ALTA SKI AREA
P.O. Box 8007 • ALTA, UTAH 84092-8007
PHONE 801-359-1078 • FAX 801-799-2340
www.alta.com

July 9, 2023

Town of Alta

Attn. Chris Cawley
Town of Alta

For Distribution to:
Alta Planning Commission
Town Council, Town of Alta

Alta Ski Area BW Exploder Installation

Project background and explanation:

Alta Ski Area is currently researching a developing technology for improving avalanche mitigation on the East facing slopes of Mount Baldy (East Baldy). East Baldy presents a complicated avalanche challenge for the efforts of avalanche mitigation performed by Alta Ski Area. The starting zones of this terrain lie above a cat road known as the EBT or East Baldy Traverse. This traverse is critical to the operations of the ski area as it is the only connection between the upper portions of the two drainages which comprise the ski area. This road is frequently closed due to avalanche hazard, forcing skiers down and across the base of the ski area so that they may ski from the Albion Basin into the Collins Gulch area and consequently increasing skier density on Devil's Elbow which is the 'easier way' off of the Sugarloaf lift.

Avalanche mitigation on this terrain is currently accomplished through three methods. The first of these methods is that of a Remote Avalanche Control System gas exploder called the Obell-X. Currently four Obell-X exploders are in place in the avalanche starting zones identified as yellow diamonds in Figure 1. The secondary method of mitigation is the use of an Avalauncher gun. This gun is used only as backup to the Obell-X exploders. The use of this Avalauncher is limited to non-operating hours due to the proximity of the Snowbird Ski Resort to the target areas. A final method of mitigation is that of the use of ski patrollers on slope executing mitigation using ski cuts and explosive delivery to the starting zones. This method presents hazard to personnel and is limited by weather and avalanche hazard. Historically several ski patrollers have been captured in avalanches while mitigating this terrain.

One limitation and hazard of using Obell-X exploders is that they must be reloaded and maintained using helicopters during the winter season. Use of helicopters is subject to weather conditions and involves some hazard to personnel. This limitation and hazard, coupled with concerns about the durability and performance of the Obell-X exploder has led Alta Ski Area to continue to explore other new technologies that could improve avalanche mitigation work for the East Baldy Area.

A developing technology that potentially could replace the Obell-X exploders is the BW Exploder. The BW Exploder is designed and manufactured in Wyoming by Alpine Infrastructure. The BW Exploder uses a mixture of Methane and Oxygen to create an explosion in avalanche starting zones. Like the Obell-X exploders, they are installed in fixed locations and operated remotely by computer. Benefits of the BW exploder are that a helicopter is not required to reload them, and they can fire significantly more shots than the Obell-X exploders before needing to be reloaded.

ESTABLISHED 1938

ALTA SKI AREA
P.O. Box 8007 • ALTA, UTAH 84092-8007
PHONE 801-359-1078 • FAX 801-799-2340
www.alta.com

The BW Exploder sits on a 4' x 4' concrete footing serviced by two 2" High-Density Poly Ethelene (HDPE) gas lines laid on the surface to a small tank farm. This tank farm is a prefabricated structure. The tank farm will sit to the east of the exploder and measures 8' high, by 8' wide, by 10' wide as designed. However, should the land use authority require, the structure could be as small as 4' wide, by 6' wide, by 6' high. This tank farm will be situated on the ridgeline near the existing ticket shack on Sugarloaf Pass between Alta and Snowbird ski resorts. The location of this tank farm is determined by access, property ownership, and the presence of pre-existing infrastructure. Numerous similar tank farms exist within Little Cottonwood Canyon on both the slopes of Mount Superior and Hellgate. The structure is shown in Figure 2. The tank farm will be of earthen color and will not be visible from the valley floor.

The exploder consists of a 24' tower with the detonation chamber mounted to the topmost portion. This device is pictured in figure 3. The exploder will be below the large cliff, will be of earthen color, and not visible from the valley floor.

The location of both the exploder and the tank farm are pictured in figure 4. Also visible in Figure 4 is the property line denoted in red. The Location and height of the proposed tower will not be "ridgeline" as seen in figures 5, and 6. The location of the exploder and property lines are visible in Figure 7.

The gases used for the BW Exploder are not regulated by the Bureau of Alcohol Tobacco Firearms and Explosives (BATFE) in their stored state within the tank farm. The exploder is regulated by BATFE once gases are mixed for detonation. This is similar to the BATFE regulation of the OBell-X device and is permitted under Alta Ski Area's Federal Explosives License/Permit (Type 20, manufacturer, and user of explosives).

Request for Variance and Conditional Use Permit:

Alta Ski Area requests from the Town of Alta the issuance of a Conditional Use Permit for installation of the BW Exploder System on the private lands of Mount Baldy to be installed in the shot 1 start zone identified by the "X" in Figure 7. Alta Ski Area also requests the issuance of a Variance to allow construction of the system on slopes over 30% in steepness.

The system will be installed in terrain of up to 40° in steepness and is similar to other avalanche mitigation devices in Alta which have been previously installed in terrain 50° in steepness. The design allows for the installation of the footing for the device on terrain much steeper than this. The installation teams which do this work are highly experienced in working in this high angle terrain. The installation consists of hand leveling a location, followed by deep rock drilling to secure the footing to the slope.

In reference to Town of Alta code requirements for conditional use:

Under code 10-9-2: Conditional Use permit.

10-9-2 Section A

1. Requirements are met through this process of requesting a permit from the Alta Planning Commission.

10-9-2 Section B.

1. Site plans for this project are depicted in attached images. There will be no required snow removal or erosion control for the project. Further, no roads, pathways, parking or grading will take place. There will be no requirement for access by either fire or police. One accessory structure will be installed (tank farm).
2. These structures do not fit the description of "buildings" by code definition.
3. This device is permitted under BATFE ruling 2022-02 for the installation and use of Remote Avalanche Control Systems. The mixing and detonation of gases is allowed by Alta Ski Area's Type 20 FEL/P issued by the BATFE. Storage of unmixed gases is not regulated by the BATFE under 18 U.S.C. 842(J).

ALTA SKI AREA
P.O. Box 8007 • ALTA, UTAH 84092-8007
PHONE 801-359-1078 • FAX 801-799-2340
www.alta.com

10-9-2 Section C, D

1. Requirements for this section are met through this process.

10-9-2 Section E.

2. The proposed use of this location meets the requirements for conditional use. The location is desirable to provide an installation of equipment which will provide for an increased level of safety for the employees and guests of Alta Ski Area. Thus, an increase to the general wellbeing through the protection of life and property.
3. Use of the proposed equipment will not be detrimental to the health and wellbeing of persons residing in the general vicinity. Conversely, the installation by design is to increase the safety of those persons.

In reference to Town of Alta code for Variances:

Under code 10-5-11: Variances.

10-5-11 Section A-E.

Pursuant to this section. It is understood by the applicant the application process and the appeal authority. It is understood that the burden of proof lies upon the applicant, and that applicant shall mitigate any harmful effects of the variance.

Under code annotated 10-9a-702. Variances

Applicant responses below meet the requirements of:

(2)(a)

- (i) Literal enforcement of the variance for slope would be unreasonable in the case of this project. The terrain is substantially steeper than the 30% stated in the code. As an avalanche mitigation tool, the installation must be installed in steep avalanche terrain.
- (ii) There are special circumstances which apply to this area based on avalanche hazard and limited other methods of avalanche mitigation are available.
- (iii) Granting the variance is desirable for the operation of the ski area and opening of ski terrain moving into the future.
- (iv) The isolation of the terrain and the limited disturbance of installation will not by any definition be contrary to the public interest or the general plan. By definition, the improved level of safety provided by the installation is in fact in the interest of the public.
- (v) The applicant seeks to observe the spirit of the land use ordinance and will continue to do so.

(2)(b)

- (i) Enforcement of the land use ordinance will not cause undue hardship under subsection (2)(a):
  - A. The property for which the variance is sought consists of private property on Mount Baldy consisting of topographically extreme terrain.
  - B. Due to the extreme nature of the terrain in topography, conditions are not general to the neighborhood.
- (ii) The request for the variance is terrain based and not economic or self-imposed.

(2)(c)

- (i) Special Circumstances apply based on the needed protection of life and property as well as the circumstances regarding extreme terrain.
- (ii) Similar installations have been installed and permissions granted within the Town of Alta on both public and private lands.

ALTA SKI AREA
P.O. Box 8007 • ALTA, UTAH 84092-8007
PHONE 801-359-1078 • FAX 801-799-2340
www.alta.com

Summary:

Alta Ski Area requests approval of a Conditional Use Permit and Slope Variance to install a single BW Exploder and associated tank farm on the slopes of Mount Baldy to begin in August 2023. The Installation will increase the level of safety provided to the employees and customers of Alta Ski Area. Further, the installation will allow the ski area to provide travel on the East Baldy Traverse on a more reliable basis. It is the opinion of Alta Ski Area that there exists an overwhelming precedent for the installation of this system within the mountainous terrain of Alta and upper Little Cottonwood Canyon based on the system's similarity to avalanche mitigation devices previously approved on both public and private lands and installed by Alta Ski Area and the Utah Department of Transportation within the Town of Alta.

The installation and testing of this new device will provide Alta with improved ability for avalanche mitigation in all weather conditions. Further, the testing of the device will help to move the avalanche industry forward with the development of new tools to better provide for the protection of life and property.

Thank you very much for your consideration of this matter. We look forward to hearing a response from you soon.

Sincerely,

David Richards
Alta Ski Area
Director, Avalanche Office

ALTA SKI AREA
P.O. Box 8007 • ALTA, UTAH 84092-8007
PHONE 801-359-1078 • FAX 801-799-2340
www.alta.com

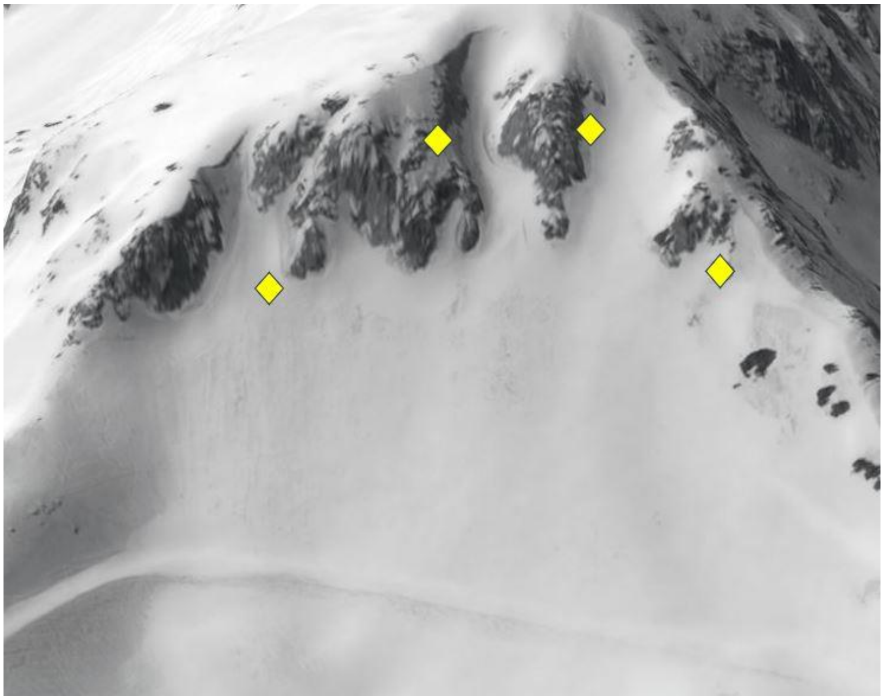


Figure 1

Figure 2
The structure will be of earthen color.

ALTA SKI AREA

P.O. Box 8007 • ALTA, UTAH 84092-8007
PHONE 801-359-1078 • FAX 801-799-2340
www.alta.com

Figure 3
The installed exploder will be a single tower and without the extra struts pictured here.

ALTA SKI AREA
P.O. Box 8007 • ALTA, UTAH 84092-8007
PHONE 801-359-1078 • FAX 801-799-2340
www.alta.com

Figure 4

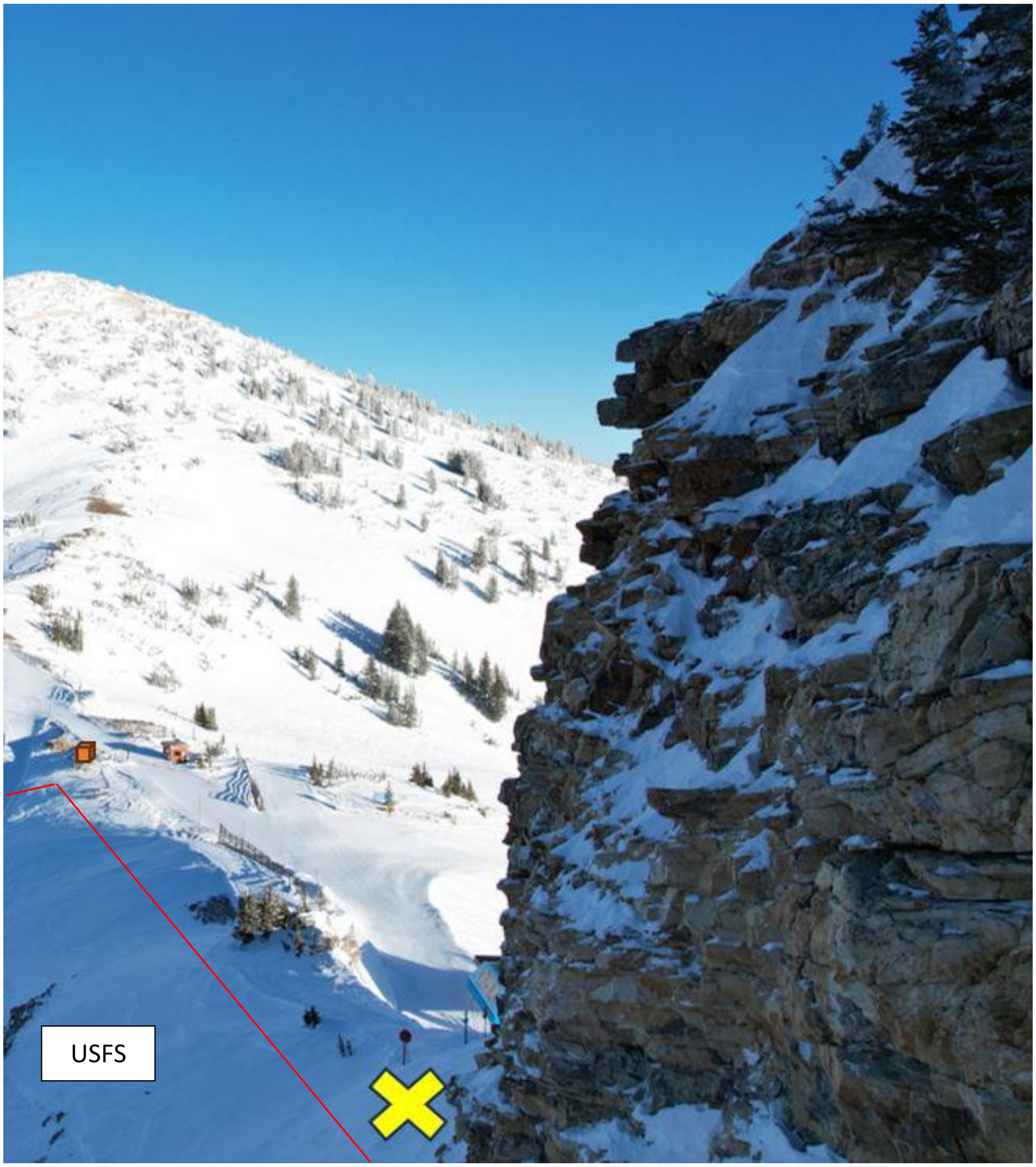


Figure 4

Figure 5
Location and height of proposed device viewed from below. The device will be of earthen color.
(Note existing Obell-X devices for reference)

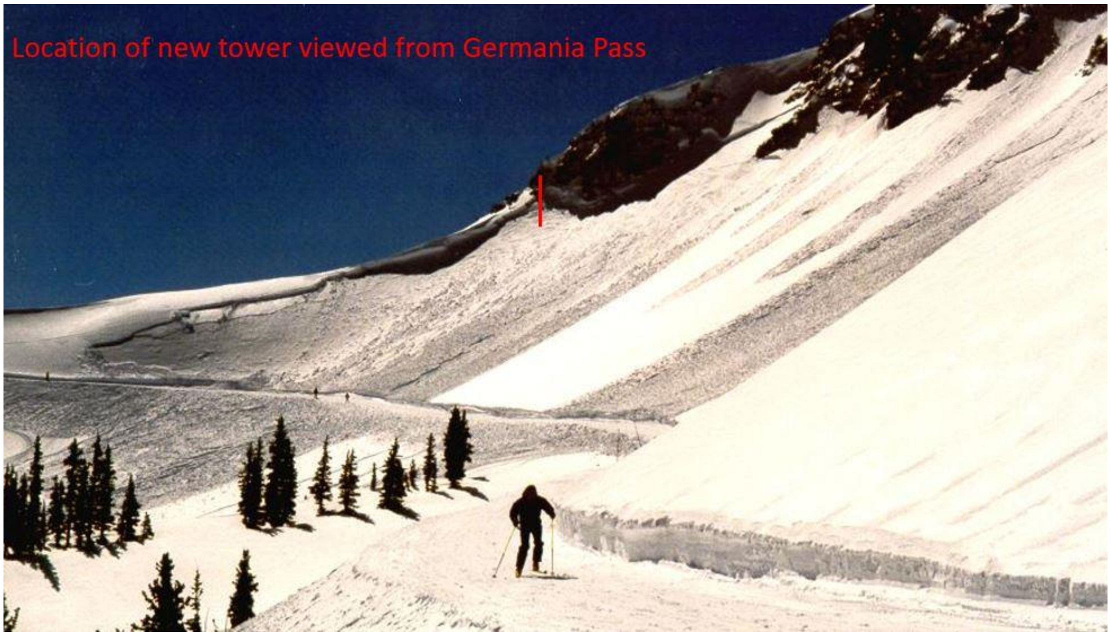


Figure 6
Location and height of proposed device viewed from Germania Pass.

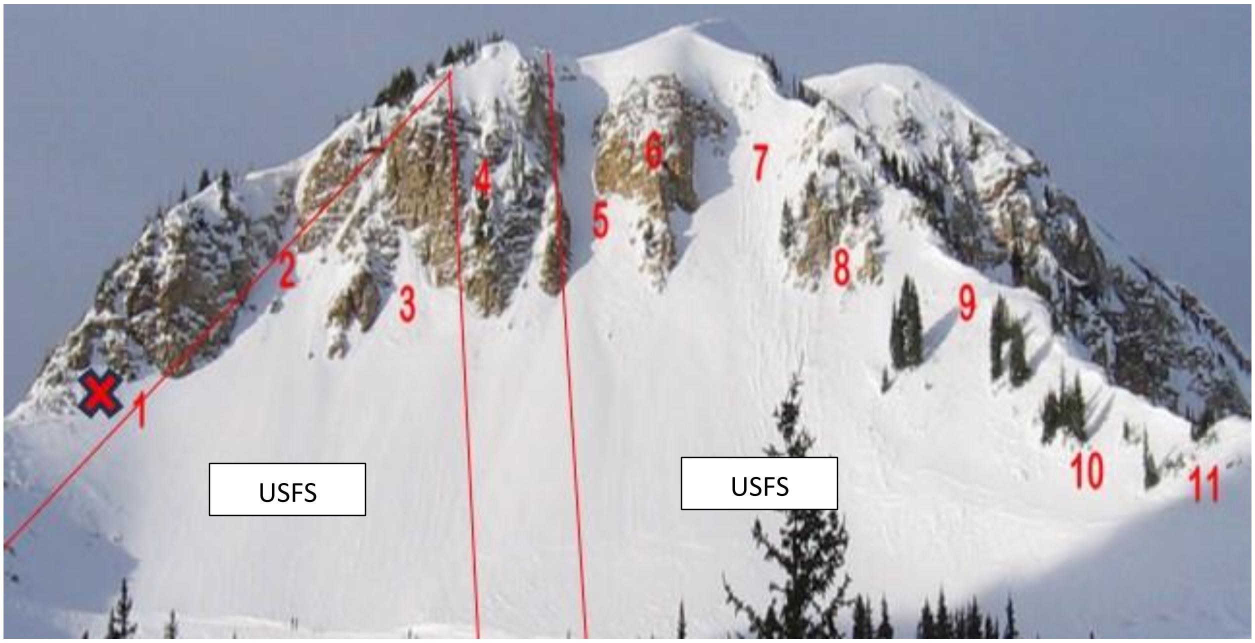
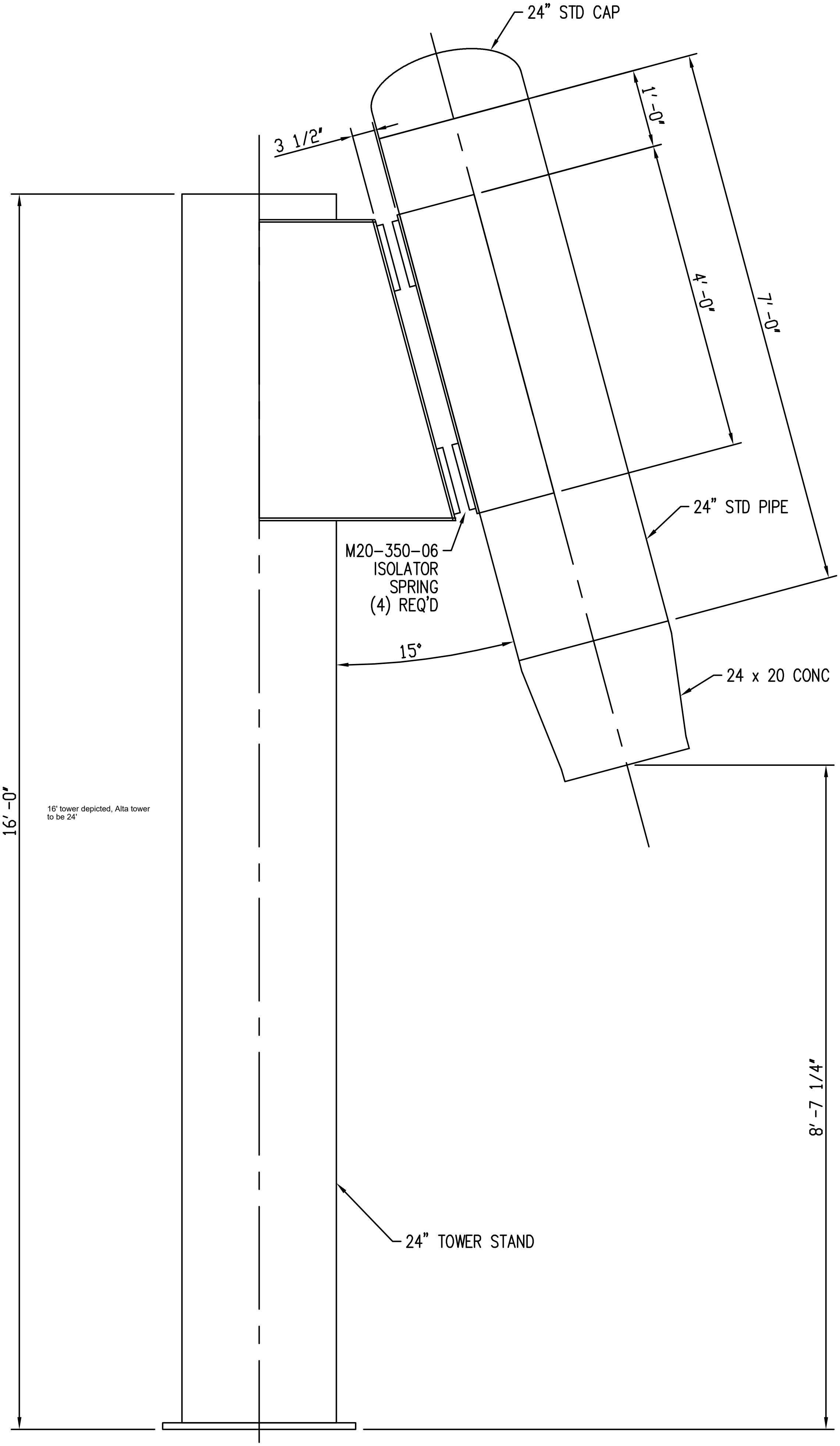
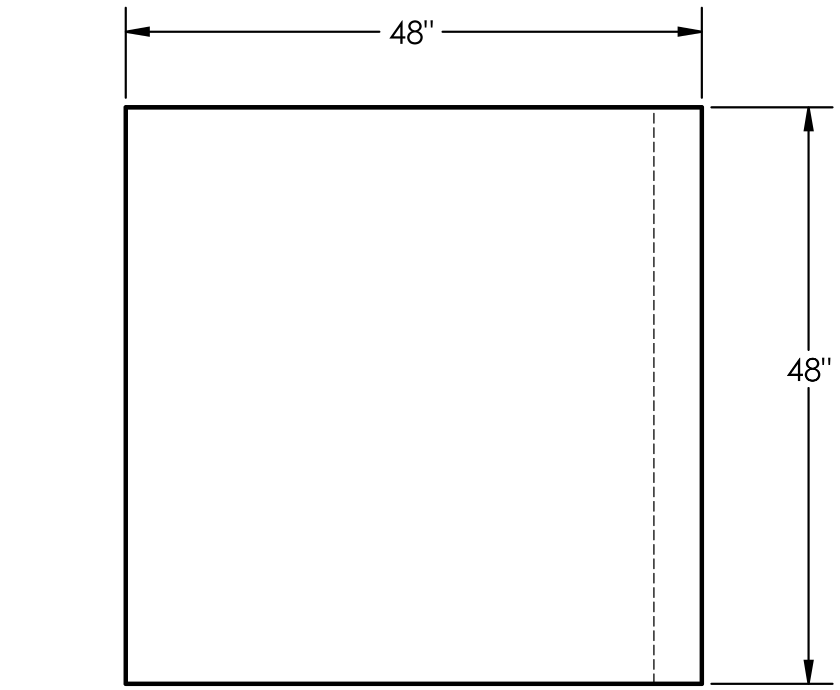


Figure 7
Exploder location denoted by "X". Property Lines shown.

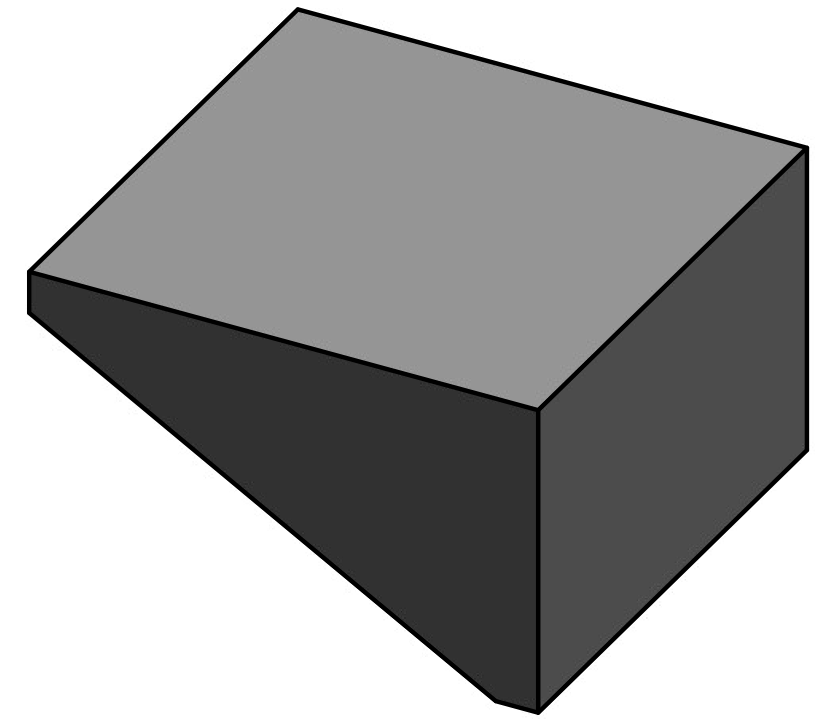

24" STD CAP
3 1/2"
1'-0"
4'-0"
7'-0"
24" STD PIPE
M20-350-06
ISOLATOR
SPRING
(4) REQ'D
15°
24 x 20 CONC
16'-0"
16' tower depicted, Alta tower to be 24'
8'-7 1/4"
24" TOWER STAND

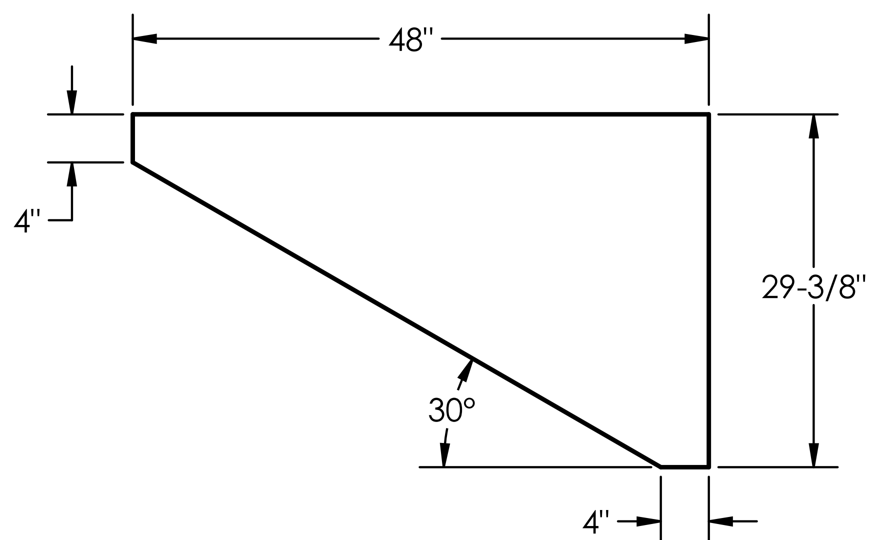
REVISIONS		
REV.	DESCRIPTION	DATE
0	ISSUED FOR APPROVAL	5/8/2023

Depth and Diameter of anchor rod
to be determined by soils/rock

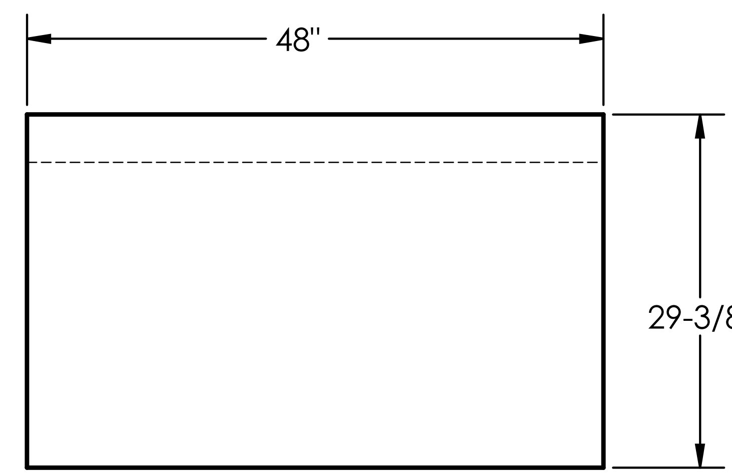


TOP VIEW





SIDE VIEW



BACK VIEW

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ALPINE INFRASTRUCTURE. ANY REPRODUCTION IN PART OR AS A WHOLEWITHOUT THE WRITTEN PERMISSION OF ALPINE INFRASTRUCTURE IS PROHIBITED.

	NAME	DATE
DRAWN	JBB	5/8/2023
CHECKED		

Normal-weight Concrete
DO NOT SCALE DRAWING

ALPINE INFRASTRUCTURE

TITLE:

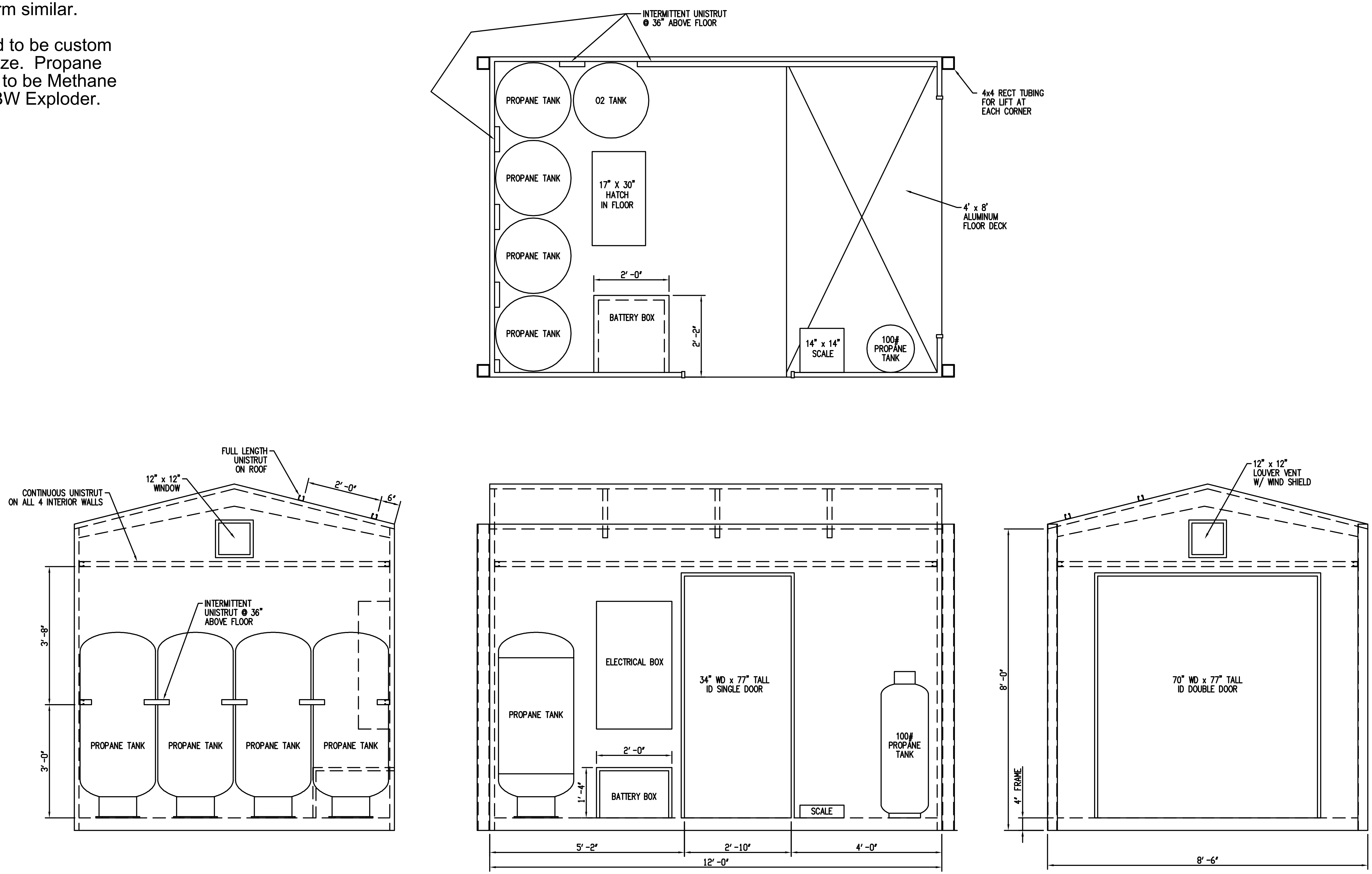
GASX TOWER PAD

SIZE	DWG. NO.	REV
B	AVI-001	0

SCALE: 1:16	WEIGHT: 3311	SHEET 1 OF 1

Tank Farm similar.

Alta shed to be custom built to size. Propane depicted to be Methane for Alta BW Exploder.



May 25,2022

Staff Memo to the Alta Planning Commission

RE: Alta Ski Area Request for a Conditional Use Permit for eight (8) Wyssen Tower Remote Avalanche Control Systems on Mount Baldy. Eleven (11) total, but three(3) on Forest property, eight (8) on private property under Planning Commission purview.

The Alta Ski Area (Alta) is requesting a Conditional Use Permit (CUP) to install 11 Wyssen Tower Remote Avalanche Control Systems (RACS), 8 on their private property and 3 on Forest property, in the Mount Baldy Area.

Alta's letter of application and background materials on the Wyssen Towers, Department of Justice ATF Approval letter and Forest Service approval letter for the towers on Forest property are attached. The application letter and attachments provide a detailed description of the proposal.

The Forest Service has jurisdiction over the RACS installations on Forest property. The town has jurisdiction over the private property requests. The RACS on Alta's property are property zoned FR-50 and require CUP approval prior to construction. They also require a variance since they will be constructed on slope over 30%, but that is an issue for the Land Use Appeal Authority and will be dealt with separately.

In the FR-50 zone, anything but a single-family dwelling and accessory uses to single family dwellings requires a CUP. The ski area is a conditional use under "Commercial and private recreation" and the RACS qualify as conditional uses since they are "accessory uses and structures customarily incidental to a conditional use."

10-6A-3: CONDITIONAL USES:

All conditional uses are subject to sections 10-6A-4 through and including 10-6A-9 of this article, except that the regulations of sections 10-6A-4 through 10-6A-9 of this article may be modified by the town council as they relate to Public Use and Quasi-Public Uses.

Accessory uses and structures customarily incidental to a conditional use.

Commercial and private recreation.

Staff analysis of Alta's CUP application:

The requirements don't really apply to the current RACS proposal. Those requirements, 10-6A-4-9, are attached separately. The requirements, established over 50 years ago, anticipated dealing with more traditional buildings and structures, not modern-day remote-controlled avalanche mitigation systems. With Alta's request there are no issues with the standard requirements such as lot size, coverage, parking, setbacks, waterway setbacks or wastewater systems. Alta will follow the Forest approvals revegetation plan for any disturbance, even on their private lands. It seems the only applicable regulations would be slope, height and building material. Slope will be delt with by the Appeal Authority. Height is determined by the avalanche paths and terrain. Building material has been determined by the design requirements of the specialized manufacturer of the racs.

Alta's application letter does an excellent job of defining the installation, character and need for the Wyssen Towers. The addition of the Department of Justice's ATF approval letter, the Forest Service

Decision Memo and the Foundation Instruction and Assembly information of the Wyssen Avalanche Structures give even more dept to the project and need. The Forest Service has jurisdiction over any structures on Forest property and has given their approval. Alta will follow the same requirements of the Forest Service and the ATF approval and conditions for the installation of the structures on their private land now under Planning Commission purview.

These racs will replace the use of military weapons for avalanche control, and the hazards associated with the use of military weapons. Plus, the Department of Defense has targeted 2025 for the discontinuation for the use of military weapons for avalanche control. It is best to get ahead of that deadline with the installation and use of modern alternative avalanche control methods like the RACS in this request.

The proposed RACS, if successful, would eliminate the need for a tram to Mount Baldy to transport ski area personnel to conduct avalanche control with hand charges, exposing those personnel to both avalanche and explosive risk.

Recommendation

Staff recommends approval of the structures as submitted, with the same requirements and conditions issued under Forest Service and Department of Justice ATF approval letters as attached as well as the Wyssen Avalanche Structure Foundation installation instructions, also attached.

MAYOR
ROGER BOURKE

TOWN COUNCIL
CAROLYN ANCTIL
JOHN BYRNE
SHERIDAN DAVIS
ELISE MORGAN

TOWN OF ALTA
P.O. BOX 8016
ALTA, UTAH 84092

TEL (801) 363-5105
(801) 742-3522
FAX (801)742-1006
TTY 711

June 5, 2022

Dave Richards Director
Alta Avalanche Office
P.O. Box 8007
Alta, Utah 84092-8007

Re: Conditional Use Permit Approval for 8 Wyssen Towers on Mount Baldy

Dear Dave:

On June 2, 2022, the Alta Planning Commission met, discussed, and approved Alta Ski Area's (Alta) request to construct eight (8) Wyssen Tower Remote Avalanche Control Systems (RACS) in the locations identified on Alta's private land on Mount Baldy.

The Commission's approval was subject to the conditions and requirements from your letter to the Planning Commission and Town Council of May 23, 2022, The Forest Service Decision Memo of January 2022, The U. S. Department of Justice's Bureau of Alcohol, Tobacco, Firearms and Explosives letter dated March 3, 2021, the Foundation Instructions for the Wyssen Avalanche tower LS12-5 and the May 25, 2022, Staff Memo to the Alta Planning Commission, all of which are attached hereto.

The Commission commended you on the completeness of your application and description of the project during the meeting. During that discussion, the earlier idea of a tram to service Mount Baldy for avalanche control operations was discussed. The discussion evolved around the thought that if the RACS worked as they should, the need for a tram to Mount Baldy would be eliminated. The Commission emphasized that point and hoped that the RACS would eliminate the need for that tram. You also noted that the manufacturer will spray the towers with a watershed friendly solution so the towers will more quickly dull from exposure to the elements to blend in more with the surroundings.

The Commission realized that the next step in this request is a request for a variance the Land Use Appeal Authority to install the RACS on slope over 30% on Mount Baldy. The Commission realized that the very nature of ski areas and avalanche control devices requires construction on slope over 30%. The Commission wished to express their recommendation for a positive consideration of that variance request to the Appeal Authority for the installation of these state-of-the-art RACS.

Congratulations on your successful request. Best of luck with the installation this summer.

If you have any questions, please don't hesitate to contact me.

Best!

john

John H. Guldner
Town Administrator
Town of Alta

Attachments

CC: Alta Planning Commission
Alta Town Council
Polly McLean
Mike Maughan

Brandt Seitz

BW Gas Exploder Testing Summary

05/26/2023

Blast Wave Evaluation of Prototype "BW" Remote Avalanche Control System

Background:

Remote Avalanche Control Systems (RACS) are reusable explosive devices that are used to trigger avalanches as part of avalanche control practices for ski resorts, highway corridors, and other developed or recreational areas in avalanche terrain. These devices can be activated electronically from a great distance to reduce the risk to avalanche control personnel who might otherwise be required to navigate avalanche terrain to use handheld explosive charges. In general, RACS either detonate a solid explosive (SE) charge or ignite a combustible gas mixture such as hydrogen or propane and oxygen to generate a directed gas explosion (DGE). The most common RACS deployed today include the Wyssen Tower – which is a mast-like structure that releases a solid explosive on a tether to be detonated above the snowpack, Gazex – which is DGE system that employs a large diameter pipe angled towards the snow surface to direct the combustion propane and oxygen, and the O'Bellx – which is an egg-shaped DGE device that combusts a mixture of hydrogen and oxygen.

In addition to these common RAC systems, Eric Bressler of Alpine Infrastructure has been developing a new DGE system known as the BW exploder. This exploder uses an inverted combustion chamber and, in its prototype form, has been configured to combust a variety of gases including methane and hydrogen (Figure 1).

Figure 1 – Prototype BW Exploder RAC System designed by Eric Bressler of Alpine Infrastructure installed at Jackson Hole Mountain Resort for system testing.

In order to evaluate and enhance the design of the BW system, it was vital to establish a baseline of system performance as well as provide a means of comparison between existing avalanche control tools such as pentolite charges and existing RAC systems. Fortunately, there has been a significant amount of research conducted over the past 100 years focusing on evaluating the efficacy of avalanche explosives. However, until recently, with the works of Bones[1], Simioni[2], Schweizer[3], Gubler[4], Larson[5], and Seitz[6] among others, there had not been a complete evaluation and comparison of in-situ avalanche control explosives, nor had an established test methodology and suitable measurement system been developed.

Based on this body of past research, both the test methodology developed by Simioni and the measurement equipment developed by Seitz were utilized to evaluate the strength, size, shape, behavior, and other characteristics of the blast waves from BW prototype exploder. The test methodology focuses on collecting air pressure measurements to characterize the peak overpressure, pressure rise rate, and energy equivalent of explosive blast waves as well as the radial decay and directionality of those parameters. The measurement equipment utilized was a subset of the original equipment developed by Seitz and consisted of six high-pressure acoustic microphones (i.e., pressure sensors) (Figure 2), connected to several independent, wireless, Raspberry Pi-based data, high-speed acquisition systems (Figure 3).

Figure 2 – 10 psi Larcor microphones used to measure explosive blast wave air pressures.

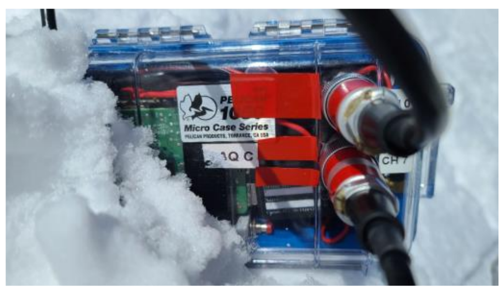


Figure 3 – Raspberry Pi-based data acquisition systems used to collect high-speed pressure data from Larcor microphones.

[1] Bones, J. A. (2012). Experimental Investigation of Interactions Between Explosive Detonations and the Resulting Snowpack Response (Issue November). Montana State University.

[2] Simioni, S. (2017). The Effects of Explosions on Snow. ETH Zurich.

[3] Simioni, S., & Schweizer, J. (2018). Comparing Two Methods of Artificial Avalanche Triggering: Gas vs. Solid Explosives. International Snow Science Workshop, 158–161.

[4] Gubler, H., & Wyssen, S. (2002). Artificial release of avalanches using the remote controlled Wyssen Avalanche Tower. International Snow Science Workshop, 41(0), 40–45.

[5] Larson, Robb, et al. Measuring Explosive Airblast of Remote Avalanche Control Systems (RACS), 2022, rosap.ntl.bts.gov/view/dot/63352/dot_63352_DS1.pdf.

[6] Seitz, Brandt. Measuring Explosive Airblast of Remote Avalanche Control Systems, Montana State University - Bozeman, 2021, https://scholarworks.montana.edu/xmlui/handle/1/16418.

Test Setup:

On Friday, May 26, 2023, two tests of the prototype BW exploder using a mixture of methane and oxygen were conducted at the Jackson Hole Mountain Resort near Jackson, Wyoming. The exploder was installed at the top of a snowy slope near the top of the Thunder chairlift (Figure 1). This device was located at an elevation of about 9,360 feet on a northernly slope with an incline of approximately 35°. Conditions at the time of testing were overcast with temperatures of about 45-55°F. The snowpack exhibited typical late-season conditions with surface melt and an overall moist to wet moisture content.

Overall, conditions were similar to those experienced by Seitz in his evaluation of in-situ RAC systems and solid explosives. However, it is important to note that the installation of the prototype exploder required it to be erected just off the edge of an access road at the top of the slope. As a result, the mouth of the exploder's combustion chamber was initially directed at a large, flat (i.e., 0° slope angle), and dense snowbank (rather than directed at an acute angle with the snow-covered slope below as would be typical for an operational RAC system) which had developed as the snow melted and receded from the access road. Efforts were made to taper this horizontal snowbank back into the natural slope angle prior to testing to better represent typical site conditions at an operational RAC system. These efforts were successful, but a small portion of the snowbank remained below the exploder which may have resulted in a greater portion of the blast wave being reflected upward rather than directed downslope towards the pressure sensor array.

Both tests of the BW exploder were conducted with the following arrangement of pressure sensors shown in the plan view illustration below (Figure 4) where the plot origin represents the mouth of the exploder's combustion chamber and the 0° axis is defined to be directly downslope (i.e., the slope's fall-line) of the exploder. Microphones were installed parallel to, and approximately 6-in above, the surface of the snow as was done for both Simioni's and Seitz's work.

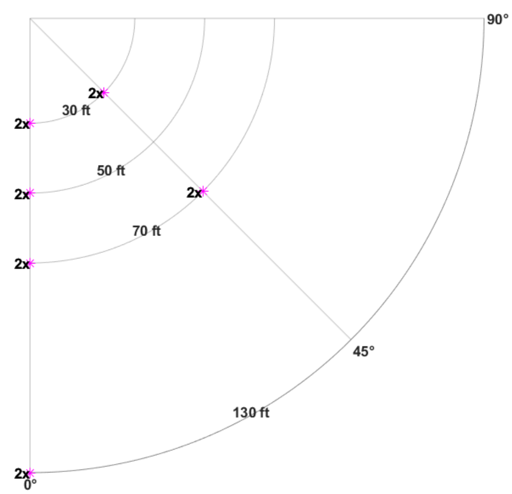


Figure 4 – Arrangement of pressure sensors utilized for both tests of the prototype BW exploder. NOTE: "2x" indicates the number of air pressure measurements taken at each sensor location, the plot origin represents the location of the exploder, and the 0° axis is directly downslope of the exploder.

Findings:

Following the testing methodology employed by Simioni and the data processing methodology developed by Seitz, peak pressures, pressure rise rates, and energy equivalents were calculated from the pressure-time measurements taken by each microphone in each test. In addition, power law curve fits were generated along each measured axis to describe the radial decay of those metrics along the axis and 3D interpolations of the power law curve fits were also calculated to illustrate and understand the directionality of those metrics.

Beginning with peak pressures, although measurements were only conducted along two axes (0° and 45°), the surface plot of peak pressures did indicate a slight directional effect common to DGE RAC systems where the blast wave tends to be stronger along the 0° axis (Figure 5). This is also supported by the axial slice plots which indicated a much stronger but more rapidly decaying wavefront along the 0° axis than the 45° axis (Figure 6 and Figure 7). The power law coefficients fit to the data along these axes are shown in Table 1. Based on these power laws, it was also determined that the reference peak pressure (used in Seitz's work) of 1 kPa or 0.145 psi was reached at a distance of about 92 ft on the 0° axis and 110 ft on the 45° axis. Lastly, the peak pressure results also indicated a high level of repeatability based on the consistency of measured peak pressures by microphones left in the same position during both tests.

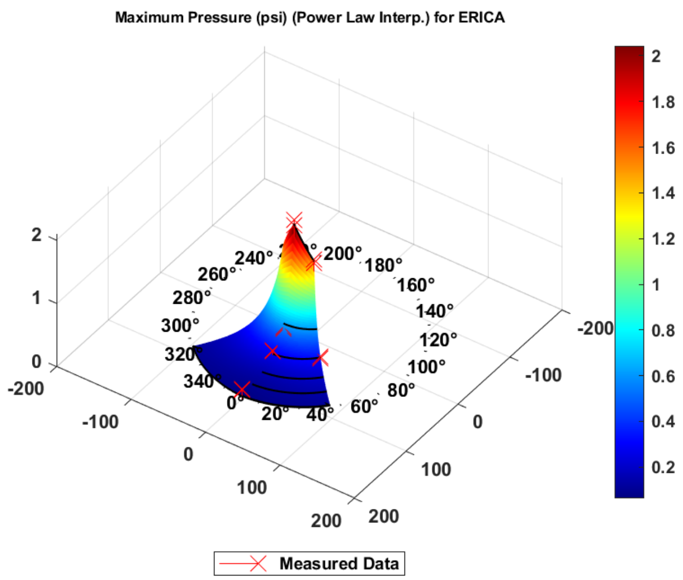


Figure 5 – Surface plot showing the peak pressures recorded and the interpolation of the power law curve fits for the prototype BW exploder.

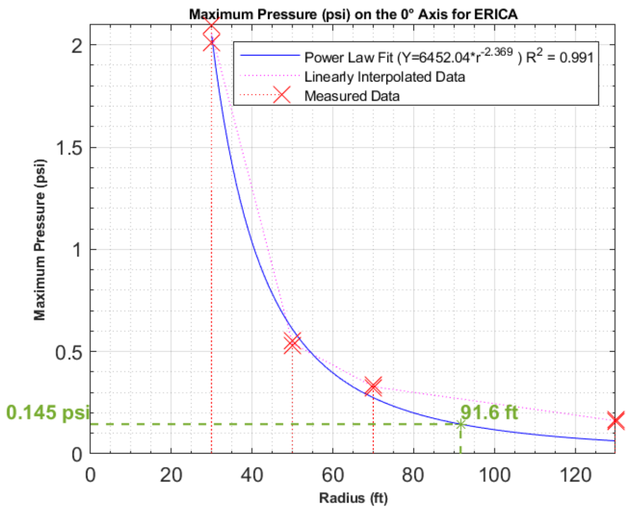


Figure 6 – Axial slice plot showing the peak pressures along the 0° axis as well as the power law curve fit to those measurements and the power law-interpolated location of the 1 kPa or 0.145 psi reference overpressure.

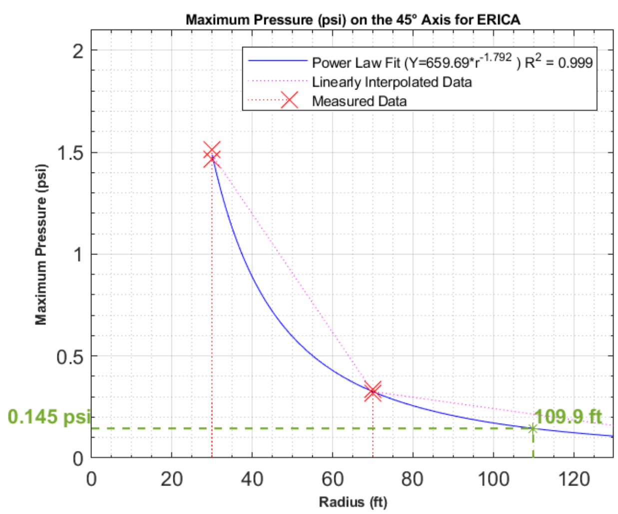


Figure 7 – Axial slice plot showing the peak pressures along the 45° axis as well as the power law curve fit to those measurements and the power law-interpolated location of the 1 kPa or 0.145 psi reference overpressure.

Table 1 – Table of power law curve fit coefficients for peak pressure measurements of the prototype BW exploder.

Axis	Power Law Coefficient a	Power Law Coefficient b	R^2
0°	6452	2.37	0.991
45°	660	1.79	0.999

The energy equivalent and pressure rise rate results exhibited the same directionality and repeatability trends as described above for peak pressures. However, the radial decay of energy equivalent was found to be the strongest along each axis, followed by pressure rise rate, and finally by peak pressures (this is consistent with the prior findings of Seitz). In other words, the energy equivalent of the blast wave decays most quickly with radial distance and the overpressures decay least rapidly with radial distance. For brevity, only the energy equivalent and pressure rise rate power law curve fit coefficients are shown below (Table 2 and Table 3).

Table 2 – Table of power law curve fit coefficients for energy equivalent of the prototype BW exploder.

Axis	Power Law Coefficient a	Power Law Coefficient b	R^2
0°	232	3.12	0.992
45°	25	2.61	0.993

Table 3 – Table of power law curve fit coefficients for pressure rise rate of the prototype BW exploder.

Axis	Power Law Coefficient a	Power Law Coefficient b	R^2
0°	8.21e6	2.45	0.995
45°	3.01e6	2.17	1.000

Summary:

Several conclusions, comparisons, and trends can be discussed from the above results. First, as was observed in Seitz's previous work (and mentioned above), the BW exploder seems to follow the same trends observed for other avalanche explosives and RAC systems whereby the radial decay of energy equivalent was found to be the strongest, followed by pressure rise rate, and then by peak pressure. One interesting departure from Seitz's previous body of work, however, was the magnitude of the radial decay of each of the three parameters. More specifically, it was previously observed that most explosives had peak pressure power law exponents of 1.2-1.7, energy equivalent power law exponents in the range of 1.9-2.5, and pressure rise rate power law exponents of 1.5-2.2. The testing of the prototype BW exploder however indicated power law exponents of 1.8-2.4, 2.6-3.1, and 2.2-2.5, respectively. Taken at face value, this could indicate that the BW simply has a stronger radial decay of its blast wave than previously tested explosives, however, as previously noted, it was found that the power law exponent seemed to exhibit a stronger correlation with site conditions than explosive. This could provide some evidence that the previously mentioned snowbank did, in fact, reflect a portion of the blast wave upward resulting in a greater radial decay of the blast wave at the snow's surface – though additional testing and a finer spatial resolution of pressure sensors would be necessary to confirm. Beyond the comparisons to previously observed trends, these results also provide an opportunity for comparison to previously tested explosives and RAC systems.

Comparing the BW first to other DGE systems, it was found that the BW behaves quite similarly to the O'Bellx RAC system in terms of absolute magnitude of peak pressures and energy equivalents (with slightly higher magnitudes than the O'Bellx at distances below about 70 feet). This, in turn, places it below a 0.8 m^3 and 1.5 m^3 Gazex system for peak pressures and energy equivalents (Figure 8 and Figure 9). In terms of pressure rise rate magnitudes, however, the BW was found have higher pressure rise rates than both the O'Bellx and 0.8 m^3 Gazex systems for distances below about 125 feet (Figure 10). At distances beyond 125 feet, all devices generally approach similar pressure rise rates (as described in Seitz's previous work).

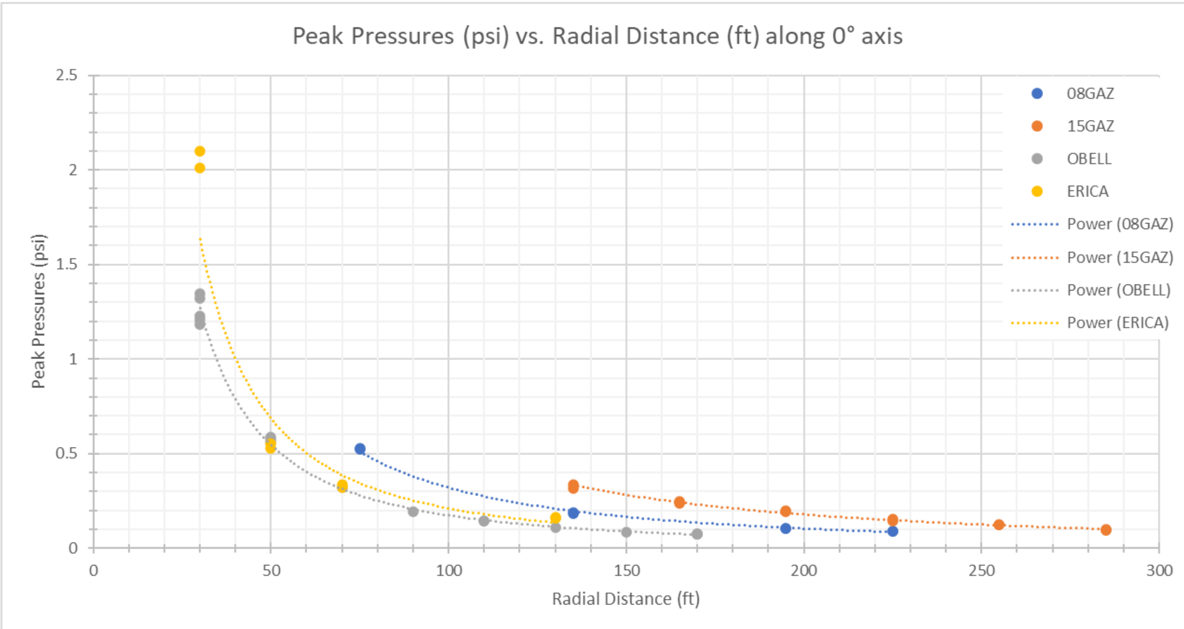


Figure 8 – Comparison of BW peak pressure results (labeled "ERICA") to other DGE systems along the 0° axis.

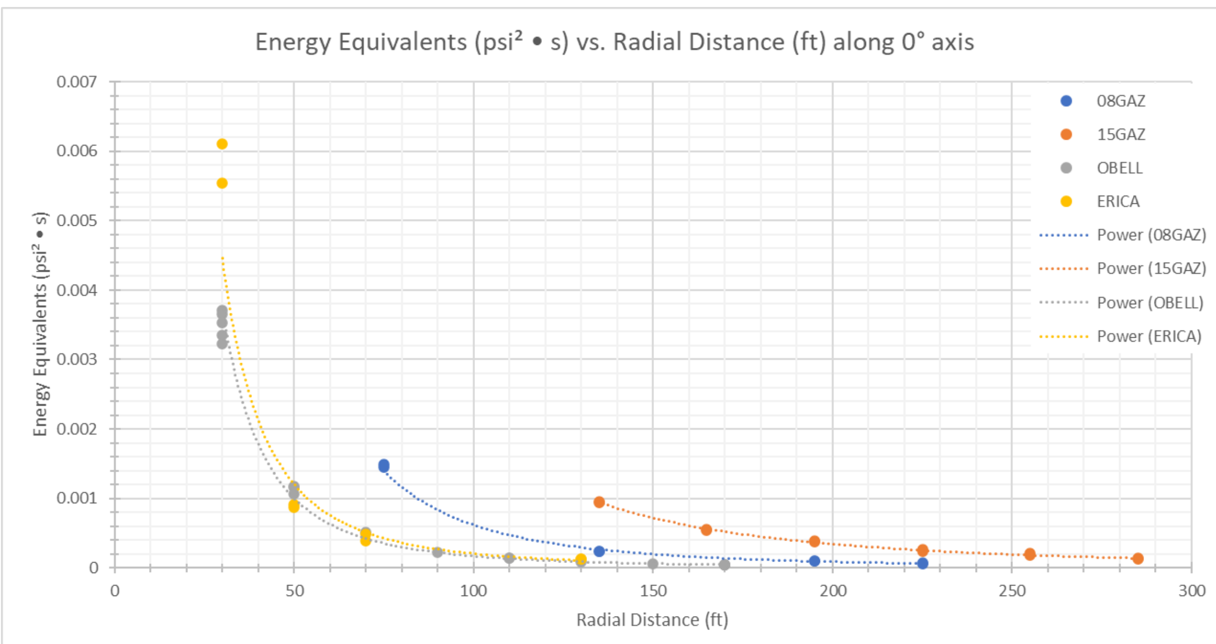


Figure 9 – Comparison of BW energy equivalent results (labeled "ERICA") to other DGE systems along the 0° axis.

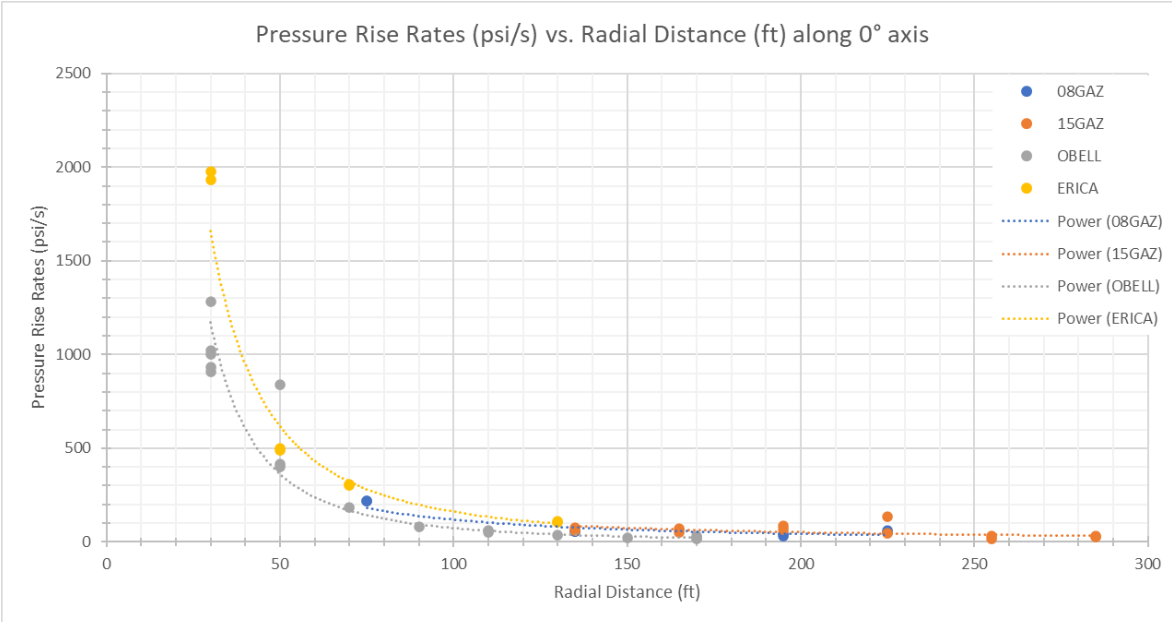


Figure 10 – Comparison of BW pressure rise rate results (labeled "ERICA") to other DGE systems along the 0° axis.

Comparing the BW exploder instead to various previously tested solid explosives, it can be shown that the BW exploder exhibited similar overpressures as (though slightly lower than) a common 2-lb Pentolite hand charge detonated 2 m above the snow surface. The BW exploder does, however, fall below the overpressures measured for gel emulsion and Pentolite-based Wyssen tower charges detonated 2 m above the snow surface as well as a simulated Pentolite-based Avalanche Guard mortar charge buried 30 cm below the snow surface (Figure 11). As for energy equivalents, the BW exploder was found to fall below the solid explosive charges at least up to radial distances of about 100 feet (Figure 12). Lastly, pressure rise rates measured for the BW exploder actually exceeded those measured for the 2-lb Pentolite hand charge at radial distances up to about 125 feet (Figure 13).

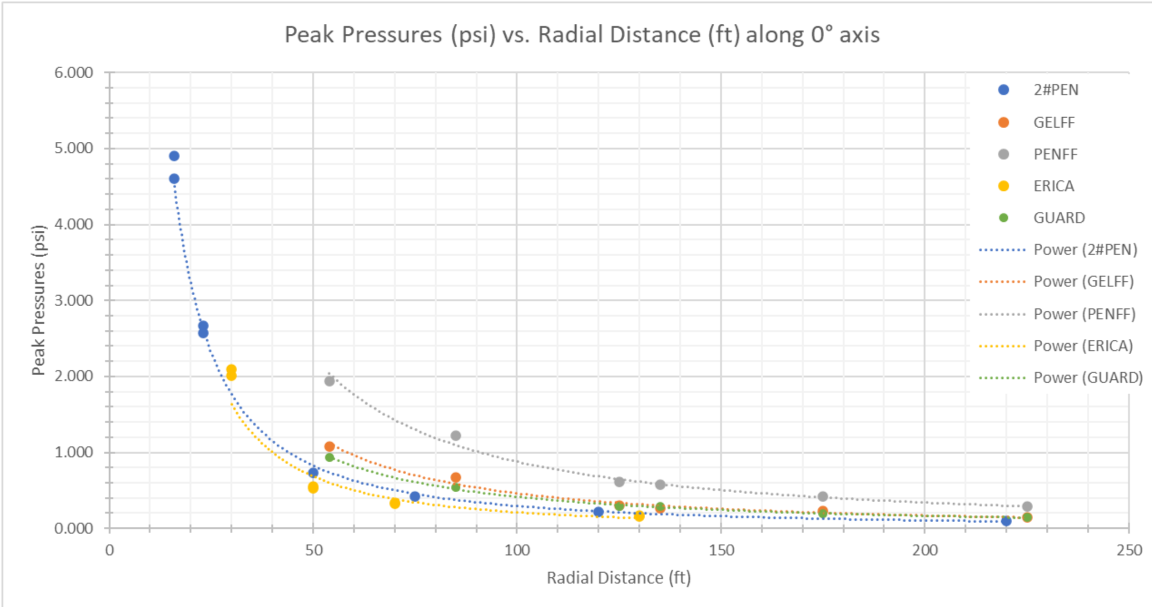


Figure 11 – Comparison of BW peak pressure results (labeled "ERICA") to previously tested solid explosive charges along the 0° axis.

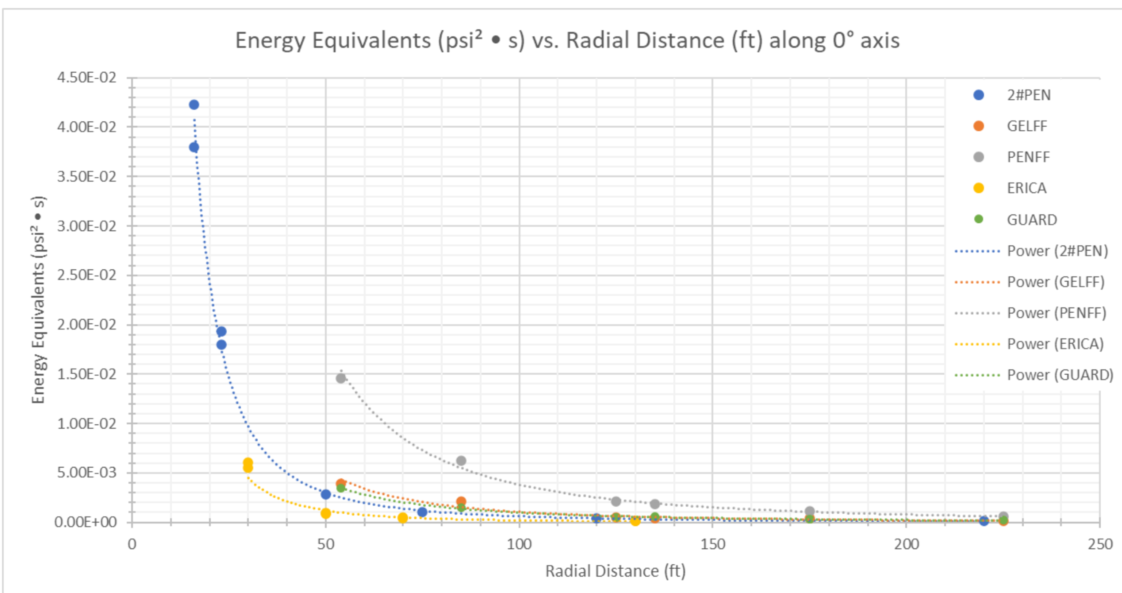


Figure 12 – Comparison of BW energy equivalent results (labeled "ERICA") to previously tested solid explosive charges along the 0° axis.

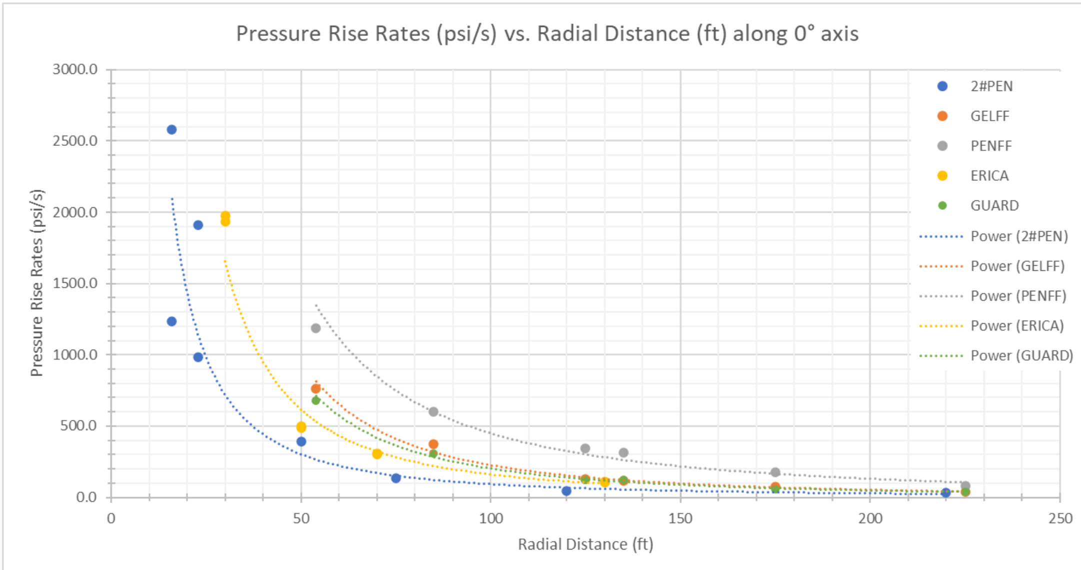


Figure 13 – Comparison of BW pressure rise rate results (labeled "ERICA") to previously tested solid explosive charges along the 0° axis.

As a final point of comparison, the interpolated radial locations of the 1 kPa overpressure for the BW exploder, and all other explosives tested by Seitz, are shown in the table below (Table 4). This again indicates that the BW is most comparable to the O'Bellx system but exhibited stronger radial decay of overpressures than previously measured.

Table 4 – Comparison to Seitz's previous work on the radial locations of the 1 kPa (0.145 psi) peak pressures.

Radial Location of 1 kPa (0.145 psi) Peak Pressure Reference (ft)													
Axis (°)	**BW**	**2#PEN**	**15GAZ**	**OBELL**	**GELFF**	**GELWT**	**PENFF**	**PENWT**	**GUARD**	**PNCLF**	**OBRCK**	**PGLY1**	**PGLY2**
0	92	138	230	115	234	239	404	345	222	429	124	477	490
30	X	X	X	105	X	X	X	X	X	X	109	X	X
45	110	141	X	X	246	238	425	346	237	317	X	576	859
60	X	X	155	188	X	X	X	X	X	X	174	X	X
90	X	128	113	245	238	215	467	313	227	280	X	X	X
120	X	X	82	97	X	X	X	X	X	X	X	X	X
135	X	X	X	X	257	212	466	300	232	X	X	X	X
150	X	X	X	110	X	X	X	X	X	X	X	X	X
180	X	X	X	96	242	198	466	319	214	X	X	X	X

In summary, the preliminary testing results of the BW exploder presented above indicate that it has very promising performance characteristics such as its overpressures and energy equivalents that place it well within the previously observed performance of established DGE systems like the O'Bellx and Gazex. Furthermore, the relatively high pressure rise rates observed for the BW system seem to place it somewhere above other DGE systems and even 2-lb Pentolite charges, but still below other larger solid explosives such as those used in Wyssen Tower RAC systems. Lastly, the BW exploder indicated a stronger radial decay of peak pressures, energy equivalents, and pressure rise rates than previously observed for any other explosive or RAC system, but it is unclear at this point whether this is an inherent limitation in the design of the BW exploder or was rather the result of environmental factors and/or testing conditions.