

AVALANCHE RESCUE SYSTEMS IN SWITZERLAND: EXPERIENCE AND LIMITATIONS

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ABSTRACT: The current study is concerned with the influence of transceiver and avalanche balloon devices on the survival probability of people caught by avalanches. From 1936 to 1999, 1592 people have been killed by avalanches in Switzerland. The data of avalanche incidents in the years 1980 to 1999 has been extensively analyzed. These investigations result in a mortality rate of completely buried people of about 50%. Considering the total number of people caught by an avalanche, the mortality rate is approximately 13%. If people are not completely buried, or if at least parts of their body or equipment are visible on the surface of the avalanche debris, they have the best chances of survival. There is a strong correlation between mean burial time and the probability to survive an avalanche incident: The mean burial time of people who were completely buried and survived the avalanche incident is about 11 minutes, where the mean burial time of people killed by an avalanche is 120 minutes. For this reason, a reduction of burial time by fast transceiver search or even avoiding burial by using an avalanche airbag device has to be achieved to increase the survival probability. The results of the current work confirm this statement.

KEYWORDS: avalanche accident, avalanche incident, avalanche accident statistics, avalanche beacon, transceiver device, avalanche balloon, avalanche airbag (ABS).

1. INTRODUCTION

The Swiss Federal Institute for Snow and Avalanche Research (SFISAR) has been collecting and evaluating any data concerning avalanche incidents in Switzerland since winter 1936/37. All information regarding fatal incidents in this time period is fully available. Due to improved information networks and technology, many non-fatal incidents can also be included in the statistics. The accident reports and statistics are annually published in the SFISAR winter reports.

The main interest of the current work does not lie in avalanche specific problems as in (Schweizer et al., 2000) but on taking stock of data on avalanche burials and on rescue methods. By doing so, basics for the development of rescue strategies are provided.

The data collected by the SFISAR has previously been used in various investigations (Brugger et al., 1997 and 1997, Falk et al., 1994).

Technical terms are explained in the glossary in the appendix.

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2. AVALANCHE FATALITIES 1937 to 1999 (63 YEARS)

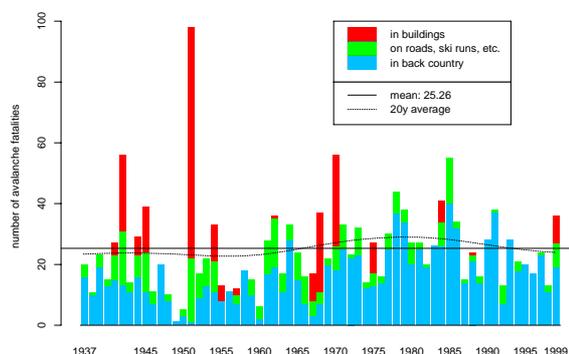


Figure 1: Location of people killed by avalanches in Switzerland from 1937 to 1999 (63 years)

In the years from 1937 to 1999, 1592 people were killed by avalanches in Switzerland. The mean number of fatalities over 63 years is 25, the mean over 20 years (1980 to 1999) is 26 fatalities per year where, in the more recent years, a slightly decreasing tendency can be observed (Figure 1).

2.1 Back Country (uncontrolled terrain)

In the period from 1937 until 1999, an average number of 16 people died in avalanches in uncontrolled areas. The mean number of fatalities

in back country terrain in the years from 1980 to 1999 was 22. However, in the latter years, there was a significant decay of the number of fatalities of this category (Figure 2).

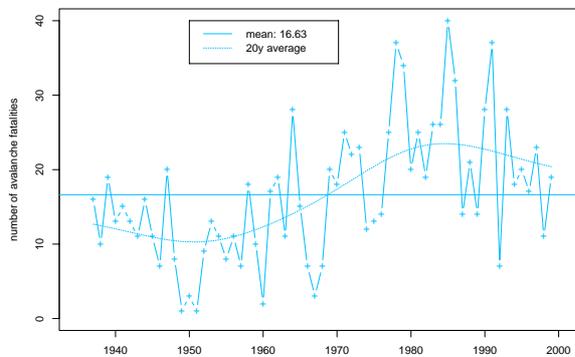


Figure 2: Trend of fatalities in back country 1937 to 1999 (63 years)

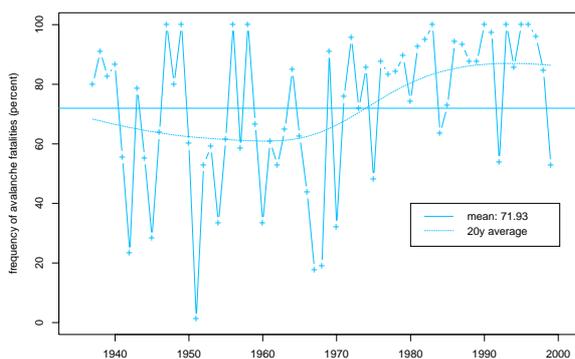


Figure 3: Frequency of fatalities in back country terrain with respect to the total number of fatalities

Whilst in the years 1970-1985 there was a constant increase of the number of fatalities in back country, a decay of fatalities in uncontrolled terrain could be observed in the 90s. The frequency of fatalities in this category was subject to considerable variations in the last 63 years. Until the mid-70s, less than 70% of avalanche fatalities belonged to this type, whereas in the last 20 years 85% of all avalanche fatalities occurred in back country (Figure 3).

3. AVALANCHE INCIDENTS 1980 to 1999 (20 YEARS)

3.1 *Consequences of burial*

In the last 20 years, 2301 people were

caught by avalanches by a total of 894 avalanche incidents in Switzerland. 523 people (23%) were killed, 1778 people (77%) survived.

1429 people (62%) were not or just partly buried, 872 (38%) people were completely buried. We assume that we are aware of about 90% of all incidents involving total burial of people without death or injury involved. On the other hand, the number of unknown incidents, in which people were caught and only partly or not buried by an avalanche and remained uninjured, is probably at least as high as the number of such incidents which are known to us. This estimated number of unknown cases is based upon a raw comparison of the number of incidents in the region of Davos, which are very well documented, with the number of incidents in the other parts of Switzerland. With respect to this data, one can suggest that about 75% of all people caught by avalanches are not or partly buried and about 25% are completely buried.

62 (4%) of the 1429 not or partly buried people were killed, 1397 (96%) survived. Taking into account the estimated number of unknown cases, one can assume the survival probability of not or partly buried people to be at least 97%.

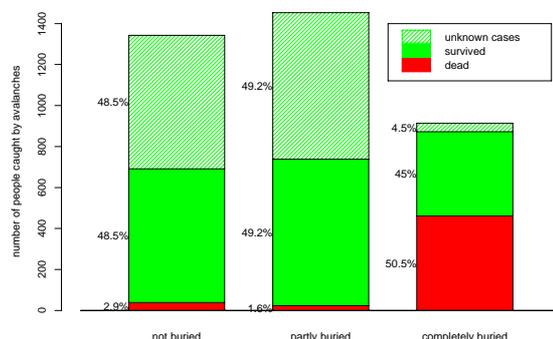


Figure 4: Consequences of burial of people caught by avalanches 1980 to 1999 (20 years)

461 (53%) of the 872 completely buried people were killed, 411 (47%) survived. If the number of unknown cases in which a completely buried person has survived is assumed to be 10%, the chance of survival in case of total burial is still only about 50% (Figure 4).

This data leads us to the following statement: We estimate the mortality rate of all people caught by an avalanche not to exceed 13%, whereas the mortality rate in case of total burial is about 50%.

3.2 Activities of completely buried people

In the years from 1980 to 1999, 872 people were completely buried by avalanches, 408 of them during ski touring, corresponding to nearly 50% of all completely buried people. The subsequent group is the out-of-bounds skiers, 200 of them were completely buried. In the considered time interval, 83 hikers and climbers were completely buried. However, 69 people were situated on open roads or skiing runs when they were completely buried by avalanches. The group of completely buried, out-of-bounds snowboarders consists of only 38 people. However, 26 of them account for the last 4 recorded years (1996 to 1999). The remaining categories of completely buried people are (Figure 5): maintenance of roads (37), buildings (23) and closed roads (14).



Figure 5: Activities of all completely buried people 1980 to 1999 (20 years)

3.3 Mortality rate of completely buried people

Considering different categories of the place of capture or activities of completely buried people, considerable differences in the mortality rate are apparent. The mortality rate of completely buried, out-of-bounds skiers or people completely buried on roads is significantly below 50%, whereas for ski touring or mountaineering the mortality rate is about 56%.

This mortality rate, which is nearly 10% higher than the one in the out-of-bounds skiing regime (47%), can be explained by various factors. In the ski touring regime, the times elapsed until rescue teams are notified are usually longer. Furthermore, there exists a great danger of serious injuries due to avalanche induced falls of climbers in alpine terrain. If avalanches are released during the ascent in the lower slope regions, there is a

greater danger of deeper burial than in avalanches which are released during the descent in the upper regions of the slope.

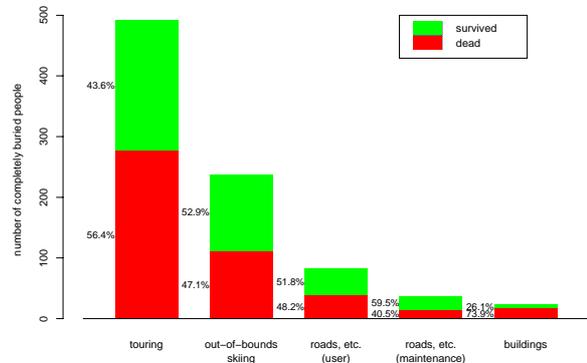


Figure 6: Comparison of the mortality rate of completely buried people 1980 to 1999 (20 years)

People who are caught by avalanches within buildings have the smallest chances of survival: their mortality rate is about 74%. This can be explained by the magnitude and power of catastrophic avalanches.

4. COMPLETE BURIALS IN BACK COUNTRY 1980 to 1999 (20 YEARS)

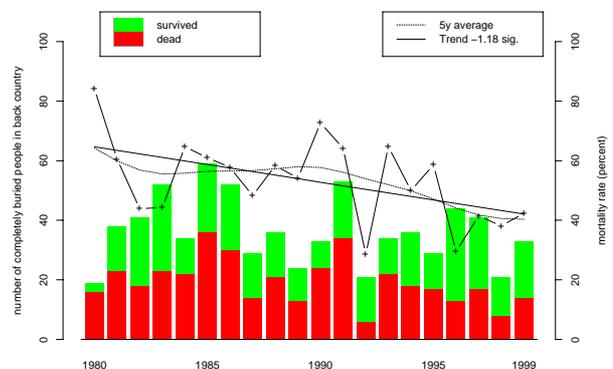


Figure 7: Trend of the mortality rate in back country 1980 to 1999 (20 years)

The data from a total of 729 completely buried people were analyzed. 389 (53%) of these people were dead and 340 (47%) survived. During the last 4 years, the mortality rate in total burials has significantly decreased (Figure 7). The reasons (successful use of rescue devices) for this positive evolution will be discussed later on.

4.1 Burial depths and burial time

The median burial depth of all 729 completely buried people is 70 cm. Omitting people who were found due to visible parts or who could free themselves due to small burial depths, the median burial depth is 100 cm. The median burial depth of all surviving, completely buried people is 50 cm. This corresponds to half of the median value of 100 cm of the dead, completely buried people. 75% of the surviving, completely buried people were less than 80 cm deep (Figure 8).

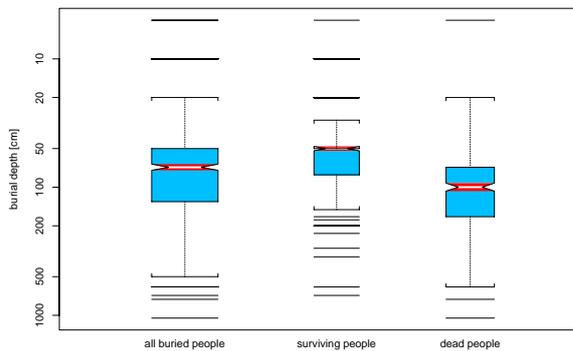


Figure 8: Burial depths in back country 1980 to 1999 (20 years)

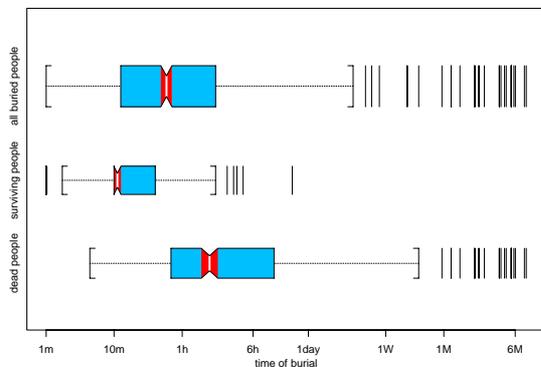


Figure 9: Burial time in back country 1980 to 1999 (20 years)

The median time of burial of all 729 people is 40 minutes. Excluding the categories „visible parts“ and „self rescue“, this results in a median burial time of 60 minutes. Additionally excluding the category „calling“, the burial time of the remaining completely buried people is 70 minutes. The median burial time of all surviving, completely buried people is 11 minutes and therewith significantly shorter than the median burial time of 120 minutes of the dead, completely buried people.

75% of the surviving people were buried for less than 30 minutes (Figure 8). These results correspond well to the ones of previous publications (Falk et al, 1994), (Brugger et.al., 1997). The characteristic numbers of median burial depth and median burial time are essential for the development of rescue strategies and rescue devices.

4.2 Rescue/Recovery

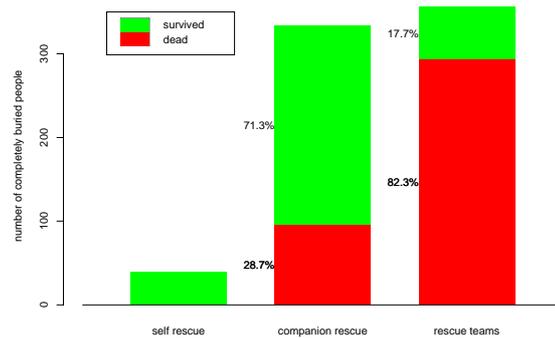


Figure 10 : Rescue/recovery of completely buried people in back country 1980 to 1999

44 (6%) of all 729 people completely buried in back country terrain could free themselves. 328 people (45%) were recovered by companions, 357 (49%) by rescue teams. 232 (71%) of the people who were recovered by companions survived, 96 (29%) were dead. On the other hand, 293 people (82%) of those recovered by rescue teams were dead and only 64 people (18%) survived. Therefore, the chances of survival by companion rescue are 4 times as high as by organized rescue teams (Figure 10).

5. TRANSCEIVER SEARCH IN COMPARISON WITH OTHER DEVICES

5.1 Location methods in companion rescue

Most of the completely buried people were found due to visible parts of the bodies or their equipment, closely followed by the number of people found by transceiver search. Whilst the survival chances of people found by visible parts are very high (85%), they are not as encouraging in the case of transceiver search (51%) as shown in Figure 11. This fact has also been stated in previous investigations (Brugger et al, 1997). The survival of completely buried people is primarily dependent on their burial time. The median burial

time of all buried people located by companions due to visible parts is 10 minutes, whereas the median burial time of people rescued by companion transceiver search is 20 minutes. If the survival chances of completely buried people who are recovered by companion transceiver search are to be improved, the entire time interval from the point of burial until recovery (including organization of the rescue, search, localization, digging out) has to be shortened significantly.

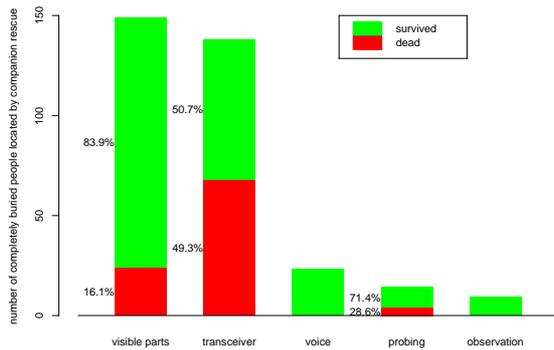


Figure 11: Companion rescue: Location methods of completely buried people in back country

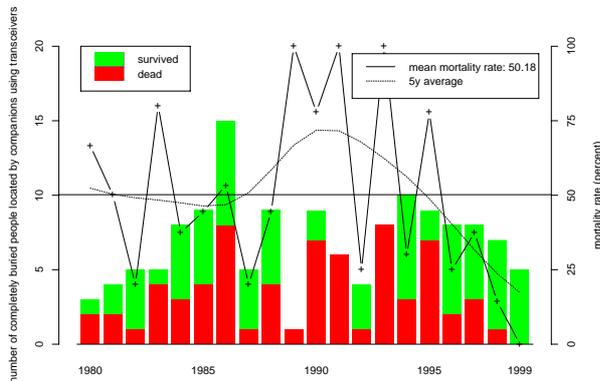


Figure 12: Companion rescue: Results of transceiver search in back country

The survival chances of 51% of the buried people who were located by transceiver search are significantly smaller than these of the total of all completely buried people recovered by companions. This can be explained by the great number of surviving people found due to visible parts. In the last 5 years however, transceiver search was significantly more successful, as shown in Figure 12. The probability of being recovered alive by companions using transceiver devices has increased from just 30% to 75%.

The burial time of the people located alive

by companions using transceiver devices is 15 minutes, and 35 minutes for those located dead. By comparison, the median burial time of people located by companions due to visible parts is 10 minutes.

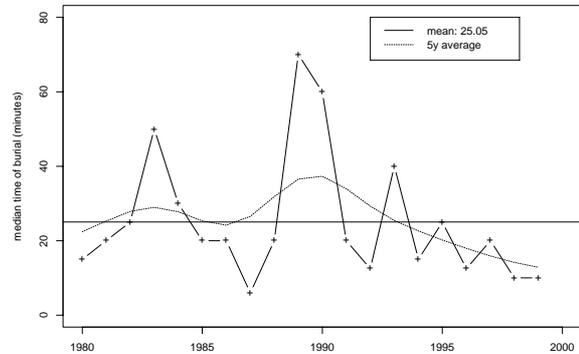


Figure 13: Companion rescue: Trend of burial time of people located by transceiver search

The number of all people located by companions using transceiver devices has been constant in the last 5 years. However, the number of people recovered alive has increased. This can be related to the fact that the median burial time has been shorter than 25 minutes throughout this time period. The mean of the last two years is just 10 minutes (Figure 13). From this, we can conclude that the state of training of the transceiver-users has probably been improved. The introduction of new digital transceivers however, does not affect this enjoyable evolution: these new devices were not widespread in Switzerland until the end of winter 1999.

The median burial depth of 85 cm for all recovered people (by companions using a transceiver device) does not significantly deviate from the median burial depth of 70 cm of all completely buried people. This can be explained by the fact that all people who were located by the visible parts of their bodies or equipment were not buried as deeply as the others.

5.2 Location methods of rescue teams

Most of the completely buried people have been found by the approved avalanche dogs. Particularly in the final years, recoveries of living people have fortunately increased (Figure 15).

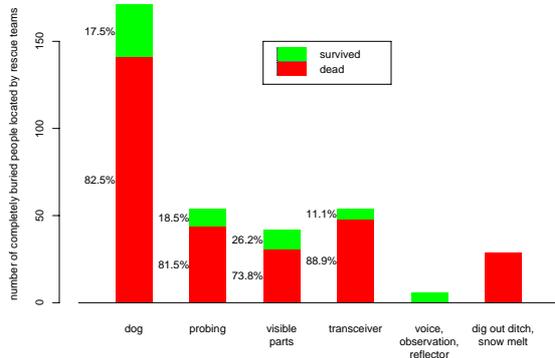


Abb. 14: Rescue teams: Location methods in back country 1980 to 1999 (20 years)

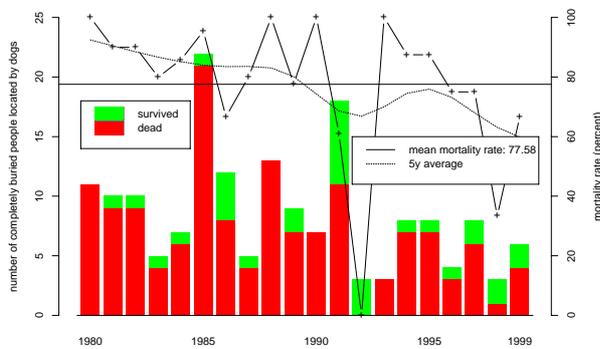


Figure 15: Rescue teams: Results of search by avalanche dogs 1980 to 1999 (20 years).

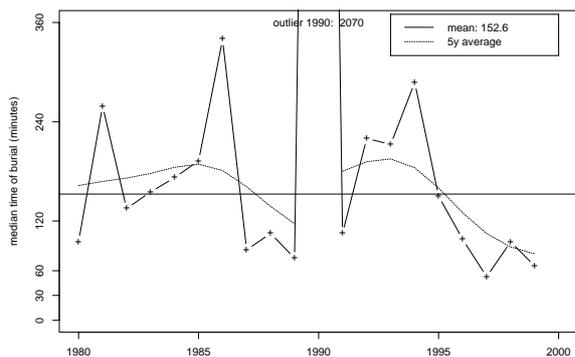


Figure 16: Rescue teams: Trend of burial time 1980 to 1999 (20 years)

This positive trend in the organized rescue actions could be due to shortened alarm times (mobile phones, radio sets, professional aid by ski patrol and helicopters) and therefore shortened burial times. In the last 5 years, the median burial

times were constantly below the year-long mean of 152 minutes (Figure 16). However, from a global point of view, the chances of survival are relatively small for all methods of search used by rescue teams.

6. THE ABS AVALANCHE AIRBAG

6.1 The function principle of the avalanche airbag

The effectiveness of the ABS system has been investigated by some preliminary experiments and by a large field test in winter 1994/95 (see Tschirky et al. 1995 et 1996).

A completely equipped skier has a mean specific weight of 400 kgm^{-3} , where the density of flowing avalanche snow is assumed to be about 300 kgm^{-3} . Therefore, the fact that a skier with inflated balloons is more likely to be near the surface of the flowing avalanche, cannot be explained by „swimming“ due to hydrostatic buoyancy. An explanation for the effectiveness of the ABS system can be obtained by interpreting a moving avalanche as a granular flow consisting of different sized discrete particles such as snow balls, lumps and blocks. Granular media moving under the influence of gravity tends to unmix in such a way that larger particles are more likely to be found near the surface, smaller ones near the base of the flow. This unmixing effect is also called „inverse grading“.

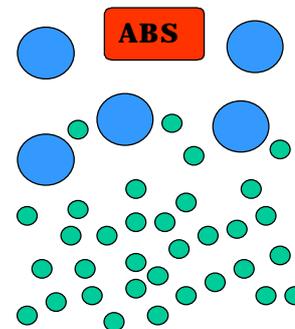


Figure 17: Principle sketch of inverse grading

The avalanche balloon converts the skier wearing it into an even larger „particle“ within the avalanche which can even better participate in the unmixing effect, as depicted in Figure 17. The effect of inverse grading has been investigated by extensive computer simulations employing a model flow of different sized spheres (Kern et al., 1999, Vulliet et al., 2000). These investigations showed that, as well as the size ratio of larger and smaller particles, the effect of inverse grading de-

depends on the material properties of the individual particles forming the granular flow.

6.2 *Known and documented avalanche incidents*

In the time between February 1991 and February 2000 there have been 26 avalanche incidents worldwide which are known and documented, and in which 40 people wearing an ABS system were involved. 32 of them successfully released the balloons. 6 people failed to tear the release mechanism, and in the other two cases the balloons probably were not inflated due to technical malfunction of the system.

16 of the 32 people with the balloons were not buried, 11 were partly buried and 5 were completely buried. In 4 of the 5 cases of total burial the balloon stayed visible on the avalanche surface, which allowed fast location and recovery companions not buried. These 4 people survived the total burial.

In an avalanche incident in South Tyrol in February 2000, 5 people were caught and buried by an avalanche. One person was wearing an ABS system and was completely buried together with the inflated balloons. The 5 ascending people were situated in the middle of a slope when an avalanche released at the top of the slope and dragged the group down to the bottom, forming a slight terrain depression. All of the people were buried 170 to 300 cm deep and were finally located by transceiver search. 4 of the people were recovered dead, one person survived the incident.

The skier who was equipped with the ABS system was one of the dead people, he had probably been lying on the avalanche surface in the flat runout zone at the slope base and been fixed there due to the „anchor effect“ of his skis. Subsequent snow masses from upper slope regions then buried him 170 cm deep despite the inflated balloons. The balloons are only effective as long as the person wearing them is moving together with the flowing avalanche. If one gets stuck in a depositional zone, the balloons are no longer effective. This problem had been previously detected in the experiments of winter 1995 and been pointed out in various SFISAR publications. An increase of survival for people who are completely buried with ABS balloons could be achieved if the inflated balloons had a mechanism which deflated them completely within about 3 minutes.

To conclude, one can state that 31 people with inflated balloons who were caught by avalanches survived the incident, only one was killed (Figure 18). There are probably an unknown num-

ber of incidents in which people wearing ABS balloons. Taking into account that the mortality rate of all people caught by avalanches is about 13%, the effectiveness of the avalanche system can also be demonstrated statistically. In cases of burial in terrain depressions however, the effectiveness of the device is at least questionable.

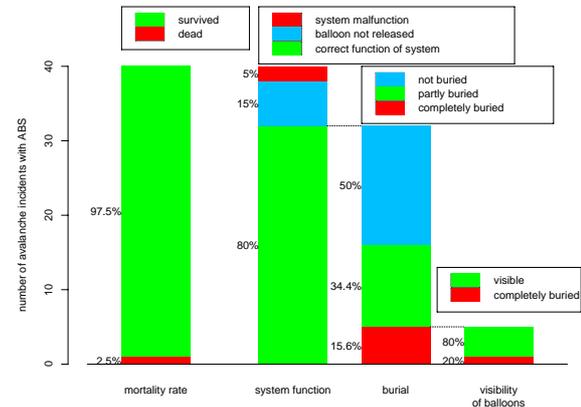


Figure 18: Worldwide known and documented incidents with avalanche airbag 1991 to 2000

7. CONCLUSIONS

If one is caught by an avalanche one has the greatest chances of survival if one is not, or only partly, buried. In the case of total burial, the survival chances are best if parts of the body or equipment is visible on the avalanche surface. Companion help is very effective. In latter years, the more frequent success of transceiver search has contributed to a positive development. The favorable development in organized rescue actions can be explained by the broad distribution of modern communication technology (mobile phones, radio sets) and by fast and professional rescue actions (helicopter, rescue services). Currently, out of the proven technical devices, the avalanche airbag provides the greatest chances of survival in avalanche incident. However, despite all positive developments and modern technical devices, one must never tolerate any avalanche incident - if only because of the enormous risk of severe injury.

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9. GLOSSARY

- *nivological year*: 1st of October of previous year until 30th September of the following year
- *mean*: the arithmetic mean is defined as the sum of data values divided by the number of the data values
- *median*: the median is characterised by the fact that each 50% of the observed data points have a value larger or equal to or smaller or equal as the median value
- *significant*: a model of a trend (such as a line) is called significant if the niveau of significance of the model is smaller than 0.05
- *back country*: people situated outside the saved terrain (touring, out-of-bounds skiing); people are responsible for themselves
- *roads, etc.*: people performing maintenance work on roads, ski runs, etc., people on open and closed roads, ski runs, etc.
- *completely buried*: a caught person, whose head is buried after standstill of the avalanche which caused danger of asphyxia
- *visible parts or parts of body*: a part of equipment (rope, ski, ...) or a part of the body (foot, hand) of a completely buried person is visible on the avalanche surface and allowed fast location and recovery by other people
- *observation*: unaffected people could determine the approximate situation of the buried person by observing the avalanche action and the point of disappearance