

**National Advanced Drilling
and
Excavation Technologies Program**

**Summary of Second Meeting
of
Interested Federal Agencies**

June 15, 1993

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National Advanced Drilling and Excavation Technologies Program

Summary of Second Meeting

of

Interested Federal Agencies

The second meeting of Federal agency representatives interested in the National Advanced Drilling and Excavation Technologies (NADET) Program took place on June 15, 1993. The Geothermal Division of the U.S. Department of Energy (DOE) hosted the meeting at the Washington, D.C., offices of DOE. Representatives from the National Science Foundation, U.S. Geological Survey, U.S. Bureau of Mines, National Institute of Standards and Technology, National Aeronautics and Space Administration, Environmental Protection Agency, and various offices within the Department of Energy attended. For a complete list of attendees see Attachment A.

The purpose of the meeting was: (1) to cover the status of efforts to gain formal approval for NADET, (2) to brief participants on events since the last meeting, especially two recent workshops that explored research needs in drilling and excavation, (3) to review some recent technological advances, and (4) to solicit statements of the importance of improving drilling and excavation technologies to the missions of the various agencies. The meeting agenda is included as Attachment B.

John (Ted) Mock, Director of the Geothermal Division, opened the meeting by welcoming all the participants and briefly outlining the agenda.

After initiating introductions around the room, **Allan Jelacic**, Geothermal Division, briefly reiterated the purpose of the meeting. He mentioned three recent efforts: NADET planning efforts by the Massachusetts Institute of Technology (MIT), the National Research Council (NRC) feasibility study of advanced drilling technologies, and the Geothermal Division's poll of industry's interest in NADET.

Carl Peterson, MIT, presented an update of progress by MIT's steering committee in developing the planning basis for NADET. He pointed out the deteriorating U.S. share of the \$1.6 trillion world market in mineral production. He emphasized that regaining competitiveness through technology development programs will require meaningful industry involvement. In addition to the detailed, formal proposal and summary being developed by the steering committee, he proposed a letter from the president of MIT to Vice President Gore to solicit the Administration's support for NADET. A draft summary of the NADET proposal is presented as Attachment C.

Allan Jelacic then presented the results of the Geothermal Division's poll of industry's interest in participating in NADET. Of approximately 400 drilling and excavating firms surveyed, about 25 percent responded. Fifty-seven firms offered tangible support ranging from financial contributions to research personnel and facilities. The majority of the respondents were from

the geothermal and oil and gas industries, rather than mining or excavating, but the results may have been skewed somewhat by the selection process for the poll. The results of the poll are depicted graphically in Attachment D.

In response to a question from Kevin Crowley of the National Research Council, Dr. Jelacic indicated that the poll did not include environmental firms.

The National Research Council's (NRC) recent Workshop on Advanced Drilling Technologies was summarized by **Peter Smeallie**. The Geothermal Division had asked the NRC to examine and evaluate the technical feasibility of advanced drilling and related technologies and concepts in order to identify research opportunities and make recommendations on research objectives and strategies in these areas. The workshop was conducted to elicit ideas and commentary from experts **Kevin Crowley**, also of the NRC, reviewed state of the art drilling and excavation technologies and described the workshop. Further information on the Council's evaluation and workshop is included in Attachment E.

Mehmet Tumay, National Science Foundation (NSF), and **Basil Dendrou**, ZEi/Mi Inc., reported on the recent (April 28-30) workshop on "Research Needs in Automated Excavation and Material Handling in the Field," sponsored by NSF, National Institute of Standards and Technology, and the Federal Highway Administration (FHWA). The purpose of the Workshop was to gather selected researchers and practitioners to exchange information and ideas on how automated construction and excavation can benefit the civil infrastructure. The objectives of the workshop were to review state of the art in automation technologies, identify promising application areas, and to recommend research programs in these areas. Details of the workshop are presented in Attachment F.

Dean Stucker from DOE's Office of Civilian Radioactive Waste Management reported on the new Dual-Wall Drilling and Coring System developed as part of the Yucca Mountain Site Characterization Project. To gain a thorough understanding of the "undisturbed" geologic conditions at the site, sampling requires completely dry, continuous coring while leaving the borehole as close to in situ conditions as possible. This need prompted development of the LM300, a dual wall drilling and coring rig based on dual wall coring technology from mining industry. The purpose of the dual wall is to protect the coring assembly from borehole failure and to protect the borehole wall from contamination from cuttings and air used as drilling fluid. The system was highlighted in a video shown during the meeting.

Marshall Reed, a staff member of the Geothermal Division, presented information on the Pulsed-Laser Water Jet, a new concept in hard rock mining under development by Interpro of Golden, Colorado. The concept involves pulsing a laser up to 2,000 times per second through a water jet focused on a rock face. The laser pulses and water jet combine to excavate rock through a variety of mechanisms: vaporization, resonance, shock wave propagation, cyclical loading, and high-pressure water jet. Attachment G contains additional information on this new technology.

Allan Jelacic then asked the participants for indications of interest and statements of support for the NADET initiative.

William Luth, DOE Office of Energy Research, expressed interest in collaborating with other

agencies in the NADET initiative and stated he had proposed funding in the FY 95 budget.

Ralph Avellanet, DOE Office of Fossil Energy, stated his office is primarily interested in recovery of oil at depth rather than drilling, and that they are assessing to what extent they might participate in NADET.

Albert Yost, DOE Morgantown Energy Technology Center, expressed interest in the program and said that his office would provide some seed money for FY 95. He promised to send a written statement of interest the following week.

David Biancosino, DOE Office of Environmental Restoration and Waste Management, briefly stated that his office was interested in improving horizontal drilling and in developing casing materials resistant to melting at high temperatures.

Dean Stucker stated that he would be prepared to submit a formal statement of interest/support from the Office of Civilian Radioactive waste Management at a later date.

Mehmet Tumay, expressed NSF's interest in underground space as it relates to civil infrastructure. He also expressed support of the NADET initiative and stated the possibility of including it in the FY 95 budget.

The representative from the National Institute of Standards and Technology, **Steven Glaser**, stated that his organization does not fund research, but that they were interested in participating in NADET.

Mike Jenkins, U.S. Bureau of Mines, stated that his organization is primarily concerned with excavation although they may become more interested in drilling as a means of mining through wells. He said his organization would like to provide some seed money for NADET in FY 95, but they would like to tie what they are already doing into the NADET program.

Mehmet Tumay suggested that a single supporting document be drafted which all interested agencies could sign, and **William Luth** suggested it would be preferable for each agency to submit unofficial statements of support.

Peter Smeallie suggested the NADET might best be managed as an interagency confederation under the auspices of the National Academy of Science.

Allan Jelacic agreed to give some thought to drafting a single document which all interested agencies could sign as an indication of their support of NADET, but at the same time asked each agency representative to consider preparing individual statements of support.

Ted Mock closed the meeting by thanking everyone for coming and urging everyone to keep the information flowing, especially as budgets are formulated.

Attachment A

National Advanced Drilling and Excavation Technologies Program

Second Meeting of Interested Federal Agencies
June 15, 1993

Participants:

Department of Energy - Geothermal Division

John "Ted" Mock
Allan Jelacic
Marshall Reed
Raymond Fortuna
Gladys Hooper

Department of Energy - Other Offices

Ralph Avellanet, Fossil Energy
David Biancosino, Environmental Restoration and Waste Management
William Luth, Engineering and Geosciences
Dean Stucker, Civilian Radioactive Waste Management
Albert Yost, Morgantown Energy Technology Center

Department of Commerce

Steven Glaser, National Institute of Standards and Technology

Environmental Protection Agency

Steve Souders

Massachusetts Institute of Technology

Carl Peterson, Department of Mechanical Engineering

National Academy of Science

Peter Smeallie
Kevin D. Crowley
Dev Mani

National Aeronautic and Space Administration

John D. Rummel

National Science Foundation

Mehmet "Matt" Tumay, Geomechanical, Geotechnical, and Geo-Environmental Systems
Basil Dendrou, MEi/Zi Inc.

U.S. Bureau of Mines

Mike Jenkins, Research Office

U.S. Geological Survey

Ray Wallace

Attachment B

National Advanced Drilling and Excavation Technologies Program

Second Meeting of Interested Federal Agencies

June 15, 1993

Hosted by
Geothermal Division
U.S. Department of Energy

10:00 am	Registration - Room 8E-809 Forrestal Building 1000 Independence Ave., SW	
10:15 am	Welcome	John Mock Department of Energy
10:20 am	Update of activities concerning the NADET Program	Allan Jelacic Department of Energy
10:30 am	Summary of National Research Council Workshop on Advanced Drilling Technologies	Peter Smeallie National Research Council
10:45 am	Summary of Federal Workshop on Research Needs in Automated Excavation and Material Handling in the Field	Basil Dendrou ZEi/Mi, Inc.
11:00 am	Recent Advances in Novel Drilling and Excavation Technologies: - Air Coring System at Yucca Mountain - Pulsed Laser Water Jet Excavation Tool	TBD
11:30 am	Drilling and Excavation Needs of Federal Agencies	Agency Representatives
12:00 pm	Closing Remarks	John Mock

Attachment C

Massachusetts Institute of Technology
Energy Laboratory

Carl Peterson *et al.*
Revised June 14, 1993

DRAFT Summary

A Proposed National Program for Advanced Drilling and Excavation Technologies

Need

Drilling and excavation are basic operations in the construction, energy, minerals, and environmental restoration industries. These industries provide the raw materials for the world's industrial economies and the facilities of modern civilization. Historically, they have been major contributors to worldwide commerce and employment. In 1991, the total value of world crude mineral production is estimated to have been about \$1.6 trillion (current dollars), with refined production (i.e., raw metals, fuels, etc.) more than double that amount. Annual expenditures on civil underground facilities are estimated in the range of \$1.8 to \$2.7 billion worldwide, while oil and gas drilling (on- and off-shore) consumes about \$50 to \$73 billion per year. In the future, these markets will expand as world population increases, as urban areas become more congested, and as improved standards of living push up demand for materials. Thus, future markets for drilling and excavation technologies will be substantial; but if we are to protect the environment while satisfying these increasing demands, we will need substantially better methods and technologies.

The United States may not benefit from that market expansion. During the first half of this century, U.S. entrepreneurs commanded a major share of worldwide markets with leading technologies in drilling and excavation equipment and operations. But by the early 1980's, U.S. competitiveness in global and even domestic drilling and excavation markets had deteriorated substantially. Increasing market shares were captured by superior foreign technologies, which were often the result of government-assisted consortia programs.

The benefits of serving as the world supplier of a new generation of leading technologies would be great. The U.S. could participate in construction projects around the world and in the production and distribution of raw materials wherever they are found. Demand for U.S. goods and services abroad would increase, foreign incursions into domestic projects would be curtailed, and the economic future of our own declining raw material reserves would be extended.

Successful development of advanced drilling and excavation technologies would ensure the nation's participation in a host of critical and growing

industries, helping to restart an important engine for U.S. economic prosperity and international competitiveness. Given this opportunity, the time to begin the necessary research and development is now.

Program Concept

To meet this opportunity, we propose a *National Program for Advanced Drilling and Excavation Technologies* that will focus on critical research and development and on timely commercial application of the technologies that result. The proposed program is committed to four overall goals:

1. creation of a new generation of advanced, environmentally sound drilling and excavation technologies by the year 2000,
2. major growth in employment in the U.S. drilling and excavation industries,
3. recapture of leadership and market share in world drilling and excavation technology by U.S.-led enterprises by the year 2005, and
4. creation of a cooperative industry structure and a continuing research program to sustain that leadership against foreign competition.

The proposed program is centered on technology rather than on specific industries. Advances in drilling and excavation will benefit many industries. By focusing on the technology, the *National Program* can provide opportunities for technical cross-fertilization and cooperation among these diverse industries while simultaneously eliciting broad public support. The program will focus on total *system development* to assure that promising technologies are brought together in workable systems that are commercially attractive and compatible with current practices where necessary. The technical scope will range from basic and applied research to full system design and demonstration. Specific contributions of the program include

- lower costs and greater speed for much-needed infrastructure expansions,
- lower costs and extended economic life for domestic energy and mineral production,
- better systems and equipment for environmental remediation and safe waste storage at reasonable cost, and
- minimum adverse environmental impacts from drilling, mining and construction projects.

Participants

The proposed program is a coordinated, sustained effort involving industry, academia, and the government. All are essential to the program's

success. Traditionally, technology advances might have come from private industry members acting in their own self-interest. But today's firms lack the financial and human resources and the research capacity necessary to compete successfully in advancing international markets, and the overall industry is too fragmented to undertake long-range cooperative research and development. Academia presents an extensive, capable research community; but it too is fragmented and widely scattered. The National Program can provide the focus and support to bring together all of these researchers, both to develop the necessary advanced technology and, in time, to revitalize industry's own diminished research capacity. Indeed, by the end of the first phase of the National Program, we hope to see a major strategy shift by mature private industry: from traditional independence and evolutionary progress toward cooperative, long-range R&D.

The federal government's role in the National Program is to provide not only essential funding but also dedicated research staffs, extensive facilities, and opportunities for large-scale testing. Existing government programs for environmental remediation, safe waste disposal, infrastructure development, mass transit, geothermal energy exploitation, earth science research, and other areas provide both economic justification for advanced technology and opportunities for its development and demonstration.

Proposed Organization

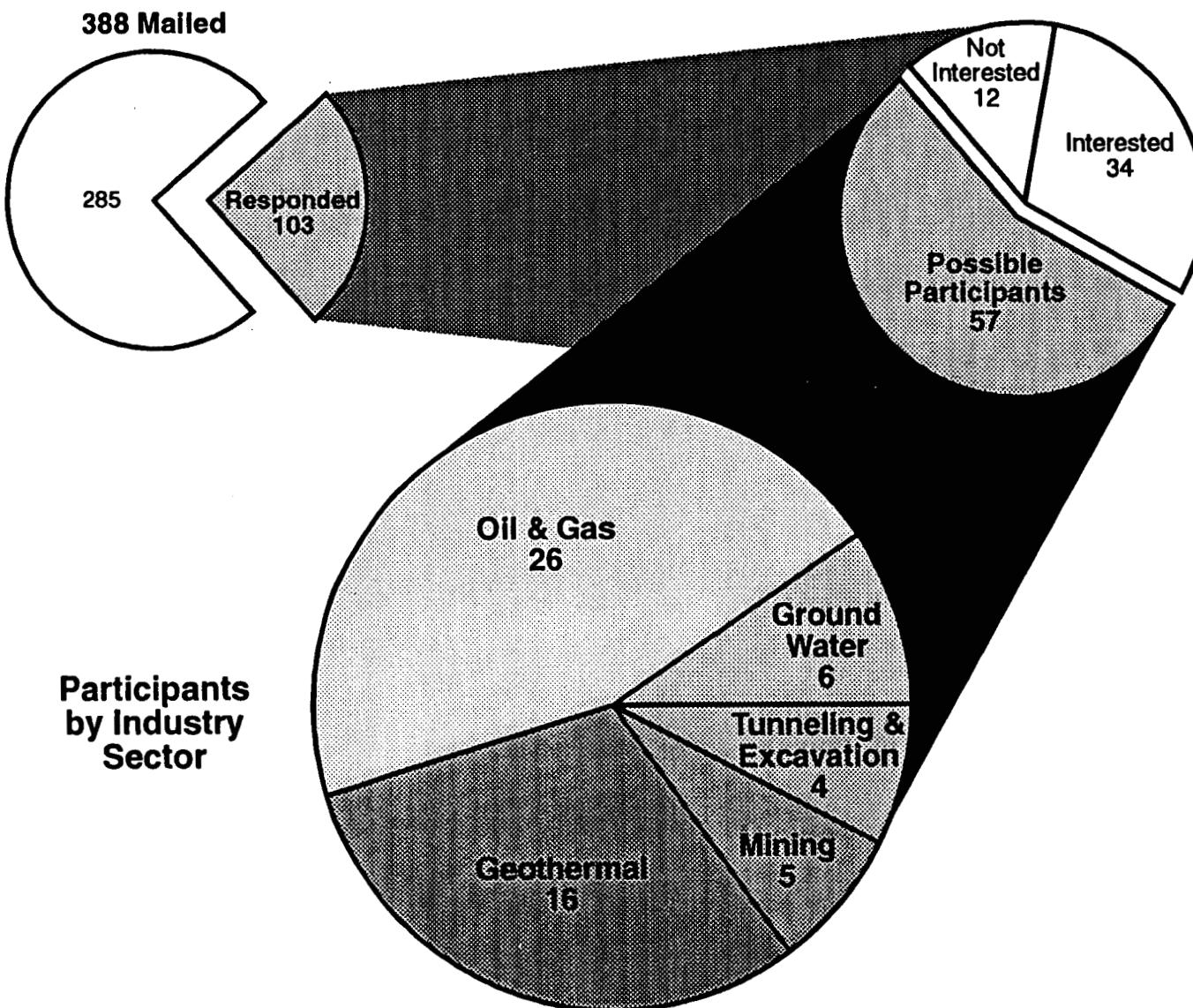
Since the *National Program* involves a variety of stakeholders and sponsors with overlapping but differing interests, the program should be executed by a consortium of the interested parties. The consortium would consist of federal agencies and laboratories, universities, and industry, working cooperatively under a central management organization. Industry will play a major role in directing and performing research, and the long-term success of the program will ultimately require structured industry leadership. Until that industry structure and leadership are developed, however, the program can be facilitated by one of several existing organizations, such as the Mining and Excavation Research Institute (MERI) of ASME, or an entirely new management entity could be created. The majority of research will be conducted in the private sector and at universities. Program oversight and guidance for policy, budget and goals will be provided by an executive committee representing funding sponsors and industry. Research projects will be selected by peer review within the context of program goals, and monitored to assure timely progress and effective focus on those goals.

Funding Needs

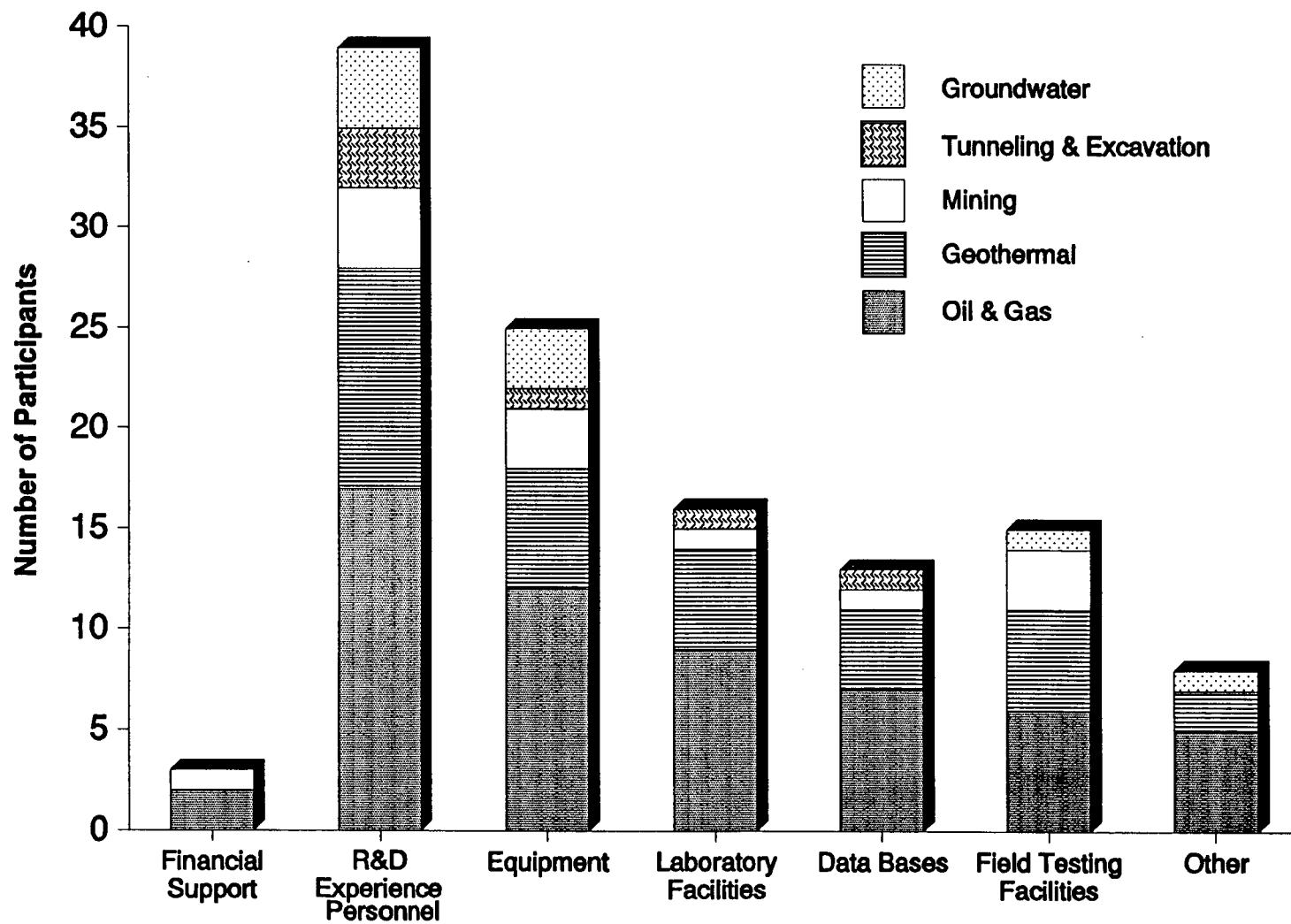
For planning purposes, a seven-year, first-phase program and budget are proposed, growing from an initial annual budget of \$5 million to \$36 million in the seventh year. Early efforts are deliberately diverse, in search of novel approaches and possible break-through concepts. As the knowledge base grows and as promising systems are identified, the program will expand. Development projects will become more ambitious, and research will focus on the specific needs of the most promising systems. The *National Program* will identify and arrange for major public projects as vehicles to demonstrate and refine new systems, thereby attaining immediate value from R&D funding and an effective vehicle for technology transfer.

The proposed *National Program* brings the essential researchers—industrial, academic, and government—and the necessary leadership to a critical challenge that has economic, societal, and environmental importance. In addition to contributing substantial technical advances, the program can revitalize mature industries, providing them with a new, forward-looking cooperative structure to restore and maintain the nation's international competitive edge in the area of drilling and excavation technology.

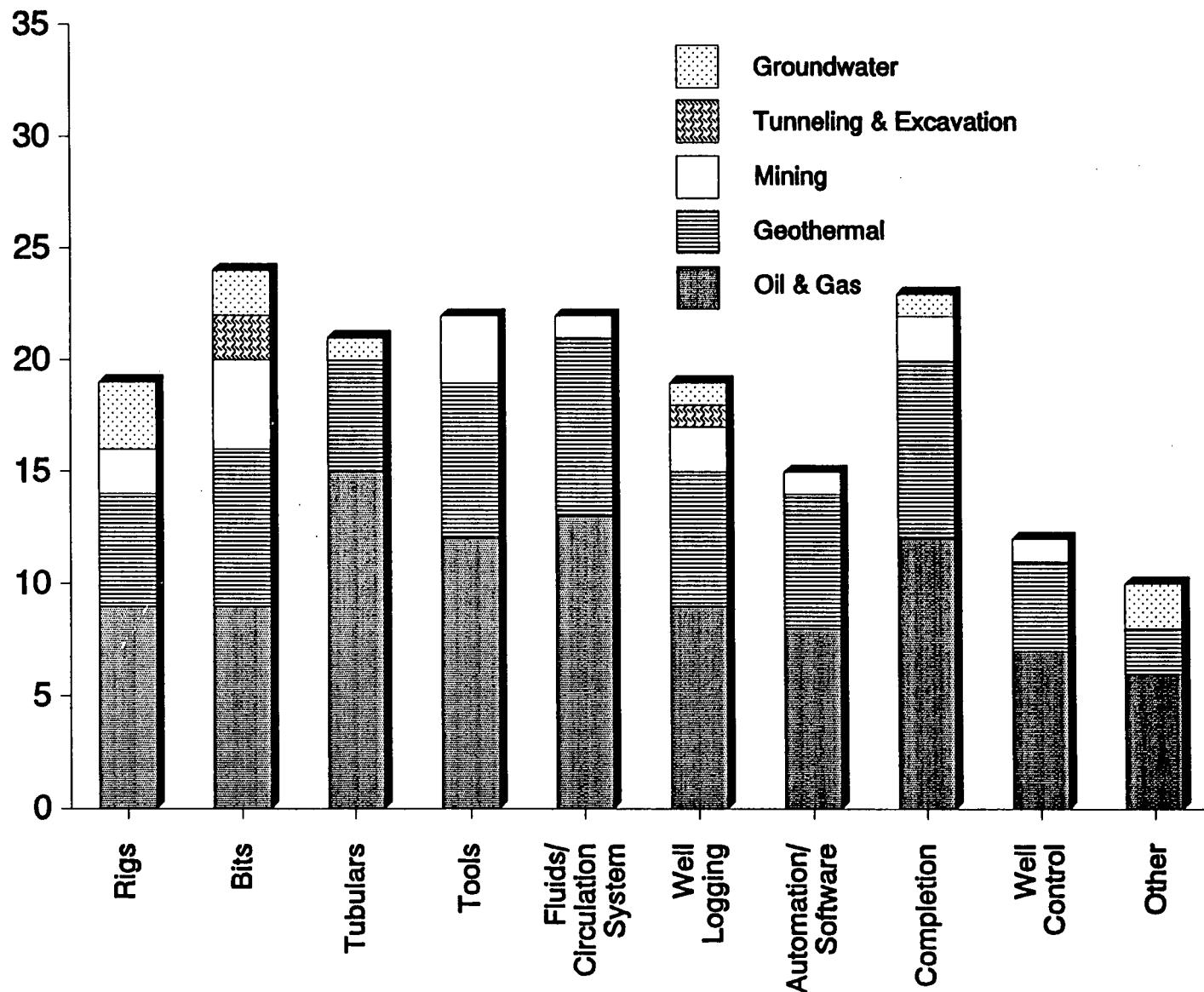
Industry Response to a National Advanced Drilling and Excavation Technologies Program



Response to a National Drilling Technologies Program Type of Participation Offered



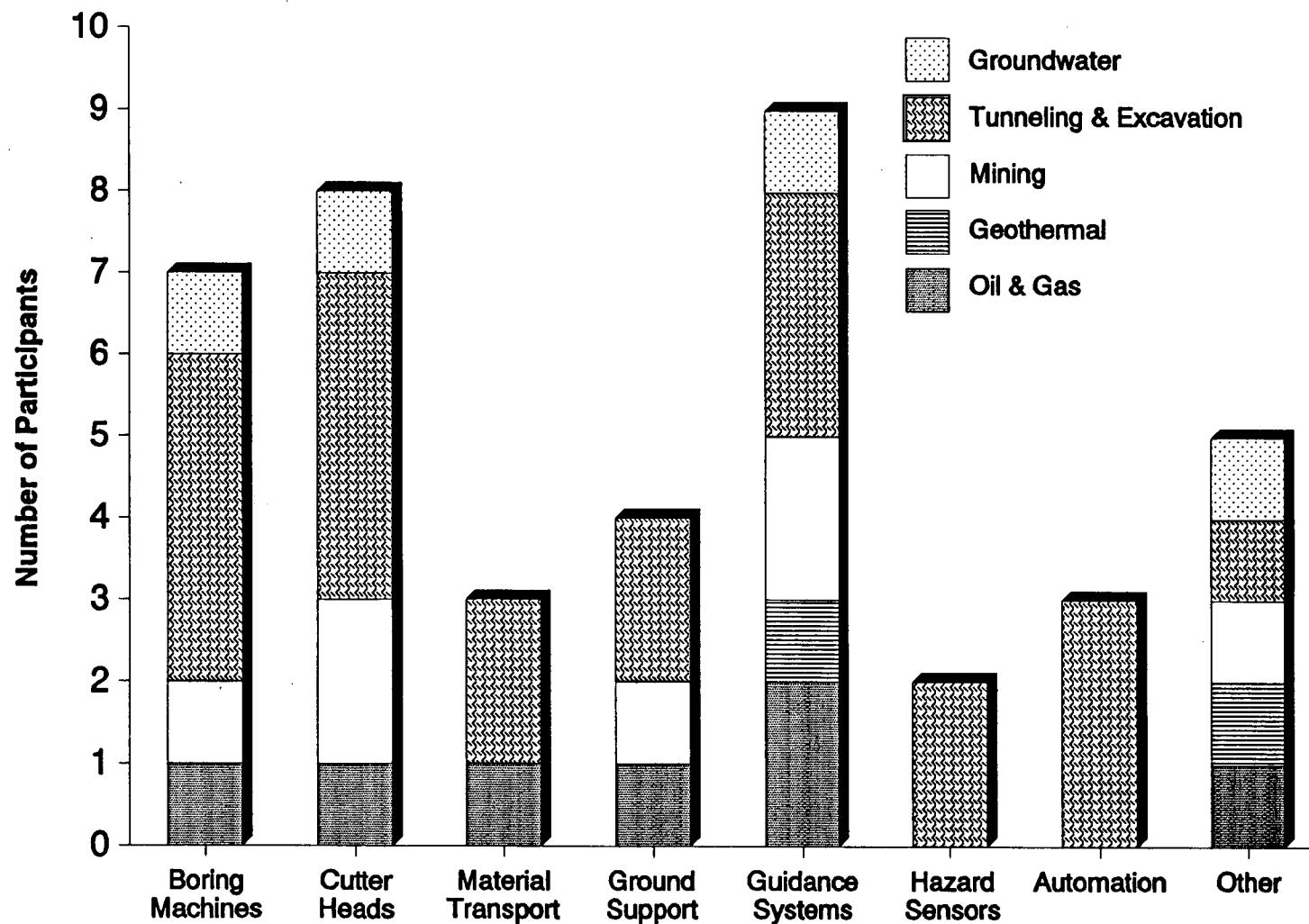
Response to a National Drilling Technologies Program Business/R&D Interests Well Drilling Category



Response to a National Drilling Technologies Program

Business/R&D Interests

Mining, Tunneling, and Excavation



GEOTECHNICAL BOARD
BOARD ON EARTH SCIENCES
AND RESOURCES

Study on Advanced Drilling Technologies

Presentation by:

Peter H. Smeallie, Director
Geotechnical Board
and
Kevin D. Crowley, Staff Officer
Board on Earth Sciences and Resources

June 15, 1993
Department of Energy
Washington, D.C.

STATEMENT OF TASK

The Geotechnical Board and the Board on Earth Sciences and Resources have been asked by the Geothermal Division of the Department of Energy to

- evaluate the technical and scientific feasibility of advanced drilling and related technologies,**
- examine concepts for new mechanical and non-mechanical drilling applications including advances in knowledge of the tool-rock interaction,**
- identify potential opportunities for research, and**
- make recommendations in a report on the scope and direction needed to realize these opportunities for improved methods for drilling rock.**

Neville G.W. Cook, Chairman
Dept. of Materials Science and Mineral
Engineering
University of California, Berkeley
(drilling technology, mineral
engineering, mining, rock
mechanics)

Ali S. Argon
Quentin Berg Professor of
Mechanical Engineering
Massachusetts Institute of
Technology
(materials science and
engineering)

George A. Cooper
Head, Petroleum Engrg. Program
University of California, Berkeley
(materials science and
engineering)

Michael M. Herron
Senior Research Scientist
Schlumberger-Doll Research
(logging)

Jean-Claude Roegiers
McCasland Chair and Professor,
School of Petroleum and
Geological Engineering
University of Oklahoma
(rock mechanics/petroleum
engineering)

Eugene D. Schukin
University Scholar, Dept. of
Materials Science and Engrg.
The Johns Hopkins University
(materials science and
engineering)

Stephen E. Laubach
Research Scientist
Bureau of Economic Geology
(geological/geophysical)

William C. Maurer
President
Maurer Engineering Inc.
(drilling technology)

James E. Monsees
Collider Project Manager
PB/MK Team
(rock mechanics/excavation
technology)

D. Stephen Pye
Drilling Superintendent
UNOCOL Corporation
(drilling technology)

Mark D. Zoback
Department of Geophysics
Stanford University
(geological/geophysical)

STUDY PLAN

● February 4-5, 1993 First Committee Meeting

A Workshop is Needed at the Front End of the Study to Generate Ideas and Involve the Greater Community

April 14-15, 1993 Workshop on Advanced Drilling Technologies

Fifty Participants from Industry, Academia, and Government

July 11-12, 1993 Second Committee Meeting

First Draft of Report Complete for Review; Committee Discusses Conclusions and Recommendations

September 1993

Second Draft Complete

November-December 1993

NRC Review Process

● February 1994

Report Published

**WORKSHOP ON
ADVANCED DRILLING TECHNOLOGIES
April 14-15, 1993**

First Day—Review of the State of the Art in:

- **Physics of Rock Fracture**
- **Drilling Techniques**
- **Muds and Borehole Stability**
- **Drilling Hydraulics**
- **Measurements**
- **Unconventional Drilling Techniques**
- **Drill String**
- **Rock Masses**

**WORKSHOP ON
ADVANCED DRILLING TECHNOLOGIES
April 14-15, 1993**

Second Day—Working Groups Assembled to Address:

- **What Is Being Done Well Now**
- **What Problems Can Be Addressed by Targeted R&D**
- **What Are Revolutionary or "Breakthrough" Concepts/Technologies that Could Make a Significant Difference in the Ability to Drill Holes**

Working Groups Addressed:

- **Systems and Automation**
- **Rock Physics; Materials; Rock Breaking**
- **Stabilization and Drilling Fluids**
- **Sensing Geological Conditions**

**WORKSHOP ON
ADVANCED DRILLING TECHNOLOGIES
April 14-15, 1993**

**Common Themes That Emerged from
Working Group Reports**

- Need to Develop "Smart" Drilling Systems—With Sensors Capable of Detecting Conditions Ahead of and Behind the Bit and a Guidance System Capable of Adapting to Changing Conditions. Such a System Would Be "Revolutionary."
- Need to Enhance Technology Transfer, Especially Between Small-Hole (e.g., Mining and Environmental) and Large-Hole (Oil and Gas, Tunneling) Applications. The Workshop Was a Successful Exercise in Information Transfer. Participants and Committee Felt That Additional Workshops Should Be Held to Attract a Wider Range of Participants.
- Need to Improve Technology for Drilling Hard Rock, Especially for Tunneling Applications.

National Research Council
Geotechnical Board
Board on Earth Sciences and Resources

**WORKSHOP ON
ADVANCED DRILLING TECHNOLOGIES**

April 14-15, 1993

National Academy of Sciences
Georgetown Facility
Cecil and Ida Green Building
Room 130
2001 Wisconsin Avenue, N.W.
Washington, D.C. 20007

AGENDA

The purpose of the Workshop on Advanced Drilling Technologies is to elicit ideas and commentary for consideration by a committee of the National Research Council charged with advising the government on the scientific and technical feasibility of advanced drilling R&D.

Wednesday, April 14th

8:00 a.m. Registration — Continental Breakfast Available

8:30 Welcome and Introductions
● *Peter Smeallie, Director, Geotechnical Board*
● *Jonathon Price, Director, Board on Earth Sciences and Resources*
● *Ted Mock, Director, Geothermal Division, DOE*
● *Neville Cook, Chairman, Committee on Advanced Drilling Technologies*

9:00 Advanced Drilling—Identification of Issues in Eight Major Areas. (Each group will leave some time for questions, but due to the tight time constraints, discussion should be deferred until the 5:30 p.m. session.)

Physics of Rock Fracture

- *Ali Argon, Moderator*
- Presenters:
 - *Teng-fong Wong, State University of New York, Stonybrook*
 - *John Kemeny, University of Arizona*
 - *Mark Zoback, Stanford University*
 - *Neville Cook, University of California, Berkeley*
 - *Eugene Shchukin, Johns Hopkins University*

10:30 a.m. Break

10:45 Current State of the Art

- *Jean-Claude Roegiers, Moderator*

Presenters:

Deep Drilling

- *Mark Zoback, Stanford University*

Slim Hole Drilling

- *Arnis Judzis, Westport Laboratory*

Directional

- *Frank Schuh, Drilling Technology, Inc.*

Geothermal

- *D. Stephen Pye, UNOCAL Corporation*

Ocean Drilling Program

- *Michael Storms, Texas A&M University*

Environmental

- *Dawn Kaback, Westinghouse Savannah River Laboratory*

12:15 p.m. Box Lunch Will be Provided

1:00 Muds/Borehole Stability

- *George Cooper, Moderator*

Presenters:

- *John Cook, Schlumberger Cambridge Research*

- *Calvin Deem, Amoco Production Company*

- *Ronald Steiger, Exxon Production Research Company*

- *Ching Yew, University of Texas at Austin*

1:45 Drilling Hydraulics

- *Bill Maurer, Moderator*

Presenters:

- *Mario Zamora, M-I Drilling Fluids Co.*

- *Mark Rankin, Pool Energy Services, Inc.*

2:15 p.m. Measurements

- *Michael Herron, Moderator*

Presenters:

- *Brian Clark, Schlumberger/Anadrill*

- *Ercill Hunt, Ercill Hunt & Associates*

- *Stephen Holditch, S.A. Holditch & Associates*

- *David Malone, Anadrill/Schlumberger*

3:00 p.m. Break

3:15 Unconventional Drilling Techniques

- *Bill Maurer, Moderator*

Presenters:

- *Ted Mock, DOE*
- *John Rowley, Pajarito Enterprises*
- *David Summers, University of Missouri-Rolla*
- *André Piché, Noranda Technology Center*

4:00 Drill String

- *D. Stephen Pye, Moderator*

Presenters:

- *Michael Sheppard, Schlumberger Cambridge Research*
- *Jamal J. Azar, University of Tulsa*
- *J. Kim Vandiver, Massachusetts Institute of Technology*
- *Bill Livesay, Livesay, Inc.*

4:45 Rock Masses

- *Neville Cook (for James Monsees), Moderator*

Presenters:

- *Bill Sharp, Colorado School of Mines*
- *Richard Robbins, The Robbins Co.*
- *Bernard Amadei, University of Colorado*

5:30 General Discussion and Identification of Working Groups and Tasks

- *Neville Cook*

6:00 Working Groups Meet (Rooms 116, 120, 122, 132, and 134 are available)

7:00 Reception, Hors d'Oeuvres, South Pre-Function Area

Thursday, April 15th

8:00 a.m. Continental Breakfast Available

8:30 Review of First Day—Open Discussion

Brief Reports from Working Groups

Page 4

10:00 a.m. **Working Groups Meet** (Rooms 110, 126, and 127 are available)

12:00 noon **Lunch, Refectory, Tickets will be Distributed**

2:00 p.m. **Reports from Working Groups**

Note: Outsiders will be invited to this session for observation

4:30 **Adjourn**

Geotechnical Board
Board on Earth Sciences and Resources

**WORKSHOP ON
ADVANCED DRILLING TECHNOLOGIES**

April 14-15, 1993

National Academy of Sciences
Georgetown Facility
Cecil and Ida Green Building
Room 130
2001 Wisconsin Avenue, N.W.
Washington, D.C. 20007

ATTENDANCE

Committee Members	Phone Number	Fax Number
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Dr. George A. Cooper University of California Department of Materials Science and Mineral Engineering Hearst Mining Building Berkeley, CA 94720	(510) 642-2996	(510) 642-3805
Dr. Michael M. Herron Senior Research Scientist Schlumberger-Doll Research Old Quarry Road Ridgefield, CT 06877-4108	(203) 431-5242	(203) 438-3819

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Dr. James E. Monsees Collider Project Manager Design Division PB/MK Team 5610 Redbird Center Drive, Suite 400 Dallas, TX 75237	(214) 708-6618	(214) 708-6627
Dr. D. Stephen Pye Drilling Superintendent UNOCAL Corporation 1201 West 5th Street, M35 Los Angeles, CA 90017	(213) 977-6262	(213) 977-6333
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Speakers	Phone Number	Fax Number
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Dr. Brian Clark Schlumberger/Anadrill LWD 225 Industrial Blvd. Sugar Land, TX 77478	(713) 275-7519	(713) 275-7619
Dr. John M. Cook Schlumberger Cambridge Research High Cross Madingley Road Cambridge CB3 0EL England	223-325200	223-327019
Mr. Calvin K. Deem Research Center Amoco Production Company P. O. Box 3385 Tulsa, OK 74102	(918) 660-3262	(918) 660-3822
Dr. Stephen A. Holditch S.A. Holditch and Associates 900 Southwest Parkway East Suite 200 College Station, TX 77840	(409) 764-1122	(409) 764-8157
Mr. Ercill Hunt Ercill Hunt and Associates 10235 West Little York, Suite 410 Houston, TX 77040	(713) 896-6773	(713) 896-6752

Speakers	Phone Number	Fax Number
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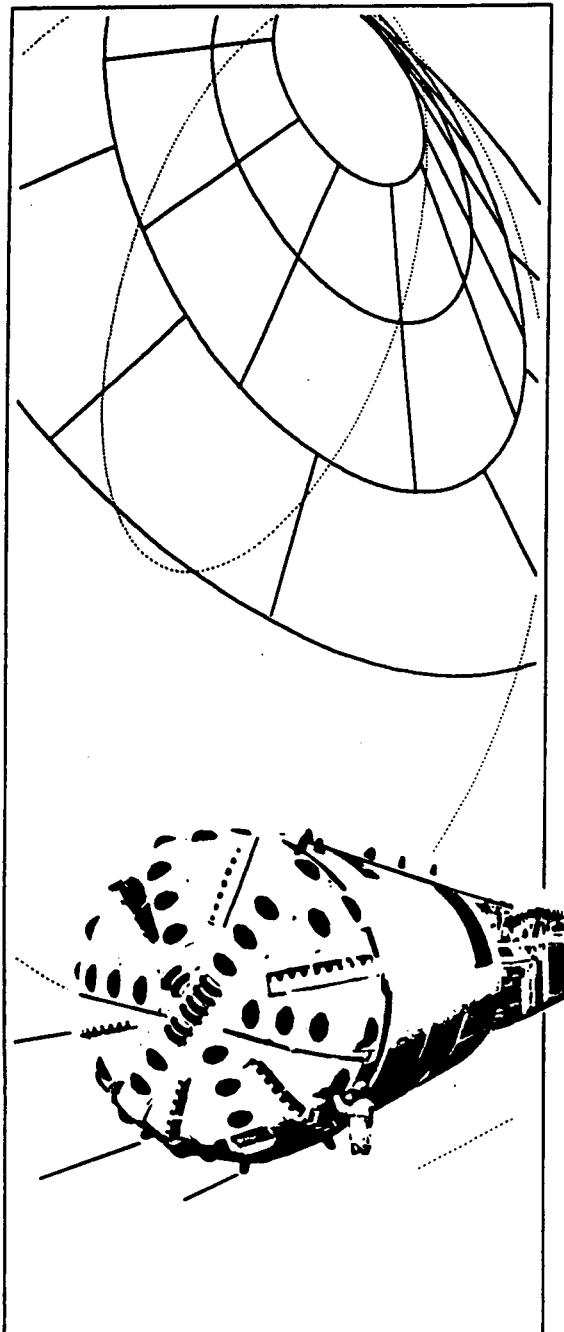
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Attachment F

Report on Workshop on

**" Research Needs in Automated Excavation and
Material Handling in the Field"**



Sponsored by NSF, NIST & FHWA

April 28-30, 1993

Organized by

Dr. B. Dendrou, ZEi/Mi Inc.

Dr. M. Gaus, University at Buffalo

Dr. R. Sterling, University of Minnesota

For

Mehmet Tumay/ Ken Chong/ Howard Moraff,

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Table of Contents

Why the Workshop?	1
Objectives of the Workshop	1
Organization of the Workshop	1
Content of Technical Sessions	2
Professionals Attending the Workshop	3
Development Trends Identified at the Workshop	3
Benefits of the "Automated" Construction and Excavation	4
Promoting and Expanding "Automated Excavation Technology"	6
Technical Challenges	6
Recommendations	8
Acknowledgements	8
References	8

Why the Workshop ?

The purpose of the workshop was to attract selected researchers and practitioners from academia, government and industry to exchange information, ideas and their vision on how "Automated Construction and Excavation" can benefit Civil Infrastructure Systems (CIS).

The size and quality of the world competition in the area of surface and underground construction and excavation technologies dictated an immediate plan of action. The workshop offered the opportunity to professionals of different background to interact with each other, be exposed to different philosophies, and contribute in identifying a coherent set of recommendations for research that will produce the highest returns.

Objectives of the Workshop

The general theme of the meeting was "Automation in Highway Construction and Excavation Technology" with the following objectives:

- Present an inventory of state-of-the-art procedures in highway construction and excavation technologies
- Identify application areas where these technologies will have an immediate return (Transportation area, Environmental Protection, Utility networks, and others)
- Produce a set of recommendations for research needs and identify potential near and long-term programs.

Organization of the Workshop

The NSF, NIST and FHWA sponsors felt that this is the time to obtain a holistic view of the challenges facing the construction and excavation industry. In today's stringent safety and performance requirements there is a need to address the construction and excavation problem from a global perspective. The common theme bonding all the contributors to this workshop was "Automation and Machine Intelligence in Surface and Underground Construction".

The broad range of automated construction/excavation machines include:

- the automated earth-moving, spreading, compacting machines, and Whittaker's family of autonomous machines at one end of the spectrum
- the continuous mining machines in coal mines,
- the continuous Tunnel Boring Machines in hard rock and weak soils,
- the drill and blast machines, and
- microtunneling machines at the other end of spectrum.

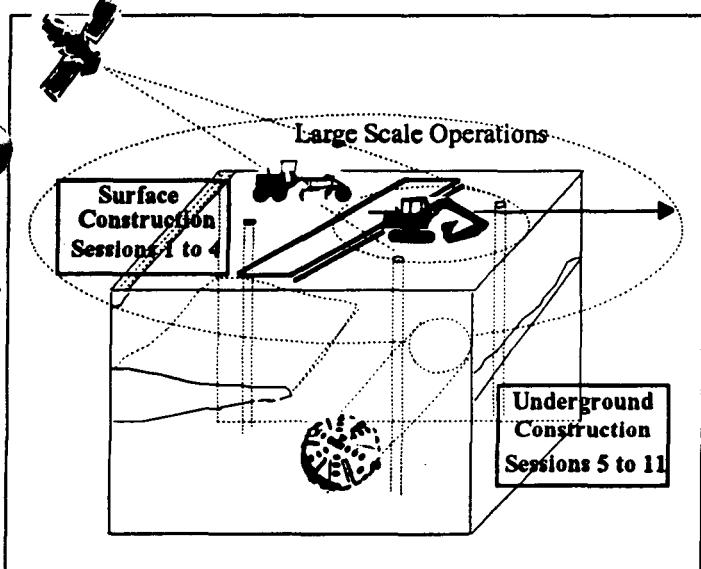
All of these machines are "semiautonomous" with shared man-machine control, operating in a highly unstructured environment. Automation is the common link between all these different in size and function machines, which encompasses:

1. The automatic movement (guided motion) of the machine
2. The automatic manipulation of appropriate tools for the realization of predetermined tasks
3. The automatic sensing and processing of real-time data for decision making and control at the local scale
4. The automatic characterization (detection) of the operating environment at the global scale (macroscale).

The selected topics for discussion covered, in twelve, technical sessions, a broad spectrum of application areas, from the highly automated excavation devices at the surface of the soil medium, to the sophisticated TBM's (Tunnel Boring Machines) used for the realization of underground mega projects, the continuous mining machines used in the coal mining industry and the different small diameter boring machines used in trenchless technology.

Content of Technical Sessions

An overview of the technical areas covered in each session is illustrated below:



In Sessions 1 to 4 the focus was on areas of automation as applied to highway construction and surface operations, while in sessions 5 to 11 the emphasis was on underground excavation and operations related to the development of the underground space. The basic topics discussed in each session are given below:

Session 1 (Chaired by A. Sanderson) focused on the design for automation in highway construction, site integration through hierarchical control, and, automated project planning and scheduling. Road construction and maintenance require

extensive coordination of workers, machines, and resources. The use of advanced computer and automation technologies provides the means to improve the efficiency, productivity, and safety of construction projects.

Session 2 (Chaired by Kerien Fitzpatrick) placed the emphasis on Technologies for automated earth-moving, spreading, compacting, lifting and positioning of materials and structural elements. Computers and communications technology have revolutionized earth-moving industries. The major changes are still to come, but they are just around the corner. These new developments include basic communication, machine monitoring and diagnostics, job and business management, planning and operations.

In **Session 3 (Chaired by Leonhard Bernold)** presentations were made on teleoperated devices, smart tools, operator-assisted automation, advanced operator interfaces, and virtual reality. The creation of intelligent controls for large and heavy machines used in the construction of highways poses a considerable challenge to engineers and scientists. For example, the unstructured nature of soil in its natural setting requires a thorough understanding of soil mechanics in order to develop dynamic control systems for robotic excavation. Problems that originate from the site conditions in which construction operations have to take place need urgently to be solved.

Session 4 (Chaired by Avi Kak) dealt with technologies for inspection of bridges and road surfaces, automated surveying, "As-Built" databases, site positioning and quality assurance. The focus of on-going research activities are on nondestructive testing of highway and runway pavements, and the application of this technology to real time sensing of the quality control of repairs or new construction.

Session 5 (Chaired by William Whittaker) discussed elements of automated excavation, hazardous waste applications, military applications, academic and corporate research. Advances in perception, reasoning and manipulation that have it technically feasible for a robot to discern objects, discriminate them from their surroundings, plan approach trajectories and grasp them. However, an important class of material handling problems related to the extrication of objects that are embedded in soils need to be solved.

In **Session 6 (Chaired by Priscilla Nelson)** new TBM technologies were presented, along with technologies for steering and control systems, perception sensors, automatic lining. New developments in TBM's design include: main beam steering, floating grippers, direct drive cutterheads, mechanical cutterhead stabilization, hydraulic clutch engagement, oil

sealing system for cutterhead drive, effective ventilation and dust control, field replaceable cutter assemblies, new safety features.

Session 7 (Chaired by Ken Stokoe) focused on geophysical methods for subsurface detection, site characterization and, subsurface utility engineering. New developments in fusing certified three-dimensional data of soil conditions and underground existing utilities into the field operator console of "smart" equipment. This would guide automated directional excavating machines past underground structures. However, presently geophysical exploration is still relying on old technologies that do not use the recent developments in automation.

Session 8 (Chaired by Ray Sterling) elaborated on today's problems and opportunities in R&D for excavation by blasting. Conventional drill and blast, while being able to excavate the hardest of rocks at acceptable efficiencies, is limited in that the technique must be applied in cyclic fashion, resulting in the inefficient and often interfering use of the equipment required for each cycle. Newly developed technologies are shown to be energy efficient for breaking hard rocks.

Session 9 (Chaired by Tom Iseley) dealt with the tracing and steering of horizontal earth boring systems, recent microtunneling innovations and applications of trenchless technology. Trenchless technology is the process of installing or rehabilitating underground infrastructure with minimum disruption and destruction typically associated with traditional methods. There are many methods that make up the family of techniques that can be utilized to install new infrastructure system.

Session 10 (Chaired by Basile Dendrou) provided the framework in which most of the new technologies introduced in the previous sections were put together in an integrated computer based environment to support the implementation of Mega excavation projects. These technologies included: an automated engineering information system, a reactive navigation scheme, real-time position measurement in underground construction, robotic perception of material properties, dynamic interface simulation for underground construction operations. It is believed that the most efficient way to handle the mega-scale problem of underground excavation projects is through the use of integrated computer platform that will assist in the management and control of automation as applied to the excavation process. The new integrated systems will expand on GIS technology to include the 3rd (depth) dimension, time, and the interaction of all processes characterizing the underground excavation.

Session 11 (Chaired by Herbert Einstein) continued the general theme of the previous session, with more details on the information technology as applied to construction, mechanistic simulations for safety analyses, data fusion and visual data bases, intelligent information systems. Information technology is the natural link between different activities of tunneling construction that include management-costing programs, and safety and risk analyses.

Finally in **Session 12 (Chaired by Mike Gaus)** the impact of the new excavation technologies on the construction industry was presented through different evolutionary and visionary implementations. Two new ideas were promoted in this session, the concept of underground freight network and the concept of underground urban corridors.

Professionals Attending the Workshop

With the large variety of topics covered in each session it was only natural to have a broad range of professionals of different background participating in this workshop. It was very interesting to see: mechanical engineers interacting with civil engineers, specialists in robotics talking to specialists in geomechanics, construction specialists discussing with manufacturers, and engineers from the military sharing their experience with the private sector. A glance at these new concepts and ideas resulting from these discussions is given in the following sections.

Development Trends Identified at the Workshop

Progress in surface and underground "Automation" technology is necessary if the construction, mining and environmental protection industry are to remain competitive in the world market. The workshop, clearly demonstrated that recent advances in automation technologies, particularly the development of fast, inexpensive computers, control software design, and sensing technology, improve construction efficiency and worker health and safety.

In the construction site of the very near future, construction workers and operators will be relocated from the relative dangerous construction site, to a protected Control Center from which the operators will be able to direct the activities of their machines via graphic/video real-time computer terminals. The new technologies for computer-assisted construction are being developed by building upon conventional, mechanized equipment used in well understood construction operations. By using familiar machines in familiar ways, the manufacturers hope to avoid confronting the barriers traditionally associated with introducing radically new machines and procedures. This trend was clearly identified in many sessions of the workshop dealing with different excavation machines. Table 1 shows typical machines and their "automation" components, as identified at the workshop.

Benefits of the Automated Construction and Excavation

The potential benefits of "Automation" in excavation technologies include: quicker and higher quality site characterization, improved craftspeople performance, improved modular construction, reduced rework, improved performance and quality improvement, and improved overall construction time.

The benefits according to preliminary estimates given by Dr. Ivan Beliveau can be more than \$150 billion per year in savings from the \$500 billion U.S. construction industry. Most of these spendings are planned for construction at the surface, however, the underground space may well be the new frontier for the U.S. construction industry.

The underground excavation industry offers a unique opportunity to attract the interests of many different professions and put into practice new technological concepts and ideas, as shown in the

closing session of the workshop. Potential new surface and underground developments for the next 5 years in the U.S. alone include:

In Surface Transportation:

- \$5-\$10 billion dollars for the rehabilitation of highways
- \$20 billion dollars for expanding the highway network

Candidates for the implementation of these projects are: Surface excavators.

In Underground Transportation:

- \$6-8 billion dollars for new programs in urban railway transportation
- \$2 billion dollars for new highway tunnels
- \$10 billion dollars during first 5 years and increasingly thereafter for the new underground freight systems

Candidates for the implementation of these projects are: TBM's, Drilling Machines.

In Mining:

- \$2 billion dollars for new Mines
- \$20 billion per year for on-going operations

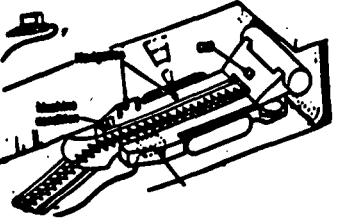
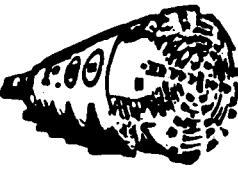
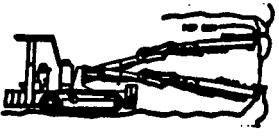
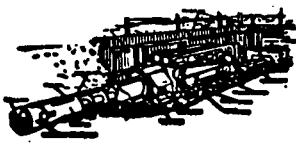
Candidates for the implementation of these projects are: Mining Machines, Drilling Machines, Surface Excavators.

In Water Management:

- \$5 billion dollars for rehabilitating existing pipe networks
- \$6 billion dollars for new construction of water facilities
- \$4 billion dollars for new sewerage networks

Candidates for the implementation of these projects are: TBM's, Trenchless technology, and surface excavators.

Table 1 Typical Automated Machines

Machine Type	Features and Functions
Surface Excavators 	Semi-autonomous machines operator assisted. Real-time Positioning: GPS, (2" accuracy) Automotive: compt. enhanced automotive fcts. Electronic Hardware: RISC +LAN's technology Software: Assembly and C on RO chips. US against Foreign Competition: Ahead
Whittaker's Family of Machines (Primarely for material handling in the field) 	Remote-supervised operating system (semi-autonomous) and automous machines Real-time Positioning: LPS (0.2" accuracy) Automotive: Traditional (Battery) Electronic Hardware: RISC Software: Assembly US against Foreign Competition: Ahead
Mining Machines 	Computer-assisted, remote-supervised operating system (semi-autonomous) Real-time Positioning: LPS (Laser Based) Automotive: Electric Power Electronic Hardware: RISC - CISC Software: Assembly and C, Video Console US against Foreign Competition: Ahead
TBM (Tunnel Boring Machine) 	Computer-assisted, manually remote-supervised operating system (semi-autonomous) Real-time Positioning: LPS (Laser Based) Automotive: Traditional Gas /Electric Software: Conventional, Video Console US against Foreign Competition: Weak
Drilling and bolting machines 	Automated mechanically-assisted operation. (semi-autonomous) Real-time Positioning: LPS (Laser Based) Automotive: Traditional Gas Electronic Hardware Traditional Software: Asmbly and C US against Foreign Competition: Even
Trenchless Technology 	Remote-supervised operating system (semi-autonomous) Real-time Positioning: LPS (Laser Based) Automotive: Traditional Electronic Hardware State of the Art RISC Software: Assembly and C, Video Console US against Foreign Competition: Weak

In Clean up Operations: (Information provided by Dr. Vernon Myers)

- \$50 billion for 2000 Superfund sites
- \$100 billion for 3,750 RCRA sites
- \$10-\$15 billion for 6,000 sites of DOD
- \$53-90 billion for 45 sites of DOE
- \$100 billion for 30,000 Real Estate sites

Candidates for the implementation of these projects are: TBM's, Trenchless technology, and surface excavators.

Underground utilities:

- \$0.5-1 billion dollars for communication networks
- \$1 billion dollars to create multi-use underground space in major cities

Candidates for the implementation of these projects are: TBM's, Trenchless technology.

These are only conservative estimates but the important fact is that the magnitude of these new financial ventures is such that "Automated excavation" can make a significant contribution towards the infrastructure investments which are necessary to help reverse the recent downward trend of the U.S. economy.

Promoting and Expanding "Automated Excavation Technology"

But technology alone is not enough to commit the governmental agencies and the investors to these new developments. The discussions at the workshop clearly indicated that there is a need to attract the popular concern as represented through the legislative institutions and regulations. According to attorney David Calverley regulations in the construction

industry either do not exist (development of underground space), or are outdated. Appropriate innovative regulations can certainly reward the use of automated machines and guide the construction industry.

However, the single biggest issue to the overall success of these technologies is to properly educate, retrain, attract, and retain well qualified professionals of the technology. It was the consensus of all the participants that the level of resources that the construction industry spends for training and education is inadequate (1% of its sales compared to 10% of sales for manufacturing). To remediate this, the participants of the workshop agreed to follow the Dr. Herbert Einstein's advice and create a "virtual network" of dedicated professionals that will actively support the promotion of "Automated Excavation Technology".

There are undoubtedly costs associated with the implementation of these technologies. But, in the final analysis, it is expected that each dollar of added effort will yield tenfold and even larger returns.

Technical Challenges

The new developments in automated surface and underground excavation place an emphasis in:

1/ Capturing the in situ conditions using the latest technology in sensor devices, 2/ Processing the insitu information through computers and expert modules to establish design and construction strategies, 3/ Adapt automatically the excavation tools for the construction phase, 4/ Remove and automatically process the excavated material, 5/ Install automatically the lining or other structural system, and 6/ Complete the job to satisfy building code's safety requirements

To implement all these tasks a broad spectrum of different technologies must be blended together in a macro-engineering framework (macro-scale approach).

The challenge now is to integrate these technologies in the "semiautonomous" excavation machines, operating in the highly unstructured environment of the real world. The following table provides a summary of the different disciplines required for the "Automation" of most of these excavation machines.

Automated Function	Disciplines & Technologies
Automatic movement (guided motion) of the machine.	Robotics: Robotic control and mobility, Task planning, Intelligent sensors and actuators, automatic drilling and lining systems. Manufacturing Automation: Flexible manufacturing, Process automation, Computer Integrated manufacturing.
Automatic manipulation of appropriate tools for the realization of predetermined tasks	Control Applications: Motion control, Guiding systems, Modeling and simulation, Signal processing, Fuzzy control and diagnosis.
Automatic sensing and processing of real-time data for decision making and control at the local scale	AI & Expert Systems: Knowledge bank, Intelligent control, AI software. Network dynamics, learning algorithms, hardware implementation Global and Local Positionning: Laser network. Infrared technologies. Computer Vision: Image processing, Dynamic Scene analysis, Machine vision, Pattern recognition. Fractals and IFS algorithms.
Automatic characterization and detection of the operating environment at the global scale (macroscale). Automatic Stabilizing counter measures.	Site Characterization and Detection: Geophysical methods, Real time sensors of evolution of mechanistic processes. Mechanistic and Construction Simulation: Prototyping, Parallel processing, Impact of automation to the environment, Reliability and risk analysis, Management and cost. Soil/Rock Sciences: Concrete admixtures, Geotextiles, Fiber anchors, Chemicals for soil grouting and stabilization.

The overall research, development, demonstration program should be on a 5 year schedule requiring a total funding of \$15 to 20 million dollars for a target machine system. TBM's and mining machines will require more research funds than microtunneling and material handling machines.

Automated Function	R & D Cost Estimate
Automatic movement (guided motion) of the machine.	Robotics: \$4 million Manufacturing Automation: \$2 million
Automatic manipulation of appropriate tools for the realization of predetermined tasks	Control Applications: \$4 million
Automatic sensing and processing of real-time data for decision making and control at the local scale	AI & Expert Systems: \$1 million Global and Local Positionning: \$1 million Computer Vision: \$1 million
Automatic characterization and detection of the operating environment at the global scale (macroscale). Automatic Stabilizing counter measures.	Site Characterization and Detection: \$ 4 million Mechanistic and Construction Simulation: \$1 million Soil/Rock Sciences: \$ 2 million

These key technologies can be tested in certain important critical missions, such as:

- The clean-up operations of the nuclear powerplants at the Hanford site.
- The nuclear waste disposal sites in Nevada.

The use of the geotechnical sites is also recommended.

Recommendations

Here are two key suggestions for what research community, and funding agencies, might well do to foster more effective research in the area of "Automated Excavation and Material Handling in the Field":

- The four areas for "Automation" are intimately interrelated and thus a mechanism is needed where sharing of ideas can take place. The idea of creating a "Virtual Information Network" is the first step, but other small workshops need to be held to discuss how to encourage multi-investigator proposals.
- The methodology for research and development in this area needs to move out from the confines of the laboratory and into real-life contexts. The field of "Automated excavation" is in an exploratory phase right now; we need to encourage *in situ* style studies.

Acknowledgements

The organizing committee would like to acknowledge Drs. Mehmet Tumay, Ken Chong, Howard Moraff at NSF and E. Kent at NIST for initiating and funding this workshop on "Research Needs in Automated Excavation and Material Handling in the Field".

The success of this workshop would not have been possible without the contribution of all the participants prior to the meeting. We are thankful to the individuals who accepted to write position papers and the chairpersons for their writing of the pre-workshop summary reports.

Finally, we would like to express our appreciation to NSF/NIST/FHWA for their support.

Companies contributing to this workshop are the following:

The Robbins Company, Caterpillar Inc.
Kraft Telerobotics Inc., Jacobus Technology Inc.
Phoenix Scientific Inc, Olson Engineering Inc.
So-Deep Inc, Sunburst Excavation Inc.
MicroEngineering Inc., Horizontal Holes International Inc., Iseki Inc, Ampower Corporation, Transystems Inc., Spectra Physics, Hayward-Baker Inc., TRW, Image Machines Corporation, AMS Research Inc. (KROME Computers).

References

JTEC, 1991. JTEC Panel on Construction Technologies, Final Report, Feb. 1991, Japan technology Evaluation Center, Loyola College, Maryland.

U.T.R.C., 1991. Potential Topics for Research and Development in Underground Engineering, Tunneling and Underground Space Technology, Vol. 6, No. 3, Pergamon Press, Oxford, U.K.

Civil Engineering Research Foundation, "Setting a National Agenda for the Civil Engineering Profession", Volume 1, August 1991, report No. 91-F1003

Attachment G

NEWS UPDATES

Hard Rock Mining Using A Pulsing Laser

John G. Sellar

INTERPRO

5906 McIntyre Street
Golden, CO 80403-7400

May 1993

INTERPRO

THE IRRESISTIBLE MINER

"News Update"

As part of a contract with the Electric Power Research Institute, under which INTERPRO is investigating the use of pulsing lasers for hard rock mining, recent testwork sponsored by the Center for Materials Production has revealed the technical and economic merits of pulsing the laser inside a high pressure water jet.

This water jet not only provides a consistently clear path between the laser and the rock surface, but also contributes to five rock excavation mechanisms which are simultaneously activated.

1. Micron-thick layers of rock are vaporized with each pulse forming a large volume of gas plasma. These gases are momentarily held against the rock surface by the water jet, creating pressures approaching 1,000,000 psi, which impart instantaneous shock waves to the rock in much the same way as traditional explosives.
2. The rate of these miniature explosions is controlled up to thousands of times per second, and is continuously adjusted to match the resonant frequency in the target area. This shock wave reinforcement increases the amplitude of vibration until the local tensile strength of the rock is exceeded.
3. The shock wave imparted to the rock is also generated in the water. This hydraulic transfer can excavate an area four to eight times the area directly affected by the laser pulse.
4. The cyclic loading of the rock surface reduces local tensile strengths of the rock by up to 70%.
5. The water jet itself is capable of excavating rock, particularly if the rock is damaged with microcracks as would be expected from the other mechanisms.

The concept of this continuous, hard rock mining tool, which receives laser pulses via fibre optics, represents the biggest breakthrough in hard rock excavation since the discovery of explosives. The tool can be easily automated or controlled remotely, and has the potential to have a major beneficial impact on the economics of mining and metal recovery. It is silent, produces negligible ground vibration, and does not release dust or fumes into the environment. It can, therefore, also be used near populated areas, day or night, for all forms of hard material removal.

The tool, known as the Laser-Water Jet, will be mounted on a lightweight two-boom jumbo, one boom controlling the Laser-Water Jet and the other controlling a vacuum removal system connected to a pumping module. The Laser-Water Jet has application not only in the mining industry, but in tunnelling, highway construction, reconstruction requiring concrete removal, demolition, and building foundation work.

Questions or requests for additional information should be addressed to Mr. John G. Sellar at:

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Hard Rock Mining Using a Pulsing Laser

March 1993

INTERPRO has recently completed testwork on the controlled application of pulsed laser energy for hard rock excavation in mining. This work, which forms part of a contract with the Electric Power Research Institute (EPRI) through the Center for Materials Production, has demonstrated the technical and economic merits of pulsing the laser beam inside a high pressure water jet. The jet will provide a consistently clear path to the rock face through the dust, fog, and other debris normally found at a mining face.

The combination of laser pulses and water (the Laser-Water Jet shown in Figure 1) simultaneously activates five interconnected and powerful rock excavation mechanisms as follows:

1. Vaporization

Vaporization has been the economic flaw in past laser-rock investigations. However, under the right conditions, vaporization produces a shock wave in rock of such magnitude, that a single pulse will cause "chunks" to be ejected from the rock mass.

The right conditions involve vaporizing micron-thick layers of material from the surface in nanosecond (10^{-9} seconds) time intervals. Provided the expanding gases are held momentarily against the rock surface with water, pressures approaching 1,000,000 psi are generated. These pressures impart instantaneous shock waves to the rock in much the same way as traditional explosives.

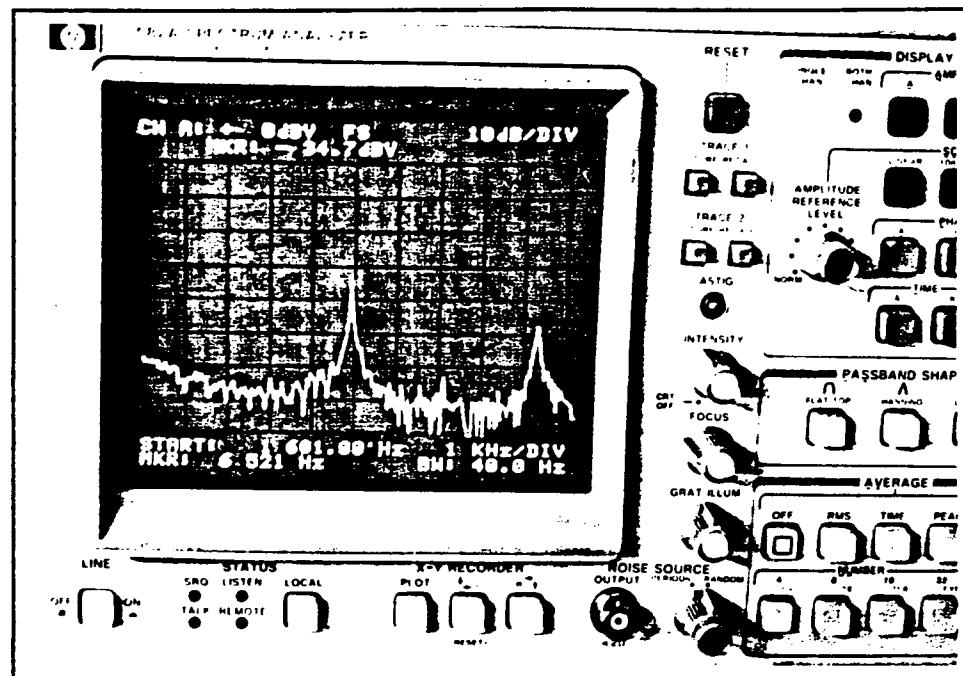
2. Resonance

The rate of these miniature explosions is controllable up to thousands of times per second, such that if the resonant frequency of the rock surface is known, successive explosions can be timed to impart reinforcing shock waves.

This reinforcing mechanism maximizes the amplitude of vibration with the least possible energy until the local tensile strength of the rock is exceeded.

INTERPRO

The ever-changing local resonant frequency is readily detectable on a continuous basis, using a commercially available laser doppler vibrometer. These resonant frequencies have amplitudes which are 10 to 100 times higher than surrounding frequencies and can be measured and coupled to the input pulsing laser at rates up to 100 times per second. A typical frequency/amplitude response spectrum is shown below depicting a rock sample with a local resonant frequency of 6,521 Hz.



3. Shock Wave Transfer

Shock waves imparted to the rock are also propagated in the water. Work by others with shock wave pressures approaching 1,000,000 psi, has shown that total material disintegration occurs in areas up to four times the originating area, with sufficient energy remaining in an area twice as large again, to cold harden most metals. The area excavated by successive pulses

can therefore be expected to be significantly larger than that associated with the laser beam diameter.

4. Cyclical Loading

Actual excavation of rock chunks or particles occurs when tensile stresses associated with the shock wave overcome the local tensile strength of the rock. Other researchers have demonstrated that cyclical loading of rock can reduce static tensile strengths by up to 70%.

5. High-Pressure Water Jet

As a water jet is required to consistently provide a clear path to the rock surface, the jet can be sufficiently high in pressure to excavate pre-damaged rock in its own right.

These five mechanisms, and the small particle sizes produced by the Laser-Water Jet, also imply the following:

- Two different lasers, whose wavelengths are transmissible in water, are required. Such lasers are available.
- Wavelengths transmissible in water are likewise transmissible in fiber optics. The laser machines will therefore be located in a benign environment, remote from the mining face.
- Water and excavated material can be vacuumed from the mining face directly to a pumping system. Ore mined in this manner will not require primary or secondary crushing.
- With the Laser-Water Jet mounted on one arm of a lightweight, two-boom drilling jumbo, and a vacuum head on the other arm, the simple controls of focus, distance from the face, and direction of the nozzle, will allow full automation or remote control.

Hard Rock Mining Using a Pulsing Laser

March 1993

Page 4

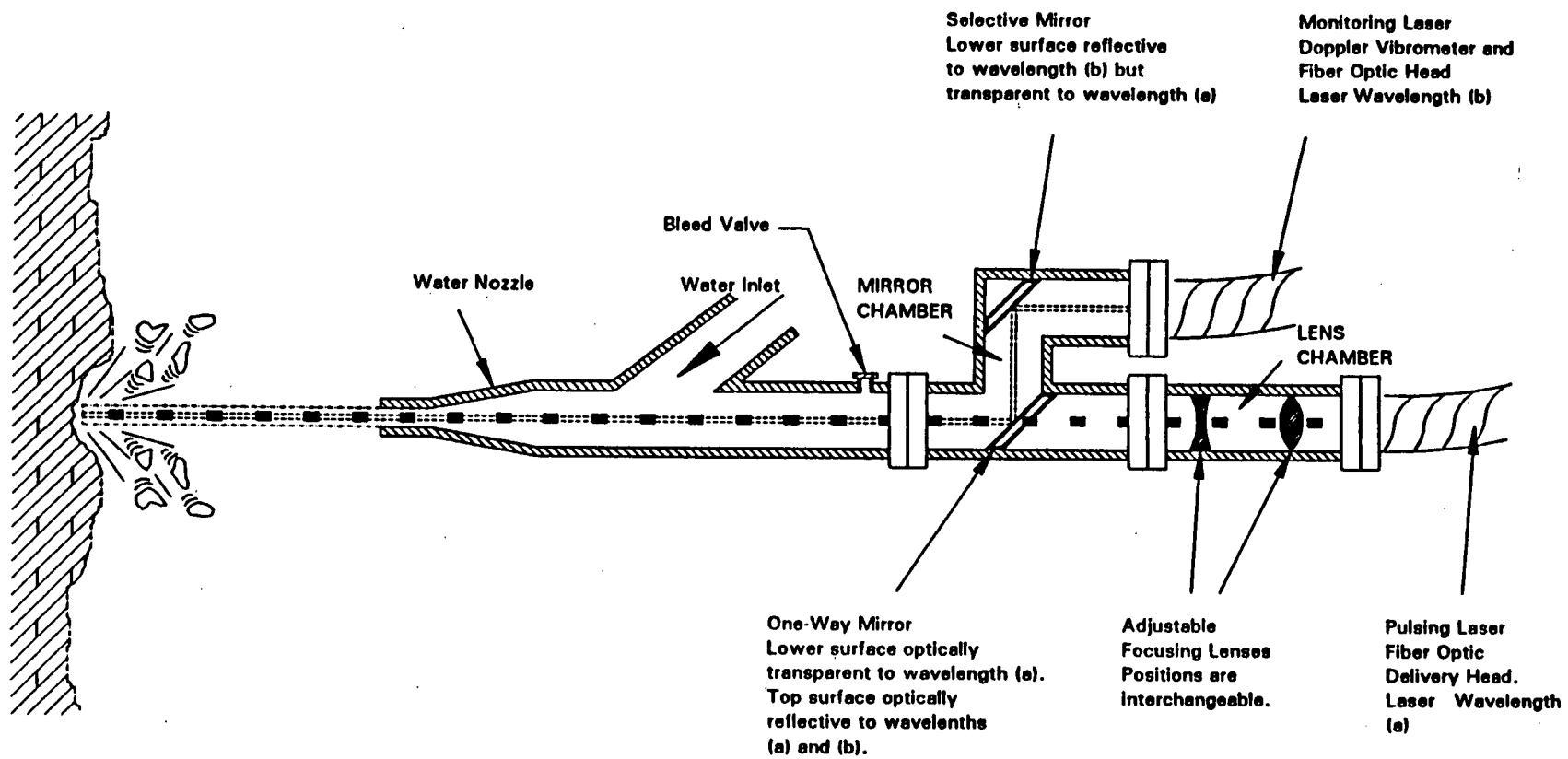
- The tool is basically silent, produces negligible ground vibration, and therefore causes minimum damage to remaining rock walls and roof.
- No dust from mining or fumes from blasting are released into the environment.

This non-contact, continuous mining tool will have application not only in the mining industry, but in tunnelling, highway construction, reconstruction requiring concrete removal, demolition, and building foundation work.

In terms of economics and efficiencies, pulsed laser output powers and electrical efficiencies are both rising, while capital costs are falling. Preliminary estimates based on modest assumptions indicate a specific energy of excavation around 170 MJ/m³, which is expected to fall below 100 MJ/m³ as wall-plug efficiencies of lasers increase.

INTERPRO is seeking industry support to conduct additional testwork and develop a working demonstration model of the Laser-Water Jet. Expressions of interest and requests for additional information should be directed to:

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NOTE: Only one pulse at a time will be in this stream at 10,000 Hz. Time interval from pulse to pulse = 1×10^4 sec. Each pulse would travel 18.6 miles in this interval.

Fig 1: The Laser-Water Jet
(Patent Pending)

INTERPRO[®]

Hard Rock Mining Using a Pulsing Laser

April 1993

Subsequent to our February mailings, additional testwork funded by EPRI's Center for Materials Production has been carried out to investigate the ability of single laser pulses to explosively excavate hard rock.

A nanosecond pulse-length glass laser was used on six different rock types, each covered by a thin layer of running water. This laser-water combination activated only one of the five mechanisms described in our previous correspondence, but this mechanism alone is sufficient to excavate rock chips as shown in Figures 1 and 2. Note that fine material was washed away by the flowing water and not collected.

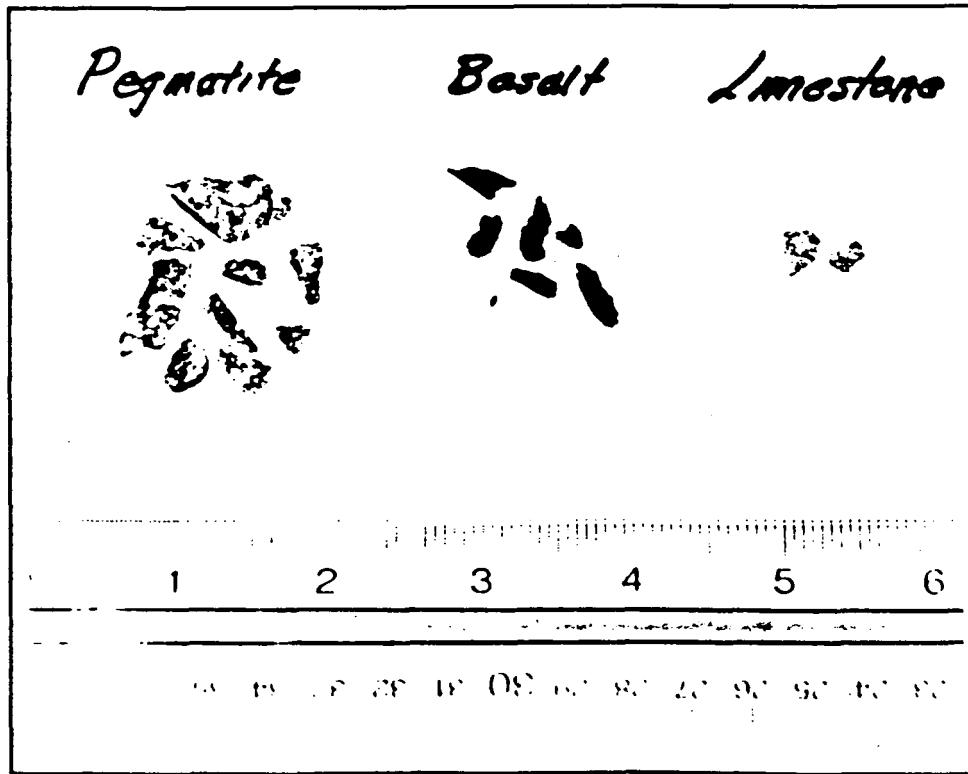


Figure 1

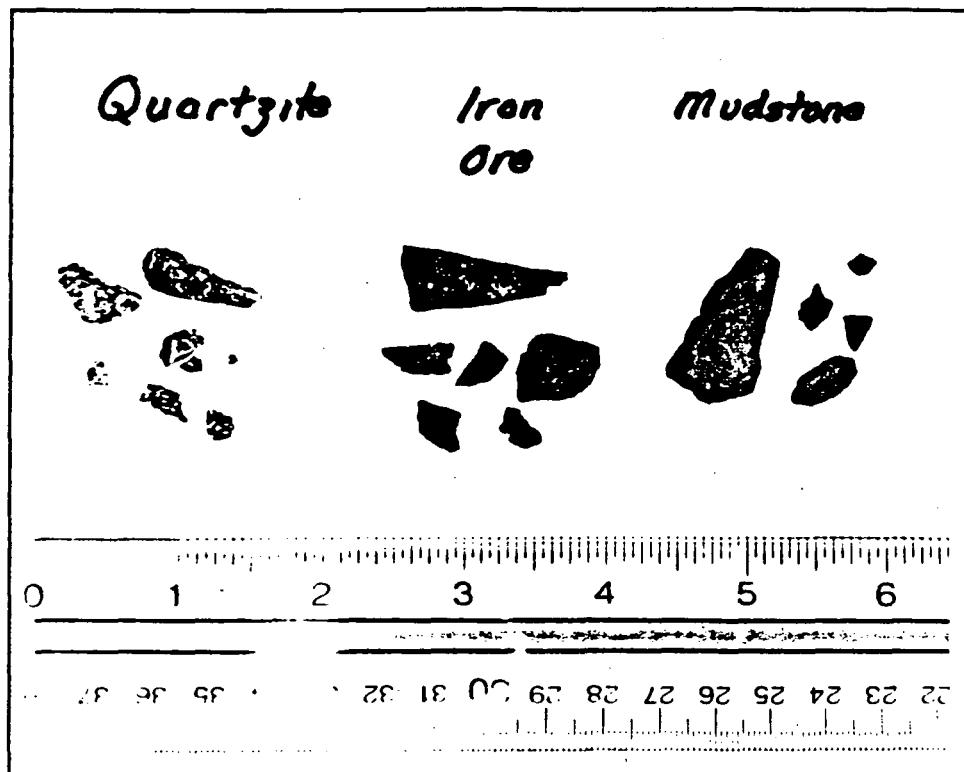


Figure 2

Chip samples in the photographs were collected after three to seven successive laser pulses, each spaced several seconds apart. This compares to the proposed Laser-Water Jet mining tool which envisages laser pulses at *several thousand* times per second.

The excavating mechanism on three of the rock types has been captured on video tape which dramatically shows the explosive nature of the process. Results of this testwork are being incorporated in an economic study. The study will compare underground narrow vein gold mining using the Laser-Water Jet to traditional drill and blast mining methods.

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