

**COMMITTEE ON MEDICAL ASPECTS OF RADIATION IN THE  
ENVIRONMENT**

**DOUNREAY PARTICLES ADVISORY GROUP**

**EXPERIMENTAL VALIDATION OF 'GROUNDHOG' BEACH  
MONITORING SYSTEMS**

July 2006

## 1. Introduction

It is over 20 years since the first radioactive particle was detected near the Dounreay Nuclear Establishment. Since then, the United Kingdom Atomic Energy Authority (UKAEA) has conducted monitoring of various beaches in the area to detect further contamination.

This report has been prepared jointly by the Committee on Medical Aspects of Radiation in the Environment (COMARE) and the Dounreay Particles Advisory Group (DPAG). It is based largely on Chapter 5 of DPAG's forthcoming 3<sup>rd</sup> Report and on an empirical evaluation under the auspices of COMARE, funded by the Scottish Environment Protection Agency (SEPA) and COMARE. The report presents an evaluation of the operational performance of the two vehicular Groundhog monitoring systems used by UKAEA on beaches close to Dounreay.



**Figure 1.** Evaluation of beach monitoring capability: Groundhog Evolution on Sandside Beach, April 2006.

## 2. The history of beach monitoring around Dounreay

The first well documented beach particle finds occurred in November 1983 through a routine radiological survey of the Foreshore of the Dounreay site itself and in 1984 on Sandside Beach. Since the former discovery, routine strandline monitoring for particles at Sandside Bay, Scrabster, Melvich, Oigin's Geo and Thurso was implemented although the methodology used (hand-held monitors) was not developed to detect the presence of particles.

COMARE (in a joint report with the Radioactive Waste Management Advisory Committee), recommended that more rapid and less manual beach monitoring techniques should be employed so that larger areas of these beaches could be covered more frequently.

Routine bi-weekly strandline monitoring has been carried out on the Dounreay Foreshore since 1983. Beta/gamma monitoring was carried out by means of hand-held Geiger-Muller tubes until June 2002. Since then, the surveys have been carried out using a hand-held single detector system based on the Groundhog Mk 1 system, as well as beta surveys using a large area beta detector. In October 2004, Groundhog Evolution was introduced. Since then, the Dounreay Foreshore has generally been monitored fortnightly the exception being during the four months of the tern nesting season.

No further particles were discovered on Sandside until 1997, when two particles were located. These finds resulted in an increase in the frequency of strandline monitoring from once every two weeks to once every week (alternately  $\gamma$  and  $\beta/\gamma$ ) at Sandside Bay, also in line with advice given by COMARE in 1995. Particles have continued to be found, retrieved and recorded at Sandside Bay, the total up to February 2006 being 59. The vehicle-mounted Groundhog Mk 1 gamma detector system was first introduced in July 1999 and replaced by Groundhog Evolution in May 2002. Prior to these systems, a beta/gamma probe system was used.

In 2005, following a survey at Dunnet Beach, a small number of radioactive items were found. These included several stones with elevated concentrations of naturally occurring radioactivity, a particle of around  $8 \times 10^3$  Bq  $^{137}\text{Cs}$  and a piece of plastic containing around  $2 \times 10^4$  Bq  $^{137}\text{Cs}$ . Other beaches have been surveyed, but no other particles have been detected up to February 2006.

A schedule specifying the beaches to be monitored and the frequency of surveying was issued by SEPA in 1999 as part of its decision on the application by UKAEA to dispose of radioactive wastes from Dounreay. Following a review in 2000, a revised Technical Implementation Document (TID) was implemented in 2001. The main difference between the two TIDs was the detection criteria set. The new (2001) TID stipulated a more challenging detection criterion of '*at least  $10^5$  Bq  $^{137}\text{Cs}$  at 100 mm depth*', to be achieved at higher monitoring frequency.

### **3. Summary of beach particle finds**

Table 1 presents a summary of the particles finds (number of particles, mean activity and range) in each year since 1984 on the Dounreay Foreshore. Up to February 2006, 239 particles had been found with a mean activity of  $5.6 \times 10^6$  Bq  $^{137}\text{Cs}$ . Four particles had no detectable  $^{137}\text{Cs}$  activity and contained only  $^{60}\text{Co}$  activity. The mean quoted in Table 1 excludes the  $^{60}\text{Co}$  activity.

**Table 1 Summary of particle finds on Dounreay Foreshore (x 10<sup>6</sup> Bq <sup>137</sup>Cs)**

<b>Year</b>	<b>Number of particles</b>	<b>Mean activity</b>	<b>Min</b>	<b>Max</b>
1983	1	56	-	-
1984	27	9.2	0.000067	92.5
1985	11	5.2	0.63	22.2
1986	18	3.8	0.011	9.9
1987	10	9.3	0.04	45
1988	11	7.3	0.43	21
1989	15	7.7	0.1	49
1990	11	2.1	0.21	7
1991	13	20	0.5	200
1992	4	0.04	0.009	0.16
1993	13	2.9	0.1	6
1994	14	4.5	0.17	20
1995	11	5.9	0.5	21
1996	20	1.9	0.0018	14
1997	10	2.1	0.0014	16
1998	6	0.47	0.016	1.6
1999	11	3.3	0.0038	14
2000	6	4.5	1.07	7.6
2001	3	2.7	0.068	7.7
2002	5	1.3	0.74	3
2003	3	2.4	1.7	3.2
2004	9	0.34	0.082	0.8
2005	7	1.4	0.043	5.9
2006(Feb)	0	-	-	-

By February 2006, 59 particles had been found on Sandside Beach and these are shown in Figure 2. It should be noted that monitoring has not been continuous, since access has been denied by the landowner on several occasions for periods of weeks or months.



#### 4. 'Groundhog' systems

In March 1999, UKAEA tested a vehicular (Unimog) mounted gamma ray detection system (Groundhog Mk I) on the beaches at Thurso and Scrabster. It utilised four independently operated 76 mm x 76 mm thallium-doped sodium iodide scintillation detectors (NaI(Tl)). The detectors were operated at about 200 mm above the surface of the beach and spaced 500 mm apart and supported from the front of a four-wheel drive Unimog (Figure 3), which was occasionally substituted by a Land Rover. The speed of the vehicle was to be maintained at around 1 ms<sup>-1</sup>. In July 1999, following discussion with SEPA, this system was brought into routine operation to fulfil the requirements of the TID. Following a detailed internal review, the vehicle velocity was reduced to 0.8 ms<sup>-1</sup> from June 2001. During the time of implementation, this system located 17 particles on Sandside Bay.



**Figure 3** Groundhog Mrk 1 system, with four 76 x 76 mm diameter NaI(Tl) Detectors

As noted above, SEPA's review in 2000 concluded that the 10<sup>5</sup> Bq <sup>137</sup>Cs detection criteria of the TID was not strictly being met. SEPA and UKAEA estimated independently that a detection level of 1.4 x 10<sup>5</sup> Bq <sup>137</sup>Cs was more realistic for particles lying between the detectors at 100 mm depth. COMARE recommended in 2002 that further improvements should be made to the current monitoring strategy and equipment to ensure that the majority of particles containing 10<sup>5</sup> Bq <sup>137</sup>Cs or above were being found.

The 'Groundhog Evolution' system incorporates 5 larger volume (76 mm x 400 mm) detectors mounted to provide a contiguous lateral cover of 2 m, representing 6.7 times increase in detector volume over the old Groundhog system. The system electronics are very similar to the original Groundhog Mk 1, the counts from the detectors are recorded in a below <sup>137</sup>Cs window, <sup>137</sup>Cs window and above <sup>137</sup>Cs window. The detectors are mounted on a Hillcat vehicle in an array maintained at around 200 mm above the sediment surface, although this geometry can change to avoid irregularities on the beach. The first system was implemented in February 2003 and a second replicate system introduced about one year later.

#### 5. Beach trials

Following recommendations of both COMARE and DPAG, SEPA made available the necessary funding to purchase a set of perspex-encapsulated point sources of <sup>137</sup>Cs and <sup>60</sup>Co. Permission to access the beach at Sandside Bay was obtained from the landowner, together with the agreement of the Scottish Executive, SEPA and UKAEA. The trials were carried out over the period 8–10 April 2006 by a small team representing both COMARE and DPAG, together with an observer from SEPA. The beach trials were designed to primarily assess and confirm the detection capabilities of the Groundhog Mk 1 and Evolution system and to provide data with which to validate the theoretical and modelling considerations of detector performance established by DPAG.

The specific objectives of the trial were to:

- conduct a test of the monitoring capabilities of both Groundhog Mk I and Groundhog Evolution; and
- verify predictions on their ability to detect particles.

In order to conduct the trials, UKAEA made available two Hillcat vehicles and a reconstruction of the Mk I detector array. The latter was towed behind one of the Hillcat vehicles, while the other was configured as the standard Groundhog Evolution system (Figure 4). The vehicles were operated by experienced staff of RWE NUKEM, the UKAEA sub-contractor responsible for the routine beach monitoring programme. This ensured that the trials were carried out under exactly the same conditions as routine beach monitoring.



**Figure 4** Example of Groundhog Evolution (picture right) and the reconstructed Mk 1 system towed behind the first Hillcat (picture left). Beach Monitoring Trials.

### 5.1 Test areas

Test runs were constructed using either 250 m or 150 m lengths of beach, and in total 3 areas of the beach were used (Figure 5), with the majority of the exercise focused on area 1 (low natural background) and 2 (elevated natural background); note that the location of the burn has changed from that shown in Figure 5. The low background area is representative of the majority of the beach, whilst the elevated natural background was selected to be at least partly representative of some of the other beaches monitored.

Prior to setting up the experimental layouts on each day, the entire area to be used was surveyed by Groundhog Evolution using standard operating procedures in order to ensure that there were no radioactive particles within the test area. This background survey extended at least 1.5 detector array widths to either side of the source positions and at least the vehicle turning areas beyond both ends of each layout. Over the three days, some 15,000 m<sup>2</sup> of beach were surveyed and no radioactive particles were detected.

A linear array of sources of different activity was buried at a given depth, the spacing between sources being 15 m. This distance was chosen in order to accommodate the requirement to reset the detector systems after each detection event.

Over the course of the trials, sources were buried at depths of 50, 100, 200 and 300 mm below the surface. The source strengths were  $10^4$  Bq,  $10^5$  Bq and  $10^6$  Bq of  $^{137}\text{Cs}$  and  $10^5$  Bq of  $^{60}\text{Co}$ .



The perspex sources were held in a steel holder, retained in place by a clip-on PTFE cover. The position for each source was located by reference to a surveyor's tape laid along the length of each layout and by the use of a differential GPS system. The use of the steel source-holder also permitted location by means of a standard metal detector.

The theoretical performance of the detector array may change dependent upon the location of any particle across the field of view. Tests were therefore conducted with the sources located in the centre of the transverse field view, with a partial offset and with the sources offset to the edge of the detector field of view.

## 5.2 Numbers of trials

If the (unknown) probability for detecting a particular activity of source at a particular depth is  $P$ , and the source is detected on  $N_1$  occasions out of a total of  $N_2$  attempts, then:

$$P_E = N_1/N_2$$

Where  $P_E$  is our estimate of  $P$ . The uncertainty on this estimate is given by

$$\begin{aligned} & \sqrt{(P_E (1-P_E)/T)} \\ & = \sqrt{(N_1(N_2-N_1)/N_2^3)} \end{aligned}$$

By assuming different values for  $P$ , table 2 can be constructed, showing the number of detection attempts required to achieve a chosen uncertainty on the value of  $P_E$ . It can be seen that there is a balance to be struck between the practicality of achieving the required number of detection attempts (given the limited time available) and deriving the lowest possible uncertainty.

**Table 2**

Detection probability	5%	10%	Uncertainty 15%	20%	25%
0.9	44	11	5	3	2
0.8	100	25	11	6	4
0.7	171	43	19	11	7
0.6	267	67	30	17	11
0.5	400	100	44	25	16

From the above table and assuming that the detection probability was better than 0.8, it was estimated that 25 measurements were required for each source/depth/background/lateral position combination in order to obtain statistically-significant results. This was obtained in most cases, although bad weather during the test period necessitated some curtailment of the programme.

The vehicles were operated at the speeds specified by the TID; Groundhog Mk I travelled at  $0.8 \text{ ms}^{-1}$ , while Groundhog Evolution travelled at  $1 \text{ ms}^{-1}$ . On each run, there was a lead-in blank area to ensure that the vehicle was at the correct operating speed on reaching the first target.

### 5.3 Results

Table 3 presents the mean results across a detector array from areas 1 and 3 (low background) and Table 4 presents the results from area 2 (elevated background) from both Groundhog Mk 1 and Evolution.

Earlier, DPAG commissioned software models of both Groundhog Mk1 and Groundhog Evolution. These enabled theoretical predictions of performance to be made and the resulting estimates are included also in the tables.

The trial results demonstrate that a  $10^6$  Bq particle can be reliably detected by both systems to depths of at least 200 mm for Mk 1 and deeper for Evolution. The results also confirm that Mk 1 is not detecting  $10^5$  Bq particles at 100 mm depth reliably and is not able to detect small particles ( $10^4$  Bq) or  $^{60}\text{Co}$  particles of at least  $10^5$  Bq. Groundhog Evolution had a probability of around 0.5 of detecting  $10^5$  Bq  $^{60}\text{Co}$  source down to at least 200 mm depth. However, neither system was specifically configured to detect this radionuclide.

**Table 3 Detection probabilities from the beach trials for the low background area (areas 1 and 3; Typical of Sandside). The modelled estimates are given beneath with two standard deviations. Probability is estimated as the proportion of successful detections out of 25 observations in most cases.**

	Detection probability							
	<b>Mk 1</b> Mean Velocity = $0.80 \pm 0.06 \text{ ms}^{-1}$							
	Depth	$^{137}\text{Cs}$		$^{137}\text{Cs}$		$^{60}\text{Co}$		$10^5 \text{ Bq}$
$10^4 \text{ Bq}$		$\pm 2\sigma$	$10^5 \text{ Bq}$	$\pm 2\sigma$	$10^6 \text{ Bq}$	$\pm 2\sigma$		
Trial	50 mm	<b>0.027</b>	<b>0.013</b>	<b>1</b>		<b>1</b>		<b>0</b>
Model		0.001	$\pm 0.007$	0.99	$\pm 0.005$	1	$\pm 0$	
Trial	100 mm	<b>0</b>		<b>0.88</b>	<b>0.026</b>	<b>1</b>		<b>0</b>
Model		0	$\pm 0.0002$	0.42	$\pm 0.27$	1	$\pm 0$	
Trial	200 mm	<b>0</b>		<b>0.067</b>	<b>0.020</b>	<b>1</b>		<b>0</b>
Model		0	$\pm 0$	0.001	$\pm 0.005$	1	$\pm 0$	
Trial	300 mm	ND		ND		<b>0.8</b>	<b>0.032</b>	
BMM								
	<b>Evolution</b> Mean Velocity = $0.98 \pm 0.08 \text{ ms}^{-1}$							
	Depth	$^{137}\text{Cs}$		$^{137}\text{Cs}$		$^{60}\text{Co}$		$10^5 \text{ Bq}$
		$10^4 \text{ Bq}$	$\pm 2\sigma$	$10^5 \text{ Bq}$	$\pm 2\sigma$	$10^6 \text{ Bq}$	$\pm 2\sigma$	
Trial	50 mm	<b>0.76</b>	<b>0.034</b>	<b>1</b>		<b>0.96</b>	<b>0.016</b>	<b>0.5</b>
Model		0.036	$\pm 0.08$	1	$\pm 0$	1	$\pm 0$	<b>0.200</b>
Trial	100 mm	<b>0.165</b>	<b>0.030</b>	<b>1</b>		<b>0.973</b>	<b>0.013</b>	<b>0.775</b>
Model		0	$\pm 0$	1	$\pm 0$	1	$\pm 0$	<b>0.167</b>
Trial	200 mm	<b>0.013</b>	<b>0.009</b>	<b>0.88</b>	<b>0.026</b>	<b>1</b>		<b>0.6</b>
Model		0	$\pm 0$	0.58	$\pm 0.1$	1	$\pm 0$	<b>0.196</b>
Trial	300 mm	ND		ND		<b>1</b>		
Model								

ND – not done

Bold numbers relate to trial results

**Table 4 Detection probabilities from the beach trials for the elevated background area are given in bold. The modelled estimates are given beneath with two standard deviations. Probability is proportion of successful detections out of 24 observations in most cases.**

		Detection probability					
		MK 1 Mean Velocity = $0.75 \pm 0.18 \text{ ms}^{-1}$					
		<sup>137</sup> Cs					
	Depth	10 <sup>4</sup> Bq	± 2σ	10 <sup>5</sup> Bq	± 2σ	10 <sup>6</sup> Bq	± 2σ
Trial	100 mm	<b>0.014</b>	<b>0.010</b>	<b>0.736</b>	<b>0.037</b>	<b>1</b>	
Model		0.03	± 0.0004	0.86	± 0.3	1	± 0
Trial	200 mm	<b>0</b>		<b>0.125</b>	<b>0.028</b>	<b>1</b>	
Model		0	± 0	0.01	0.02	0.994	± 0.03
		Evolution Mean Velocity = $1.02 \pm 0.11 \text{ ms}^{-1}$					
		<sup>137</sup> Cs					
	Depth	10 <sup>4</sup> Bq	± 2σ	10 <sup>5</sup> Bq	± 2σ	10 <sup>6</sup> Bq	± 2σ
Trial	100 mm	<b>0.083</b>	<b>0.023</b>	<b>1</b>		<b>1</b>	
Model		0	± 0	1	± 0	1	± 0
Trial	200 mm	<b>0.028</b>	<b>0.014</b>	<b>0.903</b>	<b>0.025</b>	<b>1</b>	
Model		0	± 0	0.40	± 0.20	1	± 0

Bold numbers relate to trial results

The introduction of Groundhog Evolution has made a substantial improvement on particle detection capability with 10<sup>5</sup> Bq <sup>137</sup>Cs particles being detected with almost 90% confidence to 200 mm depth. Evolution also demonstrates a low probability of detecting the 10<sup>4</sup> Bq <sup>137</sup>Cs particles and the influence of the elevated background reduces this probability further.

## 6. Conclusions

Re-analysis through theoretical calculation and empirical measurement has confirmed earlier conclusions that Groundhog Mk 1 was not able to meet the requirements of the TID under all conditions. The detection capability also varied significantly according to the potential position of the particle to be detected relative to the start and end location of each detector's acquisition time (ie, best case versus worst case scenarios). The inability to cope effectively with variations in the natural backgrounds coupled with rigid trigger mechanisms, results in higher detection limits when applied to beaches with higher natural backgrounds. These are the two principal limitations of the Groundhog Mk I system. Consequently, detection criteria as defined by SEPA were not met by the Groundhog Mk I system under all conditions. Under some conditions, ie, higher natural background and vehicle speeds of 1 ms<sup>-1</sup>, detection limits may be up to about 4x10<sup>5</sup> Bq. Groundhog Mk 1 was not configured to detect <sup>60</sup>Co.

Groundhog Evolution however, is capable of meeting the current requirements of the TID and at a monitoring speed of 1 ms<sup>-1</sup> extend these to depths of 150 mm or more. As with Mk 1, Evolution was not configured to detect <sup>60</sup>Co, although subsequent modifications might enable the background alarm to indicate the presence of <sup>60</sup>Co. Nevertheless it is not able to detect 10<sup>5</sup> Bq <sup>60</sup>Co particles reliably, should they exist in the environment.

There are likely to have been many particles containing activities of less than 10<sup>5</sup> Bq <sup>137</sup>Cs that were not detected by Groundhog Mk 1 over the monitoring period.

The results show an acceptable level of agreement for the Mk 1 beach trial results and estimates derived from the software model. The same can be said for Evolution at high degrees of detection probability. The modelled Groundhog Evolution capability underestimates the experimental data, suggesting that the theoretical detector response, derived from RWE NUKEM Monte Carlo simulations, provides a conservative estimate of either the photon fluence from buried particles or the detection capability. This detection capability was derived from RWE NUKEM Monte Carlo simulation of the detector response, and forms the basis of the software. Therefore, if this software is to be used in the future, it is important to review the data used in the software to estimate beach monitoring performance.

As recommended earlier by both COMARE and DPAG, efforts should continue to improve the detection efficiency of beach monitoring systems. Direct trials, as described above, should be carried out on any new system to permit an absolute determination of its capabilities and establish a comparison with its predecessor.

A T Elliott  
A N Tyler  
M Scott