Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Cold Regions Science and Technology 37 (2003) 429–438
cold regions science and technology
www.elsevier.com/locate/coldregions

Testing the performance of avalanche transceivers

Jürg Schweizer*, Georges Krüsi

Swiss Federal Institute for Snow and Avalanche Research SLF, Flüelastrasse 11, CH-7260 Davos Dorf, Switzerland

Received 1 September 2002; accepted 2 July 2003

Abstract

Avalanche rescue beacons are electronic transmitter–receiver devices designed to locate avalanche victims in avalanche debris. They have become standard equipment for the winter backcountry traveler. With the appearance of digital beacons or transceivers and the growing variety of beacons, the need arose for independent testing of this type of rescue equipment. Although there is a European standard for manufacturing beacons, there are substantial differences not only in how performance is defined between different brands, but also in how performance is best measured. Testing the performance is crucial, but not straightforward. There is no standard test procedure. Therefore, test designs are proposed to comprehensively measure search time and range. They should ensure reproducibility of performance results and were applied in two large field tests in Switzerland. A method recently proposed to define the width of search strip based on maximum range measurements in co-axial antenna orientation was verified by these tests and can be recommended. Results show that the maximal range of different beacons varies between about 25 and 100 m. Differences in search times were significant as well, but these were relatively small compared with the total time for recovery of a buried victim. Theoretical considerations of the relation between search time and range were also confirmed.

Keywords: Snow avalanche; Avalanche accident; Avalanche rescue

1. Introduction

Three out of four completely buried avalanche victims who survived were rescued in less than 30 min. On the other hand, 75% of the victims found dead were buried for more than 45 min (Tschirky et al., 2001). Thus, recovery time is the most critical parameter in avalanche rescue. For fully buried victims, avalanche rescue beacons offer the only practical means for immediate and effective rescue by members of the affected party. Therefore, avalanche beacons have become standard personal rescue equipment for the winter backcountry traveler.

Avalanche rescue beacons were developed in the 1960s and 1970s. They are electronic transmitter–receiver devices designed to locate avalanche victims buried in avalanche debris (Good, 1987). Originally, there were two transmission frequencies for avalanche beacons in use: 2.275 kHz in the US and 457 kHz in Europe. The higher frequency was adopted as standard in Europe in the 1980s (Meier, 1987). Nowadays, all beacons are manufactured in compliance with the European standard (ETSI EN 300 718). The European standard is issued by the European Telecommunica-

* Corresponding author. Tel.: +41-81-417-0111; fax: +41-81-417-0110.
E-mail address: schweizer@slf.ch (J. Schweizer).

0165-232X/$ - see front matter
doi:10.1016/S0165-232X(03)00082-X

tions Standards Institute (ETSI). It is a Radio Equipment and Telecommunications Terminal Equipment standard primarily to regulate electromagnetic compatibility and radio spectrum matters. Furthermore, the standard ensures the compatibility between old and new beacons and the reliability of their functioning. Nothing is said about, e.g. the minimal range or search strip width.

With the appearance of digital beacons and the growing variety of beacon models, the need arose for independent testing of this type of rescue equipment. Although there is a European standard for manufacturing beacons, substantial differences exist in performance between different brands. Because testing beacon performance is not straightforward and definitions of performance vary, differing test results have been reported by beacon manufacturers and users alike. The first and most comprehensive performance test was initiated in 1998 by the International Commission for Alpine Rescue (ICAR) (Krüsi et al., 1998; Schweizer, 2000). Since then various smaller tests have been done under varying conditions (e.g. Sivardière, 2001).

Therefore, the aim was to design performance tests that produce reliable, consistent test results under controlled conditions. Performance should be measured by search time and range. Both parameters are important for beacon users: search time relates to efficiency and ease of handling and range strongly influences the strategy and dimensions of a beacon. The test designs were applied during the winter 2000–2001 in two large field tests in Switzerland. In the first test, search times were measured and in the second test, transmit and receive ranges were measured. Four different, popular brands of beacons from the US and Europe were used in the tests. The performance of these beacons was assessed. Furthermore, a primary objective was to verify a recently proposed method to determine the width of the search strip (Meier, 2001), which was so far lacking experimental evidence. Overall, the emphasis in this paper is on the methodology of testing transceiver performance rather than on the properties of different transceiver models.

2. Method

Tests were designed to determine search time and range with the aim to maximize reproducibility and minimize bias. Novice searchers performed each test, and searchers and transceivers were systematically permuted to avoid any learning effects during the test. From the variety of beacons on the market, four popular beacons were chosen for the field tests: in alphabetical order, Mammut Barryvox, Ortovox M2, Tracker DTS and VS 2000 (so-called "old Barryvox"). Three of the beacons tested were modern types (Mammut Barryvox, Ortovox M2, Tracker DTS); one was used as a reference beacon (Barryvox VS 2000, or so-called "old Barryvox"). The beacons were standard devices as could be bought in the winter 2000–2001. Accordingly, the beacon-specific results described below represent the state of beacons available at that time. Any improvements made by the manufacturers since then are not reflected in the results presented below.

2.1. Search time

Search times were measured on 7 February 2001 at Engstligenalp, Bernese Oberland, Switzerland. The test was initiated by the Consumer Magazine of the Swiss National Television Broadcasting, designed by the two mountain guides Emanuel Wassermann and Michael Wicky, and supervised by SLF (Schweizer et al., 2001).

The search took place in a large flat area, about 700 × 700 m in size containing 16 search fields each with one beacon buried. The search fields were about 100 m apart and were 50 × 70 m in size (Fig. 1), since this is about the typical size of an avalanche deposit of a human-triggered avalanche (Schweizer and Lütschg,

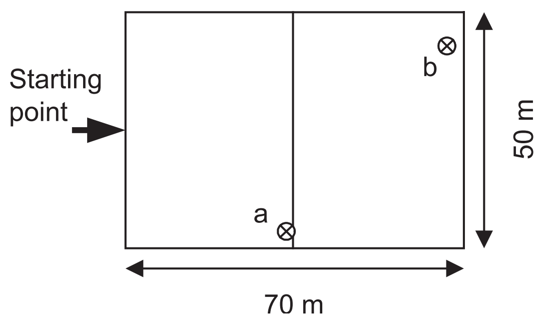

Fig. 1. Search field for measuring search time. On 8 of the 16 fields the beacon was buried near the centerline (position a), on the other 8 fields it was buried near the farther end (position b).

2001). On 8 out of the 16 search fields the beacon was buried near the centerline of the field, on the other 8 fields it was close to the farther end. So, in half of the fields the beacons were about 35 m from the starting point. In the other half the beacons were about 70 m away. The transmitting beacons were all Barryvox VS 2000 models, buried 70 cm below a wooden panel of 40×80 cm in a 45° inclined position. The beacons were equipped with new batteries and buried the evening before the test. The test fields were then planed with a snow-grooming machine.

The search time was measured from the starting point at the edge of the search field with the receiving beacon still in transmitting mode (so that switching into search mode was part of the measured search time), to the time when the searcher had located the hidden beacon, i.e. when the person hit the wooden panel with an (already assembled) avalanche probe. If the searcher could not find the buried transmitting beacon within 15 min, the search was stopped.

This design allowed 16 persons to be searching at the same time. Each person searched four times with each of the four different brands of beacons, so that 64 measurements per type of beacon, and 256 searches in total, resulted. The sequence was arranged so that each person only searched once on a specific field. Accordingly, the transmitting beacon did not need to be relocated, but stayed in place until the end of the test. All 16 searchers were novices, and were mainly students from the local school. On each of the 16 fields there was a supervisor overseeing each test so that a total of 32 persons were involved in the test.

After a general introduction to transceiver search methods prior to the test, the searchers split up in four groups of four were introduced to each of the four types of beacons for 10–15 min by a representative of the manufacturer, or an experienced guide, just before they started to search each time with a given brand. Each group of four who had searched four times with a given brand was then split up, and the groups were rearranged to avoid the bias that a given type of beacon would be rated highly because of the presumably inherent learning effect during the day.

2.2. Range

Beacon range was measured on 9–11 April 2001 about 6 km up a side valley from Davos, Switzerland. The test was organized by SLF (Schweizer, 2001, 2002). Two methods were used to measure range in order to determine the width of search strip.

The first method was previously described by Krüsi et al. (1998) and is used to measure range by walking past a transmitting beacon that is buried with a random antenna orientation (Fig. 2). The searcher slowly rotated the receiving beacon to get optimal coupling with the transmitting beacon. Optimal coupling occurred when the antennas of the two beacons were aligned (in parallel position), as indicated by a maximum signal. In parallel antenna orientation the range r is at best 80% of the maximal range r_{max} that is measured in the co-axial antenna position (Meier, 2001):

$$r = \sqrt[3]{0.5}\, r_{max}. \tag{1}$$

This type of measurement is considered to be closest to actual conditions in a rescue situation, since the searcher passes the transmitting beacon with a random antenna orientation.

Four units of the VS 2000 beacon were alternately used as a transmitting beacon. The antenna position and transmitting unit were changed after 32 measure-

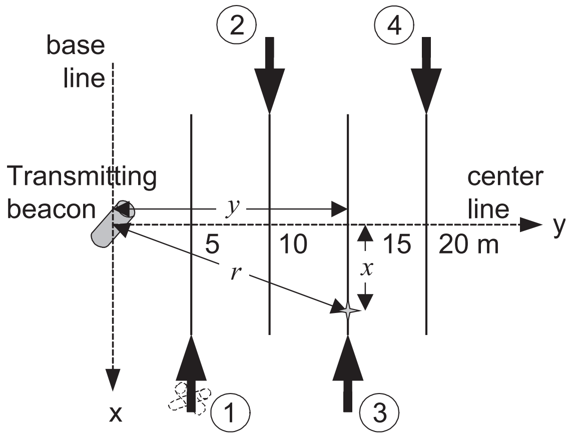

Fig. 2. Test design for measuring range r with the first method, i.e. by walking past a transmitting beacon that is buried with a random antenna orientation. The receiving beacon is rotated by the searcher to achieve optimal antenna coupling (parallel position). The search lines are parallel to the base line (transmitting beacon) in 5 m equidistant intervals. Positions 1 to 4 indicate the starting points on the search lines. An example of the distance calculation is shown.

ments. The searcher followed a line, marked with a tape measure. These search lines were parallel to the base line (where the transmitting beacon was located) and spaced $y = 5$, 10, 15 and 20 m from the base line (Fig. 2). With the searcher rotating the receiving beacon, the distance x from the centerline was read and recorded at the first reliable signal. For the Mammut Barryvox and the Ortovox M2, this was done for the acoustical (analog) and the optical (digital) search unit, resulting in a smaller optical and a larger acoustical range. The range was calculated from the distance of the search line to the transmitting beacon: $r = \sqrt{x^2 + y^2}$ (Fig. 2). Though this test design was closest to a real rescue situation, variation in test results can be large, so that a large number of measurements were needed.

On the four equidistant search lines, four teams of two (one person searching, one recording the results) were searching with a different type of beacon at the same time. After four measurements, one on each search line, the person searching and the person recording changed tasks. After eight measurements, the beacon types were exchanged. Four different units of one single brand were used alternately. For each of the four types of beacons 128 measurements, 512 in total, were made. Due to this large number of measurements needed to get reliable results only the VS 2000 reference beacon was used as transmitter.

The second method for measuring beacon range was proposed by Meier (2001). In this method, maximal range was measured when the two beacons were co-axially aligned. The experimental setup is shown in Fig. 3. On two search lines four teams of two persons approached the transmitting beacons by holding the receiving beacon in the horizontal position so that the antenna orientations of the receiving and transmitting beacon were in line. Again, four different units of a given model were available and exchanged alternately, as were searchers, transmitting beacons, and receiving beacons (see above). A total of 56 measurements per type of beacon, 224 in total, with the VS 2000 as the transmitting beacon were performed. In addition, 28 measurements per type of beacon were made with the Ortovox M2 and the Tracker DTS as transmitting beacons. Again, the optical and acoustical range were recorded for the beacons with both types of search aid.

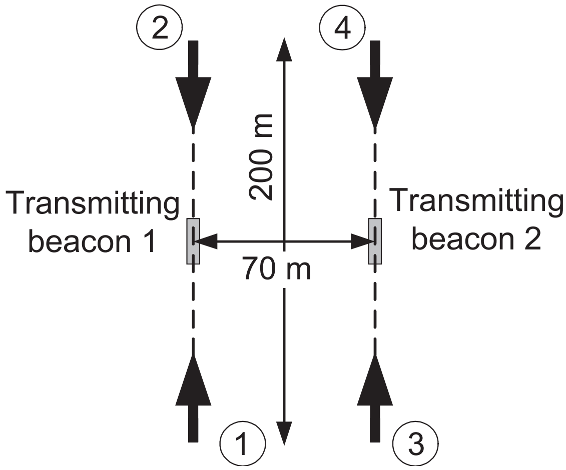

Fig. 3. Test design for measuring maximal range r_{max} by approaching with co-axial antenna orientation. Positions 1 to 4 indicate the starting points on the search lines.

2.3. Search strip width

Using the results of both methods described above to measure beacon range, the width of the search strip (one of the most important properties of a beacon) can be determined.

If measuring the range by passing (first method), the width of search strip w_1 is given by

$$w_1 = 2(\bar{r} - 2\sigma). \quad (2)$$

This is often referred to as two times the so-called 98%-medium range, assuming a normal distribution (Krüsi et al., 1998; Meier, 2001; Schweizer, 2000).

If measuring the maximum range r_{max} of two co-axially aligned beacons, Meier (2001) proposed to calculate the width of the search strip w_2 from the measurements statistics as

$$w_2 = \bar{r}_{max} - 2\sigma_{max} \quad (3)$$

where $\bar{r}_{max}$ is the average maximal range and σ_{max} is the standard deviation. This means that the width of search strip is just equal to the so-called 98%-maximum range. This method requires that in an actual rescue situation the searching person actively rotates the beacon during the signal search (or primary search). The method takes into account adjustments for reduced performance due to factors such as a non-optimally aligned search beacon, low battery power or temperature effects.

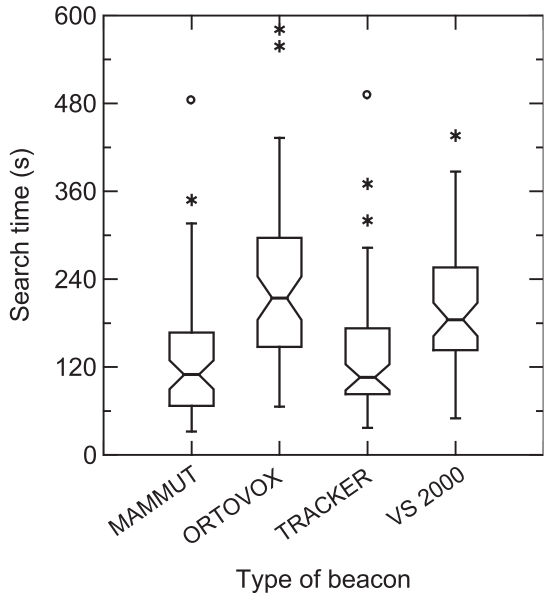

Fig. 4. Search times for the four different beacons tested. Four cases (outliers) with search time larger than 10 min are not shown. Boxes span the interquartile range from 1st to 3rd quartile with a horizontal line showing the median. Notches at the median indicate the confidence interval ($p<0.05$). Whiskers show the range of observed values that fall within 1.5 times the interquartile range above and below the interquartile range. Asterisks show outliers, open dots show far outside values.

The above proposed definition (Eq. (3)) seems to be rather bold. Traditionally, based on measurements with the first generation of transceivers in the 1960s and 1970s, it was proposed that the search strip width should be about 40% of the maximal range (Good, 1969; Good and Schild, 1990). However, this simplified assumption is only justified if range measurements show a coefficient of variation of about 30%. The results of the ICAR test performed in 1998 already suggested that this assumption is no longer valid for modern beacons (Krüsi et al., 1998). Therefore, the method proposed by Meier (2001) seems plausible, but so far experimental evidence was lacking.

Both methods assume that the measurements statistics follow a normal distribution. This is not fully the case. In previous tests, the distributions were found to frequently be slightly skewed (Krüsi et al., 1998).

3. Results

3.1. Search time

One person searching with a VS 2000 model did not find the buried beacon within the time limit; a value of 15 min was assigned to this measurement. Two persons, one with an Ortovox M2, and one with a VS 2000, gave up searching before reaching the time limit of 15 min; these two measurements were not discarded, but a search time of 15 min was assigned to these values.

Search times were fastest with the Tracker DTS and the Mammut Barryvox (Fig. 4, Table 1). The results for the Mammut Barryvox and the Tracker DTS were statistically not significantly different (nonparametric U-test, $p=0.52$). The search was significantly faster ($p<0.001$) with the Mammut Barryvox and the Tracker DTS compared to the Ortovox M2 and the VS 2000. The difference in search time between the Ortovox M2 and the VS 2000, the mean search time was slightly shorter with the VS 2000, was not statistically significant ($p=0.40$).

The search times did not substantially decrease during the day of measurements, i.e. there was no learning effect during the day. Considering all different types of beacons jointly, there was a very slight overall decreasing trend which was not significant ($p=0.82$) (Fig. 5).

The distance of the buried beacons to the starting point, approximately 35 m (position a) and 70 m (position b), respectively, for so-called simple and difficult search (Fig. 1) did, in most cases, signifi-

Table 1
Search time for the four types of beacons tested on 7 February 2001 at Engstligenalp, Bernese Oberland, Switzerland

Type of beacon	Minimum (s)	1st quartile (s)	Median (s)	3rd quartile (s)	Maximum (s)
Mammut Barryvox	32	67	109.5	167	484
Ortovox M2	66	148	215	311	900
Tracker DTS	37	83	106	173	491
VS 2000	50	144	190	276	900

Transmitting beacons were VS 2000. $N=64$.

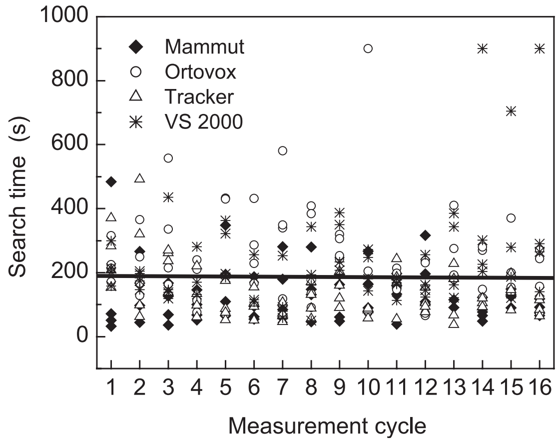

Fig. 5. Effect of search sequence during the measurement day on search time. For each of the 16 measurement cycles the according search times are given. The slightly decreasing trend (line) was not significant ($p = 0.82$), i.e. no learning effect was detected.

cantly affect search time (Fig. 6, Table 2). The effect of burial location was significant ($p < 0.05$) for the Mammut Barryvox, the Ortovox M2 and most significant for the Tracker DTS. Burial location hardly affected search times when searching with the VS 2000.

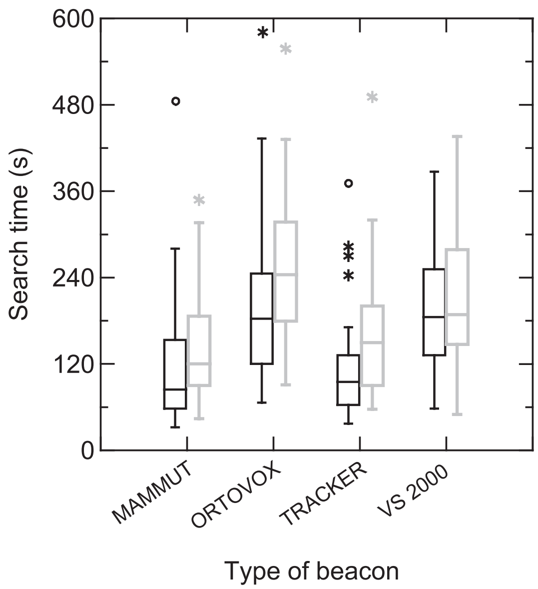

Fig. 6. Effect of distance from starting point on search time for the four types of beacons tested. For each type of beacon the search time is given for the two burial positions: approximately 35 m (left) and 70 m (right) from the starting point.

Table 2

Effect of burial position on search time for the four types of beacons tested on 7 February 2001 at Engstligenalp, Bernese Oberland, Switzerland

Type of beacon	Median position a 35 m (s)	Median position b 70 m (s)	p
Mammut Barryvox	84.5	120	0.045
Ortovox M2	183	244	0.03
Tracker DTS	95	149.5	0.01
VS 2000	186	193	0.483

Beacons were either buried approximately 35 m (position a), or 70 m (position b) from the starting point (Fig. 1). Transmitting beacons were VS 2000. Level of significance p indicates if search times were significantly different ($p < 0.05$) in respect to distance (burial location), based on a nonparametric U-test.

3.2. Range

Table 3 and Fig. 7 compile the results of the range measurements applying the first measurement method, i.e. by walking past a transmitting beacon that is buried with a random antenna orientation. Transmitting beacons were four different units of VS 2000. The frequency distributions (Fig. 8) were close to normal distributions. Fitting a normal distribution revealed a goodness of fit of generally $R^2 \geq 0.95$, except for the acoustical range of the Ortovox M2

Table 3

Results of range measurements applying the first measurement method, i.e. by walking past a transmitting beacon that is buried with a random antenna orientation

Type of beacon	N	Minimum (m)	Median (m)	Maximum (m)	Mean (m)	Standard deviation (m)
Mammut Barryvox optical	126	14.1	21.7	28.3	21.6	2.7
Mammut Barryvox acoustical	128	26	42.0	52.4	41.9	5.2
Ortovox M2 optical	126	14.9	22.6	34.3	22.7	3.4
Ortovox M2 acoustical	128	42.9	61	95.1	63.4	11.0
Tracker DTS	127	15.8	20.7	25	20.6	2.0
VS 2000	128	48.9	79.5	133.4	80.9	15.3

Transmitting beacons were VS 2000.

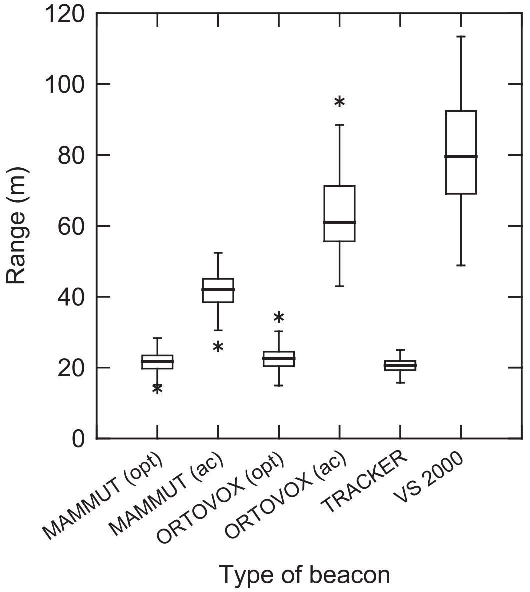

Fig. 7. Range measured with the first method, i.e. by walking past a transmitting beacon that is buried with a random antenna configuration. Results for the four different types of beacons are given, with optical and acoustical range for Mammut Barryvox and Ortovox M2. Transmitting beacons were VS 2000. $N = 126$ to 128 (Table 3).

for which the distribution was somewhat more skewed. This agreement was also indicated by the generally small difference between the median and mean of the range (Table 3).

With the second method the maximum range was determined in co-axial antenna orientation. Transmitting beacons were the VS 2000 (Table 4) in 56 cases, and the Ortovox M2 and Tracker DTS each in 28 cases (Table 5). The VS 2000 had the largest range, and the Tracker DTS had the shortest range. However, the standard deviation for the Tracker DTS was particularly small. The type of transmitting beacon strongly affected the maximal range, decreasing the mean and increasing the standard deviation. This led to smaller values of the width of search strip. The only exception was the Tracker DTS with a similar mean of maximal range and a slightly higher standard deviation.

3.3. Search strip width

Based on the results of the range measurements as presented above, the width of the search strip can be calculated (Table 6). This reveals two values

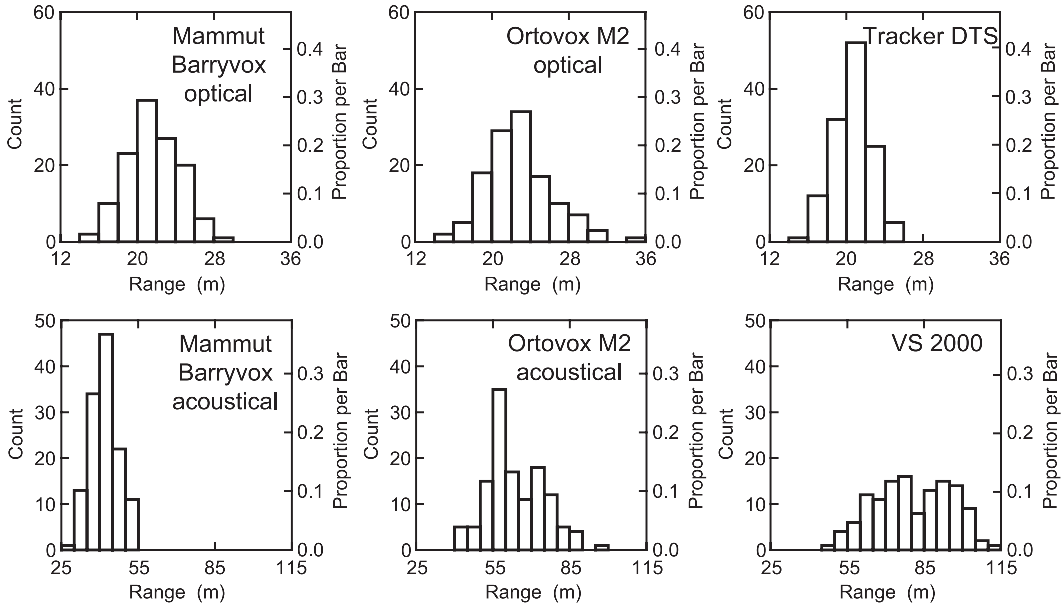

Fig. 8. Frequency distribution of range measured with the first method, i.e. by walking past a transmitting beacon that is buried with a random antenna orientation. Results for the four different types of beacons are given, with optical and acoustical range for Mammut Barryvox and Ortovox M2. Transmitting beacons were VS 2000. $N = 126$ to 128 (Table 3).

Table 4
Results of maximum range measurements applying the second method, i.e. approaching with co-axial antenna orientation

Type of beacon	Minimum (m)	Median (m)	Maximum (m)	Mean (m)	Standard deviation (m)
Mammut Barryvox optical	23.3	27	33.4	27.4	2.0
Mammut Barryvox acoustical	37.7	52	64.8	52.0	6.0
Ortovox M2 optical	20.8	27	33	26.8	3.3
Ortovox M2 acoustical	75	87.5	110	87.4	6.8
Tracker DTS	21.4	24.5	26	24.4	0.84
VS 2000	94	107	125	108.3	7.2

Transmitting beacons were VS 2000 models. $N = 56$.

for each type of beacon. The search strip width w_2 determined from the maximal range measurements (Eq. (3)) is lower than the search strip width w_1 determined from the range measurements with the first method (Eq. (2)). In the case of maximal range measurements, the effect of the type of transmitting beacon can be taken into account. An additional value of the search strip width is calculated by considering 28 cases of each time the Ortovox M2, the Tracker DTS and the VS 2000 models were used as the transmitting beacon. The three calculated values are supplemented with a recommended value for the width of the search strip. The recommended values were chosen for ease of use, and are considered for cases where the transmitting beacon is other than the VS 2000, and for the fact that the test results were obtained under ideal conditions (which rarely prevail in reality). These factors are particularly important in the case of single-antenna acoustical beacons.

Table 5
Effect of type of transmitting beacon

Receiver	Transmitter		
	Ortovox M2 (m)	Tracker DTS (m)	VS 2000 (m)
Mammut Barryvox	21.4 ± 1.7	28.3 ± 2.1	27.4 ± 2.0
Ortovox M2	20.4 ± 1.6	20.4 ± 1.5	26.8 ± 3.3
Tracker DTS	23.1 ± 1.2	26.7 ± 1.3	24.4 ± 0.8
VS 2000	87.9 ± 10	105 ± 12	108 ± 7.2

Mean and standard deviation of maximal range determined in co-axial antenna position. For the Mammut Barryvox and the Ortovox M2 only the acoustical range is given. The number of measurements is 56 for the VS 2000 as the transmitting beacon, and 28 each for the Ortovox M2 and Tracker DTS. The Mammut Barryvox was not used as a transmitting beacon.

Table 6
Results on the width of the search strip

Type of beacon	Width of search strip w (m)			
	w_1 based on range r	w_2 based on maximum range r_{max}	Based on maximum range r_{max}, considering different transmitters	Recommended
Mammut Barryvox optical	32	23	18	20
Mammut Barryvox acoustical	63	40	32	40
Ortovox M2 optical	32	20	15	20
Ortovox M2 acoustical	83	74	61	50
Tracker DTS	33	23	21	20
VS 2000	100	94	74	60

Four values are given. The first three values are calculated based on the range measurements. The third value is calculated from the maximal range measurements with different transmitters; it considers 28 range measurements with each of the three beacons Ortovox M2, Tracker DTS and VS 2000 as transmitting beacon. The fourth value is a general, noncommittal recommendation.

4. Discussion and conclusions

We have comprehensively tested search time and range, two of the most important properties of an avalanche rescue beacon. Special emphasis has been put on the test design that is considered as being exemplary for any future tests. In particular, any bias caused by the usually inherent learning process of the novice testers was avoided. In fact, no learning effect at all was detected. This is likely due to the relatively small number of tests with a single type of beacon (4) and the quite substantial differences in search method between different types. The test results show the state of the art of avalanche beacons as of winter 2001. We have not tested multiple burial situations, or ease of use in an explicit way, or other important features such as reliability.

Searchers were fastest with the Tracker DTS and the Mammut Barryvox. Hence, dual-antenna digital beacons with optical search aids proved to have an advantage. The search times found have been in general quite small, i.e. even novices can find after minimal training a single buried beacon reasonably fast. However, the search times of 1.5 to 3.5 min should be interpreted with caution. In an actual rescue search times might be substantially longer. In addition, digging out a person that has been caught and buried will easily take several times longer than locating them. A quick test after the search time measurements showed that a group of four students needed 12 min to recover a dummy that was buried 1.2 m in depth. Multiple burials have not been considered, but a good beacon must definitely be useful for this difficult situation, since avalanche incidents with multiple burial situations are not rare. Accidents statistics from the Swiss Alps show that in about 30% of the avalanche incidents in the backcountry two or more persons were completely buried (Schweizer and Lütschg, 2001).

The results of the range measurements for the VS 2000 are comparable to results from previous tests. This indicates that the present test reveals consistent values also for the other types of beacons. According to Eq. 1, the range r determined with this method should be about 80% of the maximal range r_{max}. In fact, the values found are between 75% and 84%. This again supports the consistency of our results and the choice of test design. The value of 84% for the Tracker DTS is somewhat lower than expected. The correction factor for dual-antenna beacons as proposed by Meier (2001) is therefore not applied when determining the width of the search strip.

The range measurements showed that analog beacons clearly have a larger range than the digital ones. The purely digital Tracker DTS has the smallest range, but its digital unit reveals the most consistent range values. The classical VS 2000 is still the beacon with the largest range.

The method proposed by Meier (2001) is well suited to determine the search strip width and produces relatively conservative values, which is beneficial in practice. This is in part due to the fact that the method considers non-optimal alignments between the search and transmit beacons. The method requires a smaller test sample and gives more repeatable values.

The traditional "40%-rule" to determine the search strip width is clearly outdated. For all types of beacons, the coefficient of variation is substantially smaller than 30% as assumed for the "40%-rule". Accordingly, applying the "40%-rule" would result in unnecessarily small values of the search strip width.

The results clearly show that there is no single search strip width, which applies to all avalanche rescue training. The search strip width is a device specific property that should be specified on the beacon housing. However, since range is a promotional argument it is necessary to have a reliable method to quickly assess specifications given by manufacturers. The tests have shown that the method proposed by Meier (2001) is particularly well suited for that purpose.

The comparison of search time for the two different burial positions with range measurements shows that the search times achieved with beacons with a shorter range are more affected by the increase in distance from the starting point to the burial location than for beacons with a large range. This suggests that with a beacon of short-range search time increases more strongly with increasing size of the avalanche deposit than with a long-range beacon. However, on our 50×70 m test fields, corresponding to the average size of an avalanche deposit, the different range properties did not have a significant influence on search time. Beacons with a shorter range did not produce slower search times, since up to this size of deposit, the disadvantage of shorter range was compensated by the better ease of use. It is expected that searches on very large avalanche deposits with long-range beacons will tend to be faster than with short-range beacons under the same conditions.

Acknowledgements

The authors would like to thank Emanuel Wassermann and Michael Wicky for organizing the test on the search times, as well as Marieke Bachmann, Isabella Flüeler, Patrick Hager, Martin Hess, Jürg Mannes, Jeanette Nötzli, Nina Riesen and Daniel Studer for their work on the range tests. Felix Meier has been a most valuable resource for any questions related to avalanche beacons. Many thanks to two anonymous reviewers and C. Fierz, J.B. Jamieson and I. McCammon for their valuable comments.

References

Good, W., 1969. Bericht über die Prüfung von technischen Hilfsmitteln zur Ortung von in Lawinen verschütteten Personen. Internal Report, 496, Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland.

Good, W., 1987. Electronic transceivers for locating avalanche victims, an optimal strategy for the primary search. Proceedings International Snow Science Workshop, Lake Tahoe, CA, USA, 22–25 October 1986. ISSW Workshop Committee, Homewood, CA, USA, pp. 177–182.

Good, W., Schild, D., 1990. Bericht über die Ermittlung von minimalen und maximalen Reichweiten von Sender/Empfänger Geräten der neueren Generation und Vergleich mit Ein-und Zweifrequenzgeräten-Kurzbericht über Bestimmung von Reichweiten des Prototyps Recco III. Report, G 90.12. Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland.

Krüsi, G., Weilenmann, P., Tschirky, F., 1998. Lawinenverschütteten-Suchgeräte Vergleichstest "LVS-98". Mitteilung, vol. 57. Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland. 131 pp.

Meier, F., 1987. A standard frequency for avalanche beacons—what's going on in Europe. Proceedings International Snow Science Workshop, Lake Tahoe, CA, USA, 22–25 October 1986. ISSW Workshop Committee, Homewood, CA, USA, pp. 172–176.

Meier, F., 2001. Determining the width of a search strip for avalanche beacons. Proceedings International Snow Science Workshop, Big Sky, MT, USA, 1–6 October 2000. American Avalanche Association, Bozeman, MT, USA, pp. 345–350.

Schweizer, J., 2000. The European avalanche beacon test "LVS-98". American Alpine News 9 (228), 28–32.

Schweizer, J., 2001. Bestimmung der Suchstreifenbreite von Lawinenverschütteten-Suchgeräten (LVS)-LVS-Test des SLF im Winter 2001. Internal Report, 743. Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland.

Schweizer, J., 2002. Suchstreifenbreite der neuen LVS. Die Alpen, Zeitschrift des Schweizer Alpen-Clubs, Bern, Switzerland 78 (1), 46–49.

Schweizer, J., Lütschg, M., 2001. Characteristics of human-triggered avalanches. Cold Regions Science and Technology 33 (2–3), 147–162.

Schweizer, J., Wassermann, E., Wicky, E., 2001. Die neuen LVS im Test. Die Alpen, Zeitschrift des Schweizer Alpen-Clubs, Bern, Switzerland 77 (4), 16–17.

Sivardière, F., 2001. Les ARVA en 2001. In: Sivardière, F. (Ed.), Actes de Colloque-Bilan et perspectives de 30 années de gestion du risque d'avalanche en France, Grenoble, France, 19–23 November 2001. ANENA—Association Nationale pour l'Étude de la Neige et des Avalanches, Grenoble, France, pp. 153–158.

Tschirky, F., Brabec, B., Kern, M., 2001. Avalanche rescue systems in Switzerland: Experience and limitations. Proceedings International Snow Science Workshop, Big Sky, MT, USA, 1–6 October 2000. American Avalanche Association, Bozeman, MT, USA, pp. 369–376.