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THE INITIATIVES OF THE LOS ALAMOS SCIENTIFIC LABORATORY IN THE TRANSFER OF A NEW EXCAVATION TECHNOLOGY

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ABSTRACT

The Los Alamos Scientific Laboratory is operated by the University of California under contract to the Atomic Energy Commission and its charter requires that the technical facilities and staff be capable of a broad range of activities ranging from basic science to the design, fabrication, and testing of intricate systems and devices. Research activities on metal and graphite core nuclear propulsion reactors (AEC/NASA Rover Program) resulted in significant high temperature materials science technology developments. These capabilities were recently applied to excavation technology through the introduction of a rock-melting penetrator system. Rock melting was recognized as an innovation that simultaneously attacks the three major problems of excavation, namely rock fracturing, debris removal, and wall stabilization, with an inherently integrated system. The technology transfer efforts of the laboratory have been aimed at commercial producers and users of excavation equipment as well as customers for excavations. Initiatives in the technical area have included solicitation of industrial input, industrial participation through staff exchange and joint ventures, industrial and academic input through the formation of advisory panels, and the publication of numerous technical reports and papers. Initiatives to inform the commercial sector and the public of the potential usefulness of rock melting have included public demonstrations, permanent and temporary displays, and visits and talks with all segments of society and commerce. ~~The paper details~~ LASL's experience in these technology transfer initiatives and in disseminating technological achievements which result from federally funded R&D projects are detailed.

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INTRODUCTION

The expertise of the Los Alamos Scientific Laboratory as a research and development organization is internationally recognized as a result of its many diverse accomplishments since its beginning in 1943. Its origin in a time of crisis in World War II, and its isolation at that time, required that the technical facilities and staff be capable of a broad range of activities ranging from basic science to the design, fabrication, and testing of intricate devices. By engaging in fundamental research activities in many fields, the Laboratory has achieved the ability to utilize quickly and efficiently the results of basic research conducted throughout the free world. It was also important, from its earliest years, for Los Alamos to encourage full exchange of technical information among its staff so that the results of basic research could be translated into completed and tested systems. The Laboratory is operated by the University of California under contract to the Atomic Energy Commission and has assumed a broad spectrum of responsibilities in major AEC programs and those of other government agencies. Since the completion of the wartime assignment to develop, test, manufacture, and provide a nuclear device, the largest single programmatic activity has been nuclear weapon development. With this defense oriented posture, providing the widest practical and appropriate dissemination of information concerning its activities and results has not typically been a problem.

THE TECHNOLOGY

Subterrene Design and Operating Concepts

The Subterrene is a system, invented and patented by Los Alamos scientists, for making vertical or horizontal holes in rocks and soils by progressive local melting.[1] Most rocks, including the very hard igneous rocks which are particularly difficult to penetrate mechanically, melt at temperatures far below the melting points of refractory metals such as molybdenum and tungsten. The rock melt produced can be chilled to a glass and formed into a dense, strong, firmly attached hole lining that is clearly discernible in the sample shown in Fig. 1. Thus, by the use of a melting penetrator, permanently self-supporting holes can be made even in unconsolidated sediments. The energy utilized to form a hole of a particular size and line it with rock glass is estimated to be greater for a Subterrene than for a conventional rotary drill, but this should be more than balanced by savings in material, labor, and operating costs.

The general principle of Subterrene operation can be explained with the aid of a simplified sectional drawing shown in Fig. 2. The smooth-faced penetrator, which plays the role of the drill bit, is made of a refractory metal and heated electrically by means of a pyrographite resistance-heating element. Thermal energy is transferred from the heater to a graphite thermal receptor by radiation and is then distributed throughout the penetrator by conduction. The heated portion of the device is thermally insulated from the stem advancing section by a layer of a special pyrolytic graphite.

In operation the hot penetrator is forced into the ground by exerting a downward thrust on the stem. The surrounding rock is melted and the thrusted penetrator forces the liquid rock-melt outward around the penetrator and stem where it is cooled. The melt then freezes to form a hard, obsidian-like glass lining on the wall of the hole, sealing and supporting it. The operation just described is that of the "melting-consolidating" type of Subterrene penetrator designed especially for making holes in porous rock or soft ground. Because the glass-lining formed when the rock-melt solidifies is more dense, and hence occupies a smaller volume than did the original porous rock, the molten debris from the hole can be entirely consolidated in the dense glass lining thus completely eliminating the debris removal operation necessary in conventional drilling techniques.

Holes in dense rock are produced with a "universal extruding" Subterrene which can also be used in porous rocks to make holes with a thinner glass lining. The essential structural difference from the melting-consolidating design is that the heated penetrator is not a solid conical body but has the form of a ring or torus with a small hole in the center as shown in Fig. 3. Part of the rock-melt is forced upward and outward and upon cooling forms the hard glass-like lining of the hole. Most of the melt, however, is forced up through the central hole in the penetrator into what is called the "extrusion zone". In the upper part of this zone the melt is cooled and solidified; the extruded solid debris is then carried to the surface by the cooling gas flow.

Special Features and Potential Applications of the Subterrene

With the Subterrene concept the three major facets of excavation, namely, rock fracturing, debris removal, and wall stabilization, are attacked in a single integrated operation. In loose or porous formations the debris removal operation is eliminated by density consolidation. Another unique advantage of the Subterrene system concept is that the holes are automatically lined with a hard glass-like material. It may thus be possible to eliminate the costly and time-consuming procedure of inserting and cementing metal casings typically associated with wells drilled with rotary bits.[2]

Studies made at Los Alamos combined with a survey of potential users in industry have revealed a large number of potential applications of the Subterrene. The system's inherent ability to make holes of precise diameter could be utilized in producing holes for anchoring structures such as bridges, TV towers, and transmission line towers. Emplacement holes for anchoring pipeline supports could be readily melted in difficult materials such as Alaskan permafrost. Loose gravel and other unconsolidated formations are difficult to drill and stabilize with conventional rotary equipment. The Subterrene, which would leave a glass-lined hole, provides a solution to this difficulty. Conversely, hard abrasive rocks can also be penetrated because the melting temperature, not the hardness or abrasiveness, determines the usefulness of the Subterrene.

From the viewpoint of the energy research and development programs at Los Alamos, two potential uses are of special interest. The first involves melting holes in hot rocks for the extraction of geothermal energy. Since the penetration of the Subterrene depends on the melting of the rock, the high in situ temperatures will be beneficial in saving thermal energy and increasing the penetration rate. The second is related to the LASL program for developing underground superconducting transmission lines for electrical power. At present, such lines would have to be laid in trenches which could only be dug with considerable environmental disruption. With a Subterrene, however, horizontal holes could be melted with a minimum disturbance of the ground surface.

ORIGIN OF THE TECHNOLOGY

During the past decade many innovative and ingenious ideas related to improving drilling technology have been proposed and investigated. While rock has been drilled and fractured with everything from laser beams to artillery cannons, little impact has been made on the primary method of rotary drilling. Since the drilling of wells still employs the basic technology of many years ago, the motivation for the technologist to look at other ways to make deep holes in the earth's crust is high.

The basic notion of developing an excavation tool based upon the melting of rocks and soils was generated by the need for very deep drilling as proposed in the original Mohole Project. The rock melting idea recognized that very deep in the earth extremely high temperatures - approaching rock melting points - would be encountered. Therefore a tool that formed the borehole by melting could uniquely solve this problem. The refractory materials and thermal engineering expertise that have been brought to bear on the subsequent R&D effort were spun-off from the AEC-NASA nuclear rocket propulsion program (Rover) which originated at LASL. In fact, the idea of electrically heating refractory metal penetrators came directly from an experimental heat transfer apparatus in which the fission heating of nuclear fuel elements was simulated by electrical resistance heating. The experience in thermal and mechanical design of such components is directly related to the analysis and testing of high temperature rock-melting penetrators. Research activities on metal and graphite core nuclear propulsion reactors for the Rover Program resulted in significant high temperature materials science technology developments. Of particular importance were the development and property determinations of specialized nonisotropic graphite composites currently used for heating elements and insulators in Subterrene penetrators.

DISSEMINATION OF THE TECHNOLOGY

It has been stated[3] that the dissemination of technical information is not identical with technology transfer. Not only is it possible, but in many cases even probable, that vast amounts of technical material can be disseminated without ever achieving a marriage between the problems of the users and the proposed technological solutions. Despite this obvious pitfall, what technologist with a potential solution to an existing problem would not begin the arduous task of technology transfer by advertising his system by word of mouth and written documents? It appears abundantly clear that the technologist must take the initiative in this matter. His task is to clearly delineate the problem areas, establish a definite need for his product or system, and then rise to the occasion of educating and persuading the decision makers into accepting his solution.[3]

For the general field of drilling and excavation technology, clearly delineating some of the major problem areas was a straightforward task. To name only a few, the following problems seemed significant:

- High costs associated with geothermal energy drilling.
- High costs associated with drilling deep wells, particularly as a result of trip time spent making downhole equipment changes.
- Hole stability problems in weak caving ground.
- High cutter costs and low lifetime when boring in very hard abrasive rock.
- Maintaining a sustained advance rate when boring in wet and variable loose ground.

Armed with data such as that depicted in Figs. 4 and 5, the first part of the case is prepared. Establishing a definite need for the new product or system is usually construed to mean having a design, perhaps even a working laboratory or field scale demonstration model, that offers a technological or economic incentive to the user in one or more of the significant problem areas. The technologist is now faced with the problem of educating and persuading the decision makers into accepting his solution. The first major step in this latter problem is often faced squarely in preparing a technical proposal for research and development work to a likely funding agency. Success in this endeavor, however, only qualifies one to undertake the real challenge of technology dissemination and transfer.

The technology dissemination efforts expended by members of the Subterrene program at Los Alamos have been extensive in both scope and depth. Approximately 40 technical papers and reports have been written by the project staff on all phases of Subterrene activities for distribution and presentation at various technical society meetings. These reports continue to be in demand and are forwarded to all interested organizations and individuals. The Subterrene was featured on the front covers of the June 1973 issue of "Mining Engineering" and the July 1973 issue of "Water Well Journal". Both issues contained accompanying articles. An article entitled "Subterrene Rock Melting Devices" was prepared at the request of the editor of "Tunnels and Tunnelling" magazine and appeared in the January-February 1974 issue of this internationally distributed publication. This publication is also the news outlet for the British Tunnelling Society. In conjunction with the application of rock-melting techniques to large diameter tunneling machines, all major U.S. tunnel-boring machine manufacturers were visited and briefed on the Subterrene concept. Technical comments and suggestions from their engineering staffs were utilized as guidelines in the conceptual study of a Nuclear Subterrene Tunneling Machine.

Technical briefings presented to interested individuals and groups by the Subterrene staff continue at the rate of about ten per month. Interested individuals and groups include members of the United States Congress, representatives of major industrial concerns, representatives of the armed forces, utility and power distribution specialists, drilling and oil-field specialists, University professors, professional engineers, and college students. For use at meetings which cannot be attended by a member of the technical staff, a short documentary color film on the Subterrene concept has been produced with narration via cassette tape.

Recognizing the importance of industrial participation and the desire for joint ventures, discussions held with Westinghouse Corp. led to an Industrial Staff Member being assigned to the LASL Subterrene project. In addition, a Technology Advisory Panel was structured and formed with the following initial membership:

- Chairman - A person with broad engineering experience.
- One member from a Federal Agency with interest and responsibilities in tunneling and excavation.
- A University professor from a civil, mining, or geological engineering department with well-recognized expertise in excavation technology.
- An economist with expertise in excavation technology.
- Three representatives from related industries.

The function of this panel is to overview all aspects of the Subterrene Program and provide balanced technical input and guidance on program direction, goals, technical achievements, significant shortcomings, and technology transfer efforts directed toward ultimate commercial utilization. To provide specific assistance in the area of the geological sciences, a Geosciences Advisory Panel has been formed which meets periodically at Los Alamos and addresses those issues which may have a significant impact on the technical success of the Subterrene.

Initial impact in the area of public demonstrations has been achieved through the use of a mobile Subterrene field-demonstration unit which performed successfully before several groups in Washington, DC. The demonstrations were held at the U.S. Army's Engineering Proving Grounds quarry area at Fort Belvoir, VA. Among the estimated 300 persons who attended one of the four scheduled demonstrations were representatives from Congress, U.S. Government agencies, the news media, equipment manufacturers, and excavation firms. A similar demonstration was conducted shortly thereafter at the Denver Federal Center in Denver, CO.

Direct assistance in identifying potential application areas for Subterrene technology was sought from Government agencies, Universities, industrial firms and industrial research centers through the mechanism of a survey applications letter. Portions of this letter are reproduced below:

> *"One of our tasks is to prepare an initial report on potential applications of rock melting for the practical problems of tunneling, excavating and hole boring.*
>
> *Therefore, we are attempting to survey those companies with well-recognized capabilities in the successful application of present-day excavation technology. We are particularly interested in the ways in which a potential rock-melting device might complement or supplement current equipment or methods. We are also interested in soliciting the ideas for applications relative to the practical needs of the manufacturer, contractor and engineer.*
>
> *We would greatly appreciate the cooperation of your organization in advising us of any applications that rock melting may have for your present excavation operations, or for planned projects".*

In addition to the specific suggestions and reservations that were received as a result of this survey letter, the Subterrene staff became convinced through numerous discussions, letters, and phone calls, that the contacts shared two almost universal responses to the rock-melting concept:

- The idea was recognized as a total-systems approach to the problems of drilling and tunneling and not as just another means of breaking rocks.

- Although the approach was at first considered radical by many pragmatic-minded excavation practitioners, their reactions were almost always positive and even enthusiastic. Support for continued development of the technique was nearly unanimous.

TRANSFER OF THE TECHNOLOGY

If the technologist had the same aptitude in adopting the correct marketing posture as he possessed in providing the technical stimulus for innovation, the challenge of the technology transfer task would be greatly reduced. Providing the essential ingredients for the marriage between his technological output and the cravings of his customers is often an unrecognized task of first magnitude. With regard to technology transfer and the petroleum industry, Brown[4] has stated that overcoming existing barriers with new technology will only take place if it offers advantages which can ultimately be translated into more efficient operations. The petroleum industry, like many other large industries, justifiably prides itself on its self sufficiency and competence and therefore resistance can be expected if anyone outside their confines starts telling it how to get the job done.[4]

The first significant step in the Subterrene technology transfer program occurred when eight water drainage holes were melted with a field demonstration unit at the Rainbow House and Tyuonyi archaeological ruins at Bandelier National Monument in New Mexico in cooperation with the National Park Service. By utilizing a consolidation penetrator, the required glass-lined drainage holes were made without creating debris or endangering the ruins from mechanical vibrations. Specifically, this operation has shown the following:

- Subterrenes can be operated successfully under field conditions and in areas remote from the laboratory.
- The consolidating penetrator can make its way through alluvial formations containing some moderately sized basaltic rocks by thermally fracturing the rocks and forcing the melt into the surrounding soil through the cracks.
- The Subterrene rock-melting unit was turned over to the National Park Service (NPS) after completion of the first five holes at Bandelier and after suitable training of NPS personnel. The NPS subsequently melted three more holes with minimal LASL supervision.

A Subterrene field demonstration unit was sent to the city of Tacoma, WA to participate in their Technology Transfer Field Days Demonstration at their request. After performing for the general public, the unit was viewed and operated by personnel associated with underground utility emplacements. Such demonstrations, particularly when they involve the production of useful holes by nonlaboratory work crews, are felt to be significant advances in the technology transfer arena. A brief summary of these activities is presented in Table I.

This technology is still facing, however, some of the difficult questions which arise in disseminating technological achieve-

TABLE I

LASL INITIATIVES IN TECHNOLOGY DISSEMINATION AND TRANSFER

DOCUMENTATION	BRIEFINGS	ADVISORY PANELS	DEMONSTRATIONS
LASL Reports	Technical Society Presentations.	Technology Advisory Panel	Rock Melting Demonstrations for Visitors at LASL
Technical Society Reports	All Interested Visitors to LASL	Geosciences Advisory Panel	Washington, DC Field Demonstrations
Extensive Mailing List for Reports	Visiting Lecture Tours	Industrial Staff Members	Denver Federal Center Field Demonstrations
Applications Survey Letters	Prospective Funding Agency Briefings	National Science Foundation Program Managers	Tacoma, WA Technology Transfer Field Days
Journal Covers and Articles	Major Tunnel-Boring Machine Manufacturers	Internal LASL Staff Reviews	Drainage Holes at Bandelier National Monument
Subterrene Film			
Replies to Industrial Inquiries			

ments which result from federally funded R&D projects. In particular, the areas of patents and exclusive licensing agreements are paramount. The current concept of granting "non-exclusive" licenses to stimulate commercialization of government patented technology is generally unacceptable to industry and under this procedure government owned patents by the thousands lie dormant. Unused government patents constitute more than just a simple waste of valuable resources since their very existence can exert a significant negative influence on those private sectors which might be qualified to exploit the covered technology for profit.[5] It is not difficult to comprehend why few commercial firms are interested in investing their funds or developing a market for items whose patent rights they do not control, since subsequent competition could get unfair advantage of this initial investment "for free". A postulated solution might consist of granting exclusive licenses for defined purposes within the patent, each with a specific performance clause, and including protection for subsequent government use, for any particular government patent.[5] The intended payoff to the government and the taxpayers that financed the R&D would be the timely and effective injection of the technology into the U.S. economy.

The impact of this patent problem on new technology has been illustrated in the Subterrene program. What has appeared to be keen interest on the part of industrial organizations has slowly ebbed away in light of their inability to obtain any form of exclusive licensing or protection of their proposed investments. An exception appears to be the formation of a company called Subterrene Systems, Inc. which intends to produce commercialized rock-melting penetrator components. This problem has been encountered from the proposed development of special purpose rock-melting penetrator assemblies for use by commercial organizations down to the acquisition of an industrial staff member to work at LASL, the donating organizations demanding some protection of their investment. While the solution of this problem lies outside the realm of the technologist, its eventual outcome has a significant impact on his ability to complete his technology transfer task.

In conclusion it appears that all of the preliminary steps in achieving the transfer of a new technology have been accomplished by the Subterrene staff. The technical needs were identified in depth, the applicable aerospace technology was directed toward the development and testing of a new system, and a vast program in technology dissemination was implemented. To consumate the marriage, however, a large scale commercial utilization of the technology is required.

ACKNOWLEDGEMENTS

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REFERENCES

1. R. J. Hanold, "Rapid Excavation by Rock Melting - LASL Subterrene Program", Los Alamos Scientific Laboratory Report LA-5459-SR, November 1973.

2. D. L. Sims, "Melting Glass-Lined Holes: New Drilling Technology", Petroleum Engineer, July 1974.

3. W. H. Pickering, "Some Practical Considerations in Technology Transfer", *Space Technology Transfer to Community and Industry*, Science and Technology Series, Volume 29, 1972.

4. W. E. Brown, "Aerospace Technology and the Petroleum Industry", *Space Technology Transfer to Community and Industry*, Science and Technology Series, Volume 29, 1972.

5. Private communication from W. W. Long.

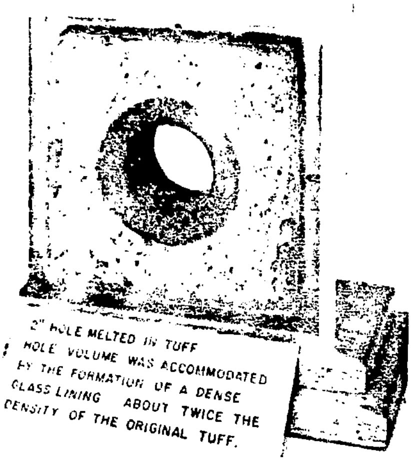

Fig. 1. Cross section of Subterrene melted hole in tuff showing thick rock-glass lining.

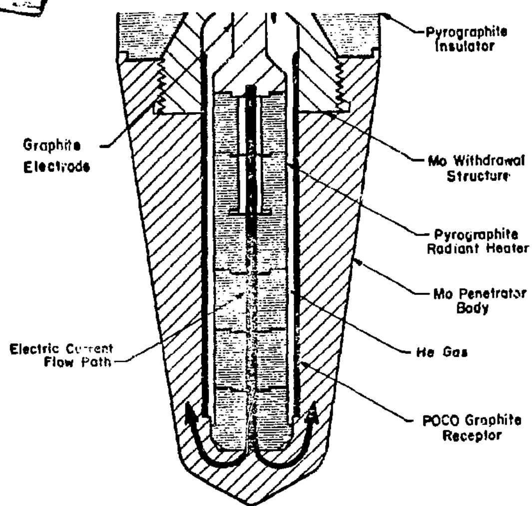

Fig. 2. Cross section of a melting consolidating penetrator design.

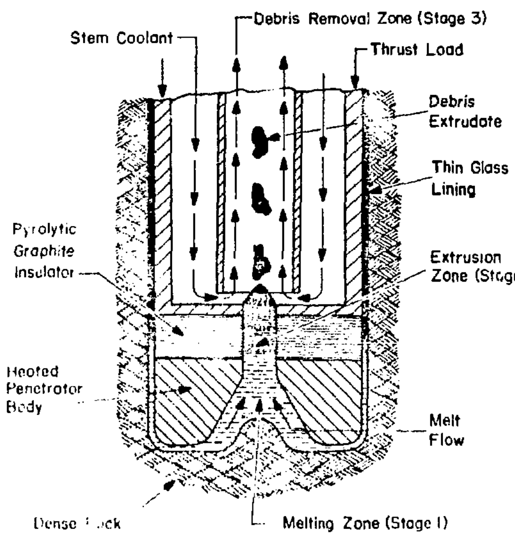

Fig. 3. Universal extruding penetrator concept.

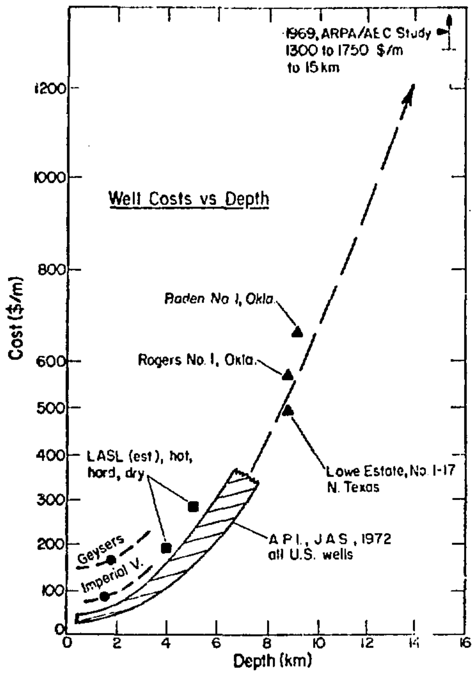

Fig. 4. Well costs as a function of depth.

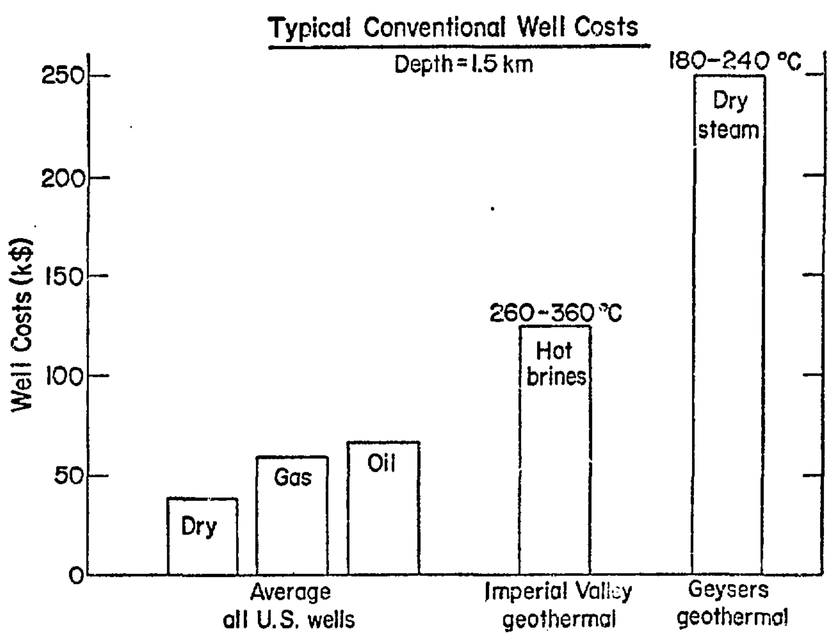

Fig. 5. Typical well costs for different applications.