areas where the seabed is reasonably regular. A video camera mounted on the system enabled us to monitor the seabed at all times, determine the nature of the seabed and check how the system was flying. Given that UKAEA only required 5% of the total area to be surveyed, we were able to complete the towed work in good time.

Weather inevitably plays a large part in operations off Dounreay, where the coast trends in a northeast southwest direction. Experience has shown that when the wind rises above about force five and is from southwest through to northeast, work is impossible. Not only must one cope with the obvious seas but often there is a swell. The swell is often present even in good weather. This obviously makes life awkward when trying to work the inshore waters along the coastline.

The nature of the seabed is varied in the survey area and ranges from rock to boulders

Figure 1: A diver descending into the water.

Figure 2: A diver on the seabed with a detector.

(often with kelp) to sand. In Sandside Bay, the water is shallow but the seabed consists mainly of a mixture of stones and boulders with some sand in places and rock outcrops. The latter occur towards the northern boundary. The rock consists mainly of shattered sandstone in sloping format. This results in there being many gullies in which sand can lodge in small quantities. Moving further north and east from Sandside Bay, one finds a strip of rock about 400m wide stretching out from the high water line. Offshore from the rock, the seabed consists of sand. Opposite the Dounreay site itself, the rock strip is somewhat thinner but there are still rock outcrops in amongst the sand. Opposite the eastern extremity of Dounreay, the rock again extends about 400m seaward. About 1km offshore from Dounreay, we found a number of ribbons of sand ripples.

Once the FITS work had been completed, the diving work was set about in earnest. Most, but not all, of the divers had been involved with the work the previous year and were therefore able to provide a good basis of experience for this survey. The more we worked, the more we realised how important it was to have experienced and dedicated divers.

On many occasions, it was the diver's sheer experience that enabled him to detect a particle when sweeping with the handheld detector. Whilst the deepest particle recovered was at a depth of about 1m below the seabed, there were many in the 40-80cm range. This ability of the divers to locate and recover particles from these burial depths provided us all with tremendous confidence in their work and the thoroughness of the survey.

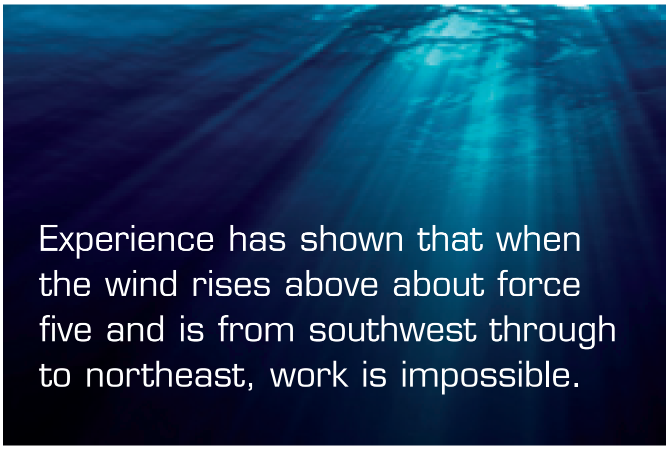
Throughout the survey, we kept reviewing the procedures and methodology to ensure that the best and most economical method was being used. We redesigned the FITS and built a new one for improved results in the latter stages of the works. This increased the productivity of the towed work. Despite the apparent archaism of using divers, we felt at the time that this was the optimum method for the search and recovery operations; especially in the inshore waters and where the seabed consisted of rock or boulders. It is questionable whether an ROV could have searched the gullies and pockets of sand with the rock structure as quickly and efficiently as a human. Certainly, the recovery of particles by the diver became a slick and quick operation.

When one considers how an ROV has to work, it is very difficult for one to replicate the diver's actions; i.e. gather up a scoop of sand, test for whether the particle was included in it, discard the scoop if necessary and then recover that scoop of sand (intact and sealed in a bag) to the surface for subsequent grading and separation.

Positioning

As with all subsea work, the recording of positions is vital. This is a two stage process with the vessel requiring accurate surface positioning and then a separate positioning system for the subsea aspects. Both are combined into specialist software that logs all parameters which, in addition to position, include the data from the detectors, vessel's heading, course and speed etc.

All data is subsequently processed to show the results in a number of user selectable formats. The results can also be exported into other packages such as GIS. Furthermore, we are able to provide the client with a copy of the track plot showing the exact area covered. It is very important to provide hard copy evidence to the client of which areas have and have not been covered.



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Surveying and positioning expertise is just as important as diving and marine skills. Indeed, this same process lends itself extremely well to surveys on land where the difficulties of working in the marine environment are removed.

Instrumentation

For the initial contract, two standard gamma detectors (one more sensitive than the other) were used. The less sensitive probe had a 19mm dia x 25mm thick NaI crystal surrounded by lead, typical background 3-8cps (counts per second). The other had a 25mm dia x 38mm thick crystal without shielding, and comparable background of 20-30cps for the same locale. These were plastic scintillators that are capable of displaying total gamma activity. The activity display was analogue and was coupled to an audible output, which fed live to the diver and to the surface control through the diver's communications umbilical. Power was supplied from rechargeable internal batteries, and both instruments were housed inside stainless steel units.

Circular sweep patterns were adopted for the majority of the areas surveyed and the results were impressive. Over 800 particles were recovered, ranging in ^{137}Cs gamma activity from E+02 to E+08 Bq, and depths of burial from 0cm up to 80cm.

The units proved robust and reliable, with a fast response to any area of raised activity. Typical background readings of seabed sediment were 35-50cps and exhibited little variation over the large areas of seabed surveyed. The majority of raised activity was associated with either the presence of a particle or in the proximity of rocks or boulders.

Although the use of the plastic scintillators has proved very successful, they cannot differentiate between the gamma activity of natural or anthropogenic origin. They simply detect gamma activity, which is output as cps. The ability to assign the activity as either natural or anthropogenic is most significant at the lower limit of detection threshold, where ambiguity is most likely to occur.

To address this shortcoming, we researched the possible gamma spectral systems available within the market place in mid 2002. The brief was to select a system capable of subsea deployment and delivering real time dynamic gamma spectroscopy.

This primarily involved the selection of a detection medium, for example NaI, BGO, Cs(Tl) etc and the electronics/software of the signal processing system. The detection system chosen was the SAM935 package from Berkeley Nucleonics Corporation.

This system consisted of a ruggedised control/display unit with an external ruggedised 78mm dia x 78mm high NaI(Tl) detector unit (and associated photo multiplier tube). The system can be powered by mains or internal rechargeable battery. The control unit uses a patented data compression algorithm, which provides enhanced statistics for analysis and display within 1s. It takes successive time samples of data continuously and the powerful 16-bit microprocessor analyses each sample concurrently. Input/output is via an RS232 connection; there is 250 spectra storage capacity in the battery backed RAM and a visual/audible alarm. The system is totally configurable to suit the task in hand and all data can be downloaded to a PC for further detailed analysis. In addition, a Windows based spectral analyser software package enabled sophisticated analysis of the collected spectra and can also run the SAM935 system live.

The major advantage of this system over conventional NaI packages is due to the patented quadratic compression conversion (QCC) process. This results in an advantage over conventional analogue to digital converters, because as all peaks are approximately the same width in channels, the peak search software can run faster

Quadratic compression conversion is a fast transformation that improves spectral statistics significantly (a similar function as performed by fast Fourier transform for image enhancement). The QCC enhancement is accomplished by utilising a large number of

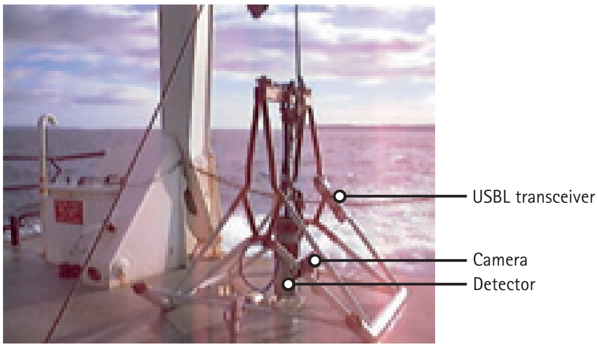

Figure 3: Trials frame.

channels for spectrum acquisition and compressing the spectrum. This takes microseconds and this compression is time sliced and updated every second. This produces peaks for any isotope present, as they have a high standard deviation above the background. QCC enhances both high and low energies and gives a constant 11 channel width to all peaks.

Two trials were undertaken by Fathoms; one in late 2002 and the other in June 2003. The initial trial tested both the static and mobile detection response, primarily against seabed particles, with the 3" x 3" detector as supplied. As the particles later underwent gamma analysis at the Dounreay labs, this allowed verification of the results achieved. In all instances the gathered spectra and the lab results agreed. Nuclides identified included ^{137}Cs, ^{60}Co, ^{40}K and ^{241}Am.

The second trial tested the 3" x 3" detector inside a 304L stainless steel housing, the proposed material and design for any future seabed deployment of the SAM935 system. Again, the laboratory and spectra results agreed excellently. Based on these results we were awarded a contract to deploy a marinised 3" x 3" detector within a static frame during August/September 2003.

Subsea static trials

The 3" x 3" NaI detector and associated photomultiplier tube were housed in a 3.2mm thick sealed 304L stainless steel marinising unit. A water ingress alarm was fitted internally with an audible and LED warning, so that power could be shut down immediately minimising damage to components. The marinised detector unit was secured within a tubular frame, with tubular skids to allow easier transit between successive spectral gathering locations. The detector in its frame is shown in Figure 3, ready for launch.

The design allowed for the deployment of other user selectable probes, sensors etc as required. When the frame was deployed to a flat seabed, the end of the stainless steel jacket was approximately 2cm from the sediment surface; this places the front edge of the NaI crystal less than 5cm from the sediment surface. A video camera was permanently attached on the frame to monitor underwater energy calibration using a ^{137}Cs standard source, the lowering of the system through the water column onto the seabed and to check positioning status during spectrum acquisition. Various aspects of the operation were recorded on DVD. A dedicated camera monitored the detector assembly in real time.

Over 1,200 drops were achieved throughout the duration of the contract, even on days with marginal operating conditions. The marinised detector withstood these repeated jolts during placement on the seabed and on retrieval to the stern, proving its design and functionality in a hostile environment.

A particle was located on 11 September 2003 and due to the significance of this find, further investigation was undertaken. Divers were deployed on 15 September to position the frame at preset offsets to this buried particle and various spectra were collected. Finally the particle was recovered to ascertain depth of burial and ^{137}Cs gamma activity.

The main conclusion from this subsea trial was that whenever the full spectrum alarm was accompanied by a ^{137}Cs alarm, this would almost certainly signify that a particle was within range, i.e. within about 50cm for this detector and geometry. This successful trial was, in the opinion of UKAEA, probably a world first in obtaining subsea gamma spectrometry in real time.

Large detector trial

A lab trial was undertaken jointly by Fathoms and UKAEA Dounreay on 30 June and 1 July 2004 of a larger 4" x 4" x 16" marinised NaI detector and SAM-935, in a submerged geometry using a purpose-built crate, bags of offshore sediment (pre-screened for radioactivity) and offshore seawater. The larger detector provides an increase in volume of over 12 times compared to the 3" x 3" detector previously tested, and so provides a much improved signal intensity and detection range.

The results of these trials reinforced the belief that real time maritime gamma spectroscopy was a viable proposition.

TROL

With the successful adoption of first class instrumentation, the next decision was to improve the delivery mechanism. Increasingly, it was being felt that the mechanisation of the divers' role would bring benefits provided that a cost-effective system could be designed and built. To this end, we considered various options and concluded that the ideal delivery platform would be a tracked ROV – this would allow precise control of speed, detector geometry and horizontal positioning.

Fathoms was awarded a contract to construct a tracked ROV capable of meeting these criteria. This was duly delivered in late August 2004 and the final phase of validation trials commenced on 3 September. Once the trials were complete, a gamma mapping survey of selected areas of the seabed began on 10 September.

TROL was designed and built in-house at our Wick base. The design brief had three guiding tenets:

- Use of tried and tested components.
- Readily available spares.
- Reliability.

The ROV had to be capable of operating to 100m water depths, and in 3 knot currents. It also had to deliver lateral/vertical movement to the detector, pan/tilt cameras, in situ ^{137}Cs calibration facility and spare capacity for additional equipment.

All of these conditions were met with spare power and umbilical capacity. TROL commenced its first contract on 3 September 2004.

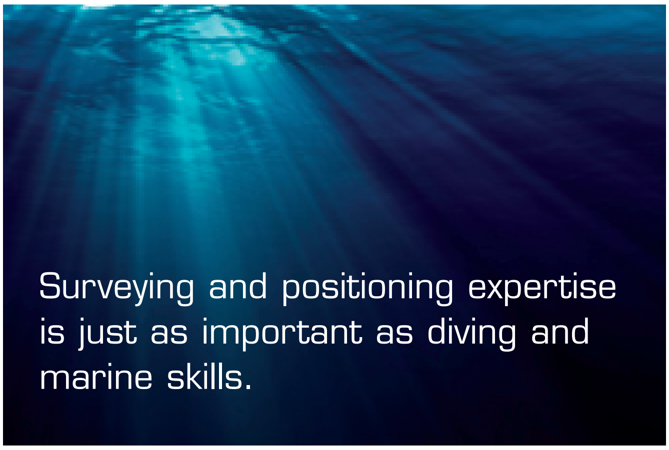

Figure 4: The TROL in mapping mode.

The image in Figure 4 shows the tracked ROV with the detector in the survey position on a flat seabed with minimal rippling of sediment.

Gamma mapping

Different areas of seabed were surveyed to test the system in varied conditions, i.e. sediment type, water depth, ripple development. Further, the results from two separate areas were compared, one with particles resident and another without.

Again, the system produced excellent results. Consequently, a series of annual contracts was let using the TROL system for the extended mapping of the offshore area off Dounreay. Gradually over the years, a much improved knowledge of the intensity of particle population of the seabed had been gained. There is a definite plume of high density particles spreading northeastwards from the outfall diffuser which is located some 500m off the coast. During these years, the accent was on more detailed mapping rather than particle recovery. The introduction of the ROV resulted in improved coverage rates, reduced risk to personnel and the ability to work in deeper water than with divers.

Remote particle recovery

With the system successfully employed, improving the knowledge of the area, the next step was to restart the recovery of particles. This was not to be achieved by divers but robotically — an extremely difficult task, especially when the vast majority of particles are buried under the seabed. Notwithstanding that, we set about redesigning the existing machine to adapt it for particle recovery as well as mapping. Given that all particles recovered from the seabed have to be returned to their 'owner' ashore, it is imperative that the quantities of general seabed material gathered in the process are kept to a minimum.

With TROL's dimensions being 1.5m x 1.3m, there is little room for a large reservoir for the sand. Thus it was crucial that the minimum quantity of seabed was collected with each particle during the recovery process. The other issue of critical importance was the necessity to ensure that the recovery unit was located as close to the detector as possible. Indeed, such is the versatility of the design that it can be adapted for other uses such as general seabed monitoring.

First trials of the adapted system took place in the summer of 2007 and showed that the concept worked really well. We were then awarded a trial in the autumn of the same year and proved to the client that the system could achieve what was required – the only system to do so. Particles were detected remotely, as before, but then recovered as part of the same operation.

This success led to two further years' contracts where the system has excelled in the ongoing process of cleaning up the offshore environment off Dounreay. Over 95% of detected buried particles have been recovered from under the seabed — often from depths as great at 50cm. All operations are continuously recorded on video, allowing the depth of recovery to be ascertained and a record kept for posterity.

TERRIER

The TERRIER system has been developed from its subsea sibling TROL, using the same technology for the radiological aspects. It has been used very successfully in a wide variety of environments from old military airfields to disused hospitals to modern RoRo vessels.

Personnel

No system could work as well as this without a strong and dedicated team. In order to fulfil such difficult requirements, the team has to be truly multidisciplinary. It includes *inter alia* an experienced mariner and skipper, ROV pilots, a hydrographic surveyor, a health physics monitor for the separation of particles from the seabed samples recovered, a radiological protection supervisor, an electronics expert and a number of experienced seamen for the handling of the machine. We were able to provide all of these in house.

Conclusion

We progressed from simple gamma activity measurement (using a fairly primitive instrument and divers) to the effective and systematic mapping and recovery of particles from the seabed (also with divers) to a remotely operated system that provides greatly increased capability and cost effectiveness.

Despite working in a hostile environment in the exposed waters of the north Atlantic off Scotland's north coast and working with radioactive material (including some very active particles), we didn't experience a single safety or health incident while recovering over 1,000 particles and transporting most of them back to Dounreay. What's more, the vehicle could be further developed, thereby enhancing its cost-effectiveness and productivity.

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Matthew's maritime career began 43 years ago as an officer in the Royal Navy where he learned surveying, diving, marine and management skills. Upon leaving the RN after two sea commands, he became a survey and marine consultant before founding Fathoms. He has also acted on a number of recent expert witness cases.
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Figure 5: The TROL in mapping and recovery mode.