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The San Juan Avalanche Project - FOR THE AVALANCHE REVIEW 19/5

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Prolog:

In early May of 1971, I was detailed by the University of Colorado, Institute of Arctic and Alpine Research (INSTAAR), to Silverton, Colorado in the western San Juan Mountains. I arrived with a State purchase order and instructions to locate a house of suitable size to establish an office and living quarters for a newly funded avalanche research project.

Most information in small towns can be found in a bar or the Post Office. I wisely visited the Post Office first and asked the clerk about the rental market. As luck would have it, she and her husband had a substantial Main Street house on the market and would love to rent the State of Colorado for as long as we could use it. A task I expected would take a week, took ten minutes.

That night I stopped at the Grand Imperial Hotel to listen in on a busy mountain community of 850 people supported by the employment of two large metal mines, the Sunnyside and Idarado. I wasn't long on the bar stool before two fellows got up from a table and sandwiched me, right and left with the admonition from the big one on the right of "…we don't allow no @#$%^&*~ hippies in here". I was fresh from the hippie-cowboy wars of Gunnison County, and not too concerned about this confrontation. My hair and beard weren't that long. I was a bit older than the average hippie, sober (being I'd just walked in) and was still running a bar of my own back in Crested Butte. I remember feeling at the time, those attributes along with carefully honed negotiation skills and friendly allies in the room (if any) could save the day. But, the bartender didn't look too supportive of customer immunity, and for that matter neither did the rest of the crowded place.

However, I didn't want to stand falsely accused, so I told the big guy, he was mistaken as to my nature. But the other guy, scrawnier and seemingly more combative said he could smell hippies from across the room, and I was the source. Hmm, this wasn't looking good, so I stuck out a hand and introduced myself to two young miners, just off shift and ready to go to work - on me. The friendly gesture slowed the pace of the confrontation for a moment. Then I said I was in town to run the logistics for an avalanche project. I said that loud enough to pass for a cry of help and to my relief, an other big guy came over and intervened, he'd heard about this deal and I was probably ok.

That was the first of many times Tuffy Foster, Colorado Highway Maintenance Foreman for Red Mountain and Molas Passes, was to contribute to the well being of the San Juan Avalanche Project. With Tuffy's blessing, it was beers all around and the project was underway.

Project Background

In the first two decades following World War II the Bureau of Reclamation (BOR) embarked on one of the greatest public works project in the nations history. It seemed the federal imperative was to let no river go undammed. Those were the days when cement was poured across river channels through-out the west. The largest program was the Colorado River Project, a complex system of storage and plumbing strategies designed for reclamation, power, recreation and job creation. Virtually all of the big western rivers except the Yellowstone and Salmon got one or more dams.

The BOR didn't get to build all the dams planned; there would be no Marble or Grand Canyon, no Dinosaur or Cataract and no Howardsville dam above Silverton. The fledgling environmental movement stopped some, geologic constraints and cost stopped others. To compensate in part for these forgone dam opportunities, the BOR looked to the storage potential of the winter snow pack. Since much of the spring melt could be stored by the new reservoirs in place, the potential for enhanced runoff was too tempting to ignore and the BOR embarked on a "snowpack augmentation program", called Project Skywater.

The snowpack augmentation was to be accomplished through cloud seeding; the introduction of chemical nuclei from ground-based generators into the atmosphere to serve as a basis for the formation of ice crystals, that would ultimately fall to earth as snow, potentially, lots of snow. Initially the BOR assured the public there would be no adverse impact because the pilot program would be conducted in an area where there was no appreciable population, the San Juan Mountains of Colorado. While there may have been "no appreciable population", what population there was didn't appreciate this assessment. They also sensed more snow would create more problems. One of the concerns was increased avalanche potential, and this was relayed to the Colorado west slope Congressman, Wayne Aspinall who sent the message on to the Bureau.

In 1970 the BOR called for proposals to determine this potential. Several groups of hydrologists, climate and avalanche specialists were formed and submitted their proposals. The award went to the University of Colorado Institute of Arctic and Alpine Research (INSTAAR), and the San Juan Avalanche Project was born. The proposal was put together by INSTAAR director, Jack Ives with extensive consultation by Ed LaChapelle, University of Washington, who was to remain a constant contributor and virtual principal investigator for the bulk of the investigation period from 1971 through 1976.

The original snowpack augmentation scheme was to encompass the entire western San Juans, but the scope was reduced to eliminate the avalanche project area. This accommodation was made so an avalanche predictive methodology could be developed in the absence of whatever effect cloud seeding might have. Research was to be directed toward study of the relationships between avalanche activity and natural precipitation patterns and other climatic and environmental factors.

The initial objective of the research was to identify and catalog those areas of significant avalanche activity within the study area consisting of the US Highway 550 corridor from Coal Bank Pass to Ouray, and Colorado Highway 110, Cement Creek and the environs of the town of Silverton. The project was to acquire an understanding of the nature and type of its snow avalanche releases. Further, the project would develop a methodology that would determine the specific causes of local avalanche activity and finally, would construct a forecast model for the prediction of avalanche occurrence.

The first systematic inventory of avalanche paths affecting Highway #550 was done by the Colorado Department of Highways (now known as Colorado Department of Transportation, or CDOT) in the form of a gunner's note book developed by Noel (Pete) Peterson in the early 50s. This included names, descriptions, target zones, and in some cases, photographs and map sections. Avalanche control at the time was by a 75 mm Pack Howitzer artillery weapon. (In 1974, Avalauncher control was introduced, and later supplemented by the 105MM Recoilless Rifle in c. 1982 and Helicopter hand charging in c. 1987. Currently the active CDOT control program effectively operates with a menu of the 105MM Howitzer, Breach-loading Avalauncher and Helicopter hand charging when warranted.)

In the winter of 1961-62 the US Forest Service Rocky Mountain Range and Experiment Station employed Hans Frutiger, Forest Engineer with the Swiss Institute for Snow and Avalanche Research at Davos, to develop a report on avalanche paths on four Mountain Passes in Colorado. The subsequent publication "Snow Avalanches Along Colorado Mountain Highways", USFS Research Paper RM-7 was published in 1964 and identified with names, size, frequency and terrain condition, 43 significant avalanche tracks crossing Highway #550 between Coal Bank Pass and Ouray.

Our inventory of the project area identified 214 avalanche paths that were to be monitored. Many additional paths affecting Highway #550 were noted (Frutiger concentrated on larger areas, and in some cases lumped distinct paths into one notation) and a total of 101 were inventoried that could affect the highway with varying frequency and magnitude. Most of these avalanche paths could severely damage vehicles, or at least push a car off one of the considerable cliffs along the corridor. Additional paths were easily visible from the highway, and naturally occurring events were systematically noted. These events were important indicators of area instability, as they were not artificially released. Whereas most of the paths were named, those that weren't needed some identification beyond a number. For instance, above Chattanooga, Sam's slide was named for my dog, and Ernest and Julio, off Red Mountain #1 were named on the morning after an evening in Ridgeway. Up Cement Creek there was the rock group of the Beetles, Stones, Who and Crème.

The Project

With the "Silverton Avalanche House", secured for the duration, that May evening in 1971, logistical and preliminary study efforts for implementing the project got underway. I went back to Crested Butte, unscathed from the night at the G.I. and in a couple of days was back, flying around the area with Rocky Warren in a 1948 Beech Stagger-wing bi-plane taking the first of three aerial photo transects of every observable avalanche path.

(Rocky, a legendary mountain pilot, now deceased, told me that he got out of the Navy in 1945 and opened a charter service in Montrose. One of his first clients was a person who wanted to sightsee up toward the Campbird Mine, in the middle of the winter on a nice day. They took off and Rocky remembered that the guy's sack lunch was really big. Once they made the turn up the canyon toward Campbird the client directed Rocky to fly a specific pattern. Rocky was surprised to see the guy fumble with the sack, pull out a long black string, open the window, light the fuse and toss out the "lunch". That must have been one of the first aerial avalanche control missions. This probably was treatment of the Waterhole Slide which threatens the access road. Rocky said there was a really big avalanche and dust cloud.)

In the meantime, back at the University, John Clark, INSTAAR Research Climatologist set about ordering the instrumentation necessary to do weather and snowpack measurements, and developing logistical support of the Motor Pool that resulted in two Dodge Power Wagons, for highway observation patrols. University Central Purchasing handled quite an order of furniture for the office and living quarters, including a controversial love seat and a number of beds. Ives and LaChapelle drafted the project design, and assembling support and field personnel. Additional input came from consultants Malcom Mellor and Willy Weeks of the US Army Cold Regions Engineering and Environmental Laboratory.

The research methodology of the San Juan Avalanche Project embraced the following objectives: 1. Collection of historical data; 2. Identification of avalanche areas; 3. Collection of current snow, weather and avalanche data; and 4. Observation of internal snowpack evolution. The field team was to be formed that would combine avalanche experience with snow and weather observation expertise and data reduction and analysis skills.

By the start of the 1971-72 season Silverton staff included Don Alford, Richard Armstrong, Betsy Vessalago (soon to become Armstrong), Rod Newcomb and myself. Richard became Field Leader after the first year, and Len Miller joined in the fourth season on the Alternate Methods Project (see side-bar). Rod and I were the non-academic field research technicians. Other personnel and many subsequent participants combined their analytical skills and graduate degree pursuits with field work to contribute to project data collection, analysis and publication.

(A companion study, "Ecological Impacts of Snow Augmentation in the San Juan Mountains, Colorado" conducted by INSTAAR and Colorado State University, was also based out of Silverton during the summers of 1972 through 1975, with field camps at Kite Lake over Stony Pass and near Williams Lake north of Pagosa Springs,.)

This Silverton Avalanche House became a year around center of project pursuits, laced with occasional parties, Thanksgiving Feasts and frequent visitors from through-out the world of avalanche control and research. In 1977 a small symposium was held to present the Project findings to a wide range of participants from Colorado ski patrollers to international researchers. The Silverton Avalanche School (SAS), led by the San Juan National Forest Staff forester, Don Fritch from 1962 - 68, (when Don transferred up to the Teton National Forest) was re energized by project personnel at the urging of then Sheriff Virgil Mason. The SAS has run every season since 1973.

The first summer and fall was a flurry of instrumentation set-up. Winter was fast approaching, and we had to be ready. Through the generosity of claim owner, Frank Baumgartner, we established a snow study site adjacent to Red Mountain Pass, and reconstructed a small cabin for observation quarters and a field office. Lorenzo Groff, Silverton carpenter (and owner/clerk of the local package store across from the Silverton house) ramrodded the Red Mountain Pass cabin and instrumentation shelter. Having fled from the post-WWII Tyrolian independence conflict, Lorenzo was a lover of the mountains (and artillery), and endeared himself to the project by doing all construction measurements in the metric system, as we were to use for data collection and reduction. We installed various recording weather and snowpack measurement instruments at the main RMP site. Supplemental totalizing wind instruments were installed on Carbon Peak, and at the Rainbow site. (Brooklyns Mine). Further weather instruments were placed in Silverton, on Molas Pass and later, at Chattanooga. Chattanooga was also the site of a geophone and seismograph installation, as well an in infrasound array for avalanche detection. Neither of these efforts became operational.

The center piece instrumentation was the wind speed and direction system on Pt. 12,325' (Putney Peak, after Richard's dog) just south of Red Mountain 3. We placed a 10 meter tower at this location and laid 7,700' of conductor cable to the Red Mountain Pass Cabin for the analog wind speed and direction recorder. That project required the use of about 20 Silverton high school students, who for hourly wage on one weekend, carefully hand dug and laid down four 2000' spools of cable. We also ran AC power up from the Lark Mine on the Cement Creek side for the lights to keep rime ice formations manageable. This site provided accurate wind speed and direction information for the duration of the project, but someone had to be sitting in front of the old strip recorder to get real time readings. Desk top computers and weather data modums, that more easily facilitate avalanche forecasting today, were not yet available.

Our trucks were stocked with food and sleeping bags, ram penetrometers and pit kits, skis and snowshoes, shovels and probes, while we always carried our new "hot dog" Skadiis, the first avalanche rescue beacon. There were two Ski-doos purchased, an Elan and a 440 Nordic. These were useful hauling gear in from the road to the cabin and snow study plot, but for the most part project personnel got around on skis and skins.

During storm periods anticipated to produce greater than 1" water equivalent, we would take new snow depth, density, temperature and settlement observations every 3 or 6 hours in the study plot. This was a 10 minute ski from the cabin, and not without peril, as we had to skirt the run-out zones of the Marmot Town and Study Plot slides. The fortunate observer staying at the Red Mountain Pass station would often enjoy the peacefulness of a closed highway and raging storms, and the bright silence of the aftermath. As long as the telephone lines held together, we would receive good weather forecasts from E. G. & G., the cloud seeding contractor in Durango. The core of the forecast was derived from the Orographic Precipitation Model developed by Owen Rhea, which would predict precipitation quantities based upon sounding data of wind speed, direction, temperature and humidity and the interaction with mapped topographic barriers.

During the four year intensive field project period over 200 comprehensive snowpack profiles were recorded through snow pit excavation including the use of the ram penetrometer, and collection of density, temperature, stratigraphy and grain morphology data. Of these profiles 53 were of avalanche fracture lines observed within 48 hours of the event. Notably, there were no lost time accidents to project personnel, though there were a few close calls: the dreaded "whumph" during miscalculated descents of avalanche tracks, occasional dust cloud anointing of sprinting control mission witnesses and close calls between avalanches and Power Wagons at the uncontrolled intersections of the highway and slide paths. We also observed that more vehicles run into avalanche debris than avalanches strike vehicles. There were no motorist/highway worker fatalities during this project period.

Avalanche observations were made of 2470 events; of these 574 reached Highway 550 or Colorado #110. Event evidence observed included parameters of fracture location, dimension and debris run-out characteristics, all of which were carefully entered in a data base, to be analyzed in context with weather and snowpack information. Project staff were able to accompany Highway Department control teams to witness control results and avalanches released by artillery. Format for these observations was provided by Art Judson, of the US Forest Service Rocky Mountain Station in Fort Collins, who had recently developed the West Wide Avalanche Network of reporting stations throughout the west. Daily observations were phoned back to Jud who used these reports and others to formulate regional avalanche advisories.

The forecasting program focused on several distinct avalanche groups including Ledge, Muleshoe, Brooklyns, Champions, Cement Fill and the East Riverside. Based on daily forecasting periods, an overall accuracy of 81% was achieved during the last two years of the project, using conventional (non-statistical) forecasting methods. Forecasting accuracy for spontaneous avalanche release and magnitude within a 3 hour period was 71%.

In order to determine forecasting accuracy, the timing of naturally running avalanche events was essential. The solution was to use a simple battery clock with leads connected to a trip wire. The clock was secured to a tree or cliff in the runout zone and the wire run across the track to a fixed object. When the avalanche ran, the wire pulled the alligator clips off the lead, stopping the clock. As soon as road conditions permitted observation, the observer would climb up to the clock, note the time and reconnect the trip wire, or install a new one. This worked very well, and even though these were 12 hour clocks with big and little hands, the AM or PM time period could be determined from careful observation of avalanche debris, storm characteristics, and observations from highway department operators.

Interestingly, the original question of whether snowpack augmentation would create greater danger from avalanches was never definitively answered. Due to concerns about down-wind drying effects of seeded storms, spring flooding potential, water rights and storage questions, operational cloud seeding came under state scrutiny and ultimately, regulation with appropriate limitations being specified. I think we felt that conservative incremental augmentation would have no demonstrable effect on avalanche occurrence or magnitude, but there was no way to effectively prove this without unrestrained broadly targeted cloud seeding episodes; no one wanted to take that risk. It was clear, however that increased snowfall and increased avalanche potential were not always related. Today, the original E.G.&G. subcontractor, Western Weather Consultants continues targeted cloud seeding operations in Southwest Colorado within regulated constraints.

The original three year contract to the Bureau of Reclamation was extended to permit data collection during a fourth winter season (1974-75) and to facilitate data analysis and write-up during the 1975-76 season. Significant publications from this period include: "Development of Methodology for Evaluation and Prediction of Avalanche Hazard in the San Juan Mountain Area of Southwestern Colorado" (Interim Report September, 1973; Ives, Harrison and Armstrong and

Final Report, December 1974; Armstrong, LaChapelle, Bovis and Ives); "Avalanche Release and Snow Characteristics" May, 1976; Armstrong and Ives, Editors, and "Evaluation and Prediction of Avalanche Hazard" November, 1978; Richard and Betsy Armstrong.

The Bureau of Reclamation continued to provide primary support in the later years, culminating after the 1986-87 season. The Armstrongs continued as principal project managers and authors with support of a number of investigators and graduate students. Tim Lane provided systematic observations during this time.

The fruits of the San Juan Avalanche Project is a series of publications including notable historical documentation of avalanche incidents and avalanche atlases for Ouray and San Juan Counties, as well as annual reports with data summaries of snow and avalanche observations, and other pertinent investigations and comparisons. A total of 16 publications emerged from this project. All of these publications are archived for review in the Silverton and Ouray Libraries, as well as at The National Snow and Ice Data Center, CB 449, University of Colorado, Boulder, CO 80309.

Epilog.

This avalanche research and forecasting project initiated 25 years ago is widely acknowledged as the most comprehensive and productive effort of its type ever mounted in North America. From of this work came a greater understanding of the avalanche phenomenon and recommendations for mitigation of the danger along the highway corridors of the San Juans. Some of the Colorado Department of Highways (CDOT) strategies used today are the fruits of these studies. The East Riverside Shed is one such result, though too short for complete protection. The Colorado Avalanche Information Center/CDOT highway forecasting and control program is another, though it took two more highway worker fatalities before that program would be initiated in the fall of 1993. San Juan County now has an Avalanche Review Board and mapping resources to facilitate growth planning and construction applications.

The San Juan Mountain landscape around Silverton is defined by avalanche terrain. The 550 corridor between Ouray and Coal Bank Pass is arguably the most avalanche prone highway in North America, though some winters avalanche cycles elsewhere like on the Seward Highway, Alaska, would challenge that ranking. Skiers, boarders and sledders are flocking to the area, where at one time the San Juan Avalanche Project folks were the only ones out and about in the winter. While Alta, Utah may be the center of the universe for developed ski area and access road avalanche forecasting and control, Silverton is the town that first comes to mind when considering avalanche risk potential to motorists, maintenance workers, (some) residents and back country recreationists.

For this reason, the Silverton Avalanche School has trained several thousand students over the past 30+ years. Rod Newcomb's American Avalanche Institute has held courses at the St. Paul Lodge on Red Mountain Pass, for the past 25 years. An academic undergraduate program in snow studies began by the late Mel Marcus and others, has been conducted for one week each winter for the past 20 years. A Prescott College class spends weeks in the San Juan snow each year. Recently more avalanche persons are coming to town to try and manage the dragon at a proposed ski area up Cement Creek, known as the Silverton Outdoor Learning and Recreation Center.

Perhaps someday a field station could be established in Silverton as support for needed snow and avalanche research efforts. There is no such facility in the US. The Western San Juan Mountains are an ideal living laboratory for such endeavors; what is needed are the logistical support facilities and knowledgeable support personnel. The promising recent interest in a year around field station by Fort Lewis College and The Mountain Institute may bring this concept to fruition. In the meantime, the avalanches don't care if they get any research attention, and will keep running, sometimes to the cadence of high explosives, but often of their own volition.

Side Bar

The Alternate Methods Study, an interesting project within a project.

The are two basic types of avalanche control; passive (engineered) and active (operational). The objectives are the same: to prevent risk to life and property.

Engineered control may prevent avalanche release, minimize magnitude and/or directly protect life and property from avalanches. Examples of engineered control strategies are starting zone structures, avalanche sheds and constructed diversions.

Operational control results in the release or probably stabilization of an avalanche at a time when risk is minimized through area closure. Examples are ski area mitigation measures (test skiing hand charge and remote explosive delivery systems) and highway explosive control programs (remote delivery systems). The remote delivery systems for both applications include helicopter bombing, artillery, Avalauncher and hand charge cableways.

In the early 70s, Ed LaChapelle was awarded funding from the Federal Highway Administration, State of Washington Department of Transportation and the University of Washington to investigate alternative methods of operational control. Field development work was on Steven's and Snoqualmie Passes in Washington state. A field site on Red Mountain Pass was established for the winters of 1974-75 and 1975-76. This area would prove ideal due to support of the ongoing research project team and the proximity of small active avalanche paths to the highway. Len Miller joined the San Juan Avalanche Project at this point to assist Ed in the program.

The first initial experimental method was an array of expandable air bags deployed at a cornice formation area of the Blue Point slide just north of Red Mountain Pass. This small path (440 vertical feet) crosses the highway over a dozen times each year. The bags were heavy duty bladders used primarily in shipping containers and rail cars to separate and immobilize heavy packing crates. These were firmly wired to bed rock and dangled over the edge. When inflated the bag would literally force the cornice mass away from the cliff to fall onto the starting zone releasing an avalanche. The bags were inflated by a compressor positioned at the near the bottom of the path. This was an effective device, but it required towing a compressor near the bottom of the path, starting the damn thing in cold temperatures and hoping the resultant slide would clean the track out. It never quite worked out that way all the time, but it was promising technology, waiting for someone to using operationally in a consistent fashion.

A second alternative method depended on both the physical rupturing of the snow pack and a detonation to initiate an avalanche. Several configurations of these exploders were lumped together under the term: Hot Lips. The first and most complicated device was four big thick walled steel canisters (big, meaning about 24" in diameter and 30" deep) buried apart in the starting zone of a 600' vertical path known as the Willow Swamp. These pots had steel lids that were free to move up about 12" against internal restraining springs, upon the detonation of an oxygen and acetylene mixture, (later, propane was used exclusively) introduced from tanks located in a safe area above the starting zone, and remotely ignited from the roadway. When the detonation occurred the shock wave would propagate in the snowpack. The steel lids would be driven up into the snow, then fall back in place, ready for the next shot. This system worked as planned once or twice but was limited by the unreliable remote detonation system, and the cumbersome steel pots and installation.

All of the assembly (as well as the air bags on the adjacent Blue Point path) had been sling loaded in by helicopter and a week or so was devoted to deployment and connections. It was nice fall weather as I recall, but a bit breezy on the day of the final testing of the gas mixture. The pots had been dug in and the gas lines buried back to the tank site. The connecting hose was about to be coupled to the pot lines, when Len and I decided we should maybe test the explosive potential of the gas mixture.

There was quite a run of flexible hose that could lay out over the slope, so as a test we attached an empty lunch sack around the end and threw it out over the starting zone with the wind. The sack was then filled with the explosive mixture and floated up to be detonated. This was a pretty impressive bang and we tried it several more times until we ran out of sacks. From that lunch sack experience, came an 8" diameter, 8' long cannon tube suspended over a release zone at Snoqualmie Pass (I-90) in Washington that was filled with a gas mixture and effectively detonated over the snowpack. Further development of the idea grew into what became the Gazex device invented and marketed by Jake Shippers around Europe and a few areas in the US west including the mountain passes of CA Highways #88 and #50, and WY Highway #20 , and the first ski area application at Snow Basin, Utah, site of the Olympic downhill venues

Variants of this buried exploding canister method were lumped together under the descriptive term: Hot Lips. One of these was a long slotted steel tube anchored on the ground in the starting zone, this time on more convenient test slopes that didn't require road closure for the experiment. This tube would be filled with the explosive gas mixture and detonated. A second assembly consisted of a heavy duty 22" radial truck tire and split rim cabled to the ground that would leap up against the snow along with a shock wave upon detonation. The tire being flexible and wired together by the steel radial strands, would last a season of testing before being reduced to a limp black doughnut to be tossed back in the Silverton dump.

Back in the Cascades there was a shaker sheet of plywood linked to a jack hammer. This contraption was buried in the snow and initiated with a compressor to rattle the snowpack into submission. The more industrial model used a steel frame with a rail car shaker to test the same theory. These devices seemed to put all their energy into sinking further into the snowpack, the result Ed theorized was a case of bad impedance mismatch.

Another alternate method was to artificially create a bed surface out of plastic sheets anchored to the ground surface. This worked great on slopes steeper than about 25 degrees, with the snow easily sliding to the bottom during every storm. This application is operational below the John

Paul race tram at Snow Basin where esthetic considerations dictated low clearance for the tram cars. The required clearance design didn't account for the accumulation zone under the lift line, so plastic sheets are now used to maintain a clear path.

Other non-tested brainstorms were briefly, but never seriously considered. One of the more promising ideas was to borrow a seismic thumper truck to park in the vicinity of small bank slide to test if the vibration would couple up the slope to a starting zone. Drawbacks to that idea had to do with and the ongoing oil boom that made those trucks scarce and expensive, positioning the truck not too close to the runout zone, and repair of the road surface after the experiment.

Acoustic noise generators were briefly discussed , until obvious environmental and health constraints were considered. However, it comes to mind that a low rider with current full volume base amplification technology could be parked near a runout zone as an experiment.

The introduction of a shock wave sufficient to propagate fracturing to initiate and avalanche is still based on detonation of some gas or gas contained in a solid explosive form. This method continues to be effective and inexpensive.

The future of avalanche mitigation research will continue to focus on improved stability evaluation and forecasting methods in order to facilitate operational control. The development of engineered control strategies will not be widely accepted until cost and safety considerations (traffic delay and increased incidents) force movement away from operational active avalanche control.