POLYURETHANE FOAM APPLICATIONS
in the Closure of Abandoned Mine Openings

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The National Park Service established a servicewide abandoned mineral land (AML) program in 1984 with five major objectives relative to mineral development sites on park lands:

- inventory all AML sites within the National Park System
- eliminate safety and health hazards
- eliminate or mitigate resource impacts
- preserve culturally and historically significant sites
- manage sites for special wildlife habitat

Today, an inventory with data on 2,421 abandoned mine sites including 10,692 individual mine openings has been collected for National Park Service lands. In realizing the objectives of the AML program, a number of methods have been employed to close and/ or reclaim mine openings, depending on the specific conditions and needs at each site. Among these is the use of rigid polyurethane foam (PUF) for plugging openings where the mine does not provide significant wildlife habitat and the objective is to totally reclaim the site.

The National Park Service has tested several different applications of PUF to close abandoned mine openings. Both shafts and adits (vertical and horizontal mine openings, respectively) can be closed with foam plugs, although shafts are generally easier. The foam is produced by mixing two liquid reagents, a resin and catalyst. This mixture is then poured on top of a lightweight form constructed out of lumber, plastic sheeting, cardboard, plywood, etc. near the mine entrance. A rapid exothermic reaction occurs generating foam that expands to fill all voids and cracks in the mine opening. Within 15-30 minutes, the foam hardens to create a rigid plug firmly bound to the rock, Since the low-density PUF typically used in mine closures (2 pounds per cubic foot, henceforth "2-pound foam") can easily be cut, decays when exposed to ultraviolet light, and is flammable, the last several feet of opening is filled with dirt and rock to protect the plug from vandalism, sunlight, and fire. This fill material also adds to the structural integrity of the plug. The chemistry of the reagents can be varied to produce different densities of foam. With low-density PUF, the volume of foam produced is 20 to 30 times the volume of the reagents. The obvious advantage to this is that large openings can be sealed using a small amount of material and minimal equipment. In sensitive, historically significant, or wilderness areas where equipment access and ground disturbance may be unacceptable, PUF offers a good low-impact closure alternative.

Physical Properties of PUF

Polyurethane foam is inert, non-reactive to acid mine drainage, and, when covered with dirt and rock, is protected from fire, ultraviolet light, and vandalism. Although the compressive strength is low (typically 10-15 pounds per square inch for the standard 2-pound foam), it is adequate for shafts in areas where heavy vehicles will not traverse the plug. One square foot of 2-pound PUF can support I440 pounds in compression. The shear strength for a typical 5-foot by 5-foot shaft with a 7-foot thick 2-pound PUF plug is calculated to be about 100 tons, although in actuality, the overall strength of such a plug would be limited by the compression rallure to 18 tons. When properly backfilled with dirt and rock to the surface, however, the compression forces are transferred to the walls of the shaft and the PUF plug is effectively "bridged," enhancing the strength of the overall closure. The closed-cell structure of PUF prohibits the release of gases from the mine if a good seal is achieved around the perimeter of the plug. In wet areas where water from inside or outside the mine could threaten plug integrity, drainage bypass tubes can be installed in the closure.

Environmental Concerns

The common use for PUF is insulation in ice chests, thermos jugs, refrigerators, and buildings. Homeowners may be most familiar with PUF available in aerosol cans at the hardware store, used to seal around window casements and door jambs to prevcnt air and thermal leaks. Combustion of PUF releases carbon monoxide and traces of hydrogen cyanide, but in mine closures, backfilling with dirt and rock precludes combustion by isolating the plug from a source of oxygen. Flame retardant additives have been developed, however, and can be used in some products (with an additional cost) at sites where fire is a concern. Although one of the liquid components is a toxic isocyanate, neither component requires Department of Transportation "red tags" for shipping. Once combined, the isocyanate is complexed into a stable, non-toxic form. The solid foam end product can be discarded in a sanitary landfill without restrictions. When mixing the reagents, any liquid PUF that contacts skin or clothing is nearly impossible to remove. Adequate ventilation, a dust cartridge respirator, gloves, protective clothing, and protective eyewear are required safety equipment for the installer.

Application Methods

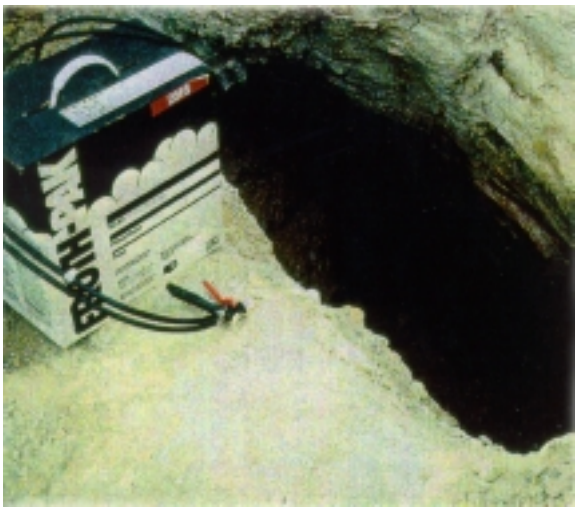
The methods the National Park Service has used to install PUF mine closures, and the advantages, disadvantages, and approximate current cost of each are summarized below. Costs quoted were taken from the direct experience of the National Park Service, supply companies, contractors, and other mine reclamation agencies. They do not include shipping charges and the cost of constructing forms in the mine opening. Although specific products and contractors are mentioned in order to document what has been done, this report is not intended to endorse or discredit any of the products or contractors used. In each application tested, and in all comparisons made below, foam of an approximate density of 2 pounds per cubic foot was used.

Truck-Mounted Application - In cooperation with the Office of Surface Mining Reclamation and Enforcement, this method was used to close two adits at the Kaymoor Coal Mine in New River Gorge National River in November 1987. The PUF reagents were contained in 500-pound steel tanks mounted on a truck. A proportioning unit was used to heat, mix, and shoot the reagents in 2-foot layers into the adits, allowing each layer to cure to some degree before shooting the next layer. After the plugs had set up, the last several feet of both openings was backfilled with rock and dirt to blend with the natural slope. The disturbed areas were fertilized and seeded with native plant species. The end effect obscured both openings to the point that park visitors are now unaware that any opening had been present. Where vehicular access is available, this is the easiest, most economic way to apply PUF, and several large openings can be "PUFed" in a day. Today the average cost of truck-mounted PUF applications is roughly $155 per cubic yard of PUF placed for smaller jobs (less than 15 cubic yards), or $135 per cubic yard for larger jobs, assuming reasonable access. As demand for this application for foam may vary in different locations, contractors with a truck-mounted system may not be available in some areas of the country.

Hand Mixed Application from 5-gallon Buckets - This method was used in January 1991 at Kodel's Gold Mine in Colorado National Monument in a cooperative project with the Colorado Division of Minerals and Geology Inactive Mine Reclamation Program. The park wanted to preserve and interpret this historic site, so instead of doing comprehensive reclamation, they installed a lockable steel gate on the adit in 1987 and left the rest of the site intact. Concern was raised, however, by a nearby accident outside the park in 1989 where three youths were asphyxiated in oxygen-

deficient air after bypassing a similar mine gate that had been vandalized. The park wanted to close two hazardous winzes (vertical shafts underground) just inside the Kodel adit that would have been exposed if the gate had been compromised. The mine, located near the park boundary, was known to be visited frequently by children from an adjacent residential area. Since there was not ample fill material on-site for a total backfill, we decided to use PUF plug closures. Vehicular access to the mine was not possible, so 5-gallon buckets of PUF reagents were backpacked 1 mile to the site. The foam used requires product and ambient temperatures to be a minimum of 40°F, and preferably above 50°F (the hotter the better) for proper foam generation, so the adit and reagents were pre-heated with a propane space heater to approximately 70°F. The PUF reagents were then mixed in batches in a separate 5-gallon bucket and poured on top of lightweight forms in the winzes. A generator was packed to the site to power small electrical equipment such as lighting and a drill with stirring attachment to mix the reagents. The last several feet in both winzes was backfilled by hand with dirt and rock to obscure their presence, add to plug strength, and prevent vandalism. For our first attempt at a "backpackable" foam closure, this project was highly successful. Mixing the PUF is a little messy, so a respirator, gloves, protective clothing and eyewear are imperative for the installer. The 5-gallon buckets are somewhat cumbersome for packing over rough terrain or great distances. Cost varies greatly with contractors and product dealers, and often decreases significantly with larger quantities. For instance, one supplier currently packages reagents for foam in 5-gallon pails for $1.95 per pound ($105 per cubic yard of foam), or in 55-gallon drums at $1.25 per pound ($67.50 per cubic yard of foam).

lnsta-Foam Froth-Pak® Application - Under a contract administered by the Utah Division of Oil, Gas, and Mining Abandoned Mine Reclamation Program, a small subsidence hole into Oyler Uranium Mine at Capitol Reef National Park was closed in June 1993. A bulkhead was constructed in the small underground passage in the area of subsidence and the void was filled with PUF from three 38-pound Froth-Pak® kits. (Four kits were taken to the site, but one of the kits malfunctioned.) The remainder of thc void was hand-backfilled with local rock and dirt. At Oyler Mine, PUF was chosen not only to fill the subsidence area, but also to support the intact portion of the mine roof and prevent further subsidence. Froth-Pak® kits come in various sizes, and consist of two disposable metal tanks packaged in a cardboard carrying box. Included in the kit are instructions, a 7 1/2' gun/hose assembly, and 10 spare nozzles for the gun. While this system is portable to some degree, packaging is rather bulky for packing into remote areas. These kits are a good, self-contained systems for park maintenance staffs to close a small opening without going to the time, money, and trouble of contracting a job to private bidders. Disadvantages of Froth-Pak® kits are several. Multiple nozzles are included with each kit because the nozzles have a great tendency to clog. As with the previously described systems, this product has temperature limitations, and should only be used at temperatures above 75°F. Froth-Pak® kits generate a fair amount of trash that must be removed from the site. The leftover tanks are not reusable or recyclable. Currently the 38-pound Froth-Pak® Model 180 kits retail at $260, yielding 15 cubic feet of foam (0.56 cubic yards at $468 per cubic yard). The 113-pound Model 600 kits retail at $595, yielding 50 cubic feet of foam (1.85 cubic yards at $321 per cubic yard).

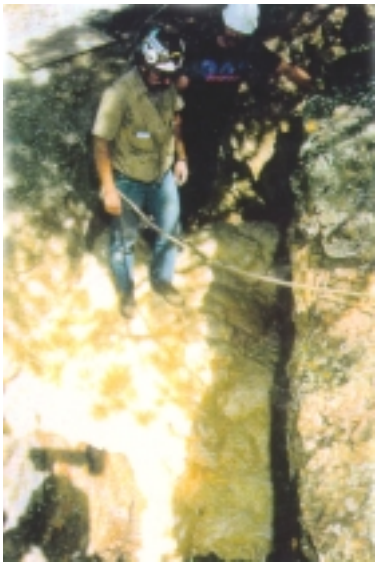


Hand Mixed Application from Plastic Bag Kits - In cooperation with the Colorado Division of Minerals and Geology Inactive Mine Reclamation Program, a demonstration of plastic bag PUF kits was arranged by the National Park Service in July 1994 with a contractor from Minnesota who is new to the mine closure business. The test site consisted of one adit and one shaft at the Little Bear Creek Gold Mine just outside of Idaho Springs, Colorado on National Forest Service land (not in a National Park). In this application, the catalyst is stored in a lighter-weight plastic bag stored within a heavier-weight plastic bag containing the resin. The installer ruptures the catalyst bag into the larger bag of resin, which remains intact. The two components are then mixed together by kneading the large bag. When the components are thoroughly mixed, the entire kit is

placed in the opening and the foam expands until the outer bag ruptures, releasing foam into the opening. The PUF flow can be directed, and splash from bag rupturing can be avoided, by cutting the mixed bag before its internal pressure builds, and pouring the mixture where needed.








This method precludes the need for power generation and is not hindered by malfunctioning nozzles, guns, and hoses. Since the reagents are pre-measured and mixing is a simple matter of kneading the bag, proper proportioning is virtually guaranteed. All waste materials are enclosed in the foam plug, so trash is minimal. This foam product is water-based and does not contain chloro-fluorocarbons used in other PUF products. The different chemical composition enables use of this product at much lower temperatures than other PUF products, which can be quite helpful in northern latitudes or at high altitude where temperature fluctuates greatly through the day. The rigid foam produced is more granular and less resilient than the other PUF products tested, but thoroughly capable of supporting the loads anticipated over a mine opening. A 22-

pound bag set generates 10 cubic feet of foam. The bags are conveniently sized and are easily carried in a conventional backpack. Bag placement for the shaft closure was much easier than for the adit, in fact, the installers got fairly covered with PUF on the adit closure. Protective clothing and gloves for hand installation of adit closures is essential. We recommend rubber gloves duct taped to a Level D disposable Tyvek® hazmat suit. With more practice and experience, the installer may have fewer problems. Each 22-pound bag kit is available for $130, which amounts to $350 per cubic yard of foam generated. Discounts are available for bulk orders. In this demonstration, high-density foam (8 pounds per cubic foot) was used to construct the last two feet of the adit plug, with the thought that this could act as an additional shield against vandalism if the plug were ever exposed. While the high density foam is much tougher than the standard 2-pound foam, it is more difficult to install, its foaming properties were not as good, and since it is four times as dense, it is much more expensive and requires more material transported to the site. It is therefore not recommended for normal applications. Earthen backfill on top of a 2-pound foam plug should provide adequate plug protection.

Conclusion

Each application of PUF has its merits, and choosing the method or product to use must be based on factors of site access, availability of products and contractors, cost, and size of the job. In areas where site access and disturbance is not an issue and sufficient material is available on-site, an earthen backfill using heavy equipment is preferred over PUF for mine closures. PUF has proven to be a useful material for mine closures, however, especially in remote areas, sites with access and disturbance restrictions, and at sites where adequate backfill material is not available.