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SURFACE DRILLING TECHNOLOGIES FOR MARS

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ABSTRACT

We propose rock drilling and coring conceptual designs for the surface activities associated with a manned Mars mission. Straightforward extensions of equipment and procedures used on Earth are envisioned for the sample coring and shallow high explosive shot holes needed for tunneling and seismic surveying. A novel rocket exhaust jet piercing method is proposed for very rapid drilling of shot holes required for explosive excavation of emergency radiation shelters. Summaries of estimated equipment masses and power requirements are provided, and the indicated rotary coring rigs are scaled from terrestrial equipment and use compressed CO_2 from the martian atmosphere for core bit cooling and cuttings removal. A mass of 120 kg and power of 3 kW(e) are estimated for a 10 m depth capability. A 100 m depth capacity core rig requires about 1150 kg and 32 kw(e). The rocket exhaust jet equipment devised for shallow (3m) explosive emplacement shot holes requires no surface power beyond an electrial ignition system, and might have a 15 kg mass.

INTRODUCTION

Achievement of manned Mars mission scientific exploration and permanent human occupation of the planet will require drilling and coring operations associated with subsurface exploration and facility construction [1,2]. These operations will include: (1) subsurface geologic sample coring, (2) geophysical instrument emplacement, (3) seismic source (explosive shot hole) emplacement, and (4) shot hole drilling for explosive excavations. Successful execution of these drilling operations will be essential for energy, water, and mineral resource assessment and for understanding the origin, evolution, and present structure of the planet. We suggest that rather straightforward extensions and adaptations of terrestrial equipment are possible to effectively solve the required subsurface sampling and shot-hole formation problems. The suggested systems were developed on Earth in response to much the same needs as will exist for the Mars exploration scientific efforts.

DRILLING AND CORING REQUIREMENTS

We will assume a Mars surface exploration scenario[1] consisting of five landings at three different sites. The ultimate objective of the missions will be to establish a permanently manned outpost to serve as a base for the scientific exploration of the planet. This implies drilling through a wide range of rock and soil types for both scientific and construction purposes. In all cases, the drilling and coring operations should be as automated as possible (where consistent with reliability and mobility) to minimize the expenditure of valuable crew time.

Scientific Drilling and Coring

Drilling and direct sampling of the uppermost materials of the martian surface will be essential to the emplacement of instruments, determination of near-surface stratigraph, and interpretation of geophysical measurements. Core samples should be large enough to encompass anticipated textural inhomogeneities and the holes should be as deep as possible. Because little is known of the materials that are likely to be encountered, arbitrary decisions on the drilling parameters are inevitable and final details will be largely controlled by anticipated power and mass availabilities on the martian surface. Consequently, as outlined by Black et al [2], we propose that two basic scientific drilling and coring capabilities be developed: (1) capability to drill and core a single ~ 100m "deep" hole at each landing site with support (e.g., power) provided by the landing craft, and (2) a highly mobile drilling and coring capability for many ~ 10m deep "shallow" core holes supported by roving exploration vehicles. In both cases, we suggest hole diameters of about 15cm and oriented cores of 7cm diameter. Furthermore, since volatile materials are likely to be contained in the rocks, refrigerated storage of a substantial portion of the core (say, 25%) should be provided.

Explosive Shot Holes

Mars exploration will need extensive drilling of shallow, noncored holes for the emplacement of explosives in support of both scientific[2] and operational[3] objectives. In most cases, shot holes for explosive excavations need only be a few meters deep and a few centimeters in diameter. The holes can be drilled as rapidly as possible with no regard to preservation of the host rock or samples. In the case of the remote, rapidly excavated radiation emergency shelter[3] that will be needed, the explosive emplacement shot holes must be drilled in a matter of minutes. Emplacement of explosives for active seismic surveys can be in the same shallow core holes drilled for the rover vehicle geologic and resource explorations.

CORING AND DRILLING APPROACHES

We assume that coring hardware is required that is relatively insensitive to rock and soil type. The device should reliably yield high quality cores at a high recovery rate. Limited manpower requirements and restrictions on mass and power are anticipated. The major problem to be addressed is the cooling of the core bit and clearing of rock chips and cuttings from the core holes. We suggest that an electric powered, rotary driven core rig is appropriate. The optimum fluid for core bit cooling and hole cleaning appears to be compressed CO_2 from Martian atmosphere. To achieve cores in permafrost-like material will require a reverse CO_2 fluid circulation with cold CO_2 flowing in contact with the core hole wall. A stock of a variety of core bit types and configurations will be needed to achieve the desired core quality and recovery because of the expected wide variability in rock and soil conditions. These bits will be the major expendable items needed for the proposed core rigs. Characteristics and descriptions of the core rigs are summarized in Table 1.

The second type of hardware we envision is designed to drill small diameter shot holes for emplacement of high explosive charges for tunneling and other excavation tasks. The best choice for this application would appear to be a percussion drill powered by compressed CO_2. Hole cleaning of these relatively shallow, small diameter holes would be accomplished by exhausting the CO_2 drive gas into the bottom of the hole to lift the cuttings. The percussion drill approach would provide rather rapid production of holes in a wide variety of media. This type of equipment is well developed and widely used for similar applications on Earth. The additional use of this tool as a jack-hammer for construction purposes is possible. Table 2 summarizes the descriptions and characteristics for these two shallow shot hole drilling techniques.

TABLE 1

MARTIAN CORE RIG TYPES AND CHARACTERISTICS

Hole Type[a]	Depth Capability (m)	Hole Diameter (cm)	Core Diameter (cm)	Average Coring Rate[b] (m/hr)	Deployment Mode
Deep	100	15	7	8	From landing craft.
Shallow	10	15	7	2	From rover vehicle, possibly towed.

(a) Visualized is rotary drive by electric motor with compressed CO_2 for bit cooling and hole cleaning.

(b) Core rig concepts wireline type core run-in and retrieval capability with a 2-meter core tube length for ease of core handling and equipment mobilization.

TABLE 2

MARTIAN SHOT HOLE DRILLING TECHNIQUES AND CHARACTERISTICS

Application or Hole Type	Depth Limit (m)	Hole Diameter (cm)	Drilling Time (min)	Deployment	Technique
Explosive Tunneling or Seismic Shot Hole	3	5	30	From rover and manual.	Percussion drill w/ star drill bit & CO_2 hole cleaning
Emergency Shot Hole	3	5	5	From rover with manual set up and firing.	Solid rocket exhaust jet; hole cleaning by exhaust gas

Finally, we consider equipment that could be deployed very rapidly to create high explosive shot holes almost instantaneously. These holes are required for explosive excavation of emergency shelters from solar flare radiation[3]. The approach that is envisaged uses solid rocket exhaust penetrators[4] that can produce holes in any rock or soil type in a matter of seconds. Such solid rocket ground piercing units appear optimum for this application for reasons of drilling speed, long-term storage, mobility, rapid deployment, safety, and simplicity of set-up and firing.

EQUIPMENT CONCEPTS

We now turn to some specifics of the requirements for coring and drilling on the martian surface and to preliminary descriptions of equipment. The following drill rig and equipment descriptions are based on analogous terrestrial drilling applications. The major constraints in the selection of the approaches, concepts, and initial designs we present are the need for (1) simple and reliable technology, (2) drilling and coring in variable ground (hard rock, soils, and frozen rock and soil), (3) use of an expendable fluid for bit cooling and hole cleaning, (4) minimum mass and power consumption, (5) rapidity of progress, (6) possibility of automation, as a trade-off against simplicity and mobility, and (7) safety and reliability of equipment and procedures.

Scientific Drilling and Coring

As discussed above, two types of coring equipment are proposed based on analogies to exploration activities routinely conducted on Earth. Our concept is illustrated in Figure 1 where the rig with deep coring capability is depicted. A direct adaptation from terrestrial hardware is envisaged, with compressed martian atmosphere (CO_2) used as a core bit cooling and hole cleaning fluid. Core drilling can be extensively automated. However, we believe that manual set-up, core barrel run-in and retrieval, and core removal operations are likely to be more reliable, at least initially. The unit is shown trailer-mounted, so that deeper holes away from the lander site might be planned if found to be needed and if justification is developed by the shallow core hole traverses or other exploration activities. Power can be supplied by cable for relatively short distances from the landing craft. Preliminary selection of the features of this core rig are indicated in Table 3. All parameters,

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TABLE 3

CORE RIG EQUIPMENT SPECIFICATIONS

Core Rig Type	Derrick Height (m)	Core Barrel Length(m)	Rig Mass[a] (kg)	Rotary Power (kwe)	CO_2 COMPRESSOR Pressure (MPa)	Power (kwe)	Flow Rate (m^3/s)	Comments
Deep (100m)	12	3	1150	32	2	5	0.004	Mass estimate includes 100m length of drill string.
Shallow (10m)	6	2	120	3	1	2	0.002	Mass estimate includes 10m length of drill string.

a Includes draw works, CO_2 compressor, and rotary drive. Note that draw works are required for core-barrel wireline (cable) retrieval and run-in. Mass estimates are scaled from terrestrial equipment both structural and material optimization included.

TABLE 4

SUMMARY OF SHOT HOLE DRILLING EQUIPMENT CHARACTERISTIC

Hole Type	Depth Capability (m)	Mass[a] (kg)	Mobility Mode	Drilling Time (min)	Power Sources	CO_2 Compressor Pressure (kPa)	Power (kWe)	Comments
Percussion	2-3	90	skid Mounted	30	Electric Motor & Compressed CO_2	0.7	2	Hole cleaning injected through hollow drill rods.
Solid Rocket Jet	2-3	30	Pallet & Tripod	5	Solid Rocket Propellant	N/A	N/A	Reverse reaction jets reduce together and guide tripod requirement. Hole cleaning by high exaust velocity and vaporization of rock "cuttings"

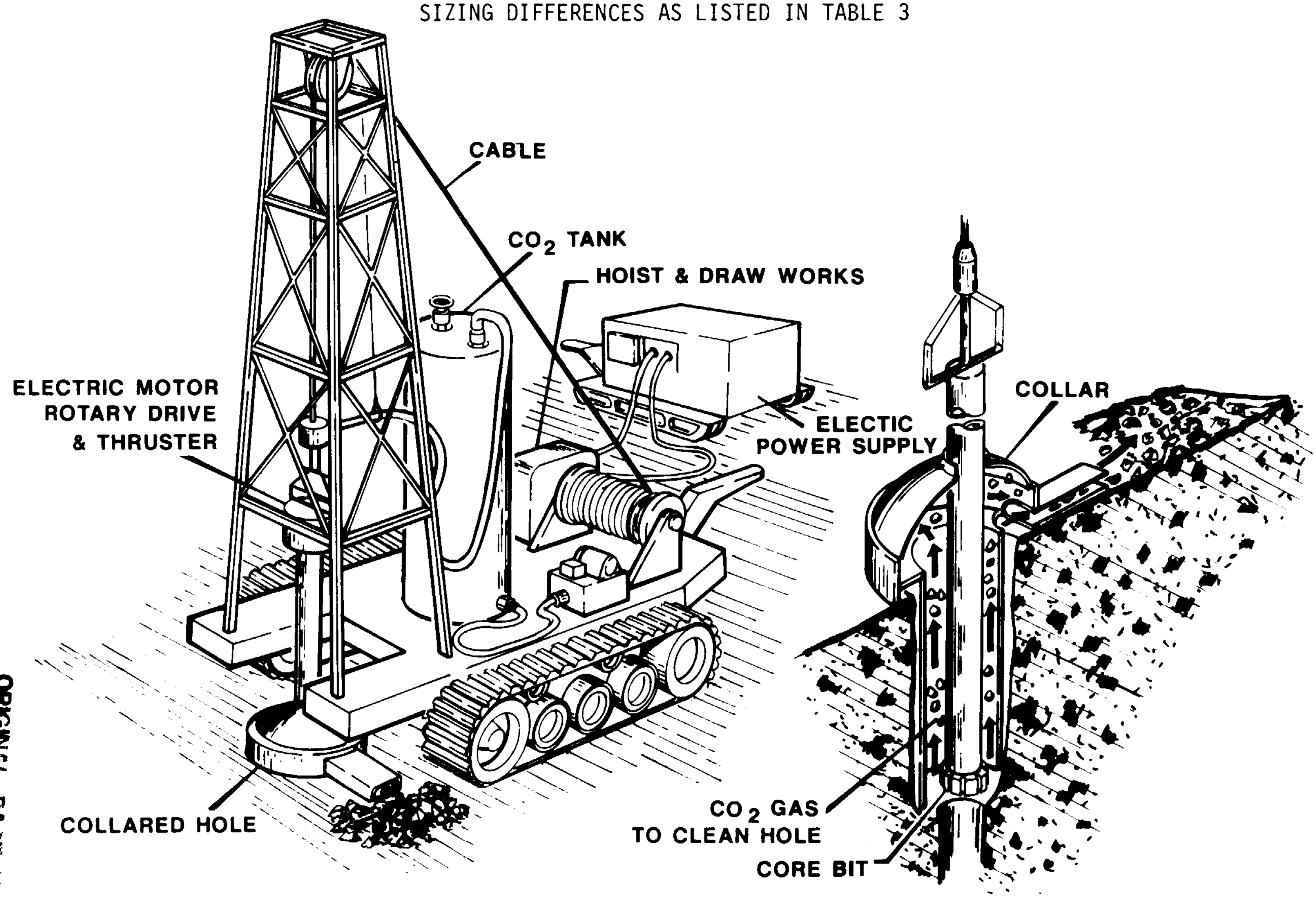
a Scaled from similar terrestrial equipment.

FIGURE 1

GENERAL CONCEPT FOR A MARS CORING RIG

THE BASIC LAYOUT WOULD BE THE SAME FOR BOTH THE DEEP AND SHALLOW DRILLING RIGS:

SIZING DIFFERENCES AS LISTED IN TABLE 3



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sizes, power requirements, and flow capacities were scaled from existing equipment[5]. Considerable optimization should be possible with detailed design, trade-off analysis, and efficiency enhancement studies.

The shallow core rig design is also specified in Table 3, and is visualized as a highly mobile rig that can be mounted on skids or trailer to be towed by a rover vehicle or even manually. It should also be designed for ease of disassembly and assembly into light weight sub-components so that it can be "back packed" into rugged and remote areas.

The core drilling procedures and operations are completely analogous to those on Earth. One person operation is visualized with attention and activity requirements mainly focused at core barrel handling intervals. This approach is suggested because of the anticipated complexity and high mass requirements of an automated system. Also, consideration must be given to maintaining core quality during the crucial stage of removal of core from the barrels.

Percussion Drill

The conceptual sketch in Figure 2 indicates our suggested approach for a mobile, shallow depth capacity shot-hole drill. The concept is a direct analogy to the terrestrial jack hammer or pneumatic percussion shot-hole drill widely used in mining. The equipment requirements are illustrated in Table 4 and are scaled from typical hardware currently in use[4]. The compressed atmospheric CO_2 is used both to drive the oscillating impact mass and to clean chips from the hole. A hollow-shaft drill rod is used with a star drill bit. Slight rotary motion of the drill rod is provided to enhance cutting rate and cleaning. We estimate that a 3m-long, 50mm diameter hole can be cut in one-half hour in hard rock and more rapidly in loose soils or gravel. Table 4 records the estimated characteristics for this shot hole drilling device. The mobility is by a light weight sled on skids. Manual operation is considered optimum due to the many potential applications of such a device. We anticipate wide use of this tool concept in a variety of construction chores. Also, the same basic approach can be adapted for repetitive, specialized applications such as an automated drill, blast, and muck tunneling machine[3].

FIGURE 2

CONCEPT FOR A MOBILE ROTARY PERCUSSION DRILL FOR PRODUCING SHOT HOLES

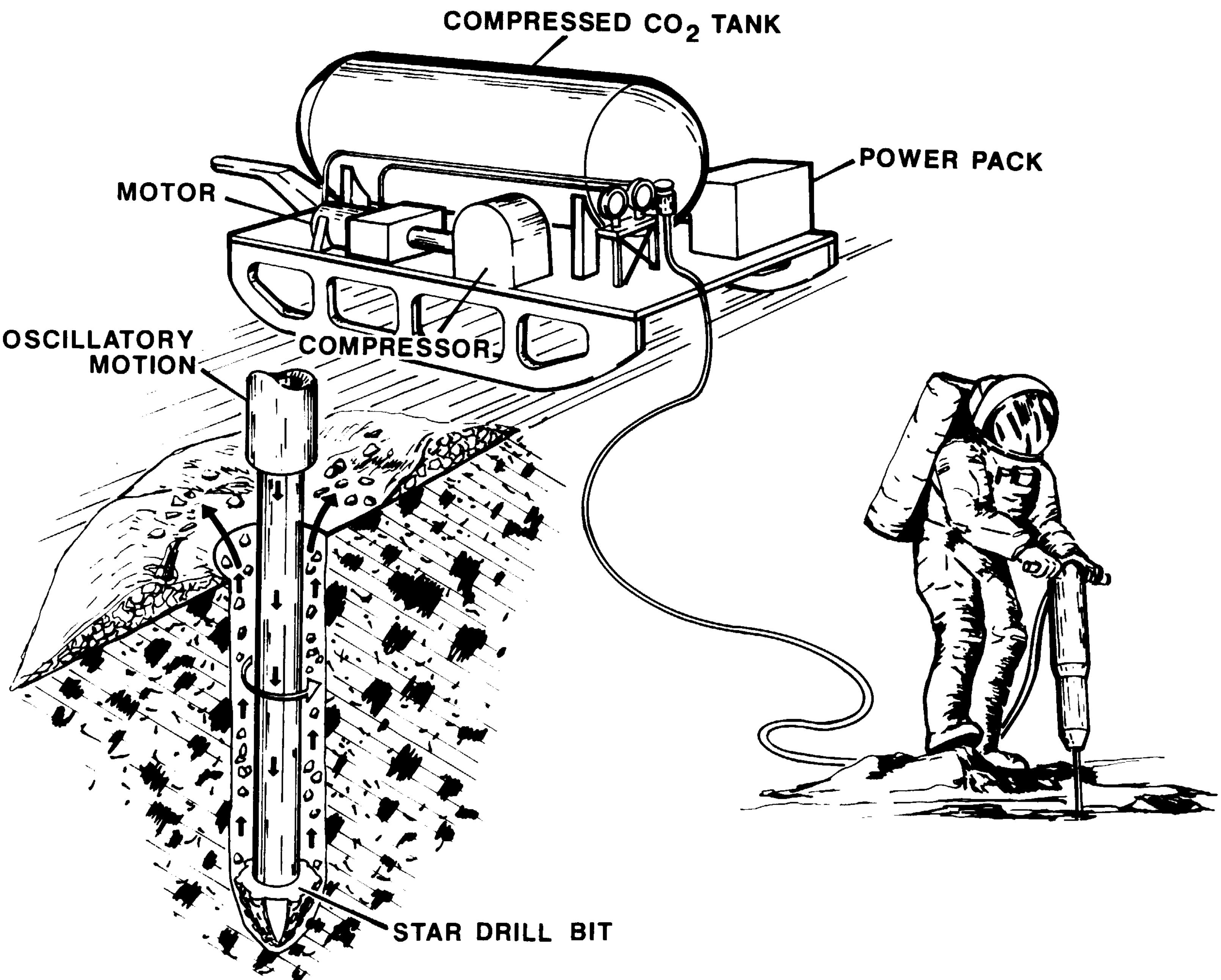
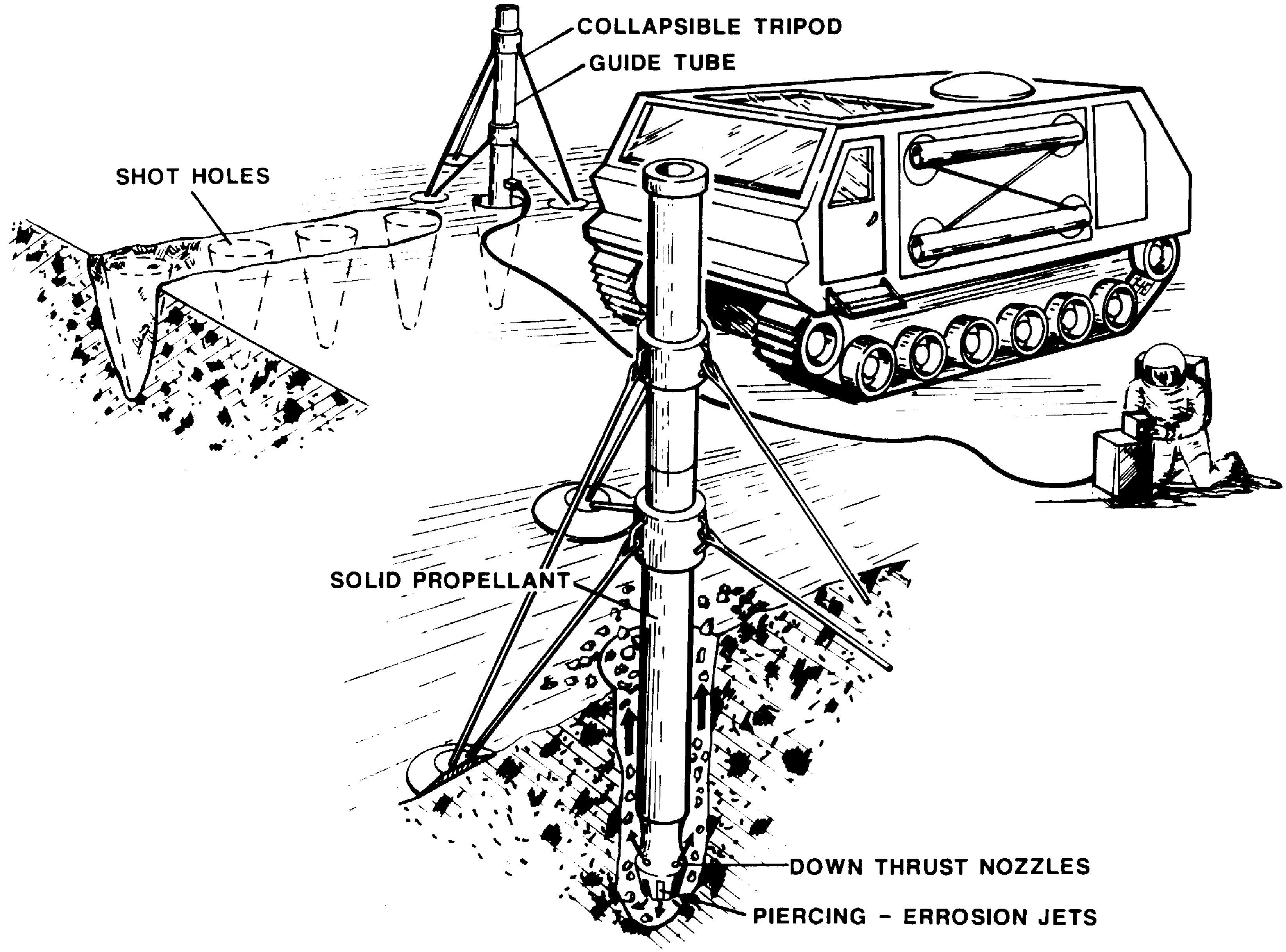


FIGURE 3

RAPID DRILLING CONCEPT USING THE ROCKET EXHAUSE JET PIERCING TECHNIQUE
SOME SIMPLE SET-UP METHODS ARE INDICATED IN THE UPPER LEFT
SCHEMATIC DETAILS OF THE ROCKET NOZZLE ARE SHOWN IN THE LOWER RIGHT



Rocket Exhaust Drill

Extremely rapid shot hole drilling for emergency shelter construction can be achieved by use of tethered, solid rocket exhaust jet piercing technology[4]. In this approach, a section of tubing and a following guide tube are erected with a light weight tripod. Figure 3 shows the proposed equipment configured to be used in conjunction with a rover vehicle. A single shot hole can be made in a few seconds after a few minutes to deploy, assemble and fire (ignite) the solid propellant. A row of holes can be made in sequence if only one tripod is provided, or a mutiple set-up is possible. This is the most rapid drilling method (including set-up) we know of for shallow shot holes.

CONCLUSIONS

The manned Mars mission drilling applications of geologic sampling, emplacing scientific explosive sources, producing shelters and other constructions, and rapid excavation of remote emergency shelters are projected to be rather straightforward adaptations of terrestrial equipment and procedures. The proposed approaches rely on established technologies and should be safe, reliable, easily automated to the degree deemed desirable, and adaptable to a wide range of anticipated applications on Mars. The concepts feature manual operation of essential activities where its employment can minimize mass, power, and complexity. Equipment designs can be accomplished and optimized for martian conditions. Design of the required CO_2 compressors should be a priority task, but can rely on the extensive Earth-bound experience in this area. All the designs outlined can be built in prototype hardware forms and tested at atmospheric pressures, temperatures, and compostions expected on Mars and in simulated materials likely to be encountered in the martian subsurface.

REFERENCES

[1] Blacic, J.D., 1985, "Manned Mars Mission Scenarios", Manned Mars Mission Workshop position paper.

[2] Blacic, J.D., M. Ander, and D.T. Vaniman, 1985, "Mars surface science requirements and plan", Manned Mars Mission Workshop position paper.

[3] Dick, R.D., J.D. Blacic, and D.R. Pettit, 1985, "Use of chemical explosives for emergency solar flare shelter construction and other excavations on the Martian surface", Manned Mars Mission Workshop position paper.

[4] Maurer, W.C., 1980, Advanced Drilling Technologies, Petroleum Publishing Co., Tulsa, OK, pp. 488-507.

[5] Stock, B., 1982, Handbook of Mining and Tunneling Machinery, John Wiley and Sons, New York, pp. 12-42.