AVALANCHE CONTROL AND HAZARD FORECASTING TECHNIQUES

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Introduction

The Snowbird Corporation controls approximately 450 starting zones which affect the ski area, and an additional 47 starting zones which affect the access road in Little Cottonwood Canyon. In five seasons of operation (1971 we have used 11,540 artillery rounds and 27,700 hand charges protect over 10^6 visitors (Table 1). So far, we have had no fatalities in our area, although we have had several non-fata accidents which reinforce our need to continue and improve ou avalanche safety programme.[1] In the period 1971-76, we avera nine avalanche accidents per season. Most of the victims eit freed themselves or were immediately rescued by members of th own parties. However, on three occasions in this five-year period, the victims were rescued by rapid search of our ski patrol team dispatched from our upper tram station.

Avalanche Control System

The Snowbird area is comprised of two separate valle Peruvian Gulch and Gad Valley, divided by a prominent ridge. Depending upon weather and avalanche conditions, limited porti of the area will be opened and other portions opened as the weather or avalanche hazard improves.

The terrain is such that many of the upper avalanche paths, more susceptible to buildup, run down onto the lower more sheltered ones. Therefore, in order to open any of the area at all, a fair amount of avalanche control must be carried out.

The morning control work usually begins with firing a 75 mm - Howitzer and a 75 mm recoilless rifle from the Snowbi Village area on starting zones above the ski area, the village, and the access road to the village. However, if the hazard is extreme due to slides which descend into the village area, control teams must first ascend the Snowbird Lift System, and reach 75 mm recoilless positions on fixed towers high in Gad Valley and on the ridge separating Gad Valley and Peruvian Gulch Depending on the hazard, artillery firing may require 1½ hours.

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*See List of Participants for Affiliations.

[1]Subsequent to the presentation of this paper, one avalanche fatality did occur during the Winter 1976/77.

After the artillery work has been completed, up to eight hand-charge teams are dispatched from Hidden Peak, once again dependent upon the day's activity. These teams consist of two to four people and up to 30 hand-charges per route. All teams have radio communication and work in conjunction with one another by throwing protection shots and entering certain areas only after clearance from other routes. Even if skiing is to be limited to the lower runs, a certain minimum of artillery work and at least four hand-charges routes must be carried out.

Of the eight teams departing Hidden Peak, three teams control the interior of Peruvian Gulch. The remaining five confine their efforts to the slide paths starting on the ridge. The control of the interior of Gad Valley is divided between seven additional hand-charge teams starting from chairlifts in Gad Valley. Usually a limited amount of work is carried out in this area due to heavy ski traffic and sheltered runs. Deep slab instability, however, is not uncommon to Gad Valley and a close watch must be kept on about 150 smaller starting zones.

After the main area has been controlled and fair weather is forecast, the outlying bowls are controlled and opened for skiing. This is carried out in the same fashion, artillery fire preceding hand-charge teams.

If intense storm conditions persist for several days, travel restrictions are enacted within the village area and on the access road until protective firing clears the hazard.

A full control morning requires up to 250 hand-charges and 125 rounds of ammunition. It takes 23 people up to six hours to carry out this work. A control strategy is planned in late evening and then revised early in the morning, depending on latest weather information.

Hand-Charge Methodology

On a storm day our work begins well before dawn. (The evening before we crimp caps to pre-cut lengths of fuse.) In the morning two men travel in the dark at a prearranged time by snow-cat to our underground explosives storage vault on the mountain. They obtain the quantity of hand-charges requested by the Snow Safety Director, usually 100 to 250 charges depending on conditions. Seven other men travel, guided by head lamps, to our three artillery pieces to begin blind firing the higher slopes. Meanwhile our avalanche hazard forecasters take instrument readings and make decisions as to what control measures will need to be taken. Other patrolmen assemble at the Tram dock. They place a full circle of chairs in the front end of the Tram car. When the cases of hand-charges are delivered to the Tram dock, they are placed in a predetermined spot. A specially-assigned patrolman is responsible for obtaining caps and fuses from storage and for handling them. While the tram moves up the mountain, the patrolmen, sitting in the circle, tape and stack charges according to a procedure which we actually practice in advance in order to assure continuity and precision. Once at the top, inside the Patrol building, the Snow Safety Director assigns hand-charge routes to 18 patrolmen, and he outlines any unusual or special procedures he feels are necessary. (Each patrolman is responsible for a particular route all season so that he understands thoroughly its characteristics and peculiarities.) Route and radio assignments are noted by the dispatcher who coordinates and keeps records of all activity. Each team leader carries a radio. All patrolmen carry a Skadi, shovel and ski poles that fit together to make a 3 m avalanche probe.

Route leaders consult with each other to plan coordination of movement among routes. Members of the same team get together to estimate the degree of hazard they think they will find on their route and to decide on the number of charges they will carry. They also plan specific movement. For example, one patrolman may protect the other by blasting a slope before his partner ventures out on it.

Once the guns have completed the portion of their firing which protects the hand-charge teams, the teams begin going out at prescribed intervals. As examples, route 3 starts by throwing protection shots for route 2. Route 5 does the same for route 6. Completion of protection shots is radioed to the dispatcher who cues the remaining routes that they can begin. Once all the routes are out, 22 men and 11 radios are involved in what can only be described as a military-type operation.

All this seems routine, but what we have not yet considered is the weather. The wind is often gusting to 100 km per hour. The temperature is often -20°C or less; wind-chill factors of -60°C are common. Blowing and drifting snow makes for poor visibility and difficult manoeuvering on skis. It makes oral communication between members of the same team and radio communication between different teams difficult. Under such conditions, what contributes most to safety is calm, alert minds and even, precise movements -- no hasty actions, no short-cuts, no anger at malfunctioning equipment or bodily discomforts.

Each shot of each route is marked by a numbered placard wired to a stake or tree located in a safe zone above the target point. In addition, the patrolman memorizes all the shot points. The team leader decides exactly who is to do what along the route. For example, the leader might tell his partner, "Go stand above the big tree, and throw shot 14 while I watch from the side. When you're done, I'll ski across the controlled slope to shot 15 while you watch me. I'll throw 15 and once you see that I'm safe, we'll both ski to 16 and meet. There we can devise how to handle 17 and 18." Charges are thrown from prearranged marked points whenever possible, so that no time is needed to move to a safer location.

What we emphasize is the importance of fostering a safety-oriented spirit among blasters through good training and insistence on proper procedures. Imposing regulations as to fuse lengths or any other matter will contribute nothing to safety if these factors are overlooked. Another essential factor is proper personnel recruitment to select responsible, mature, alert and safety-oriented individuals. No quantity of regulations will assure safety unless capable, conscientious people are involved exclusively in the work.

Hand-Charge Components and the Mammoth Accidents

At Snowbird we have always used the following materials for hand-charging:

a) Trojan brand pentolite cast 1 kg primers (we had the manufacturer separate the cap and fuse wells from approximately 2 mm to more than 12 mm to preclude the possibility of premature detonation).

b) Orange Sword-brand safety fuse, manufactured by Ensign-Bickford Co.

c) Du Pont or Atlas No. 6 fuse caps.

d) Martin and Shaft pull-wire fuse igniters.

e) Black friction tape.

We have never experienced any problem with any of these materials, with one exception. On at least two occasions, the pull-wire igniters have ignited spontaneously while being slipped over the fuse, i.e., prior to pulling the wire. As a result, we teach our blasters, and constantly remind them in safety meetings, to place the pull-wire on the fuse only when they are in position ready to throw the charge. The importance of this procedure is especially critical during snowstorms or when the wind is strong because ignition of the fuse by the fuse-lighter can be imperceptible under such conditons. Also, occasionally pull-wire igniters fail to ignite the fuse. If this happens, we teach our personnel to remove the igniter, determine if the fuse is lit by touching the end, if not quickly re-crimp the fuse, and only then place a fresh igniter on the fuse. Finally, we do not allow double-fusing in which two pull-wire igniters are wrapped together in order to be pulled simultaneously. This is clearly an unsafe procedure due to the limited reliability of fuse lighters.

Except for the occasional problems with pull-wire igniters, we have always been completely satisfied with the materials we use. We are, by a considerable margin, the largest users of hand-charges for avalanche control in the world. Although we keep in mind at all times that an accident could occur, fortunately we have not yet experienced one.

We were deeply saddened by the two accidents which occurred at Mammoth Mountain in 1974. Naturally, they caused us to re-evaluate our methods as well as to re-examine the materials we use. Based on the information we have received regarding those accidents, we would make the following observations:

The possibility that pull-wire fuse lighters might ignite a fuse without this being perceived by the blaster has long been known to us. The unreliability of these fuse-lighters is a problem with which we are accustomed to dealing. However, if the blaster is fully aware of their limitation, then they can be used safely. Needless to say, if a new fuse-lighter were to prove to be more reliable, as easy to use, and not too much more costly, then we would be interested in using it.

Pentolite cast primers are especially well-suited to avalanche control work, and we feel that their desirable characteristics deserve mention:

1. They are high-velocity and deliver adequate shocks to the snowpack.

2. They are far more stable with respect to shock and fire than gelatin. They will break up into pieces, if smashed, and will only detonate if set off with a cap or primer cord. They remain stable and functional, even if soaked through with water.

3. They do not cause headaches, do not fragment if handled properly, and have excellent storage properties.

4. They can be packaged in various sizes suitable to avalanche control. The most commonly used 2 lb (1 Kg) size is easy to carry and to throw.

5. A fuse and cap can be looped through the charge so that they are secured and the cap is actually protected by the primer. This makes them safer to use.

6. If properly used, the dud ratio (at least with Trojan brand) is negligible.

Pentolite cast primers were not involved in the accidents at Mammoth, where a minol explosive (20% aluminum powder) with a cast-in pentolite booster was being used at the time.

The possibility that static electricity might cause a blasting cap to detonate should be regarded seriously. If a new fuse system can be developed which conclusively demonstrates that it is unaffected by static electricity, then it should be adopted.

At Snowbird, we have developed certain procedures for dealing with static electricity. Electrical storms are rare in the Wasatch mountains in winter. However, when such a storm approaches our area, the National Weather Service at the Salt Lake airport notifies us. If we are doing avalanche control work when we receive a warning, or if we sense that electricity is in the air, our patrolmen are instructed to do the following: Team leaders are informed by radio of the condition. They immediately notify their partner (or partners). Each team places their remaining hand-charges down at an identifiable location, such as a shot-point marker. Each team follows a planned, avalanche-free route to the bottom, remaining in visual contact with each other. The hand-charges are retrieved when the danger has passed.

With regard to possible future improvements in hand-charge design, we offer the following suggestions: The ideal fuse-lighter would be not only reliable and safe but also reusable to avoid littering the mountainside. It should also be reasonably inexpensive. The ideal fuse and cap combination would be highly resistant to static electricity. In other respects, we feel that what we are using is satisfactory. The ideal explosive for hand-charging would have all the characteristics of pentolite primers. A good case could be made for one which would deteriorate if left for a period of a few weeks in the snowpack, but we would not like to see the other excellent qualities of pentolite cast primers compromised to achieve that single purpose. One way in which pentolite primers could be improved would be to colour them fluorescent orange to make them more visible if lost in the snow.

Artillery and Its Future

U.S. Army, World War II vintage artillery has been used for thirty years to control avalanches in Little Cottonwood Canyon, Utah. Presently in the western United States, 18 ski areas and five state highway departments continue to employ artillery due to its special characteristics, notably:

a) pinpoint accuracy at up to 5 km range

b) safety and reliability

c) blind-firing capability

d) mobility, ease of use

e) sufficient but not excessive explosive charge of the projectile.

Some ski areas, including Snowbird and Alta, depend on artillery for their existence due to the remoteness and small size of avalanche starting zones which hang above ski runs and inhabitations. Despite the success of the artillery programme, including an excellent safety record maintained over many years, the U.S. Forest Service in the early 1970's, up until January, 1975, hoped to "get out of the artillery business". The Forest Service had good reasons for wanting to abandon its traditional role in artillery procurement and administration:

1. Supplies of weapons and parts had diminished to critically low levels. Only one or two years worth of certain key components remained in Army stocks.

2. The ever-present concern of liability in the event of mishap disturbed them.

3. A promising alternative to artillery appeared to be forthcoming in the form of the RAMPS rocket.

The Forest Service contracted with the Whittaker Corporation to develop the so-called RAMPS rocket for avalanche control. They hoped that ski areas and highway departments would be able to purchase the rocket and its projectiles directly from the manufacturer. Unfortunately, design criteria for the RAMPS fell somewhat short of the needs of most users; range was limited to 1,500 to 2,000 m and design accuracy was only within 30 m. Also, the rocket failed its initial field tests and indicated such little promise that the project was shelved in the latter part of 1974.

Meanwhile, a solution was found to the artillery problem. This came about as a result of some aggressive and imaginative probing on the part of certain Forest Service officials, especially Cliff Blake of the Wasatch Ranger District, and also as a result of some timely support from certain Army officials. We learned that the Army could rebuild used weapons and that they could re-manufacture vent assemblies, supplies of which had become exhausted.

The only problem remaining was that the Forest Service did not have in its existing budgets adequate funds to finance the front-end production costs. Snowbird Corporation, realizing this, sought an appropriation from the U.S. Congress. This effort was supported by all the western ski areas which use artillery and by the congressional delegations of most of the western states, led by Utah's Senator Frank Moss. In the end, we were successful in obtaining $300,000, which is adequate to initiate the procurement programme. The programme will be self-sustaining. As ski areas and highway departments reimburse the Forest Service for the components actually used by the Forest Service to protect them, these monies will return to the fund. The fund will then revolve, i.e., it will be used for further procurements.

The Forest Service is now fully supportive of the artillery programme, and, incidentally, so is the Army. The Army has indicated that all supplies of the type we currently use have been "earmarked" for avalanche control.

The Forest Service has ordered the following quantities of artillery components, for which the $300,000 appropriation is to serve as front-end funding:

70	75 mm RR vent assemblies	@	$1,600.00
38	105 mm RR vent assemblies	@	$2,600.00
5	75 mm RR rebuilt weapons	@	$2,000.00
10	105 mm RR rebuilt weapons	@	$2,300.00

The Forest Service order was based originally on our study of industry-wide usage rates and projected future requirements. However, they modified the order subsequently in response to information they received from the Army regarding changes in prices and delivery lead-times.

Delivery of vent assemblies has been postponed until fall, 1977 for reasons known only to the Army. However, it is hoped that sufficient 75 mm RR vent assemblies are on hand in Army stocks to get us through the coming season. The picture with regard to 105 mm RR vents is bleaker, and some areas may be forced to order a complete weapon which they otherwise would not need just to obtain the vent. Fortunately, this situation should be rectified prior to the 77-78 season.

The latest information we have received regarding remaining inventories of ammunition is as follows:

75 mm Pack Howitzer HE:	approximately 15,000 rounds
75 mm Recoilless Rifle HE:	approximately 210,000 rounds
75 mm Recoilless Rifle HEP:	approximately 44,000 rounds
105 mm Recoilless Rifle HE:	approximately 108,000 rounds
105 mm Recoilless Rifle HEP:	approximately 36,000 rounds.

The major portion of the above supplies are listed as being in unserviceable, repairable condition. This means that some modifications are required for which we can expect to be charged.

The latest price information we have received regarding the above ammunition is as follows:

75 mm Pack Howitzer HE	@	$20.09 per round
75 mm RR HE	@	$14.75 per round
75 mm RR HEP	@	$ 4.71 per round
105 mm RR HE	@	$16.47 per round
105 mm RR HEP	@	$ 4.71 per round

The latest information we have received regarding the remaining inventories of weapons in Army stocks is as follows:

75 mm Pack Howitzers	9
75 mm Recoilless Rifles	264
105 mm Recoilless Rifles	123

These quantities differ from information which we previously disseminated to ski areas. The Army has not been consistent in the figures it has released, and it is virtually impossible to extract any in-depth explanations from them. Fortunately, these latest figures are more promising than earlier ones.

Most western U.S. ski areas are aware of, and concerned by, the fact that the Forest Service, prompted by the Office of the Inspector General and assisted by the Army, is about to impose new, stiffer storage standards for military ammunition. Apparently, the Army has already approved, or is about to approve, the recommended new storage standards submitted to them by the Forest Service. Thus, official announcement of the new requirements should be forthcoming in the near future.

Construction of new storage facilities or modifications of existing ones to meet the new code, will impose a considerable burden on ski areas.

Avalanche Hazard Forecasting Techniques

Avalanche hazard forecasting and control are not really separate entities, but must be used together in the decision process.

The general patterns of wind speed and direction, snow density, temperatures, etc., are observed for slide paths in the ski area and the highway to the west of Snowbird. Extensive snowpit study is then included with emphasis on crystal structure, homogeneity of the snowpack, extremes in weakness/strength, and temperature. Record of weather conditions is kept on a 24-hour basis. These records include wind speeds, direction, air temperature, precipitation, humidity, and barometric pressure. The combination of daily weather data, snowpit studies, and past history of avalanche activity, form the basis for our daily forecast.

We have, so far, not applied numerical evaluations to the factors contributing to hazard development. Subjective interpretation of the data has been successfully applied, but may not be utilizing our resources to the fullest. We are presently attempting to establish our own "numerical-intuitive" forecast based on a numerical evaluation of slide path loading derived from monitoring the weather, combined with a numerical value of the strength/weakness of the snowpack. Applying a numerical value to the latter is still questionable, but if a figure of strength could be applied to the snowpack or to various weak layers, and combined with the value applied to the loading, perhaps a workable formula will be attained. We envision it should be possible to measure the breaking strength of any weak or potentially dangerous layer, and then measure the existing load above the layer, adding the additional weight of H_2O from subsequent storms or loading. This information will be of little practical use unless interpreted by an experienced forecaster who can add the intangible concept of intuition and avalanche control experience in that area to these numerical values.

The output of our forecast is the amount of hand-charges to be prepared or artillery rounds to be fired for the morning control work, and areas to be opened for the day. If our forecast has been incorrect, we usually find out after several hand-charges have been thrown from the tram or when the first reports come in from gun teams and hand-charges routes.

The morning control work and avalanche activity form the first phase in our forecast for the rest of the day and contribute to the decision for further action, if necessary. Factors contributing to the avalanche hazard development tend to change somewhat as the season progresses. The hazard forecasting and control work tend to vary accordingly (Table 2).

The early season is the most difficult time in respect to hazard and control work. It is also the most difficult period with regard to accurate forecasting. Extensive snowpit studies and close observations of weakness and loading of each slide path is most important at this time.

The nature of deep slab, temperature-gradient release is still one of which we are uncertain. Often the forecaster is "flying by the seat of his pants" due to the often unpredictable and very dangerous early season climax avalanche cycle. The reaction of the snowpack to explosives during this time is often misleading and long periods of closures must take the place of effective control work.

As the winter progresses and snowpack depths increase, the T.G. pattern is altered either from extensive climax avalanching or from the sintering process due to increased snow cover and the more uniform temperatures of mid-winter. The general rule (with many notable exceptions) is that most avalanche activity is confined to the upper snowpack. Hazard development is mainly dependent on rapid loading, intra-storm layering and old snow surface-new snow bonding. During this time, explosives generate an accurate indication of stability and are used extensively to control and to verify the forecast of avalanches.

With the spring, we enter the third phase. This is usually associated with free water present in the snowpack in varying degrees. The hazard development can be monitored visually by inspection of the snowpack for free water and by watching temperature extremes. Explosives have little direct effect on avalanches of this nature. Therefore, temporary closures must be enacted for certain slopes during critical times of the day.

Conclusion

With all of our extensive control work, time, money and talent, we realize that our efforts will fail from time to time. Considering the intensity of our problem, we feel we have been fortunate in maintaining our safety record to date.

We are constantly on the alert to improve our methods to meet the challenge of increased skier usage and the intrinsic uniqueness of each weather and avalanche cycle.

TABLE 1

Avalanche Control at Snowbird, Utah

Year	Skier Days	Avalanche Accidents[1]	No. of Hand-Charges	Artillery Rounds
1971/72	85,000	5	6000	2217
1972/73	195,000	4	4500	2492
1973/74	220,000	8	5200	2583
1974/75	230,000	14	7500	2916
1975/76	320,000	15	4500	1332

[1]No fatalities in these first five years of operation. Organized rescue was required in three cases. During the season, 1973/74, two vehicles were damaged. Also, out of 46 accidents, only 11 involved the skiing public; the remainder involved ski patrol and snow rangers doing avalanche control work.

TABLE 2

Hazard Forecasting at Snowbird, Utah

	Characteristics	Factors of Instability	Hazard Forecast	Control Procedures
EARLY SEASON	Least Predictable. Most Dangerous. Climax cycles sometimes follow negative results of extensive explosive control work.	Very weak snowpack. Combinations of wind,slab, crusts, and weak TG - underlying conditions. Increasing load upon stronger layer until critical point reached. For example, slab collapsing through crust into weak TG - sublayers.	Dig many daily pits throughout the area: observe snow structure and temperature. Need experience with area in severe TG - season. Reaction to explosives or test skiing often not indicative of true hazard.	Closures are frequently used, since explosives often do not do the job. Burying shots down to TG level. Det cord & numerous shots. Throwing "low" shots. Boot packing.
MID-SEASON	More predictable. Many shallow slides. Often widespread fracturing.	Improvement of underlying conditions. Old snow surfaces, i.e., crusts, surface hoar. New snow instability due to temp-density change, wind, crystal type. Rapid loading.	Close observation of weather factors-storm data. Past records. Explosives & test skiing good indicators of stability. Upper level snow pits.	Wide use of explosives or ski checking as determined by storm activity. Closures usually due to continuing storm or rapid hazard build-up.
LATE SEASON	More predictable. Upper level & ground avalanches.	Temperature extremes: hi-day, lo-night. Free water & thermal weakening of likely sliding surface in snowpack. Condition of snowpack resulting from winter evolution. Late season storms.	Close watch of air and snow temperatures. Shallow snowpits to see if free H_2O in pack. Visual observation of "critical" slopes. Test skiing	Explosives have little direct effect. Closures of "critical" slopes and their runouts during certain times of day. Thorough control work during winter keeps tracks & starting zones more shallow. Ski checking.

Discussion

WEYGANDT: How do you deal with skiers who violate avalanche closure signs?

ANDERSON: We have a county ordinance in Little Cottonwood Canyon that allows the Sheriff to arrest and charge the violator. We sometimes resort to this ordinance if the violator acts deliberately with obvious disregard for public safety. More typically, we deny the violator lift privileges for periods of one week to one month, depending on whether it is his first or second offense. There was a violator at Alta who thought he knew more about avalanche closures than we did, and he made quite a scene that it was his right to ski where he wanted. We had to prohibit him from using the lifts. Ironically, we understand he was seriously injured in a helicopter skiing avalanche the following winter in Canada.

HAMRE: How do you evaluate and protect ski-patrolmen against the hazard of lightning?

FITZGERALD: Our long tramway cable and metal structures at top of Hidden Peak are good indicators of static buildup. Unfortunately, static electricity develops quickly and is a serious and tricky problem. We had one incident where a ski-patrolman arced a spark to a closure sign. If we get an indication of static buildup from our cable meter, or from any other warning (buzzing, thunder), we radio contact patrolmen to immediately leave exposed areas by an avalanche free route.

ISRAELSON: Do you use the safety-fuse assembly that comes with a static-bypass staple?

FITZGERALD: No, we do not believe this provides complete protection. We believe we use the highest quality safety fuse that is possible for our work (Orange Sword Brand, manufactured by Ensign-Bickford). The manufacturer of our safety fuse studied the static discharge problem, and decided against marketing the staple assembly. We would be very much interested in seeing data that indicate whether or not the staple actually protects against premature detonation, because if we were to adopt the staple assembly, we would have to give up using what we consider to be an extremely well-made safety fuse. As a matter of interest, several explosive engineers feel that inserting a staple next to a blasting cap introduces a greater hazard than the protection it gives against static discharge. We would be very interested in seeing this question resolved.

KUCERA: Are your gun towers grounded?

FITZGERALD: Yes, but of course this will not protect against a strike. At Alta, a gun tower was actually hit by lightning but, fortunately, there were no casualties. With regard to the static problem, the best line of defense is immediate evacuation from exposed areas after the first indication that an electric-field is building.

GALLAGHER: What is your dud-rate using artillery?

FITZGERALD: Last season we fired 3000 rounds and had 15 duds.

SERFOSS: Do you foresee changes in requirements for storing artillery rounds?

ANDERSON: After much consultation with government agencies, Army engineers at Toole Depot, Utah, devised a set of definitive standards. We are optimistic that these standards will last for some time. The basis of my confidence is that the standards were written by Mark Zaugg, who is Supervisory Safety Engineer and Chief of the Safety Division, Toole Army Depot, Utah. Mr. Zaugg formerly worked for the Department of Defense Explosives Safety Board in Washington, D.C. on similar matters and is one of the top experts in the field of artillery safety. His extensive knowledge of relevant U.S. Army and NATO regulations is reflected in the new standards. Since his credentials and expertise are unassailable, the standards he has written should prove difficult to challenge. Furthermore, the standards were based specifically on several live mass detonation tests sponsored by the Forest Service and conducted by the Army in 1976 under Mr. Zaugg's supervision. The tests were conclusive, which is reflected in the standards also.

Also, I hope that area operators will find it somewhat reassuring to learn that Mark Zaugg is genuinely concerned with the economics of the storage problem and interested in helping area operators to keep costs down. Mr. Zaugg has assisted Snowbird in designing its new storage facilities so as to meet the new standards in as cost-effective a manner as possible.

WILLIAMS: You gave an example of a stubborn slab that would not release in spite of the fact that the slope was peppered with shots. How did you finally get the slope to release?

FITZGERALD: The stubborn slab that would not release was formed of dense wind-deposited snow up to 2 m thick resting on a firm crust composed of TG crystals having gone through some melt/freeze metamorphism, up to 8 or 9 cm thick. (This crust was very firm but could be broken by a ski boot.) Under this crust was a layer approximately 20 cm thick of advanced, weak TG.

The slope faces N-NE and is controlled by hand-charges thrown from the tram and then by a hand-charge team. We were aware of all the bad conditions and were somewhat hesitant to go out on the slope. The slope was large, roughly 80 m across and descending 250 m to the flats below over small but deadly cliff bands. We deposited probably 50 kg of high explosives on the slope from the tram in all known trigger zones, without any results. During this same period approximately 75% to 80% of the slide paths in the ski area released to the ground. Most of them artificially.

We finally ventured out onto the slope and began descending as we were throwing hand-charges from "islands of safety". At the slab compression zone, we buried a 1 kg charge on the crust layer at a depth of approximately 2 m. The charge set off a full depth slide 50 m wide and 1 to 2 m deep and travelled 175 m vertically.

GEISLER: Was there an air temperature change during the last successful shot?

FITZGERALD: No, the temperature remained cold all day.

ISRAELSON: I would like to comment on the practice of going out on unstable slopes to bury charges. We prefer not to do this under any condition, but we would rather drop a large charge from a helicopter. Although $350/hour for helicopter time sounds extravagant, it is cheaper than paying someone's widow.

GALLAGHER: Have you tried using 2 kg charges rather than 1 kg charges to activate deep slab instability?

FITZGERALD: We could argue about this subject for a long time. We agree that, the larger the explosive charge, the greater the chance of obtaining an avalanche. On the other hand, we have observed accidental releases of avalanches (post-control releases) after slopes have been controlled with charges greater than 1 kg. Thus, the use of large charges does not guarantee protection.

FITZGERALD: In connection with the optimum time for placing hand-charges, we feel that one of the trickiest situations occurs when a slab overrides a crust which in turn overrides a layer of weak recrystallized snow (temperature gradient metamorphosed). The layer is stable until the slab load reaches a critical value, then the crust collapses. We are presently developing techniques for evaluating this type of instability.