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Final Report

March 1966

COOLING WATER FOR FALLOUT SHELTERS

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF THE ARMY
WASHINGTON, D.C.

CONTRACT OCD-PS-64-201
WORK UNIT 1234A

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STANFORD RESEARCH INSTITUTE
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By: F. HUGHES-CALEY

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COOLING WATER FOR FALLOUT SHELTERS

By F. Hughes-Caley
Stanford Research Institute
March 1966
Work Unit 1234A

DETACHABLE ABSTRACT

In the event of nuclear attack on the United States, the population of affected areas will enter designated shelters to escape exposure to nuclear fallout. Confinement may extend for periods of up to 14 days. Utilities such as electric power and city water are likely to be inoperative. The solution of problems relating to food supplies and potable water appear to be reasonably well in hand, as in ventilation with manually operated equipment. However, in certain areas of the United States, the ambient environment during summer months is such that outside air is too hot to be useful in ventilating fallout shelters directly.

The objective of research reported here was to determine the feasibility of prospecting for, tapping, and recovering ground water, working from within fallout shelter boundaries, for use as a shelter ventilating air coolant.

A literature search was made into the background of established techniques of soil penetration and well construction, with particular emphasis on those that might lend themselves to manual operation in the event of a complete absence of power. This search was supplemented by a parallel series of discussions with knowledgeable personnel of the Division of Water Resources, Department of the Interior, U.S. Geological Survey and with practicing engineers having longtime experience in the construction of both shallow and deep wells by long established basic techniques. This background study permitted an assessment of the relative practicability of existing techniques in the light of the limiting circumstances of fallout shelter environment.

Findings and implications arising from the above studies and discussions are that post-attack, in-shelter well construction is not feasible, particularly for the following reasons:

> The severe limitations imposed by the physical (configurational) environment likely to be encountered in the typical designated shelter.
>
> In only a limited number of instances is it likely that a reliable pre-attack prediction can be made that ground water is present beneath a shelter either in a sufficient quantity, or at all, or in penetrable subsoil and/or at an attainable level.

A method of sonic well drilling was investigated, which holds promise of removing some of the present objections to pre-attack well construction.

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In the event of nuclear attack on the United States, the population of affected areas will enter designated shelters to escape exposure to nuclear fallout. Confinement may extend for periods of up to 14 days. Utilities such as electric power and city water are likely to be inoperative. The solution of problems relating to food supplies and potable water appear to be reasonably well in hand, as in ventilation with manually operated equipment. However, in certain areas of the United States, the ambient environment during summer months is such that outside air is too hot to be useful in ventilating fallout shelters directly.

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I INTRODUCTION

A. STATEMENT OF THE PROBLEM

The project work statement contemplates that, in geographical areas where outside temperatures preclude direct cooling of a shelter by forced circulation of ambient air alone, a need may arise under attack conditions for immediate development of ground water supplies from sources within and beneath the shelter.

As a reasonable model, we have selected a 100-occupant shelter and postulated conditions requiring an estimated 1 to 15 gallons per minute (gal/min) of cooling water, (depending on the type of cooling system) to maintain the effective temperature* (ET) of the shelter at a maximum of 85°F (see Appendix A). This water need not be potable, although if in ample supply, it might also be used for other utilitarian purposes.

The above requirement supposes the use of simple, relatively low-cost well-drilling and water-recovery equipment, capable of manual operation in the event of power failure. That this is [illegible]ble--where lead-time is not a limitation--has been and still is being proved in many parts of the world. Restriction of headroom in a shelter environment will naturally narrow the choice of techniques and involve modification to equipment. It will, however, not affect technical feasibility.

In order to provide background for discussion and comparison, we have provided a broad description of the methods and equipment that might typically be used to tap and recover ground water at shallow depths, i.e., water that might be reached and used within a period of time during which a shelter requiring cooled ventilating air could be

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* ASHRAE[1] defines effective temperature as an empirical sensory index, combining into a single value, the thermal effect of temperature, humidity, and movement of air upon the human body. Combinations of temperatures, humidities and air velocities that produce the same feeling of warmth are assigned the same "ET" value.

without it and remain habitable.[1*] This report does not concern itself with the means for actual utilization of the cooling water after it has been tapped, except as an index to the flow required per occupant (see Appendix A). It does, however, suggest means for storage or for disposal of used water.

It has become apparent that even recent (1965) ground water surveys are concerned only with reserves lying at depths of from several hundred to thousands of feet[2], rather than generally unimportant water-bearing strata at a shallow depth or under a relatively thin and easily penetrable overburden. The latter conditions would be a prerequisite to successful and reasonably fast tapping and recovery of ground water through primitive techniques and the use of simple, manually operated, packaged equipment.

Therefore, unless conditions favorable to the use of simple means are known to exist in an already designated shelter or one under consideration, test boring would be the only reliable method of determining whether ground sources might be tapped rapidly enough after an attack to maintain the shelter effective temperature at or below survival level.

The history of building construction in certain heavily populated areas of the United States yields numerous instances of subsurface water in such quantity as to be a problem during excavations for foundations. However, these heavily saturated formations frequently dry up when, due to increased building and street coverage in an area, they cannot become replenished by seepage. For the purpose of this report it is assumed that for areas in which it is essential to cool shelter-ventilating air, fallout shelters will be designated only in locations where a survey or local experience indicates positively that ground water underlies the shelter floor in usable quantities, at a depth not more than 25 ft, and in readily penetrable formation [see (2) and also (4a) under "General Limitations"]. Even so, because local subsoil conditions vary considerably, it is only possible to generalize as to the type of well

* References are listed at the end of the report.

construction and pumping equipment best suited for in-shelter application, and also the time required to complete a producing installation.

B. GENERAL LIMITATIONS

(1) Availability of ground water is assumed at a sufficiently shallow depth, say within 25 ft. This implies a high degree of confidence in existing information relating to the nature and penetrability of subsoil, the level of the water table, the capacity of the water-bearing strata, and ability to yield water to the well at the required rate, based on local and/or national surveys.

(2) It is assumed that a producing well must be completed and ready for operation within four hours after occupancy if the shelter is to remain tenable. This includes time required for withdrawal of equipment from storage, assembly and instruction, and development of the well to provide adequate flow after penetration into the water-bearing strata. Penetration through rock, boulders, or other recalcitrant material is not contemplated.

(3) Drilling equipment should have multipurpose utility so far as is practicable, so as to permit choice of more than one procedure in the face of local subsoil conditions.

(4) All equipment:

   (a) must be of simple, robust, and relatively low-cost design and be capable of manual operation. It should be modular, easy to assemble, operate and maintain, and require a minimum of simple and familiar hand tools.

   (b) must be operable with a headroom not exceeding 7 ft and be capable of low-bulk packaging for storage.

   (c) must have high resistance to deterioration during storage.

(5) Penetration techniques must be practicable without the use of water from an exterior source, whether for tool lubrication, softening or loosening of the subsoil formation, or for removal of debris from the bore while drilling.

(6) All operations must be capable of manual accomplishment. It is necessary for liner piping sections to be limited to 2 inch ID to satisfy the assumption that this is the maximum diameter to which wells can be bored manually by whatever technique. It is probable that 5 ft is the maximum length of pipe section that will permit manipulation of these sections in conditions of restricted headroom.

(7) Manually operated means for penetrating through 4 to 6-inch thick steel-reinforced concrete flooring must be provided. Drilling of the well itself cannot commence until this obstacle is overcome.

(8) Pumping equipment must be capable of "developing" the well after drilling, in addition to delivering water subsequently for cooling purposes.

II SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY OF RESEARCH FINDINGS

In certain geographical areas of the USA, the temperature of the outside air is such that it must be cooled before it can be used for shelter ventilation. Research during this project was to determine the feasibility of post-attack tapping and recovery of ground water from beneath the floor of designated shelters for use in cooling the ventilating air.

The existence of an adequate reservoir of ground water lying under a relatively thin and easily penetrable overburden would, of course, be a prerequisite ot successful and reasonably fast tapping and recovery using the primitive techniques and simple, manually operated equipment envisioned in the limiting environment of a fallout shelter under post-attack condition. While the history of building construction in certain heavily populated areas of the United States yields numerous instances of subsurface water found in such quantities as to be a problem during excavation for foundations, it has also been noted that these heavily saturated formations frequently dry up when, due to increased building and street coverage in an area, they are not replenished by seepage.

Even using the preferred state-of-the-art techniques (described in Sec. III and compared in Appendix B), the time to complete an operating well from a standing start would be, at best, in excess of 24 hours. This is true even under the following conditions.

- subsoil conditions favorable for penetration
- techniques least limited by the in-shelter environment employed
- prior exploration or recent construction experience yielding relatively positive indication of ground water in suitable quantities below the shelter location
- packaged equipment, capable of manual operation, stored within the shelter structure for immediate use at time of need.

If gasoline or diesel auxiliary power units were available for operation of the well-drilling equipment, it is estimated that the time for construction would still be in excess of 24 hours.

The probability is high in areas where shelter cooling will be required that, during any 24-hour period in the four summer months, one or perhaps two faily extended plateaus of effective temperature (ET) in excess of 85°F will be experienced by experienced by shelter occupants cooled only by ambient air. During the period of post-attack well construction (i.e., prior to availability of cooling water; at a minimum 25 hours) collapse from heat prostration can be expected, particularly in view of the arduous nature of the work involved on the part of the well drillers. Consider the following example: Assume the ambient air used for ventilation to be at a dry bulb temperature (DBT) of 95°F and an ET of 86°F. Adiabatic calculation indicates that 60 CFM/occupant are required to hold shelter DBT to 95°F and ET at 87°F. This indicates that a 1° rise in ET occurring almost immediately upon occupation of the shelter leveling off at this value (provided air flow is maintained until means for cooling become available).

Physiological studies have shown that lightly clothed, untrained males, in good physical condition, can reach the point of collapse in 20 minutes of moderately hard physical labor in an environment of 95°F ET; the point of collapse is reached in about 60 minutes <u>if resting</u>. On the other hand, <u>trained</u> Navy boiler room personnel on watch duty (mainly observation, with light physical activity) survive duty spells of four hours at 91°F ET without collapse. Extrapolation of the "working" curve shows that sustained physical effort at a moderate level is possible in an environment at around 85°F ET, but only for trained and acclimated personnel.

During research into various techniques for post-attack soil penetration, the existence of a new "sonic" technique for rapid penetration came to light. This technique, described briefly in Sec. V and Appendix F, and compared with existing techniques in Appendix C, is not suitable for post-attack well construction. The equipment involved is highly specialized, would require trained personnel for operation, and must be power-driven.

B. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

It is concluded from research during this project that consideration of post-attack well construction from within a designated shelter is unrealistic because:

(1) Even the simplest system for post-attack tapping and recovery of ground water reserves for shelter cooling is impracticable with the well known state-of-the-art techniques, whether auxiliary or manually powered, since the rise in temperature within the shelter during the 24-hour construction period would be such as to cause abandonment of the shelter or collapse of the occupants.

(2) In addition, the positive existence of an adequate reservoir underlying the shelter floor in an easily penetrable formation cannot be predicted with certainty even if local records affirm its presence. Therefore any post-attack drilling operation undertaken must be considered as prospecting, which may or may not result in a dry hole. This, in the circumstances, would constitute an unjustifiable risk.

Therefore, it is recommended that pre-attack prospecting, followed by immediate well construction where appropriate, be reconsidered in the light of the information contained in Sec. V.

It is specifically recommended that the overall feasibility and estimated operating cost of the Sonic Co. technique (discussed in Sec. V) for pre-attack in-shelter well construction (and also other techniques appearing comparable) be fully investigated at the earliest opportunity. In the event that the outcome is favorable, an attempt should be made to review and where possible remove objections to pre-attack construction previously entertained by owners, lessees, or other interested parties. This could make possible planning of a realistic and mutually agreeable program of contract "test-drilling" (followed where appropriate by well installation), to commence immediately following the availability of suitable equipment and the development of a mutually agreeable contracting arrangement.

III SHELTER WELL-DRILLING TECHNIQUES

A. PIERCING THE SHELTER FLOOR

Since piercing the shelter floor is superimposed upon the task of subsoil penetration, it is dealt with separately. Before penetration of a formation lying under the shelter floor can be attempted, the floor itself must be pierced or broken through. Designated shelters on ground floors or in basements may be expected almost without exception, to have reinforced concrete slab floors from 4 to 6 inches thick. This reinforcement will in most cases be heavy wire mesh or perhaps steel rod, 3/8- to 1/2-inch in diameter.

Ordinarily, penetration of such a floor presents no problem to a carbide-tipped electric or pneumatic tool. However, piercing or otherwise creating a 4- to 5-inch diameter hole with manually operated tools is a lengthy and arduous task, especially if reinforcing members are encountered. A long-handled star drill positioned by one operator and struck by another with a sledge or maul would be the only simple way to open a hole of adequate size. Such an operation could take several hours.

B. PENETRATING THE SUBSOIL

1. General

Choice of techniques for subsoil penetration after the shelter floor is breached is severely limited by the conditions under which the work must be carried out. In the following parts we present brief descriptions of techniques in common use for subsoil penetration and illustrate the most significant differences between them, thus permitting a general assessment of their utility under the limitations imposed.

2. Cable Tool Drilling

a. Equipment

Cable tool drilling is a percussive technique employing a steel tool bit attached to the lower tip of the series of jointed pipe or rod sections suspended from a long rope or cable. The entire assembly is rhythmically raised and permitted to fall, so that the tool bit penetrates and breaks up unconsolidated materials (e.g., clay, gravel, or glacial fill). Alternatively, the bit chips and pounds rock formations into fragments small enough to be readily removed from the hole by means of a bailer. The tool bit is rotated in operation, so as to present fresh material to the cutting edges at each stroke. In order to maintain an efficient fragmenting or cutting action the length of the operating rope or cable must be such that it is capable of sufficient elastic extension or "stretch" to permit a pecking or chipping action against the surface under attack. A "dead" blow such as would result from a short cable is much less effective.

Water must be injected into the bore as drilling proceeds so as to combine with the drillings in forming a mud or slurry. The debris is removed from time to time, by means of a "bailer" equipped with a foot valve (Fig. 1). Fragmented debris cannot be permitted to accumulate at the working face, as it tends to damp out the impact of the descending tool bit.

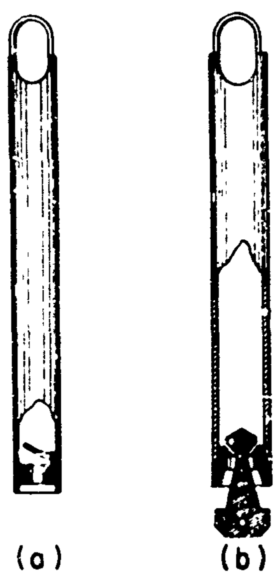


FIG. 1 TYPICAL BAILERS
(a) Differential pressure type
(b) Mechanical type

Cable-operated tools are unsatisfactory and often unusable in soft, loose, unconsolidated materials such as dune sand, quicksand and river gravels, where the pounding of the tool bit can cause the unsupported bore to cave in. In order to prevent this, the hole must be lined with casing, lowered or forced down in serially coupled sections immediately behind the progressing tool bit.

Rates of penetration using the cable drilling techniques can, under favorable conditions with a good rig and trained team, be as high as 30-50 ft in an eight-hour day for a 4- to 6-inch diameter hole in shale or similar materials, and perhaps 75-100 ft/day in clay or other unconsolidated materials. However, it is clearly not feasible to consider this technique for in-shelter well construction since:

(1) Water for formation of slurry is not likely to be available.

(2) Disposal of semifluid (or indeed any) debris could be a serious problem.

(3) Headroom would almost certainly be insufficient for a sufficiently long stroke coupled with the correct tool-bit action, thus penetration would be slow even through uncompacted formation.

(4) Means would be required to force down the liner tubes, either concurrently with or subsequent to drilling.

(5) The shelter occupants could not acquire, in the time available, the skill and judgement essential to coordinate the operation of this technique.

3. Rotary Drilling

a. Equipment

Rotary drilling is, under all ordinary conditions encountered in the field, much faster than cable drilling. Therefore small rotaries have been adopted almost universally for structure hole and seismograph exploration drilling, and also, wherever possible, in water well drilling. As the title implies, rotary drilling requires a cutting tool or bit, a means of imparting a rotary motion to the tool, a means of maintaining tool pressure against the material being cut, and a means for removing the cuttings or debris displaced by the tool. In all operational circumstances the boring tool must be rotated at a reasonably constant speed and fed at a regular rate under uniform downward pressure.

The basic component is a drill bit, coupled to a revolving steel pipe extending from the drill point upward to some distance above the ground. The top of the drill pipe is accommodated in a splined bushing, which enables it to move vertically as it is rotated by the drive mechanism. The speed of rotation is regulated according to the type, form, and size of cutting tool and the formation to be drilled.

The drill pipe is suspended from a steel cable by a swivel bearing, which permits the pipe to rotate while the cable remains stationary. The whole tool and pipe assembly may be raised or lowered by the cable, running over a sheave at the top of the derrick.

b. Description of Operation

The hoisting drive controls both the drilling pressure and the rate of feed applied to the cutting tool. The swivel, drill pipe, and tool bit are hollow, allowing fluid ("slurry") to be pumped from an outside supply to the cutting edge of the bit, where it picks up and carries the loosened material to the surface between the drill pipe and the walls of the well. The debris-loaded fluid or mud overflows the well mouth, and is carried to a settling pit for later recirculation. This mud or slurry is an essential ingredient in the rotary drilling technique: By virtue of its viscosity and weight, aided by a "plastering" action exercised by the rotating drill pipe, it helps prevent the otherwise temporarily unsupported walls of the well from collapsing during construction. Although this type of rig ranges from small, light, and compact units to those able to penetrate thousands of feet, the principle of operation remains the same for all sizes. In all cases, wells are lined to prevent collapse or "cave in" of the formation. The lowermost liner is equipped also with a screen to exclude the larger particles of gravel. Development of this type of well is carried out in a manner similar to that associated with other penetration techniques (see Section III-C).

The rotary technique is very efficient under the proper conditions. On the other hand, it is clearly not suitable for in-shelter application, even though it can be adapted for manually operated equipment. Among other disadvantages, it requires fairly large quantities of water from an outside source during construction of the well. Also the driving and hoisting mechanism is fairly complex and bulky, and disposal of the debris-loaded slurry could be a major problem.

4. Hydraulic "Jetting"

a. Equipment

Equipment used in the jetting technique consists essentially of an inner and outer pipe (Fig. 2). The inner pipe--the "jetting" tube--operates within an outer tube, which ultimately serves as the well casing. A pump with suitable hose attachments supplies a continuous flow of high-pressure water to the jetting tube during drilling.

Smaller rigs use a block and tackle together with a tripod for suspending and controlling the casing [see Fig. 2(a)].

b. Description of Operation

Water is fed under pressure into the top of the inner or "jetting" tube and down to the end of the tool, which rests, together with the outer tube, either on the surface or at the base of a shallow "dug" hole. Material loosened and disintegrated by the high-pressure jet is carried upward between inner and outer tube and eventually out through the side of the "drive tee". During the drilling operation, the swivel to which the pressure hose is attached enables the jetting tube to be turned from time to time to ensure a straight hole. Casing is usually sunk as rapidly as drilling proceeds. In the softer materials, by using an "expansion" bit [Fig. 2(c)] a hole may be made somewhat larger than the outside diameter of the casing, and the casing can be lowered for a considerable distance into the bore under its own weight. Ordinarily however, a drive weight or other means are employed to force it down. As a rule, unless the well is quite deep--viz., to several hundred feet--, a single "string" of casing sections with the same diameter is used. In fine-textured sand or sandy clay, the hole may be jetted to the full required depth and the casing subsequently inserted. The wall of the hole in such instances becomes "puddled" by the muddy water so that it will stand temporarily unsupported, without collapse. Where hard layers are encountered, they can sometimes be

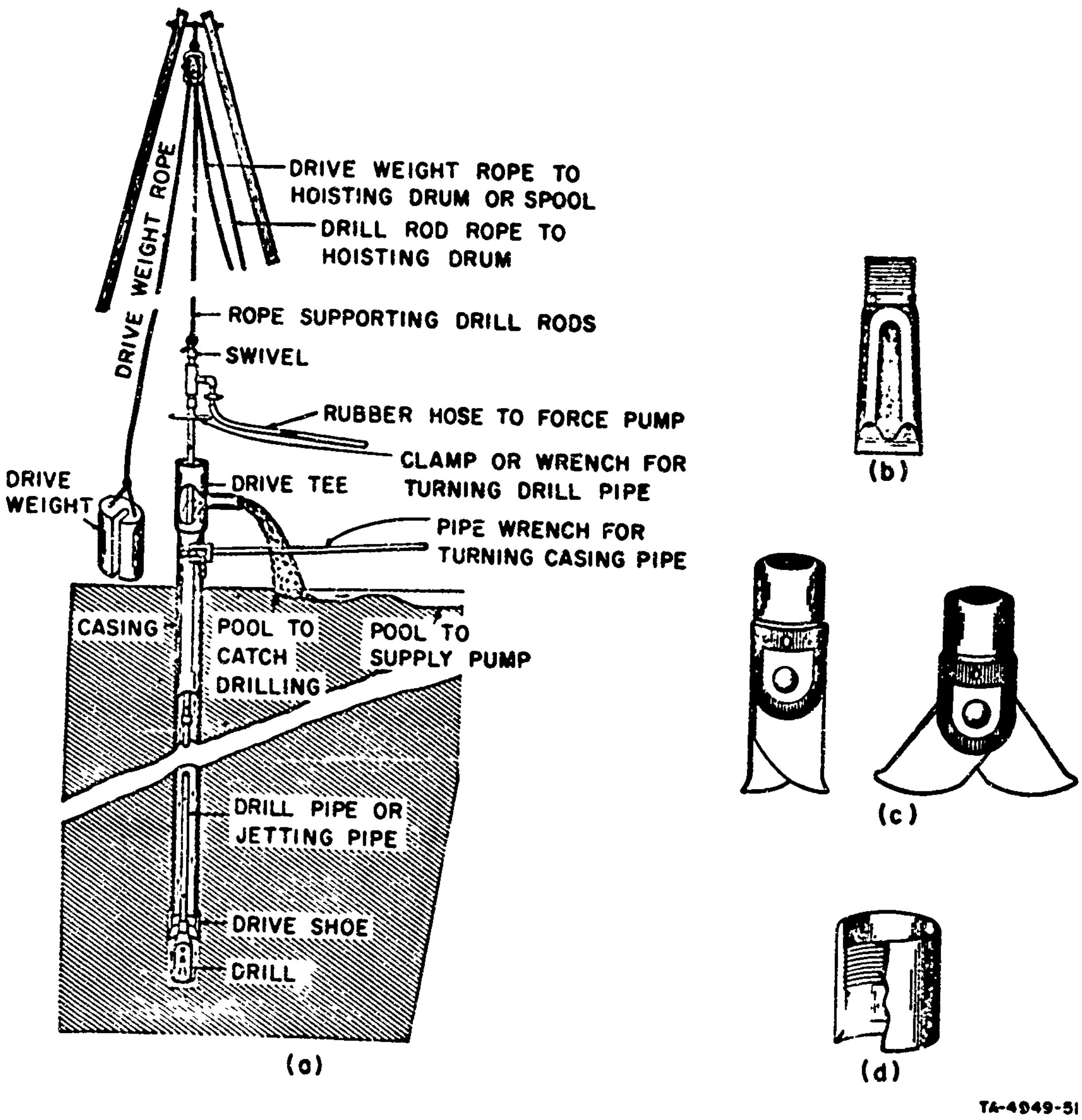


FIG. 2 JETTING EQUIPMENT

(a) Jetting process
(b) Common jetting drill
(c) Paddy or expansion drill
(d) Drive shoe

penetrated by withdrawing the jetting tube and substituting a hollow drill bit for the jetting tool. The tube is then raised and dropped rhythmically so that the tool strikes and shatters the obstruction--somewhat as in the cable drilling technique--until the hard layer has been pierced.

In the main, the jetting technique is intended to be used, and is particularly successful where water is known to be present at fairly shallow depths in easily penetrable formations. It is exceedingly simple and dependable when used under the proper subsoil conditions. The equipment, other than perhaps the pump, can be manually operated and is not dependent on bulky, difficult to transport drilling rigs. Using this technique it is possible to sink wells in suitable material very rapidly so that a really shallow source can be tapped in a few hours. Jetted wells, like those constructed by other techniques, must be developed after drilling.

The technique would appear to be quite impracticable for in-shelter operation, however, due to the need for an ample supply of high-pressure water and disposal of large quantities of debris-laden slurry.

5. "Bored" Wells (Augered)

a. Equipment

Bored wells are constructed using either hand or powered earth augers. The technique is used where speed and economy are essential and where relatively small quantities of water are needed and can be obtained at shallow depths by penetrating unconsolidated formations. The use of water as a lubricant or for softening the subsoil is not required, though in certain instances, a small amount is advantageous.

An auger is ordinarily used only where the formations, though relatively soft, permit an open hole to be bored to depths ranging from 25 to 60 feet. Formations most suitable for auger boring methods are glacial fill and alluvial valley deposits. In favorable locations auger-bored wells may be constructed using manual equipment only. During construction of a well, the length of the auger stem is increased with threaded-coupling extensions, until the required depth is reached (Fig. 3). In manual operation and where height is not restricted, a light tripod with rope and sheave is used, especially when a depth of 30 to 40 ft is exceeded, in order to support or lift the auger and extensions and prevent "whip" or damage to the stem, and to avoid the need for uncoupling and then recoupling the sections each time the auger is withdrawn to unload borings. Bores are normally lined with casing. Where loose sand and gravel are encountered, as in alluvial formations, progress below the level of the water table is actually impossible without lining the bore to prevent cave-in.

b. Description of Operation

The usual expedient is to lower a casing, through which the original or a slightly smaller diameter auger can be threaded. Boring is continued to the desired depth, and the casing is forced down at the same rate of penetration, and as material is removed from the hole.

A casing and screen are lowered into the hole after reaching the desired depth to exclude large particles and pebbles from the well bore during development to prevent cave-in, and to provide an airtight intake and support for mounting a suction pump or a rod-operated force pump.

Heavy rigs driving powered augers from 8 inches to several feet in diameter are used for larger wells in suitable formations. Actual rate of penetration, exclusive of preparation, coupling and uncoupling of sections for

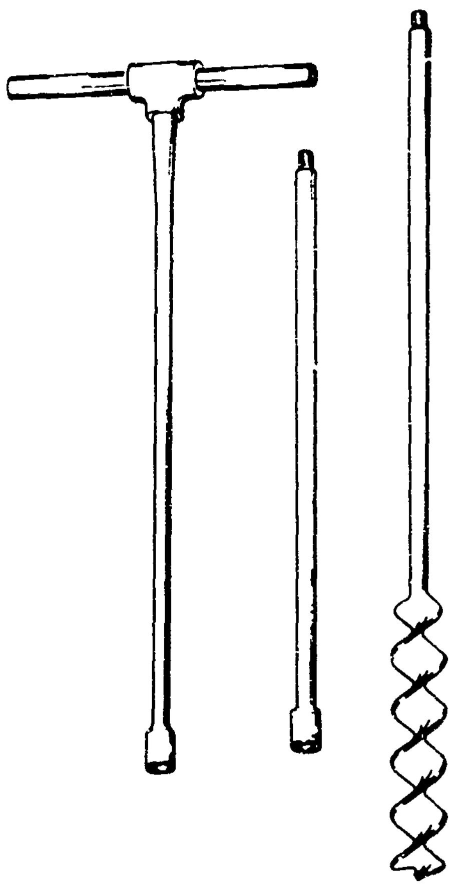


FIG. 3 HAND-OPERATED AUGER, WITH HANDLE AND EXTENSION

unloading, and (later) lining and developing the well, can be from 2 to 25 feet per hour, depending on the nature of the soil and the size of the rig.

The auger technique described is one of the more practicable state-of-the-art approaches to in-shelter well construction, and is discussed further in Sec. IV, "Summary of Drilling Techniques."

6. Driven Wells

a. Equipment

A driven well is constructed by driving a steel drive point, (Fig. 4) coupled to a perforated tube and tubular extensions directly into a water-bearing formation. The point, screen, and liner tubes remain in place and constitute the finished well. During driving, the subsoil is pushed aside and no debris is produced. If a suitable aquifer is found at a depth of 25 feet or less, a suction pump is fitted to the uppermost section of the liner tube. In the case of a deeper well, a force pump must be used. The casing for a deep well probably cannot have a bore diameter of less than 2 inches since it must accommodate a pump cylinder at or below the level of the water in the bore. As a matter of normal practice, drive points are not made to a diameter greater than is required to accommodate a pipe having 3-inch diameter bore.

The chief use for drive wells is in emergency operation, where water is known to be near the surface. The equipment, like that used for the jetting technique described elsewhere, is simple and in the right circumstances, economical of time and labor. General limitations are:

(1) The formation to be penetrated must not be too highly compacted as this makes penetration very slow and laborious. Medium to large boulders cannot be negotiated.

(2) The water-bearing formation must have moderately high permeability in order to provide adequate yields, this is especially important with small diameter wells.

(3) Driven wells must, as in the case of wells constructed by other techniques, be properly developed to obtain maximum output.

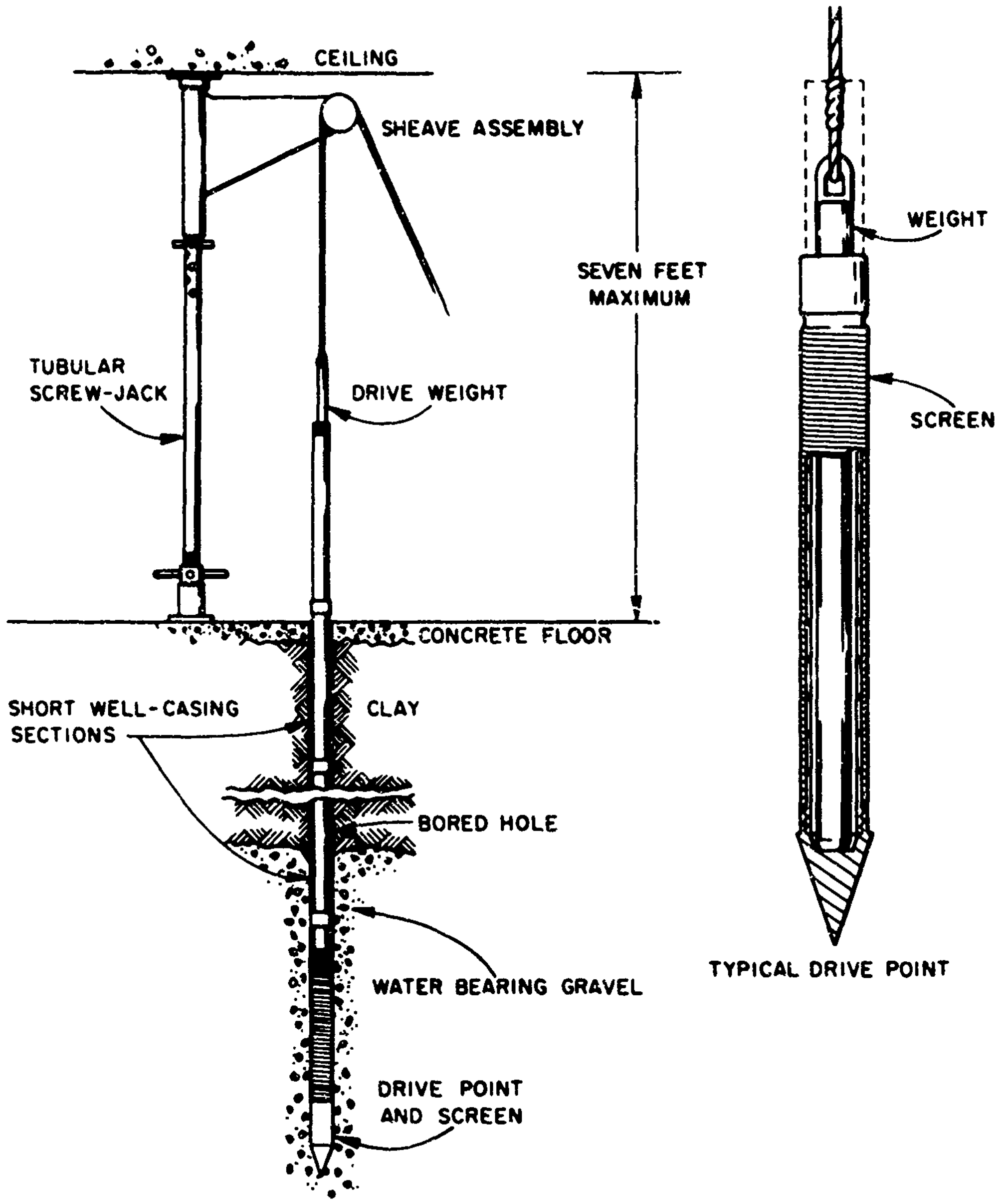


FIG. 4 DRIVEN WELL EQUIPMENT

(4) Unless the drive point is so designed that its major diameter is greater than that of the screen, the latter will be damaged by abrasion.

(5) Unless the point is securely anchored to the screen section and the following pipe sections firmly butted when coupled, they can loosen under the pounding of the drive-weight and subsequently leak air so that suction is lost and the yield of water impaired; i.e., airtight casing joints must be maintained where suction pumps are used.

b. Location

Driven wells are located only after a field study of the local geography and topography shows that there is a reasonably high probability of tapping a usable supply of water. Suitable locations for driven wells are likely to be found in the following:

Location	Common Subsoil Type
River valleys	Sands, silts, clays
Beaches and coastal dune areas	Sands, gravels, silts, clays
Deltas of large rivers	Sands, gravels, silts
Sandy glacial deposits	Sands, gravels, silts

c. Description of Operation

The well is usually started by drilling a shallow hole with a hand auger of a diameter large enough to permit the drive point to be inserted. A rig similar to that shown in Fig. 4 is erected over the hole. An extension pipe is coupled to the drive point and a weight with rope or cable attached, lowered into the pipe and onto the heel of the drive point (Fig.4). The other end of the rope is passed over the sheave. Driving now proceeds, the operator hauling on the rope and raising the weights as high as headroom permits, then allowing it to fall freely but without losing control of the rope.

This sequence is continued steadily and rhythmically, adding liner extensions as penetration progresses, until indications are that the water table has been reached. Rate of penetration will vary according to the type of subsoil encountered, the diameter of the point, and the means for driving. In moderately compact, unconsolidated formations, and, with limited driving stroke due to low headroom, it is estimated that a 3-inch OD point can be driven at a rate of about 18 inches per hour with only 7 feet of headroom at the commencement of operations. The drive point technique is not feasible in rocky formations or in material where large boulders may be encountered.

Only fairly simple, easily handled equipment is required and water from an outside source is not needed. The technique is not very fast except under especially favorable subsoil conditions and is noisy in operation. On the other hand, it is one of the practicable means for in-shelter well construction (see Sec. IV, Summary of Drilling Techniques).

C. WELL PUMPING AND DEVELOPMENT

1. Pump Considerations

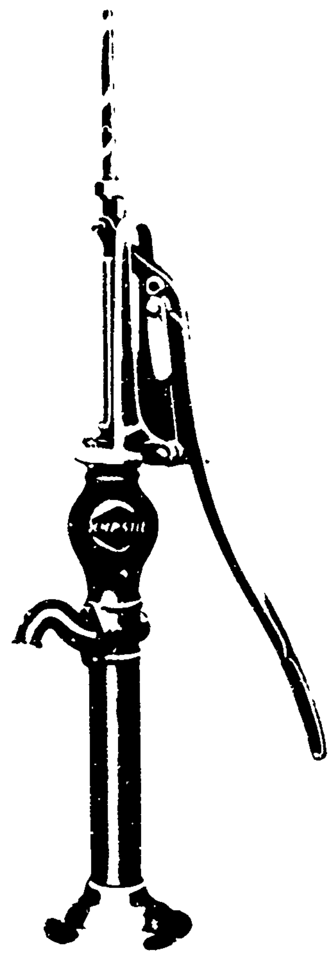
Regardless of the techniques used to construct an in-shelter well, equipment used to raise ground water to the level of buffer storage or the cooling unit must meet certain requirements. Depending on the locality of the shelter, its summer outdoor temperature environment, the temperature of available cooling water, and the type and efficiency of the cooling system considered most feasible, a ground water well might be required to yield at rates of from 1 to 5 gal/min for up to 24 hours a day over a maximum period of two weeks for a 100 occupant shelter.

With regard to well output, neither verbal inquiry nor literature search has provided much reliable information as to the yield that can be anticipated from a 2 to 3-inch diameter shallow well. Experienced predictions range all the way from a conservative 1 gal/min to an optimistic 5 gal/min. There appears to be some question as to whether even these modest flows could be maintained for two weeks without overtaking the natural inflow from the aquifer.

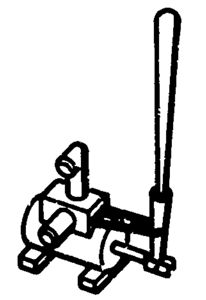
Since there is a definite possibility that a power-off situation will exist during and after a nuclear attack, the choice of pumping and circulating techniques is narrowed considerably unless auxiliary power sources are certain to be available. Assuming, however, that the pump is capable of manual operation, it would appear that a positive displacement type would fulfill requirements. Figure 5(a) depicts a typical positive displacement pump, which can be either manually operated, or (by simple conversion) adapted for drive by electric or gasoline motor, or by wind power. This type of pump can be used as a suction pump for lifts of up to 25 ft or as a force pump in deeper wells. In the case of a shallow well, the pump cylinder can be housed at ground level within the pump body, with the suction tube extending to below water level. For deep wells, the cylinder must be mounted in the well tube, below water level.

A double-acting suction pump, such as is illustrated in Fig. 5(b), offers an alternative for the case of shallow wells (viz., less than 25 ft to water level). This pump has a 5-inch diameter barrel and will deliver 1000 gal/h (16.5 gal/min) from a depth of 18 ft at an operating rate of 30 strokes/min. At this depth, a force of about 47 lb is required at the tip of a 36-inch long lever, which can easily be adapted for push-pull operation by two shelter occupants. With operation by pairs of occupants in rotation, a continuous flow of up to 15 gal/min could be maintained for short periods in an emergency (provided, of course, that the inflow from the aquifer can replenish the well at this rate).

Only single-action cylinders [Fig. 5(c)] are available for pumps of the type shown in Fig. 5(a). Internal diameters of standard cylinder assemblies range from 1-11/16 to 3 inches and stroke lengths from 6 to 12 inches. However, since a major consideration is to provide for manual operation and for ease of well construction, it is desirable to hold the well to as small a diameter as will permit adequate inflow of water from the aquifer. This would probably limit bore diameter of the typical in-shelter well casing to 2 inches. A casing of this size would accommodate a pump cylinder with a 1-13/16-inch diameter bore, which (using a six-inch stroke) will deliver 1.0 gal/min at 15 strokes/min. Pumping five minutes each hour should provide enough water to replace the estimated 5 gal/h that the recirculating system of an evaporative cooler would lose in operation (see Appendix A).



PUMP FOR SHALLOW OR DEEP WELLS
(TYPICAL)
(a)



SHALLOW WELL PUMP
(TYPICAL)
(b)

PUMP CYLINDER FOR DEEP WELLS
(TYPICAL FOR DRIVEN WELLS)
(c)

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FIG. 5 TYPICAL MANUALLY OPERATED PUMP EQUIPMENT

The effort required to operate a pump is estimated as follows: With a 2-inch column of water, each foot of well depth requires 1.17 lb of water to be lifted. Thus, for a 50-ft well, approximately 59 lb of water would have to be raised. To this must be added 25 lb for 50 ft of wooden pump rod. Assuming a 5:1 mechanical advantage in the pump and neglecting friction (in part offset by the buoyancy of the wooden pump rod), the force required at the tip of the operating lever of the pump shown in Fig. 5(b) would be about 17 lb. If a pressure tank is used for buffer storage, the required force is increased, but intermittent manual operation would be practicable.

2. Well Development

a. General

Well development refers to the post-penetration treatment of a well to establish its maximum rate of water yield. Wells are developed by pumping, backwashing, surging, etc., to wash fine sand, silt, and clay from the water-bearing formation around the well screen. Removal of these materials opens up channels through which water can flow and reduces the resistance to inflow. The coarse particles that remain around the screen help inhibit further movement of fine particles into the well casing. The discharge capabilities of a well are directly proportional to the permeability of the material in the water-bearing stratum. We do not pursue further the numerous soil and environmental factors that affect well output: it is assumed that an area of flow openings and screen mesh will be used which are suitable to the capability of a suction pipe, pump, and system requirements associated with a given location.

b. Shallow Wells

The simplest and most appropriate means of developing shallow wells under the conditions with which we are concerned is as follows: The suction pipe is lowered until its end is immersed in the water in the casing. The pump is now run until a full column of water is present in the pipe, as evidenced by discharge from the pump. A valve is opened on the suction side of the pump, permitting air to enter and the water column to fall rapidly (owing to gravity) to the bottom of the well, thus temporarily increasing the head and producing a backwash of water through the screen. The process is repeated until the water from the pump discharge port is judged to be sufficiently clear. The process may require as little as a few hours or as much as several days, depending on the nature of the subsoil, the energy and diligence of the operating team, and most importantly, the degree of success in penetrating the water-bearing stratum to an optimum degree.

c. Deep Wells

In developing deep wells, the well is pumped slowly at first and gradually at higher and higher rates. At each rate the pumping is continued until no more sand comes into the well. The pump is not shut down after starting until this preliminary pumping is completed because of the danger of the sand clogging the well or pump if it is not kept moving. The pump is not started at maximum capacity because of the tendency for the sand particles to bridge if the water is drawn from the formation at too high a rate.

After pumping has continued at a high rate until the water begins to clear, the pump is shut down until all water has drained back into the well and the water table has returned to approximately normal. The pump is then restarted and the process repeated. The alternate starting and stopping of the pump stirs up the material surrounding the casing and causes the fine particles to come into the well until the water passages are cleaned out.

The time required to develop a well by this process varies widely. Sometimes only a few hours are required, but usually at least a day is required. When no more sand is brought in, the work is complete.

IV SUMMARY OF DRILLING TECHNIQUES

A. STATE-OF-THE-ART WELL-DRILLING TECHNIQUES

Table I presents the advantages of the state-of-the-art techniques for well drilling as they apply to post-attack, in-shelter utilization. It appears clear from this tabulation and the analysis that the time to complete an operating well from a standing start would be, at best, in excess of 24 hours. This is true even under the following conditions:

- Subsoil conditions are favorable for penetration
- Those techniques least limited by the in-shelter environment are employed
- Prior exploration or recent construction experience yields relatively positive indication of ground water in suitable quantities below the shelter location
- Packaged equipment, capable of manual operation, is stored within the shelter structure for immediate use at time of need.

If gasoline or diesel auxiliary power units were available for operation of the well-drilling equipment, it is estimated that the time for construction would be reduced only about as follows:

Technique	Manual Construction	Powered
Auger boring	27-3/4 hours	25 hours
Driving	27 hours	25 hours

B. IN-SHELTER ENVIRONMENT

In areas where shelter cooling will be required, it is reasonable to suppose that during any 24-hour period in the four summer months. one or perhaps two fairly extended plateaus of effective temperature (ET) in excess of 85°F will be experienced by shelter occupants cooled only by ambient air. During the period of post-attack well construction (i.e., prior to availability of cooling water; at a minimum 25 hours) collapse from heat prostration can be expected, particularly in view of the arduous nature of the work involved on the part of the well

Table I

PHYSICAL SUITABILITY OF VARIOUS WELL-CONSTRUCTIO

	Cable Tool Drilling	Rotary Drilling	Hydraulic Jetti
ADVANTAGES	Nil for in-shelter construction	Nil for in-shelter construction	Requires less headroom cable tool or rotary d
DISADVANTAGES	Shelter headroom insufficient for correct "chipping" action Requires use of outside supply of water to make slurry Drilling debris and slurry constitute disposal problem Very noisy Casing must be forced down immediately behind tool bit Extensive skill, judgment, training, and experience required	Drive and hoist mechanism too bulky and complex for low headroom and confined area Requires outside supply of water to make slurry Drilling debris and slurry constitute disposal problem Casing must be forced down immediately behind tool bit Extensive skill, judgment, training, and experience required Gearing ratio required for manual operation would result in extremely slow penetration	Requires more headroom available in shelter Requires large amount from outside at high p auxiliary pumping equip Debris-laden slurry cre problems of containment disposal Suitable only in softer boulder-free formations

Table I

IOUS WELL-CONSTRUCTION TECHNIQUES FOR IN-SHELTER USE

Hydraulic Jetting	Auger Boring	Driving
quires less headroom than ible tool or rotary drilling	Relatively fast penetration in uncompacted formation free from large boulders Requires little overhead equipment (though ample headroom is desirable) Manual operation practicable up to 2-1/2 inch diam in uncompacted formation No water required Quiet in operation Requires little skill or training	Requires simple technique; easily handled equipment No water required No debris for disposal Low headroom not as severe a limitation as for cable drilling, rotary drilling, or jetting Drive point, screen, and well tube are installed as part of drilling operation Amenable to auxiliary power to improve rate of penetration
quires more headroom than vailable in shelter equires large amount of water rom outside at high pressure; uxiliary pumping equipment ebris-laden slurry creates roblems of containment and isposal uitable only in softer, oulder-free formations	Debris must be disposed of (fairly dry, easy to handle) Construction to more than 25 ft depth beyond average physical capabilities; probably impracticable in shelter environment Extension rods must be uncoupled for each unloading in low overhead space, resulting in slow penetration	Low headroom limits force that can manually be applied in driving Need to add section of tubing would slow progress Noisy Suitable only for uncompacted formations, free from boulders

B

drillers. This view seems to be supported by Ref. 1 and by the following example: Assume the ambient air used for ventilation to be at a dry bulb temperature (DBT) of 95°F and an ET of 86°F. Adiabatic calculation indicates that 60 CFM/occupant are required to hold shelter DBT to 95°F and ET at 87°F. This indicates that a 1° rise in ET occurring almost immediately upon occupation of the shelter and leveling off at this value (provided air flow is maintained until means for cooling become available).

A further interpretation of Ref. 1 is given in Fig. 6, in which it is shown that lightly clothed, untrained males, in good physical condition, can reach the point of collapse in 20 minutes of moderately hard physical labor in an environment of 95°F ET; the point of collapse

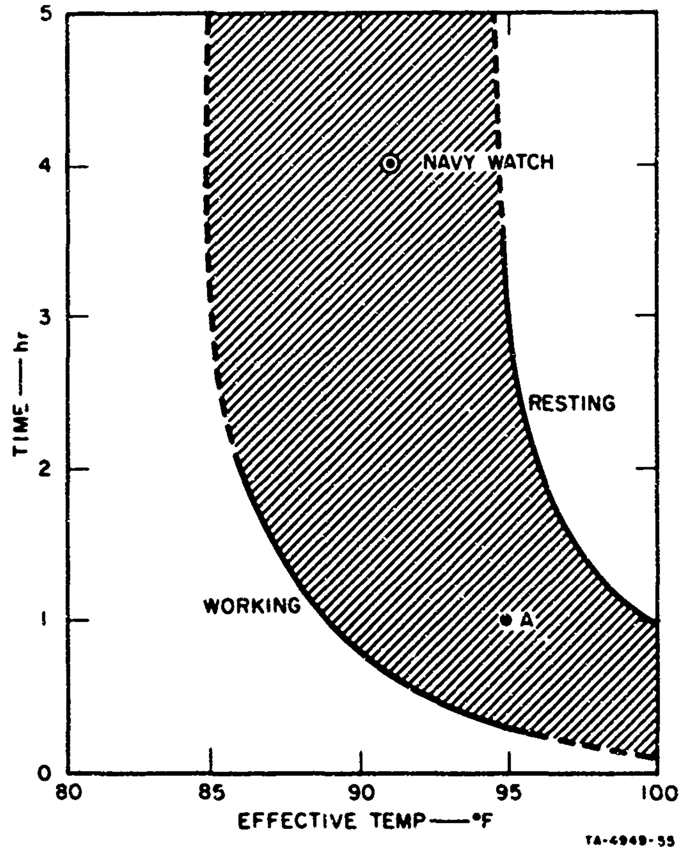

FIG. 6 SAFE TIME LIMIT FOR EXPOSURE TO A STEADY EFFECTIVE TEMPERATURE

is reached in about 60 minutes if resting. On the other hand, trained Navy boiler room personnel on watch duty (mainly observation, with light physical activity) survive duty spells of four hours at 91°F ET without collapse. Extrapolation of the "working" curve shows that sustained physical effort at a moderate level is possible in an environment at around 85°F ET, but only for trained and acclimated personnel.

We therefore conclude that even the simplest system for post-attack tapping and recovery of ground-water reserves for shelter cooling is impractical with state-of-the-art techniques, whether with auxiliary power or hand power alone.

C. ALTERNATIVE APPROACHES

The need thus arises for alternative post-attack means of reaching ground water for shelter air cooling; specifically, the feasibility of a pre-attack program to establish the presence and ready availability of ground water beneath or adjacent to structures whose features qualify them as fallout shelters.

Accordingly, an attempt has been made to determine if newly developed penetration techniques could be applied. Among possible power sources considered are solid-fuel gas generators to provide energy. Operating temperatures and pressures generated would be in the region of 1500°F and 1000 psi. The fuel would probably be ammonium nitrate, with a suitable binder. However, when ignited this would produce noxious nitrogen compounds that would have to be exhausted immediately and completely from the shelter. Further, this type of reaction cannot be throttled down or shut off once underway, since burning rate increases with pressure and the fuel contains it own oxidizer. If these objections could be overcome and the energy harnessed, the material would probably be quite stable in storage (if anything, the material would become more difficult to ignite after five years in storage). For a short-duration task such as well drilling, a 5-lb cylinder or cartridge of 3-inch diam, 3 ft long, would provide about 10 hp for 7-10 minutes. However, even if such a technique were theoretically acceptable, considerable research would be required to make it practical for the proposed application.

V PRE-ATTACK WELL CONSTRUCTION

A. GENERAL DESCRIPTION

The most interesting and seemingly most practicable approach to in-shelter well construction, which also would encourage consideration in the immediate future of a program of pre-attack well construction, is the "sonic" technique of soil penetration.

Chellis[4] quotes two sets of data giving measurements on various kinds of soils subjected to oscillation. The two sets of data are in fair agreement that the range of natural frequencies is from 7.5 to 28 c/s. Soils subjected to forceful vibrations above 28 c/s behave as will soils of whatever character when stressed beyond their elastic limit: They lose their cohesive character and behave as a fluid, particularly in the zone immediately adjacent to the source of vibration.

The authors of a Russian treatise published in 1959 sum up their findings in the following statement:

> "Relatively easy penetration by the drilling instrument into the ground is due to a considerable decrease in friction between the sides of the drill stem and the adjacent ground. The essence of this phenomenon is fundamentally different from vibrations in sandy and clayey soils (sic) as appears from the data in Chapters I and II. During vibration in sands only the bond between particles is broken; the sands acquire something of a suspended character, and this facilitates the penetration of the drill bit into the ground. In clayey soils, because of their cohesion, vibration of the particles themselves, such as is observed in sands, is difficult, but the vibration breaks down the diffused envelopes. Molecules of water surrounding the soil particles, and clinging to these particles by electrostatic forces, are disoriented by the vibration, and as a consequence part of the physically bound water is liberated. In addition, immobilized water is also set free. The presence of suspensions between the sides of the drill stem and the soil furnishes a kind of "lubricant" and this permits easier penetration of the drilling instrument into the ground. As we have shown, this phenomenon

represents one of the stages of thixotropic transformations of clayey soils."

Elsewhere, the authors deal at great length with experiments on noncohesive soils and with the subject of thixotropic phenomenon in clays. Soils with no structure of clay minerals show no evidence of thixotropy; the presence of particles of nonspherical configuration and very small dimension (under 10μ) is essential to the phenomenon; a content of such particles as low as 2 per cent can cause a soil to become thixotropic.

In discussing the sonic technique of penetration, it is appropriate to consider the consequence should the tube penetrating element encounter a boulder or similar obstruction. Such an obstruction will be shunted aside (provided it is not too large) shortly after the penetrating element encounters it. The reason for this is that crystalline rock vibrate in unison with the encountering element, causing the soil surrounding the boulder to fluidize and yield in turn. On the other hand, should the obstruction be a large timber or root mass, or a "nest of boulders," the penetrating element will "refuse," whereupon the energy normally utilized in driving is rapidly converted to heat. However, warning of such a refusal is immediate, and the vibrating element can in this event be speedily withdrawn and a fresh site selected in the same general area. Little time is lost in such an event since the rate of penetration and/or withdrawal by the sonic technique is so rapid.

The sonic technique is well developed and in regular use. Quite large sonically driven equipment has been successfully applied to the sinking of sheet piling in commercial undertakings. Appendix F, a report dated 2-3-66, gives a general description of experimental equipment built, tested, and now under continuing development by the Sonic Co., Inc., (a division of Shell Oil Co.) San Diego, California.

Development has been carried to the point of practical application in drilling seismic shot holes. This equipment is a simplified and greatly scaled-down version of the commercial pile-driving equipment referred to above; it has already been applied successfully in constructing tubular wells to depths of 40-60 ft, using tube sections about 3-inch OD by 12 ft long, thread coupled as required. As the attached appendix states, eight-foot long sections have since been successfully driven, and no difficulty is anticipated in driving four- or five-foot lengths serially coupled to a depth of 100 ft or more.

B. NOISE

The noise generated by the above experimental oscillator itself throughout its operational frequency range appeared to be very low. No attempt has been made, however, to efficiently muffle the exhaust of the internal combustion prime mover used to drive it, so that the overall noise from the experimental equipment, while not objectionable in the field, would have been unacceptable in a closed space. It is confidently expected that either an electro-hydraulic direct-coupled drive to the oscillator shaft, or a hydraulic motor drive powered through hose from a pressure source exterior of the structure, would enable the oscillator system to be operated at an acceptable in-shelter noise level.

C. ELIMINATION OF GROUND-QUAKE

During a demonstration witnessed on 1 February 1966 at San Diego, ground-quake was almost imperceptible, even to observers placing their feet within 12 inches of the tube being driven. This absence of vibration could be of vital importance in locations where

(1) Conditions of normal occupancy might otherwise be disturbed

(2) Delicate equipment might be damaged

(3) Old and/or unreinforced brickwork or block construction might be dangerously weakened by vibration.

D. ADDITIONAL DEVELOPMENT

In the opinion of Sonic Co. technical representatives, a modified version of the present experimental equipment could readily be developed:

(1) To use tube lengths compatible with the limitation of in-shelter construction.

(2) To be of modular construction, capable of rapid assembly and dis-assembly transportation, etc.

(3) To be operated from a power source exterior to a shelter structure, where necessary.

E. FURTHER RESEARCH

It is recommended that the overall feasibility and estimated operating cost of the Sonic Co. technique for pre-attack in-shelter well construction (and also other techniques appearing comparable) be fully investigated at the earliest opportunity. In the event that the outcome is favorable an attempt should be made to review and where possible remove objections to pre-crisis construction previously entertained by owners, lessees, or other interested parties. This could make possible planning of a realistic and mutually agreeable program of contract "test-drilling" (followed where appropriate by well installation), to commence immediately following the availability of suitable equipment and the development of a mutually agreeable contracting arrangement.

APPENDICES

Appendix A

ESTIMATED COOLING WATER REQUIREMENT

1 GENERAL

The task order does not call for consideration of the amount of cooling water required. However, it appears necessary to make such a determination, at least to the extent that a judgement may be formed as to the basic feasibility of providing sufficient ground water for shelter cooling.

In certain localities where relative humidity is low, evaporative cooling can be successfully applied for comfort air conditioning at considerably lower initial and operating costs than for mechanical refrigeration. The evaporative, or "air washer cooler" may involve any of the following processes:

> Evaporative Cooling--Adiabatic cooling takes place, a transfer from sensible heat to latent heat occurs with no change in enthalpy of the air-vapor mixture. The process results in lower dry bulb temperature, constant wet bulb temperature, and higher relative humidity.
>
> Sensible Cooling with Moderate Humidification--Dew point is raised but dry bulb and wet bulb temperatures are lowered.
>
> Sensible Cooling Only--Dew point temperature of air is constant; dry bulb and wet bulb temperatures are lowered.
>
> Sensible Cooling with Dehumidification--Dry bulb and wet bulb temperatures and dew point are all lowered.

In general, when the cooling water temperature is lower than the DBT of the incoming air, the air is cooled. When water temperature is lower than dew point temperature of incoming air, the air is both cooled and dehumidified. Efficiencies of air washers are dependent on many factors, including air velocity, nozzle design and pressure, number of spray banks, entering water temperature and water temperature range, and also entering air wet and dry bulb temperatures.

It is practical to consider wet bulb design temperature rather than relative humidity when considering evaporative cooling. The WBT governs the temperature of the air as it leaves the evaporative cooler; that is, a low wet bulb ensures a lower conditioned dry bulb temperature. Evaporative techniques do not provide adequate humidity control; therefore, comfort cooling under conditions of high ambient humidity is not possible. However, since present thinking permits us to consider survival at 85°F ET for fallout shelters, it would appear that evaporative cooling techniques might be applied in almost any area of the United States.

The following figures illustrate examples of cooling using evaporative equipment, indicating cooling requirements for a hot, arid area and a hot, humid area. (Ambient air cannot be used for shelter cooling in these areas.) It is assumed that the metabolic (shelter) load can be removed by the forced ventilating air, if cooled sufficiently.

2. CASE A: HOT, ARID AREA, WITH EVAPORATIVE COOLING

The one percent conditions from ASHRAE Guide 1965-1966 Chapter 27 for two southwest cities are listed in Table A-I. The DBT and WBT are assumed to be coincident for the example. An adiabatic evaporative cooling system would be used in which the spray water temperature would reach equilibrium with the WBT of the ambient air. Spray water is continuously recirculated and 100 percent outdoor air is drawn through

Table A-I

WEATHER CONDITIONS FOR TWO SOUTHWEST CITIES

Factor	Location	
	Las Vegas, Nevada	Phoenix, Arizona
Dry Bulb Temperature (°F)	108	108
Wet Bulb Temperature (°F)	72	77
Relative Humidity (%)	17	25
Effective Temperature (°F)	85.2	87

the air washer. For a system operating at approximately 80 percent efficiency, the quantity of ventilating air and of recirculated cooling water required would be approximately as shown in Table A-II.

Table A-II

EVAPORATING SYSTEM OPERATION ASSUMING 80% EFFICIENCY

Factor	Location	
	Las Vegas, Nevada	Phoenix, Arizona
Air velocity through cooler	500 cfm	500 cfm
Shelter DBT	90°F	90°F
Shelter ET	85°F	85°F
Total load	400 BTU/occupant	400 BTU/occupant
Supply water temperature	72°F (Reaches WBT when recirculated)	72°F (Reaches WBT when recirculated)
Required air quantity	9.7 cfm/occ	16.5 cfm/occ
Circulating water	0.04-0.08 (gal-min)/occ*	0.06-0.13 (gal/min)/occ*
Make-up water	5 gal/h--as required*	5 gal/h as required
Water pressure	20 psig	20 psig
Water temperature	79.5°F†	83.5°F

* Depends on system efficiency

† Cooling capacity greater due to the lower WB temperature.

Shelter DBT is determined by the cooling efficiency and the sensible heat (SH) load (enthalpy-humidity ratio). For the metabolic load (occupant heat-dissipation), the SH ratio is dependent on the shelter DBT temperature, which would therefore be calculated by an iterative method. In the evaporative system where water is recirculated, only a small quantity of make-up water (about 5 gal/hr/100 occupants) is required. Ground water temperature is already relatively high in the regions where shelter-cooling is required. Therefore, if spray banks only are used in the cooler, a double rather than a single 8-ft bank would be needed with nozzle operating at pressures not less than 15 psig.

Water re-circulation through the cooling system could probably be accomplished using a "Jabsco" or similar rubber-impeller-type pump, driven by a P.V.K. pedal unit.

An alternative to the spray-only technique would be to use a cellular or similar type of evaporator screen, wetted by a single spray bank. Circulating water requirements are reduced to about half those listed above for spray only. Other advantages are a smaller cabinet and the filtering performed by the wetted cells or screens. Further, the quantity of make-up water required would be only about 5 gal/h for a 100 occ shelter.

3. CASE B: HOT, HUMID AREA SENSIBLE COOLING WITH DEHUMIDITY

Table A-III

WEATHER CONDITIONS FOR GALVESTON, TEXAS

Factor	Value
	Galveston, Texas
Dry Bulb Temperature (°F)	91
Wet Bulb Temperature (°F)	82
Relative Humidity (%)	68
Effective Temperature (°F)	85
Dew Point (°F)	79.5

Evaporative cooling equipment can also operate as a cooling and dehumidifying device. However, a larger quantity of fresh cooling water at 73°F is required, since (due to the high temperature of the ground source) the water has a reduced cooling capacity, and it can only be circulated once. It then may be usable for other purposes. Ordinarily, for "comfort" air-conditioning, inlet water at this temperature is not used directly for cooling and dehumidification. The cooling process differs from the purely adiabatic techniques and depends on the temperature rise of the water, which in this case is expected to be very small--approximately 1.5° to 2.5°F, depending on the system efficiency. Requirements would be approximately as shown in Table A-IV.

Table A-IV

SENSIBLE COOLING WITH DEHUMIDIFICATION

Factor	Value
Ambient air intake	15 cfm/occupant
Ground water flow required	0.33 (gal/min) occupant
Delivery pressure to cooler	15-20 psig
Ground water temperature (assumed)	73°F
Temperature of cooled ventilating air	78°F

The values in Table A-IV should maintain the shelter environment at a dry bulb temperature of 87°F and an effective temperature of 85°F. This system requires a flow approximating 0.33 (gal/min)/occupant of ground water. Indications are that flow of from 1-3 gal/min is the most that can be anticipated from 2-3-inch diam.

Nevertheless, if a purely evaporative technique is employed in a hot, humid climate, a shelter effective temperature of 85°F might still be maintained provided the ambient inlet-air supply could be increased to 40-45 cfm. It would be necessary to maintain water re-circulation at a flow-rate of 0.30 to 0.35 (gal/min)/occupant. The recirculated water would reach and stabilize at a wet bulb temperature close to that of the shelter air.

From the foregoing, a reasonable conclusion might be that, since power-off conditions must be anticipated, a purely evaporative cooling process using manual power for water re-circulation would be the only practicable and economical approach, given the rather small well-outputs which may be expected.

On the other hand, it is highly probable that in hot, very humid areas such as Galveston or New Orleans, where the incoming ventilating air would have an unusually high moisture content, and because of the inherent inability of a purely evaporative system to control humidity, the shelter environment at an effective temperature of 85°F could become so distressing as to be insupportable over long periods.

Appendix B

COMPARATIVE ESTIMATES OF TIME REQUIRED FOR SUBSOIL PENETRATION AND WELL CONSTRUCTION USING AUGER AND DRIVE POINT TECHNIQUES

It has become evident that, in the limiting circumstances, only two of the penetration techniques described in Sec. III-B may be even remotely feasible. These are the drive point and the auger techniques.

Of the two, the drive point appears to have the greater overall versatility with respect to range of formations that can be penetrated. It also has the advantage that no debris is produced during penetration. Limited headroom would require that the drive point, screen, and short casing sections be serially assembled into one unit in that order as penetration proceeds. Once in place, they are a complete well installation. Only simple overhead gear is required for manipulation of the falling weight used to drive the point through the formation (see Fig. 6).

The auger technique, which is feasible only in a narrow range of formations, produces a considerable amount of debris, including semi-fluid material (as the water-bearing stratus is penetrated). The auger itself must be unloaded frequently, as depth increases, to avoid fouling. This entails repeated uncoupling and recoupling of the extensions, resulting in slow overall progress.

The bore must be lined after completing penetration and a screen inserted. In many instances, this requires forcing serially-coupled, short sections of liner pipe into the bore as a separate operation, rather than concurrently with penetration (as with the drive point technique).

Of the two techniques, the drive point calls for more operator judgment and skill. It also requires the use of a simple overhead rig and falling weight for application of the driving impact, while the auger technique does not. On the other hand, the weight of the auger and its extensions, the load of drilling debris, and the friction of the auger and its load against the sides of the bore would make the task of withdrawal for unloading extremely onerous unless some mechanical advantage--such as a ceiling or tripod-mounted pulley system--were provided. Literature studies and a number of consultations held with various informed individuals at United States Geological Survey Water Resources Division[5] and with others having long experience in the field of well construction and ground water recovery[6] indicate that, under average conditions of subsoil formation reasonably favorable to both of the above techniques, an actual penetration rate of 18 inch/h for a tube having a 3-inch OD could be considered good performance for trained hands. It is felt that for untrained personnel, particularly when operating under limitations, even this rate might be considered optimistic.

Based on the various data and references, an estimate of the total time required to construct a well and assemble a ground-water cooling system for a 100-occupant shelter, using pre-packaged equipment from storage within or adjacent to the shelter areas, is as shown in Table B-I.

Recent government and other surveys indicate that ground water exists in considerable quantity beneath most of the heavily populated areas of the U.S.

The reserves are, however, with few exceptions, located at depths much greater than could be reached even by skilled occupants within 24-30 hours, using simple, almost crude manually operated equipment to penetrate the overburden. This is especially true because of the extremely limiting conditions under which the work would be carried out.

In addition, consultation with experienced well drillers indicates that output from shallow wells of from 2-3-inch diam rarely exceeds 5-7 gal/min and is usually from 2-4 gal/min.

Table B-I

ESTIMATED TIME FOR CONSTRUCTION OF 3-INCH OD WELL

Operation	Estimated Time Required (hours)	
	Auger	Drive Point
Withdraw packaged equipment from adjacent storage, unpack, assemble and instruct team on location	1.0	2.0*
Break through reinforced concrete floor (6 inches thick) using any manual technique	1.0	4.0
Penetrate subsoil to a depth of 25 ft at a rate of 1.5 ft/h	16.5	16.5
Uncouple auger extensions, remove debris from auger, recouple, and lower auger to work face at each 12-inch cycle of penetration (19 cycles at an average of 5 min)	1.5	--
Couple threaded liner tube section--5 ft long x 2-inch ID (4 cycles at an average of 4 min)	--	0.25
Insert (or force) 4-ft long liner tube extensions into bore (6 cycles at an average of 5 min)	0.5	--
Insert screen and mount preassembled suction pump and cylinder unit	0.75†	--
Insert "in-bore" screen and mount preassembled pump and cylinder unit	--	0.75†
Develop well	3.0§	3.0§
Connect plumbing between pump and cooling unit and test	0.5	0.5
Total	27.25	27.00

* Instruction more complex than for auger technique

† Assembly and readying of pumps can be performed by other shelter occupants under direction of shelter manager while well is being constructed

§ Absolute minimum figure for well development: 3 to 8 hours (and occasionally more) may be required to develop full flow

Appendix C

TENTATIVE ESTIMATE OF TIME AND COST FOR PRE-ATTACK IN-SHELTER WELL CONSTRUCTION USING STATE-OF-THE-ART AND SONIC DRILLING TECHNIQUES

The comparisons presented in this appendix are based on information obtained through the United States Geological Survey Water Resources Division, experienced members of the well-drilling and irrigation industry, and the Sonic Company of San Diego, California. In obtaining the estimates, reference was made to the strict limitations imposed by the in-shelter site. Since the incidence of relatively (or completely) unfavorable formations that may be encountered is unknown, an allowance has been made in estimated times for penetration.

The estimates for state-of-the-art techniques are for suitable modified, power-driven versions of either the drive point or auger techniques discussed in Sec. III-B of this report. Informed opinion holds that except under extremely favorable soil conditions, neither of these techniques will be practicable for in-shelter construction to depths of greater than 25 ft. However, it is also possible that insufficient water for shelter air cooling can be found at less than 100 ft.

Table C-I lists estimated materials costs for well construction to 25 and 100 ft. Quoted prices are approximate list. Those construction items that would be suitable for long-term storage (subsequently to be employed in the post-attack period on a prepared well) are also listed in Table C-II.

Table C-III compares the estimated times to construct a 100-ft well using state-of-the-art and sonic techniques. The total time-and-materials estimates for 100-ft wells are given in Table C-IV.

The labor charge of $30.00/hour indicated in Table C-IV is about average for small rigs employing state-of-the-art design. However, since it is likely that special equipment would have to be prepared for in-shelter construction; the in-shelter features would reduce the utility of such devices in the field. Accordingly, development and manufacturing costs

Table C-I

MATERIALS COST FOR PRE-ATTACK WELL CONSTRUCTION

Item	25-ft Well	100-ft Well
2-inch OD x 5-ft threaded tubing at $10	$ 40.00	$190.00
Well point, including internal screen	20.00	20.00
Threaded couplings at $ .70	2.00	13.00
Threaded cap	1.00	1.00
Hand-operated pump (Dempster 210F or equivalent)*	70.00	70.00
Special pump-rod sections at $1.60/ft*	40.00	152.00
Pump cylinder for shallow well (Clayton Mark No. 450 Eureka)*	31.00	--
Pump cylinder for deep well (Dempster 750 or equivalent)*	--	29.00
Miscellaneous plumbing fittings, hand tools, and 3/4-inch ID plastic well pipe*	31.00	39.00
SUBTOTAL	$233.00	$514.00
15% Handling Charge	35.00	77.00
TOTAL MATERIALS COST	$268.00	$591.00

* Items marked with an asterisk could be included in long-term storage kit for post-attack use.

Table C-II

COST OF ITEMS USED IN PRE-ATTACK WELL CONSTRUCTION AND MAINTAINED IN LONG-TERM STORAGE FOR POST-ATTACK USE*

Item	25-ft Well	100-ft Well
Hand-operated pump (Dempster 210F or equivalent)	$ 70.00	$ 70.00
Special pump-rod sections at $1.60/ft	40.00	152.00
Pump cylinder for shallow well (Clayton Mark No. 450 Eureka)	31.00	--
Pump cylinder for deep well (Dempster 750 or equivalent)	--	29.00
Miscellaneous plumbing fittings, hand tools, and 3/4-inch ID plastic well pipe	31.00	39.00
TOTAL COST OF LONG-TERM STORAGE KIT	$160.00	$290.00

* Extracted from Table C-I.

Table C-III

COMPARATIVE PRE-ATTACK WELL CONSTRUCTION TIMES
USING STATE-OF-THE-ART AND SONIC DRILLING TECHNIQUES

Construction Step	Estimated Time Required (hours)	
	State-of-the-Art Techniques	Sonic Techniques
Assemble modular equipment on site	2.0	2.0
Pierce concrete floor using power tool	1.0	1.0
Penetrate subsoil to 100 ft using power-operated means of coupling extension tube joints	40.0	0.33
Connect powered service pump and develop well flow	3.0*	3.0*
Remove service pump and cap well mouth. Remove equipment, clean up, and restore premises	4.0	4.0
TOTAL ESTIMATED TIME	50.0	10.33

* Assumed average time.

Table C-IV

COMPARATIVE PRE-ATTACK WELL CONSTRUCTION COSTS
USING STATE-OF-THE-ART AND SONIC DRILLING TECHNIQUES

Item	State-of-the-Art Techniques	Sonic Techniques
Materials (from Table C-I)	$ 591.00	$ 591.00
Labor (from Table C-III, assuming construction labor cost at $30.00/hour)*	1500.00	310.00
TOTAL ESTIMATED COST	$2091.00	$ 901.00

* Mechanic and helper.

would probably have to be amortized on a Government contract, resulting in a higher rate for in-shelter construction than the $30.00/hour. The same comment may apply to sonic techniques, though to a lesser extent: The basic functioning modules of this equipment should be similar for in-shelter and in-the-field use.

While the cost estimates presented here are cursory, it appears that when drilling to 100 ft, the sonic technique offers great advantages. The apparent 5:1 advantage of sonic over conventional techniques may be even greater, since the rate of penetration for state-of-the-art techniques will decrease with depth because of increased friction between bore and boring device and the difficulty of adding extensions.

As pointed out in Sec. V, groundquake and noise are virtually eliminated as hazards and nuisances in sonic drilling, whereas the constant pounding of the drive technique through many hours would be almost certain to disturb building occupants and, if severe enough, could develop structural weaknesses in older buildings.

Appendix D

TENTATIVE ESTIMATE OF COST OF POST-ATTACK
DRIVEN WELL-CONSTRUCTION KIT
(25-ft deep, 2-inch bore)

Item Description	Estimated Cost
Drive Assembly (Knocked Down) Tubular, collapsible, with hinge pin and stay bars, $24.00; pulley assembly, $2.50; 50 ft 1/2-inch polyethylene rope, $5.00; 25-lb weight for 2-inch shafting, drilled for rope, $6.00	$ 37.50
Well Tube Extensions 2-inch bore × 5 ft long, threaded and equipped with coupling; 4 at $10.70	42.80
Well Point 2-inch bore, with screen	20.00
Hand Pump with Cylinder	99.00
Pump-Rod Extensions Special 5-ft length, octagon ash, 25 ft at $1.60/ft including couplings	40.00
Star Point Cold Chisel With attached extension handle	5.00
Sledge Hammer 8 lb, 36-inch wooden handle	7.00
Earth Auger 3-inch diameter, with handle for starter hole, screw type	13.00
Miscellaneous hardware Plumbing fittings, plastic tubing (100 ft), and hand tools	40.00
TOTAL KIT COST	$304.30

Appendix E

ESTIMATED COSTS FOR PACKAGING MATERIALS OF POST-ATTACK WELL-CONSTRUCTION KITS

1. INTRODUCTION

The estimated costs presented in this appendix are intended to provide such comparison as is possible at this stage between the most-favored (though still infeasible) post-attack construction concept and the recommended pre-attack well construction. The estimated costs are for a driven well kit. If pre-attack well construction were adopted, only the pump, pump cyclinder, pump rod extensions, and drive rod would need to be stored. In this event, the cost of packaging would be lower than for a post-crisis well-construction kit. The costs below, however, are estimates for well digging and pumping equipment.

2. PACKAGING PHILOSOPHY

Packaging is assumed to be in four specific packages per kit. Due to the difference in bulk and configuration of the contents of the four containers, there would be no particular advantage in consolidating the four boxes into one wooden shipping container. This is especially true in that each of the four packages would be sufficiently small and light (none exceeding 150 lb) to be handled easily by one or two people.

In addition, while the various items in the kit may originate from different sources, they mav merge at some buffer storage facility for irspection, application of preservatives, and repackaging for long-term storage in containers similar to those illustrated in Figs. E-1 through E-4. Separation of the kit into four packages will also permit accommodation in the various storage configurations likely to be encountered in shelter areas across the country.

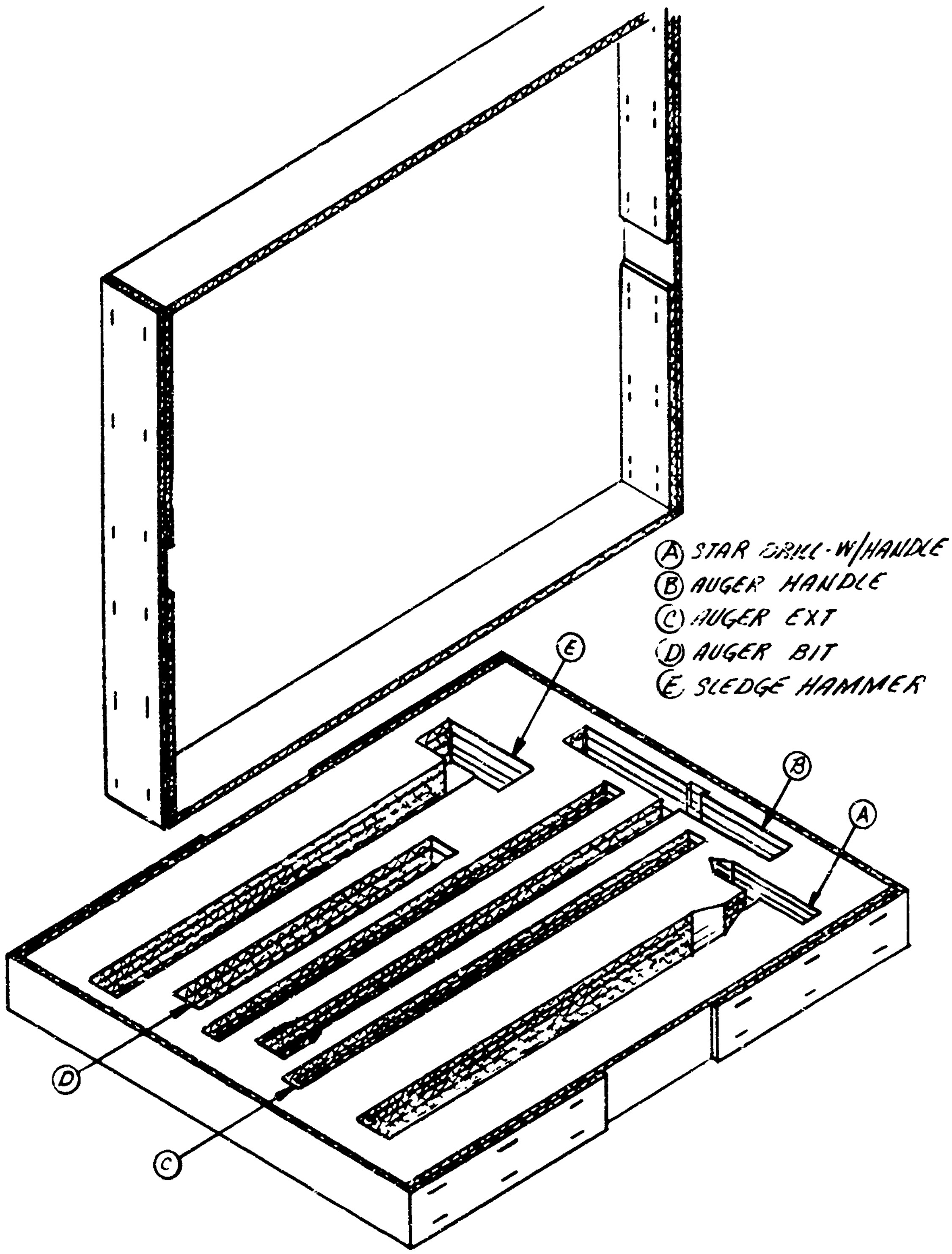

FIG. E-1 CONCEPTUAL PACKAGING FOR BORE-STARTING EQUIPMENT

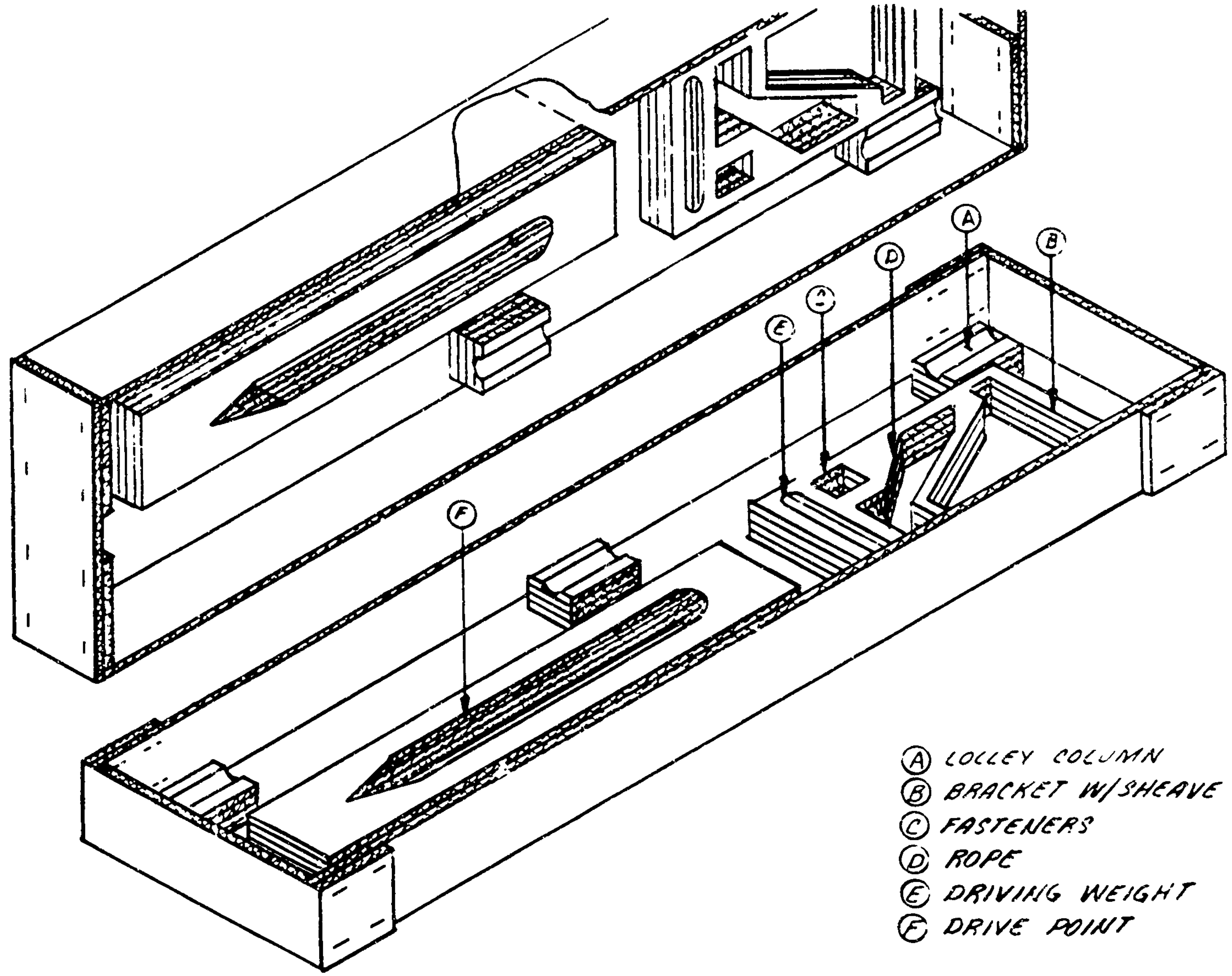

FIG. E-2 CONCEPTUAL PACKAGING FOR SHEAVE AND WEIGHT DRIVE

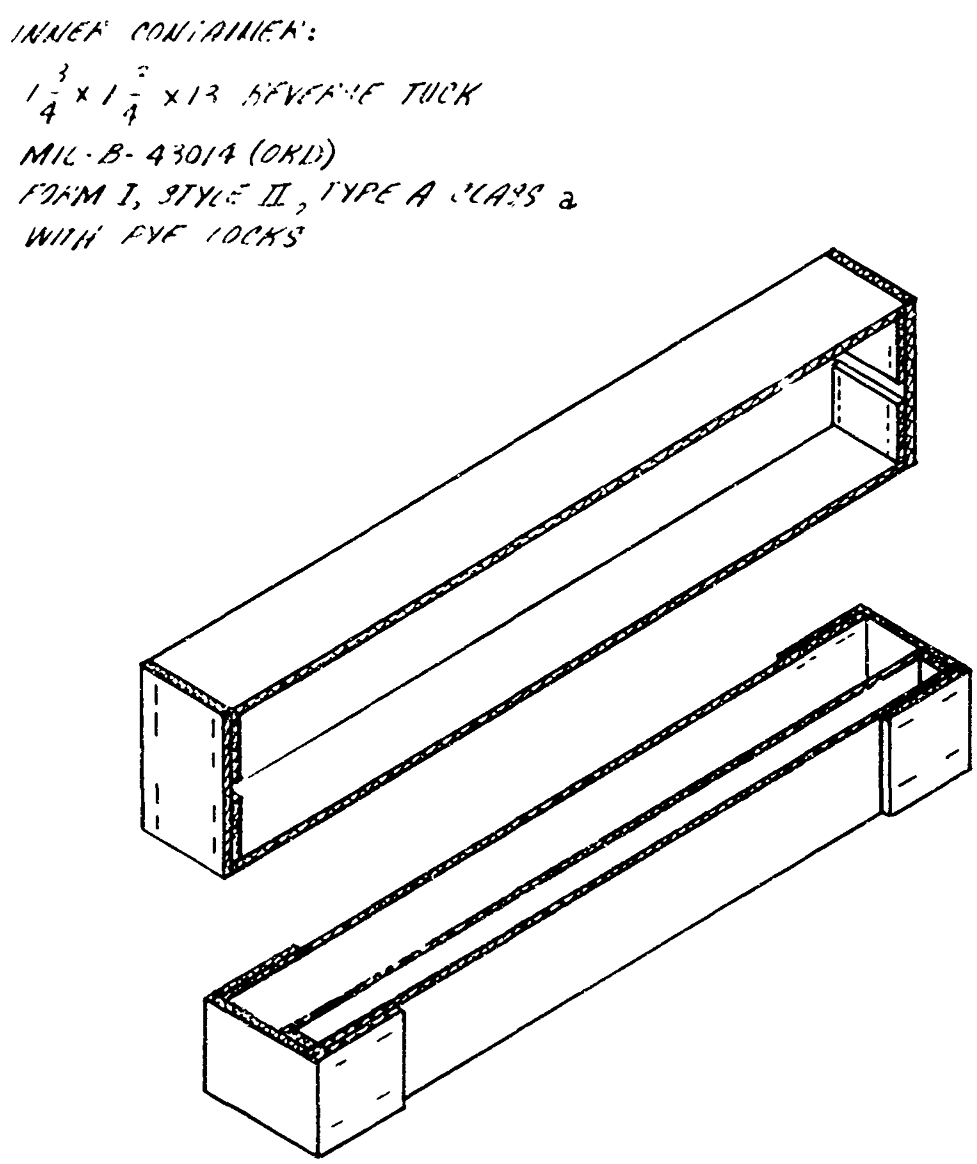

FIG. E-3 CONCEPTUAL PACKAGING FOR WELL CASINGS AND PUMP RODS

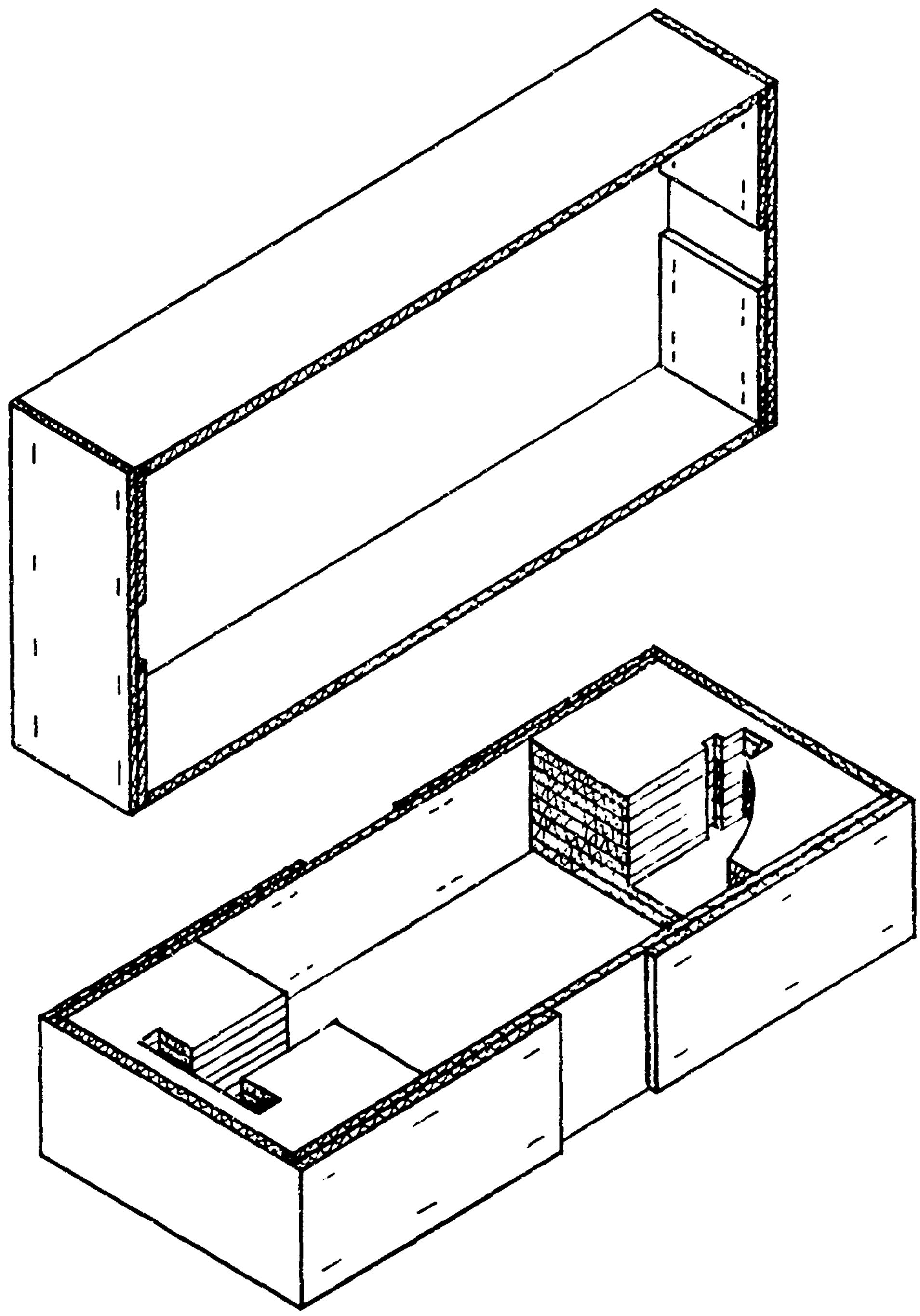

FIG. E-4 CONCEPTUAL PACKAGING FOR PUMP WITH HANDLE

It is not anticipated that any problems would arise out of storage under cover for ten years. On the other hand, it is recommended that those items sensitive to corrosion be coated with preservative grease in accordance with MIL-G-10924 and wrapped in grease-proof paper to MIL-B-121. The rope for operation of the drive point (see Sec. III-B-6) should be of nylon to resist attack by fungus, etc.

3. ESTIMATED COST OF PACKAGES

The cost of labor for repackaging for long-term storage is excluded from the estimated packaging costs of Table E-I, since labor costs depend greatly on how contracts for the kit are written. For example, OCD might elect to make one regional contractor responsible for either one or all four containers and contents to be delivered to an area storage facility for distribution. Alternatively, OCD may decide to contract separately for all items, to be shipped in temporary bulk containers to several regional packaging contractors, who would be responsible for applying preservative and repackaging the equipment for long-term storage.

Table E-I

ESTIMATED COST FOR PACKAGING MATERIALS

Quantity of Kits	Cost per Kit
1,000	$35.70
2,500	$30.20
5,000	$21.70
10,000	$17.10

Appendix F

STANFORD RESEARCH INSTITUTE
Engineering Sciences & Industrial Development

CONTACT REPORT

3 February 1966

Company Name and Address:	Sonic Co., Inc. San Diego, Calif.
Date and Place of Visit:	1 February 1966 San Diego, Calif.
Company Representative:	Leo Newfarmer, Vice President Jack Holzman, Project Manager
SRI Representative:	G. F. Hughes-Caley James F. Halsey

Object:

(1) To attend a field demonstration of soil penetration using Sonic Techniques.

(2) To make preliminary assessment of the basic feasibility of pre-crisis "In-Shelter" well construction using this technique and

(3) To determine in addition, the degree of interest on the part of Sonic Co. in developing a version of the existing equipment for the above application.

Discussion:

The equipment used in the above demonstration is that which was viewed in disassembled form during the authors visit to Sonic Co. on Dec. 15th and 16th, 1965 and described in a Contact Report dated 29 December 1965, G. F. Hughes-Caley.

The demonstration was staged in an open area covering a thick alluvial formation comprising a fairly well compacted mixture of sand, clay, medium gravel and small boulders. Mr. Holzman had gathered together seven 3" O D x 8 foot long tubes (all that were available) taper threaded externally and internally at opposite ends so that when assembled they would form a continuous, flush jointed tube, 56 feet long. It was proposed to drive all but about 2 or 3 feet of this into the ground, joining the 8 foot lengths as required, lower a dummy shot charge on a wire in simulation of one of the present applications of the equipment (i.e. that of drilling Seismic Shot-Holes) and then withdraw the tube, decoupling the sections as they appeared above the surface, finally leaving the dummy charge at the bottom of the hole with wire attached ready for firing. The sequence of operations was as follows: - (1) The first (bottom-most) tube section was threaded onto the oscillator coupling and wrenched home by rotating the coupling through an electrically driven ring gear while the tube was clamped against rotation. (2) A loosely fitting cap (or foot) was located under the lower end of the tube and the whole mass lowered so that the cap rested on the ground under the weight of the oscillator and drive motor assembly. (3) The oscillator was then speeded up to about 30 cps causing the tube to sink into the ground at a fairly rapid rate even though the frequency of the oscillator movement did not match the natural resonant frequency of the short tube section at this stage.

(4) At a point when the upper end of the first section was within about two feet of the ground, the connection between tube and oscillator was de-coupled by rotating the ring gear, and the Oscillator-Drive assembly raised to permit the introduction of a second pipe section. (5) The previous cycle of re-coupling, penetration and decoupling was repeated for the 2nd through the 7th and last section. (6) The dummy explosive charge, (a short length of aluminum tube suspended by a twin insulated cable) was lowered to the bottom and the upper end of the cable secured against loss down the bore by anchoring it to a simple elastomeric device inserted in the mouth of the uppermost tube, and capable of supporting the cable by friction against the tube side walls.

Timing of the actual rate of penetration was only possible in a somewhat imprecise manner especially as the oscillator frequency was cranked up as each section was added, until it reached approximately 100 cps. In any event the rate, as "eyeballed" during the sinking of any one section varied somewhat, due probably to the resistance encountered from obstructions such as small boulders and differences in soil compaction at various strata-levels.

However, from a rough observation of the time (seven minutes) consumed in coupling and decoupling, tube handling and other equipment manipulation, up to the completion of penetration to approximately 53 feet, which occupied a total of 10 minutes, the overall average rate of penetration was about 11.3 seconds/foot.

The tube was now withdrawn by exerting a pulling force through the hoisting mechanism, with the oscillator operating at a fairly high frequency, say between 80 and 100 cps depending on the subsoil formation. Withdrawal was interrupted only long enough to permit sequential de-coupling of the 7 tube sections as they appeared above the ground surface, and was completed in 7 minutes, making a total time of 17 minutes for penetration and withdrawal.

The cap (or foot) applied to the first tube section prior to commencement of penetration and carried down with the tube, remained in the ground, together with the dummy charge.

Horsepower requirements

While the prime mover presently used on the equipment described is rated at 80 HP, Mr. Holzman stated that not more than about a fifth of this was required to carry out the demonstrated task.

Reporter: G. F. Hughes-Caley

Distribution: Standard + James F. Halsey

GFH-C:bjd

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13 ABSTRACT

In the event of nuclear attack on the United States, the population of affected areas will enter designated shelters to escape exposure to nuclear fallout. Confinement may extend for periods of up to 14 days. Utilities such as electric power and city water are likely to be inoperative. The solution of problems relating to food supplies and potable water appear to be reasonably well in hand, as in ventilation with manually operated equipment. However, in certain areas of the United States, the ambient environment during summer months is such that outside air is too hot to be useful in ventilating fallout shelters directly.

The objective of research reported here was to determine the feasibility of prospecting for, tapping, and recovering ground water, working from within fallout shelter boundaries, for use as a shelter ventilating air coolant.

A literature search was made into the background of established techniques of soil penetration and well construction, with particular emphasis on those that might lend themselves to manual operation in the event of a complete absence of power. This search was supplemented by a parallel series of discussions with knowledgeable personnel of the Division of Water Resources, Department of the Interior, U.S. Geological Survey and with practicing engineers having longtime experience in the construction of both shallow and deep wells by long established basic techniques. This background study permitted an assessment of the relative practicability of existing techniques in the light of the limiting circumstances of fallout shelter environment.

Findings and implications arising from the above studies and discussions are that post-attack, in-shelter well construction is not feasible, particularly for the following reasons:

> The severe limitations imposed by the physical (configurational) environment likely to be encountered in the typical designated shelter.
>
> In only a limited number of instances is it likely that a reliable pre-attack prediction can be made that ground water is present beneath a shelter either in a sufficient quantity, or at all, or in penetrable subsoil and/or at an attainable level.

A method of sonic well drilling was investigated, which holds promise of removing some of the present objections to pre-attack well construction.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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