Micro Encapsulation In Situ with Super Permeating Molten Wax

E. Carter, P.E.
Carter Technologies Co
9702 Garden Row Drive, Sugar Land, TX 77478
USA

A new class of grout material based on molten wax offers a dramatic improvement in permeation grouting performance. This new material makes a perfect in situ containment of buried radioactive waste both feasible and cost effective. This paper describes various ways the material can be used to isolate buried waste in situ. Potential applications described in the paper include buried radioactive waste in deep trenches, deep shafts, Infiltration trenches, and large buried objects. Use of molten wax for retrieval of waste is also discussed. Wax can also be used for retrieval of air sensitive materials or drummed waste. This paper provides an analysis of the methods of application and the expected performance and cost of several potential projects.

INTRODUCTION

Permeation grouting has traditionally been limited to highly permeable soil conditions such as sand. Even water-thin chemical grouts such as acrylamide have a very limited permeation range of a few feet. Recent experiments with soils, rock and molten wax have demonstrated that molten wax may be useful in a variety of new grouting applications related to buried waste and contaminated soil.

Unlike Montan wax grouts that are water emulsions of solid wax particles, WAXFIX™, the molten wax grout described herein, does not contain any water. The molten wax grout has the ability to totally saturate relatively low permeability materials such as clay soil, shale, limestone, sandstone, volcanic tuff, and wood. The wax adhesively bonds to materials such as glass, metal and all plastics and polymers.

The proprietary molten wax considered here has surfactant properties above the 51.6 Celsius, (125 degree F) melting point, but not when below this temperature. This makes it possible for the grout to displace water in a soil or rock formation and yet be insoluble in groundwater. The molten wax grout not only works in dry soil but also works in wet or even saturated soil conditions. The wax is non-toxic and resistant to bio-degradation. The permeability of the wax is very low and similar to synthetic liners.

When molten wax is applied to a cold ground surface the wax flows only a short ways before cooling enough to solidify. The wax travels through the soil until it cools to near its melt point. However if the soil is pre-heated to a temperature well above the melting point of the wax, permeation through the soil appears to continue indefinitely. The special surfactant modified wax is also able to permeate through many earthen materials more readily than water. This behavior makes possible some interesting grouting applications.

In conventional grouting of soils, one problem is that the available grouts are at least as viscous as water and can find it difficult to rapidly permeate soil formations such as clay. Cementitious grouts contain relatively large particulate that cannot even penetrate most sands. Our tests show that molten wax can easily penetrate most any soil or sedimentary rock. Another issue in grouting is the control of penetration of a soil. Most grouts are placed by pressure and so they tend to take the path of least resistance and may only finger through a narrow pathway when the goal is to treat the entire mass of soil in an area.

Generally molten wax will not travel far beyond the pre-heated zone and it will tend to gravity pool within the heated zone to completely fill all the heated volume. This makes it possible to control precisely what soil is grouted and what is not grouted. Grouting of fractures in rock is difficult with traditional grouts because the distance the grout travels through a fracture system is determined by grout viscosity and pressure and the unknown fracture properties. Pressure grouting of vertical fractures is particularly difficult. Molten wax grout will flow easily into even a small fracture system and will travel only as far as it takes to cool before solidifying as a perfect seal within the fracture. Vertical fractures can be easily grouted.

FIELD PROCEDURES

Molten Grouts may be used to form a waterproof and air-tight seal around legacy buried waste and also microencapsulate the soil materials in a radioactive waste landfill. The first step in micro-encapsulation is to gently pre-heat the soil and waste. In Radioactive zones this may be done by driving closed end pipes into the soil and installing electric resistance heaters in the pipes. Heater pipes driven in on 2.4 meter, (8 foot) centers in relatively dry soil can heat the ground to minimum temperatures of 71 degrees Celsius, (160 degrees F) in about 2 months. This modest level of heating does not pose any significant hazard for most waste types. After the soil is heated the molten wax may be introduced to the heated area by gravity flow directly from the delivery trucks. No pressure injection is required.

Heaters may also be placed in open drilled holes or vibrated into place using resonant vibration, or “sonic” rigs. The molten wax may be introduced from the surface or from pipes that open on the heated soil volume. Many wastes are disposed in long narrow trenches that have an angled “V” bottom. The heater pipes may be driven into the ground at the waste soil interface to heat the soil under the waste as well as the waste. Molten wax may be introduced into the area below the waste. The molten wax will fill the lower area first. As more wax is introduced, the molten wax fluid level will then rise to permeate and fill the soil and debris within the waste zone.

Molten wax can also be applied by jet grouting methods. In 2004 a grouting project used over 182,436 kilograms, (400,000 pounds) of this molten wax to encapsulate buried radioactive Beryllium reactor blocks at the Idaho National Laboratory.

Figure 1: After 24 hours in Waxfix, capillary action has saturated this rock

Work procedures for grouting with molten Waxfix grout require no fundamentally new technology. All that is required is a method of heating the soil above the melting point of the wax. Heating soil to desorb volatile organic compounds has been done commercially for over 10 years. Closed end pipes are mechanically driven into the ground and electric heaters or steam is used to introduce heat into the ground over a period of weeks or months. Waxfix soil pre-heating does not require as high a temperature as thermal desorbing. Soil pre-heating for wax is slow and limited to less than the boiling point of water so hazards and off-gases are minimal.

After a subterranean soil area is pre-heated to above the melting point of the wax, a simple gravity flow of molten wax can permeate the entire heated volume, forming a waterproof, non-friable mass. The wax will lose heat passing through cold soil so it will not travel far into cold soil, but in the heated zone it can travel indefinitely. A heated volume of soil is essentially gravity-filled like a container. There are no areas missed and all of the grout will remain in the treatment zone. Treatments can be applied at depths over 27.4 meters, (90 feet). The Waxfix molten wax grouts form a slightly sticky and malleable product that is resistant to radiation and biological attack. Neutron capture of wax is similar to cement grouts but special Boron modified wax is also available if needed for criticality control.

Heating soil in a radioactive environment poses special challenges. Holes drilled in rock may require special contamination control procedures. Softer soil formations may permit a pointed pipe to be vibrated or hammered into place. Heating means may then be installed in the inside of the pipe, which is free of contamination. Heat transfer through the pipe and the soil slowly warms the soil around the pipe.

Soil Vault Example

As an example, consider a radioactive metallic waste buried in the bottom 6 meters, (20 feet) of a 1.8 meter, (6-foot) diameter hole 12 meters, (40 foot) deep and above the water table. One or more heating pipes, closed on the bottom end, are driven to depth within the boundary of the original excavated hole. (Holes could also be drilled just outside the boundary if this is preferable.) Electric heaters are lowered into the heating pipes and the soil in the bottom of the hole is heated above the melting temperature of the wax. Each pipe is capable of heating a five-foot radius in rock or soil around it in less than 8 weeks. Using more closely spaced heaters can reduce the required time to heat the soil.

Additional pipes may be driven for use as temperature sensors and liquid level sensors. Molten wax is then introduced into the heated zone filling it from the bottom to the top. The molten wax will flow into all the empty space between the grains of the soil and surround and encapsulate the waste contained within the heated area. If the bottom 3 meters, (10 feet) of this site is within the water table, the molten wax would be introduced from the top of the heated zone. The wax will float on the water and stack up in the heated zone above the water table until the additional hydrostatic head displaces the water back into the lower and surrounding cooler soil. The ability to displace water while wetting all the soil with the molten wax is a key feature of the technology.

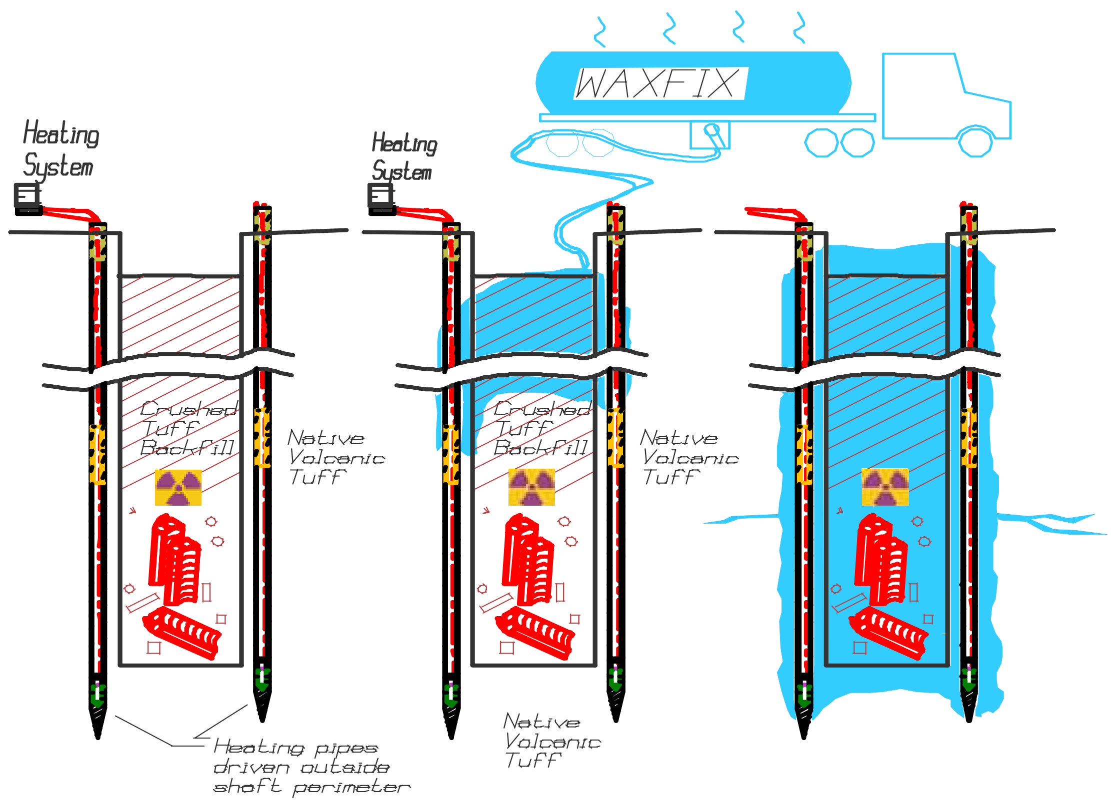

Figure 2: Encapsulating soil vaults

Estimated Contractor costs of the above Soil Vault Procedure are about $100,000, based on mobilization and fixed costs of $50,000 plus variable cost of $2624 per meter, ($800 per foot)of driven heating pipe and $706 per cubic meter, ($20 per cubic foot) of soil volume treated, assuming a 25% void ratio.

Caisson Example

Consider another waste site 9 meters, (30 feet) deep containing a metal or concrete structure 3 meters, (10 feet) in diameter filled with containers of waste. It may be desirable to avoid penetrating any waste containers so the heating pipes could be driven around the outside perimeter of the structure. However at least one fill pipe would be at least partially driven into the interior of the structure so that it may be filled internally to avoid floating the hollow structure. The wax will not permeate intact metal containers but will surround and encapsulate them. Otherwise this method is essentially the same as the above soil vault example except that costs of treated volume of empty void space are about $2,825 per cubic meter, ($80 per cubic foot).

Vertical Pipe Unit Example

This waste form consists of a vertical pipe made from multiple 208 liter, (55 gallon) drums welded end to end. Sealed buckets of Remote handled waste were dropped down these pipes from the surface. Again the procedure requires driving closed end pipes along the outside of the waste structure and then slowly heating the soil to achieve a waste temperature of at least 71 degrees Celsius, (160 degrees Fahrenheit). After heating, the 93 degree Celsius, (200 degree F) molten wax is introduced by gravity flow to the heated area. The entire heated area will fill with molten wax and form a waterproof mass. The finished mass can be excavated by ordinary construction methods because no free dust will remain. All the containers within the pipe will be totally encapsulated. Costs are similar to the soil vault example but fixed cost and pipe driving costs will be less since the sites are relatively shallow.

Infiltration Trench Example

Consider a gravel-filled infiltration trench in a fractured shale and clay formation. Presumably, the idea of such sites was that the water would perk into the formation and leave the radionuclides behind within the trench. These trenches are usually intensely radioactive and so are not candidates for excavation but they also are potential sources of contamination to local creeks. A traditional remedy is to grout with cement grout to stabilize the contamination within the trench. Fracture networks also exist around the trench and these may be grouted with low viscosity acrylamide gel. The acrylamide gel stops water flow but is itself slightly permeable to water and can also shrink if it dries out in a dry season. Grouting these trenches with molten wax will produce a far superior final waste form and is more effective than acrylamide gel in flowing into fractures. Molten wax grouting is not only safer and more controlled, but it is up to 1000 times less permeable than conventional cement grout.

Heating pipes could be driven vertically or horizontally within the boundaries of the trench as well as the surrounding soil that is contaminated. For this example, two rows of these pipes would be driven vertically on 1.6 meter, (6 foot) foot centers down the length of the trench. The Oak Ridge trenches are typically less than 1.6 meter, (6 foot) wide at the top and much narrower at the bottom. Positions of the pipes would try to strike the outside edge of the bottom of the trench. Areas of the native formation that are heated will also become completely filled with wax. Additional pipes could be driven in areas adjacent to the trench that are thought to have fractures. Small pipe can be driven through gravel with relative ease by hydraulic impact drivers. The pipes could also be driven horizontally using direct push directional drilling as shown below. Depending on ambient temperature and moisture, heating may not be required in some cases because the molten wax may carry sufficient heat to treat 50% void gravel zones without additional heat.

After heating the area to be treated, molten wax is introduced into the trench and into the surrounding soil at gravity flow for an extended period. If there is no standing water in the trench, or if the trench can be pumped dry, the molten wax will fill the gravel from the bottom upward and also fill the larger soil fractures first and then fill the porosity of the soil within the heated area.

If the bottom of the infiltration trench is partially filled with water such as was known to occur in trenches at the Oak Ridge National Laboratory. The fill procedure is modified slightly. The wax is injected near the top of the gravel zone and allowed to stack up on top of the now hot water. While continuing the heating process, molten wax is then introduced through a standpipe with just enough head pressure to force the water back into the shale formation, but not enough to allow any leak to reach the surface. The molten wax fills the heated zone beginning at the top. The wax/water interface will slowly move toward the bottom of the trench as the water is displaced back into the ground around and below the heated volume. The molten wax will also follow the water out of the trench for some distance until it cools and solidifies. The hydrostatic head of the wax forces the water to downward and outward into the fractures and permeable portions of the soil formation. The flow of hot water causes the fractures to heat up. These heated fractures and shale laminations are then filled with the super-permeating wax as far as the heated path extends. This filling of the fracture system waterproofs and immobilizes the sorbed contamination on the soil along those fractures.

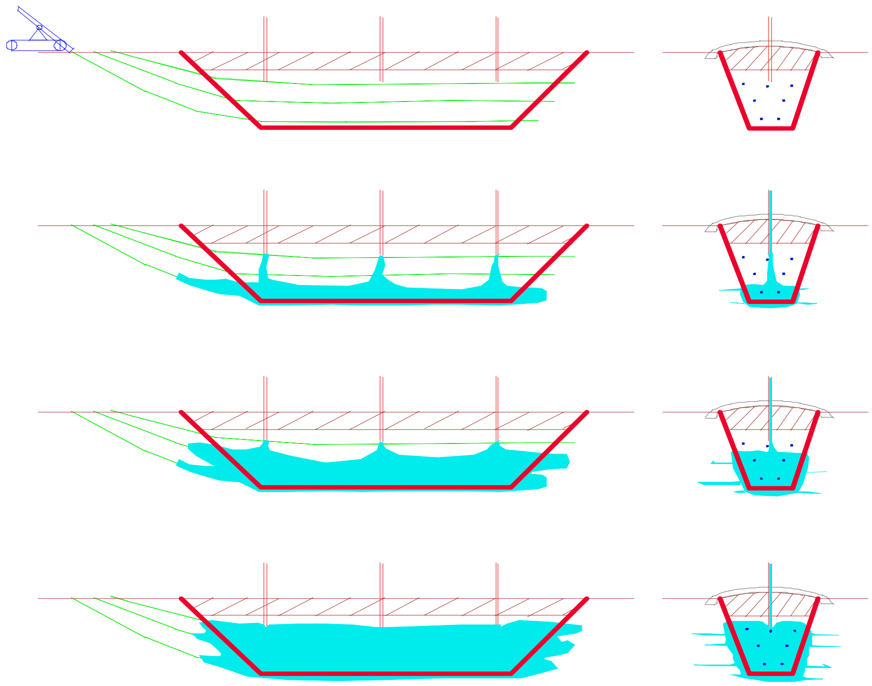

Figure 3: Filling Infiltration trench with molten wax, using horizontal drilling

An infiltration trench at the Oak Ridge National Laboratory that was recently grouted with cementitious grout had a total porosity of gravel of about 50% and total porosity of soil averaging 25%. The trench had a cross sectional area of 6.22 square meters, (67 square feet) and a length of 30.48 meters, (100 feet), has a historical liquid capacity of 189 cubic meters, (50,000 gallons). About half this volume of molten wax would be required to fill all the void spaces and readily accessible fractures in the trench. Cost for molten wax would be $200,000. Contractor cost for installing 304 meters, (1000 linear feet) of driven pipes, heaters, and electrical heating cable and power systems has been estimated at $800,000. These costs compare favorably to the estimated $8,000,000 dollar cost of cement grouting. The wax impregnated material remains sticky and malleable and may be excavated with a larges tracked excavator at some future time, preferably after several half-life's of radioactive decay, without releasing contamination.

Waste Burial Pit Example

Waste burial pits containing radioactive wastes can be very costly to remediate. Excavation of radioactive mixed waste materials and soil may require temporary containment buildings to be constructed over the site and the shear volume of material often dictates that potentially contaminated soil and debris be left or returned to the excavation. Containment methods are more economical but can leave uncertainties about the integrity of the containment. Traditional grouting and even jet methods may not fully encapsulate the waste because cement grout slurries cannot flow through the soil. Burial pits and trenches contain a wide array of waste types and are often poorly documented and randomly dumped.

Molten wax fills the void spaces within the waste and soil so the tighter the soil the less wax is required. Full encapsulation with molten wax is estimated to cost $530 per cubic meter, (15 dollars per cubic foot). While the heating process is relatively slow, the wax infusion process is limited only by the speed of wax delivery. Rail service is the preferred method of delivery but tanker trucks each carrying 26,500 liters, (7,000 gallons) are widely available. A pit 9.1 meters by 15.2 meters by 9.1 meters deep, (30 foot by 50 foot and 30 feet deep) filled to within 2.4 meters, (8 feet) of the surface would cost $495, 000 to fully encapsulate with molten wax. This would be reduced for metal drum waste with intact containers since they would not adsorb any wax.

Molten grout encapsulation works by thermal means and is able to fully permeate all soil and porous waste within the pre-heated area. If left to cool, the waste will be encased in a tough waterproof matrix that will isolate it from groundwater for millennia. However, while the wax/soil/waste mixture remains molten it is also possible to retrieve solid objects such as drums, boxes and hardware. A long reach excavator with a grappling thumb or a sieve rake can reach into the molten area and scoop up these objects and place them in a roll-off box or other container. Many buried waste packages are of sufficiently low density that they will float in molten wax.

When molten wax is poured into heated soil, the soil liquefies and loses cohesion. The unheated areas around the heated zone freeze the wax and increase the strength of the soil. This effect allows a molten wax excavation process to work like a slurry trench and automatically keep the walls from caving in except in the area that has been heated. The face of the excavation that is heated will continually slough off and free up the waste packages. Most of these will float but the heavy ones may be excavated off the bottom of the molten pool. A sensitive gamma detector mounted on the end of the trackhoe may serve to guide the operator in locating remote handled waste.

Molten wax is relatively expensive at about 5 to 8 dollars per gallon in railcar quantities. For a 15.24 x 247 x 9.1 meter size, (50 foot wide by 900 foot long by 30 feet deep) V trench such as the 618-11 trenches at Hanford, only a smaller 12 meter, (40 foot) square area need be a liquid pool during excavation work. This liquid pool would be continually displaced forward with soil bentonite slurry. The top 1.5 meter, (5 foot) of soil is typically clean and may be pulled off leaving a V trench holding a volume of 12742 cubic meters, (450,000 cubic feet). The retrieved waste is drained as it is removed from the molten pool so it requires only a small amount of wax to fill and permeate it. Estimating this as 10% of the original in place volume yields a wax volume requirement of 1274170 liters, (336,600 gallons). The molten pool area will require as much as 30% extra wax. At $1.585 per liter, ($6.00 per gallon) this is $2,625,480. just for wax. The heavy equipment and personnel operations to perform the retrieval work will cost about this much as well. The rest of the molten wax in the excavation may be continually re-used by displacing it forward with a backfill of soil-bentonite slurry made with local soil. The extra 30% of molten wax from the liquid pool may be transferred from one excavation to the next adjacent pit through a shallow trench and re-used if multiple trenches are treated at once. Note that if the waste was encapsulated in situ, 2.5 times more wax would be required because the porosity of soil averages 25 percent compared to the 10% wax retained in drained soil.

Retrievable Buried Waste Example

Molten wax carries a considerable amount of thermal energy and in some cases it can be applied without any pre-heating of the soil. In very dry conditions or when there is a large ratio of void space, the heat carried by the wax may be sufficient to warm the treated areas.

Retrievably stored TRU waste at some dry soil sites such as Laos Alamos consists of low-density boxes and drums stacked in a trench excavated into the dry volcanic tuff and covered with crushed tuff. Conventional grouting methods cannot achieve the required level of encapsulation because they cannot flow through fine grain soil and may miss some spots. With pre-heating it should be possible to produce a near perfect encapsulation with molten wax grout. The retrievably stored waste is somewhat unique in that the weight and size of each package is recorded. Based on an analysis of the waste records, this site has such low-density waste with so many open spaces that it may not require pre-heating to achieve total permeation grouting. The necessary heat can be applied with the wax itself. It is also possible to drive closed end pipes into the material to facilitate placement of electric heating units.

The molten wax will permeated the void spaces in the waste in all the wooden and the unsealed boxes and will also permeate and waterproof the tuff under and around the original excavation traveling as much as a foot into the tuff and sealing any fractures.

Vertical injection pipes will be driven down to the bottom of the trench in several points along the long sides of the trench. The injection pipes will be perforated within in the waste zone.

Molten wax will be gravity flow injected at a rate of up to 1514 liter per minute, (400 gallons per minute) into injection points and temperature probes can monitor the spread of the molten material. The injection points will be moved as needed to allow only the bottom third of the pit to fill with wax. The weight of the waste and soil above will prevent the drums and boxes from becoming buoyant. Pre-heating of the waste will not be required due to the low thermal mass of the waste and the high void ratio.

When the bottom third of the pit is filled, the injection will then stop, until the temperature of the wax falls substantially below the solidification point. At this point, the drums and boxes in the bottom trench will be fully encapsulated and secured against floatation. The wax will permeate a limited distance into the tuff under the waste but cannot travel very far because it loses heat to the tuff. The first 45 centimeters, (18 inches) of tuff under the waste will likely be permeated with wax. Wax permeation makes the tuff highly impermeable and makes it very tough and crack resistant.

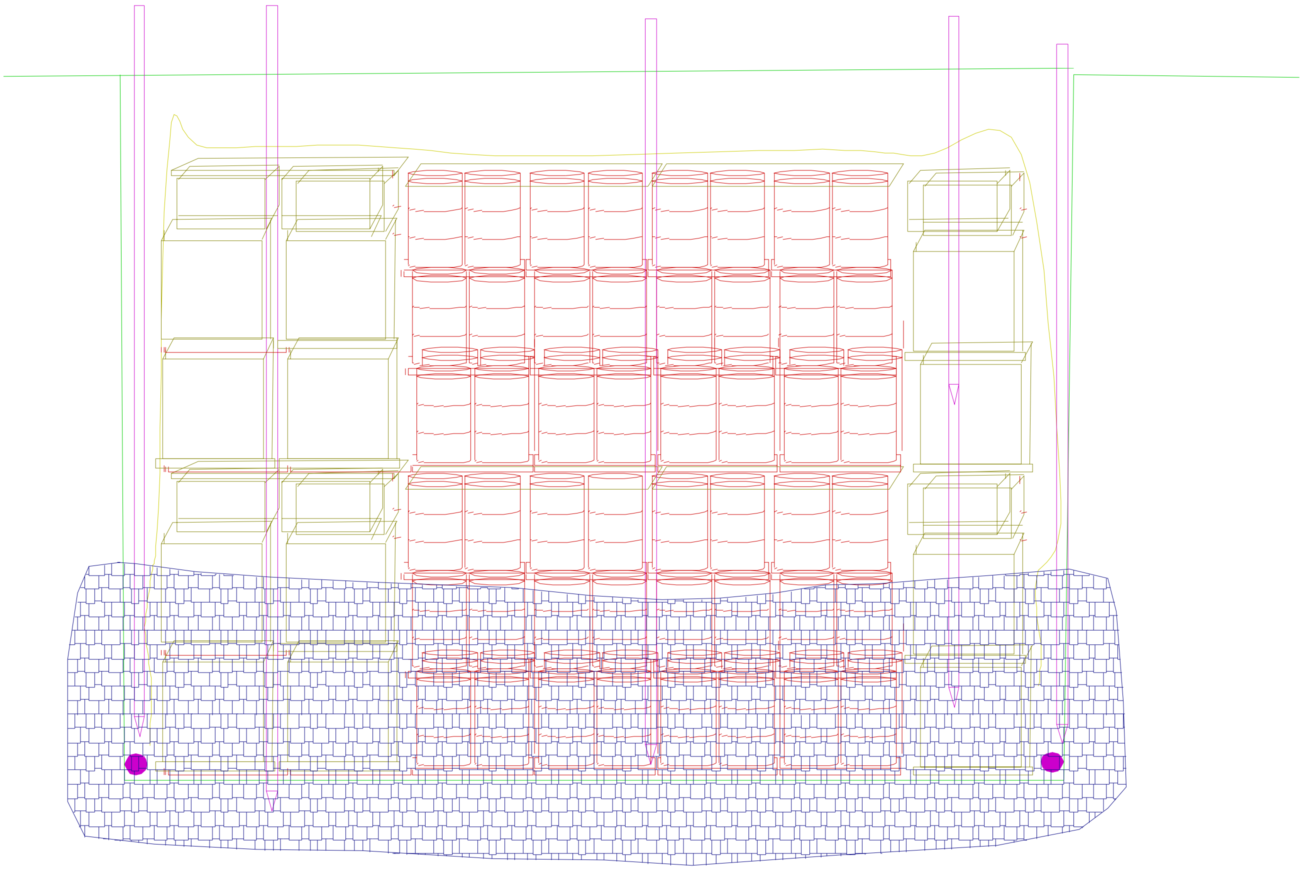

Figure 4: filling bottom third of waste with molten wax

Injection of wax will then continue and fill up the next vertical third of the trench. The wax will migrate easily around the edges of the tarps and will permeate most wooden crates. Holes will be drilled along the locations of the crates and boxes to help assure that they are filled with wax. Temperature probes will again monitor progress of the fill and fill locations will be moved as needed. This second layer will then be allowed to cool to its solidification point.

The final layers of wax may be applied in successively thinner stages to minimize buoyancy. The shallow ditch along the long sides of the pit will provide pressure relief and collect any excess fill to prevent it from coming to the surface randomly. It also provides a clean sampling point if future generations wish to evaluate the properties of the aged wax. After the wax has cooled, the injection pipes will be cut off at grade and the relief ditch will be filled. A cap may then be installed. If future retrieval is ever desired, heating probes may be driven into the monolith.

After the final stage is filled, the wax fill pipes may be cut off flush and capped.
The entire process is requires a fraction of the man-hours of an excavation-based remedy.

The final waste form is waterproof and will also extend at least a foot into the volcanic tuff along the sides and bottom of the original excavation. The material is quite firm but could be easily excavated with a trackhoe if it ever became necessary.

If the above pit had a waste volume of 3822 cubic meters, (5000 cubic yards) with an average accessible porosity of 50% it would require 1,911,633 liers, (505,000 gallons) of wax. At $1.585 per liter, ($6.00 per gallon) this would be a little over three million dollars ($3,030,000) for about 75 truck loads of wax. Using a rate of $2624 per meter, ($800 per linear foot) of driven pipe and 122 meters, (400 feet) of pipe yields $320,000 in setup costs. Total cost is 3,350,000.