Design and Construction of Deep Underground Basing Facilities for Strategic Missiles: Report of a Workshop Conducted by the U.S. National Committee on Tunneling Technology, Commission on Engineering and Technical Systems, National Research Council. (1982)

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Design and Construction of Deep Underground Basing Facilities for Strategic Missiles

Volume 2 Briefings on System Concepts and Requirements

Background Information Presented at
a Workshop Conducted by the
U.S. National Committee on Tunneling Technology
Commission on Engineering and Technical Systems
National Research Council

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Preface

In response to a request from the Chief of the Strategic Structures Division, Defense Nuclear Agency, the U.S. National Committee on Tunneling Technology (USNC/TT) convened a workshop on the technology for design and construction of deep underground basing facilities for the MX missile. In its request, dated October 9, 1981, the Defense Nuclear Agency (DNA) indicated its interest in "evaluating the constructibility, vulnerability, and survivability of deep underground defense systems," and called on the USNC/TT to help in assessing current and developing tunneling technology that would be important in designing and constructing deep basing facilities. Citing an "urgent need to respond quickly to changing defense needs," DNA asked that the workshop be held in early November and that a report on the proceedings be completed in April 1982.

The workshop was held on November 5 and 6, 1981, in Washington, D.C. In attendance were all available members of the USNC/TT and several of its subcommittees, as well as selected past members of the committee and others whose expertise was judged indispensible. The first day, after a brief executive session dealing with procedural matters, was devoted to public briefings by representatives of the U.S. Air Force, the Defense Nuclear Agency, and several contractors (Merritt CASES, Inc., the Boeing Company, and R&D Associates, Inc.) that have performed conceptual and design work on aspects of the deep basing problem. Transcripts of these briefings, which were arranged for by the sponsor as background for the committee, appear in this volume. The subject matter and content of the briefings, as well as the views expressed therein, are the responsibility of the speakers.

As part of its request, the Defense Nuclear Agency had asked for specific guidance in six areas: (1) costing, contracting, personnel, and management; (2) siting; (3) use of existing underground space; (4) egress; (5) mechanical mining; and (6) construction planning and validation. The USNC/TT accordingly had established a working group to deal with each of these topics. In the evening of the first day the six working groups met separately and developed preliminary draft reports for presentation on the following day.

The morning of the second day was occupied with the presentation of working group reports, again in open session. In the afternoon the assembled tunneling technologists met in executive session to discuss the preliminary working group reports and agree on the general outlines of their revision as chapters in the committee's report, which appears as Volume I, *Evaluation of Technical Issues*.

That report avoids the strategic and political issues surrounding the MX missile siting decision. It concentrates instead on the as yet vaguely defined technical requirements of the deep basing option, discussing in general terms the technical and management issues raised by the proposal. Its aim is to help the Defense Nuclear Agency and the U.S. Air Force to refine their plans in preparation for a final decision on the MX missile's basing mode, expected in 1984.

Air Force Deep Basing Program

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SUMMARY: It is well known that the President recently announced a new strategic modernization plan and that the MX missile is a key part of the plan. This briefing states why intercontinental ballistic missiles are important and why the United States needs the MX missile in a survivable basing mode.

The reason we have strategic forces is to deter an attack on the United States or its allies. That objective has been achieved over several decades with the use of a "triad" of strategic forces, consisting of (1) bombers with air-launched missiles, (2) submarines, and (3) land-based missiles. Each of the triad's elements has different strengths and weaknesses, but the diverse capabilities of the combined forces make it very difficult for an adversary to attack all elements successfully. The Soviets cannot guarantee that they can wage a successful attack without suffering devastating retaliation and destruction on their own homeland. This has provided strong deterrence.

Intercontinental ballistic missiles (ICBMs) contribute unique and essential characteristics to the triad of forces, such as accuracy, speed, good communications, low cost, and a high state of readiness. However, ICBM survivability is degrading due to a massive Soviet buildup of its ICBM force, technical improvements in accuracy and warhead technology, and extraordinarily high expenditures on their military forces.

Many alternative responses have been proposed, including launch under attack, giving up the triad for a dyad, establishing a ballistic missile defense, and rebasing the MX. Rebasing is the alternative addressed in this presentation.

The MX in a survivable basing mode can help restore the military balance and enhance world stability. There are many reasons why the MX in a deep basing system makes sense. The Air Force needs the U.S. National Committee on Tunneling Technology's help to resolve key technical, cost, and schedule issues, which are discussed in more detail by Lt. Colonel Rule in his presentation.

As you know, the President recently announced a new strategic package to upgrade our strategic forces, and MX was a very key and a very knotty problem for him. He kind of came out with the conclusion that we really did not have the right answer now. I am going to tell you today very briefly why MX is important—why missiles are important—and hopefully it will be a speech that you have not, very many of you, heard before.

The reason we have strategic forces is to deter the Soviet Union from going to war with us, and clearly that is a worthwhile objective. Now, maybe we stumbled into it or maybe we planned it, but it doesn't make any difference—somehow we came out with a triad of strategic forces. First of all, we have the airplane; the bomber was the first of these, and we went for some time with just bombers as strategic forces essentially. Then along came the intercontinental ballistic missiles (ICBMs) and the submarine-launched ballistic missiles (SLBMs). Each of the three has different characteristics. An attack on one does not necessarily mean an attack on all, and the Soviets have to be able to attack them all successfully, or, in fact, you have deterred them.

Figure 1 shows the weapons inventories' changes over the years 1950 to 1979, in each of the three categories. In the early to middle 1950s, we built up something like 1,500 or 1,600 airplanes, and then in came the ICBMs and SLBMs. So, we have some 2,000 strategic systems of three different kinds.

I will talk to you now for the rest of the presentation about ICBMs, and the MX in particular. Figure 2 shows some of the advantages of ICBMs. I want to point out the word "survivable." The reason we are in this room today is that the ICBM has lost its survivability. Now, one of the beauties of the triad is that if you have three legs—three sets of strategic weapons—and one leg becomes vulnerable, the other two can carry you through that period of time so that the Soviets cannot attack you with great ease or even be promiscuous in a world political situation, I might say. But the ICBM leg has become more and more vulnerable, and through the 1980s it is definitely not going to have the survivability characteristics that we wish, and that is why we are looking for a way to base the MX missile.

I might also add that in the President's recent strategic package he said that we are going to buy the B-1 bomber. The B-52 bomber, I always thought, was designed in 1952. I asked the president of the Boeing Corporation once, and he said, "No, it was designed in a motel room in Dayton, Ohio, in 1948." I don't care what year it was; I know that it is an old airplane, and we either have to have a new bomber or we sort of have to give up on bombers, and the President went that way. So, we have two legs of the triad that are having some problems, and hopefully you are going to help us solve this one in the ICBM leg.

Figure 3 shows where the present ICBMs are located. We have three Titan wings—in Arizona, in Kansas, and in Arkansas. We have six Minuteman missile wings: Whiteman in Missouri; Warren in Wyoming; Ellsworth in South Dakota; Grand Forks and Minot in North Dakota; and Malmstrom Air Force Base in Montana.

Just to show how obtrusive a missile site is, Figure 4 is a photograph of one. It covers about an acre or so, and it sits out here in the farmland. That particular one sits out in the farmland of North Dakota, and it doesn't seem to bother the neighbors a whole great deal. That is what one looks like.

Through the 1970s, as you have heard, the Soviets have spent a lot more money. I have got a couple of illustrations that show that. I just want to talk first of all about development (Figure 5). It used to be that the United States spent a great deal more money than the Soviet Union on the development of strategic and defense technology, but sometime about 1970 there was a crossover, and although we made progress toward the end of the 1970s, it is clear that the Soviets are spending a great deal more money than we are.

Now, that is development money. Figure 6 shows that into the 1970s their research, development, test, and evaluation (RDT&E) dollars, their development funds, had gone up by 92 percent, and ours were actually down 20 percent.

Figure 7 shows that the Soviets spent more on equipment and facilities than we did during the time period. I read in a newspaper sometime in the very recent past where the Soviet Union actually for military expenditures during the decade of the 1970s had spent almost $500 billion more than the United States, but in this period—like 1970 to 1978—they had spent for equipment and facilities $104 billion more than the United States had. That is documentable, and these are the kinds of things that we could have bought with $104 billion. If we had spent that $104 billion the B-1, the MX, and the Trident would be in the field, along with the XM-1 tank and the F-14, F-15, F-16, F-18, and A-10. It would have paid for all those programs, and we are still struggling in the Department of Defense to do some of those things.

What that has led to is the area of rough equivalence here that we talk about, whether we are roughly equivalent with the Soviet Union. The "in" phrase in town now, I think, is "window of vulnerability." Back at the end of World War II it was clear that we had superior strength and certainly in the early 1950s and 1960s. There was no question that we had a deterrent force because in the Cuban missile crisis there is very little doubt that the Soviets looked at us and blinked and backed away. Now, I am not sure that if that were to occur today they would blink and back away.

We have 1,000 Minuteman missiles (Figure 8), and we have 54 Titans, which we are now taking out of the field. The Minuteman II missiles are roughly 20 to 25 years old; the Minuteman IIIs are a little newer. The Titans are 25 years old. You can also see the Soviet missile forces in the figure. Those indicated as under development are actually, it seems, beginning to come out into the field. The SS-18 and the SS-19—they have about 1,000 of the smaller missiles that you see and about 300 SS-18s, and they are brand new as compared to our 1,000 Minuteman IIs and IIIs. That is why we are trying to build the MX missile, and you people here today, hopefully, are going to help us figure out a good way to base the missile, because there is very little question that we need the missile. The only question is about how we base it.

Figure 9 illustrates what the Soviets have been doing over the years. At first they started out with single reentry vehicles. They have now put MIRVs on their big missiles, and while this shows that there are 7 or 12 on there, the number is not particularly important at this point in time; the fact is that if you can kill a target with one of those on the left, you could kill 12 targets with one of those on the right. That is where the problem comes in, because they have very large missiles, and they can put an awful lot of warheads on them, and each one of them kills a separate target.

Figure 10 shows that also, through the years, they have moved their Circular Error Probable (CEP) in. Now, CEP is a term that you don't really have to understand, but all it says is how accurate the missile is.

If I am trying to kill Washington, D.C., and I put a warhead over Baltimore, obviously it doesn't kill Washington, D.C., and so accuracy is very important. While the figure is an unclassified chart from the 1978 to 1987 time frame, I can only tell you that their missiles are becoming very accurate, and they are at the point at which they can destroy with one warhead virtually any target that they shoot at. They are that accurate.

Figure 11 lists some of our alternative responses. One thing is to launch under attack. That means that if we see their missiles take off, and the President decides that we are going to lose our systems, then we can launch while we are under attack to avoid that loss.

Now, that is not very pleasing to many people; it is not very pleasing to the President; it is not very pleasing to the Congress, but that is one of the things that can be done. Clearly that is not our national stated objective, although we do have the capability to do so.

We could move from a triad to a dyad, and one of the problems with moving to a dyad is that then if one of those legs gets vulnerable you don't have two legs to help support you. If you move to a dyad, and one leg is vulnerable, and all of a sudden they make a breakthrough on the other leg, you know that you are pretty well held hostage. We can defend silos or we can rebase, and the rebasing of the MX is what we are talking about here today.

Through the years we have looked at an awful lot of ways to base the MX missile. Each and every one of them, for one reason or another, has been rejected, and that is why we are in the room today.

Figure 12 gives some statistics on the MX missile. It is 92 inches in diameter. It weighs 190,000 pounds. It is about 71 feet long. It has about 8,000 pounds of throw weight, and could throw 10 reentry vehicles on that missile. It is, also, the largest U.S. ICBM allowed under SALT II. (Even though the SALT II agreement was never ratified here in this nation, both sides have chosen to live to the terms of that agreement.)

Figure 13 shows what the missile looks like. It is a three-stage solid rocket motor missile. The first stage weighs some 106,000 pounds and is about 50 feet long; the second stage weighs about 40,000 pounds. The third stage kind of looks like a donut, or a doorknob. It is very small. Of course, as soon as the propellant is burned out these stages fall off, and finally you are left in space with the fourth stage, which maneuvers and very precisely releases each individual reentry vehicle to go to the target.

Figure 14 compares the Minuteman III missile with the MX. Remember I told you that the Minuteman is some 15 to 20 years old. It weighs 78,000 pounds. It is 66 inches in diameter at the bottom stage. Then it narrows down to 52 inches all the way, and we only can throw three reentry vehicles with that, compared to ten with the MX.

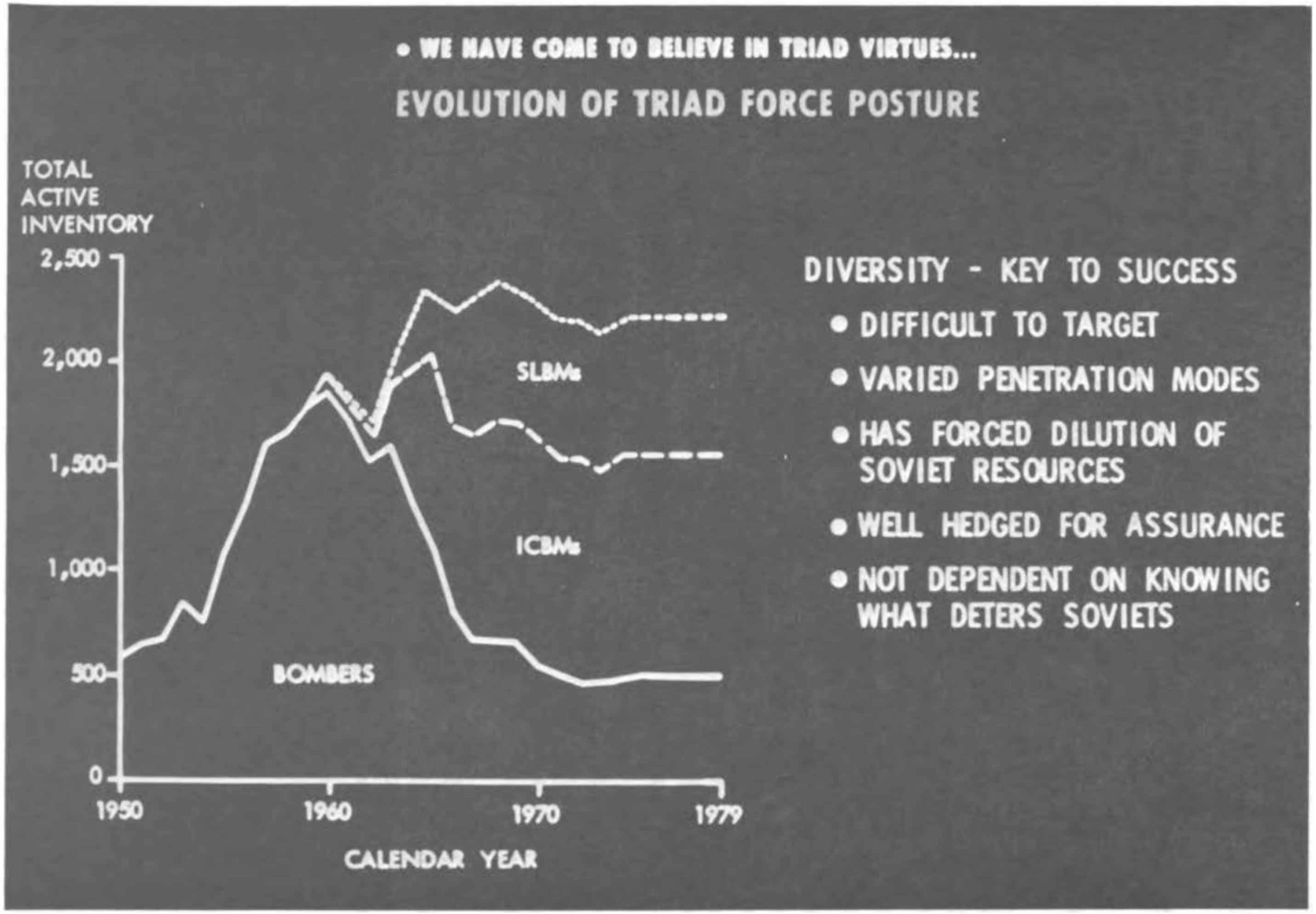
Hopefully, if we are successful, the MX missile will be added to the U.S. inventory. Essentially it is equivalent in size to the smaller Soviet missiles, which they are allowed about 1,300. The MX, of course, is probably a little more capable than the Soviet missiles of the same category, but they are probably going to have 1,000 of those and we are talking about 100 or 200 MXs. So, even if we get MX based as we desire, we are still not asking for an equal inventory.

It is very clear. The Soviet Union has built up a very large inventory of missiles, and it has got to be for other than self-defense reasons. You just don't built an inventory of these things without a purpose. It is pretty clear that their intentions are not all honorable.

The President has told us, "Develop and produce 100 MX missiles; deploy some of these missiles initially in silos." Part of our job out at the Ballistic Missile Office is to design and produce the hardware necessary to go in some 40 or 50 Titan or Minuteman silos. We have also been instructed to pursue as long-term options each of three categories of things; the decision date for the choice among these three options is late 1984. The first option is continuous patrol aircraft—very large airplanes that fly slowly and low but can stay in the sky a long time. The optimists believe that perhaps we can get an airplane to stay in the air for 10 days at a time, and the idea is if you have an airplane that can be in the air for 10 days you fly from the East or West Coast out over the ocean, and the Soviets could not find it. Therefore, the argument goes, that would be a nice, survivable way to base missiles.

The second concept is that of ballistic missile defense whereby we could actually defend our silos with our own ballistic missile defense system. Right now there is a treaty that prohibits an effective ballistic missile defense, because it allows you only 100 interceptors. Now, if this option were chosen, of course, then we would have to tell the Soviets that it was in our best interests that we did not continue that treaty. We have not done that as yet; maybe in 1984 we will. The third option, which is why I am standing here talking to all you folks today, is deep underground basing. It is felt that if we can put these missiles, in some numbers, very deep below the surface, the Soviets will be unable to destroy the system. Then the real issues are how much it costs to build a system like that and how we get the missiles out once we want to fire them.

As I said, we are going to select the long-term basing modes in 1984. All of the Air Force people in this room are advocates of deep basing, and if you ask them questions I am sure they will all tell you all the reasons why we think we can do this. But we certainly need your help.



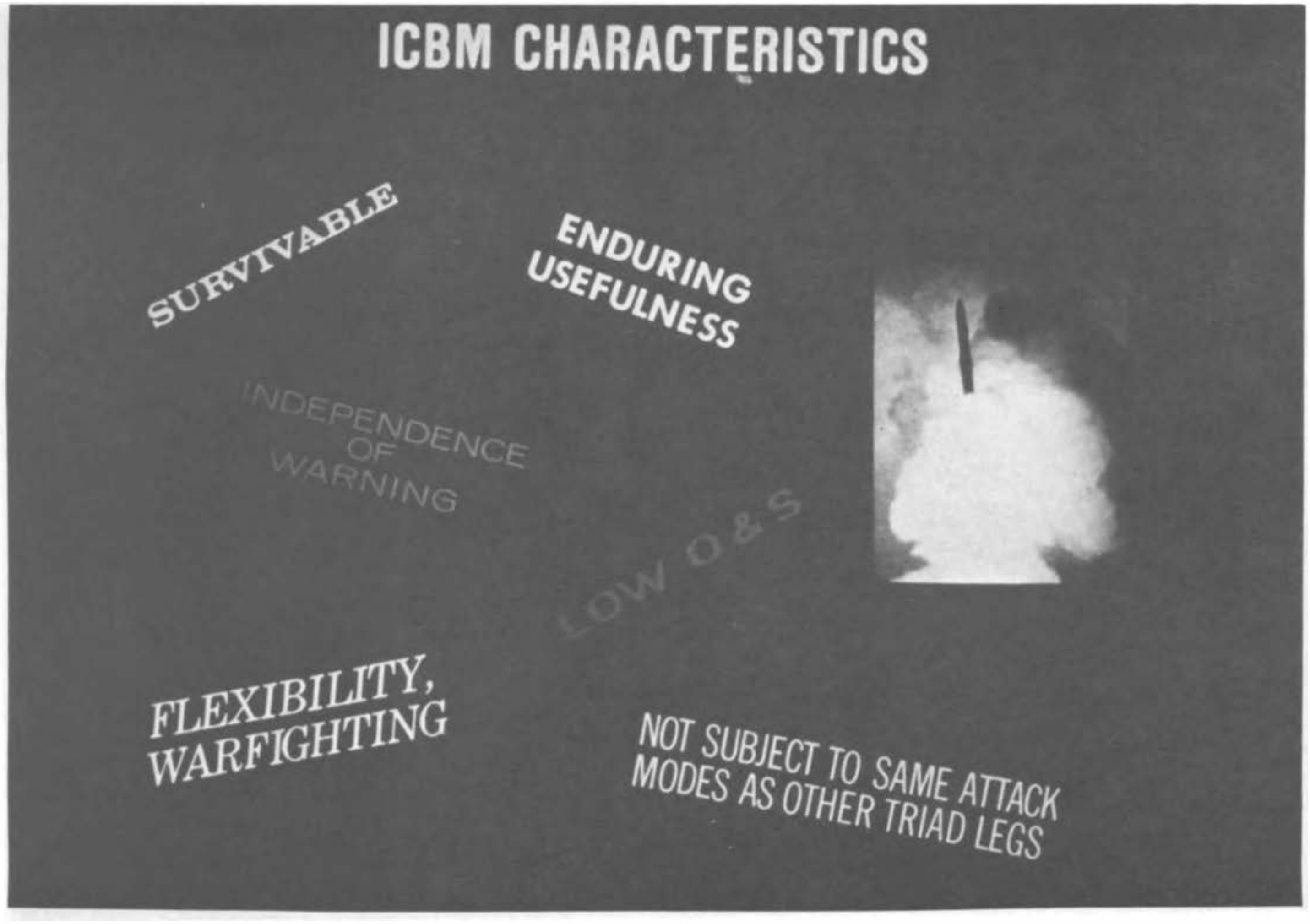
- WE HAVE COME TO BELIEVE IN TRIAD VIRTUES...

EVOLUTION OF TRIAD FORCE POSTURE

DIVERSITY - KEY TO SUCCESS

- DIFFICULT TO TARGET
- VARIED PENETRATION MODES
- HAS FORCED DILUTION OF SOVIET RESOURCES
- WELL HEDGED FOR ASSURANCE
- NOT DEPENDENT ON KNOWING WHAT DETERS SOVIETS

FIGURE 1



ICBM CHARACTERISTICS

SURVIVABLE

ENDURING USEFULNESS

INDEPENDENCE OF WARNING

LOW O&S

FLEXIBILITY, WARFIGHTING

NOT SUBJECT TO SAME ATTACK MODES AS OTHER TRIAD LEGS

FIGURE 2

FIGURE 3

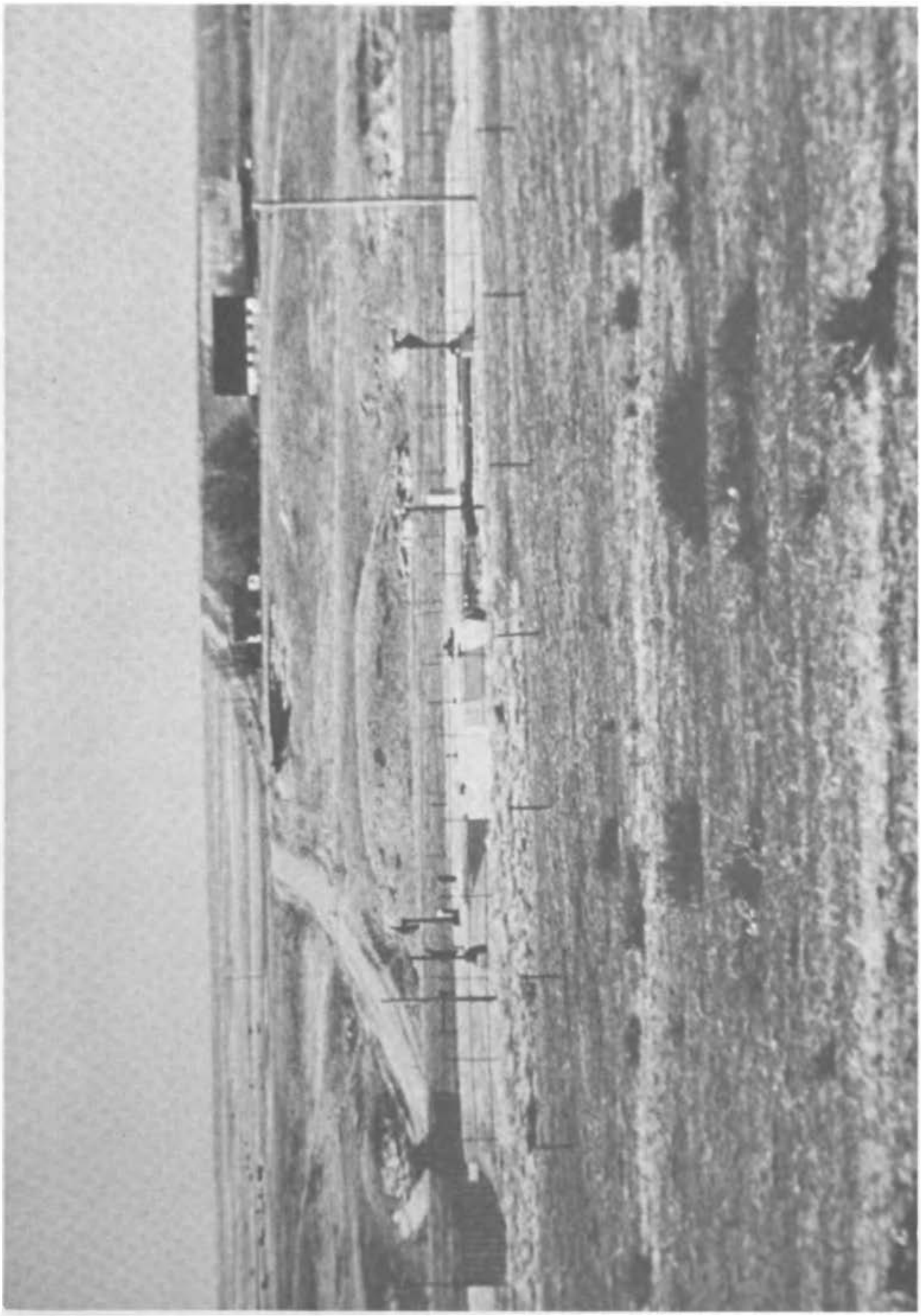


FIGURE 4

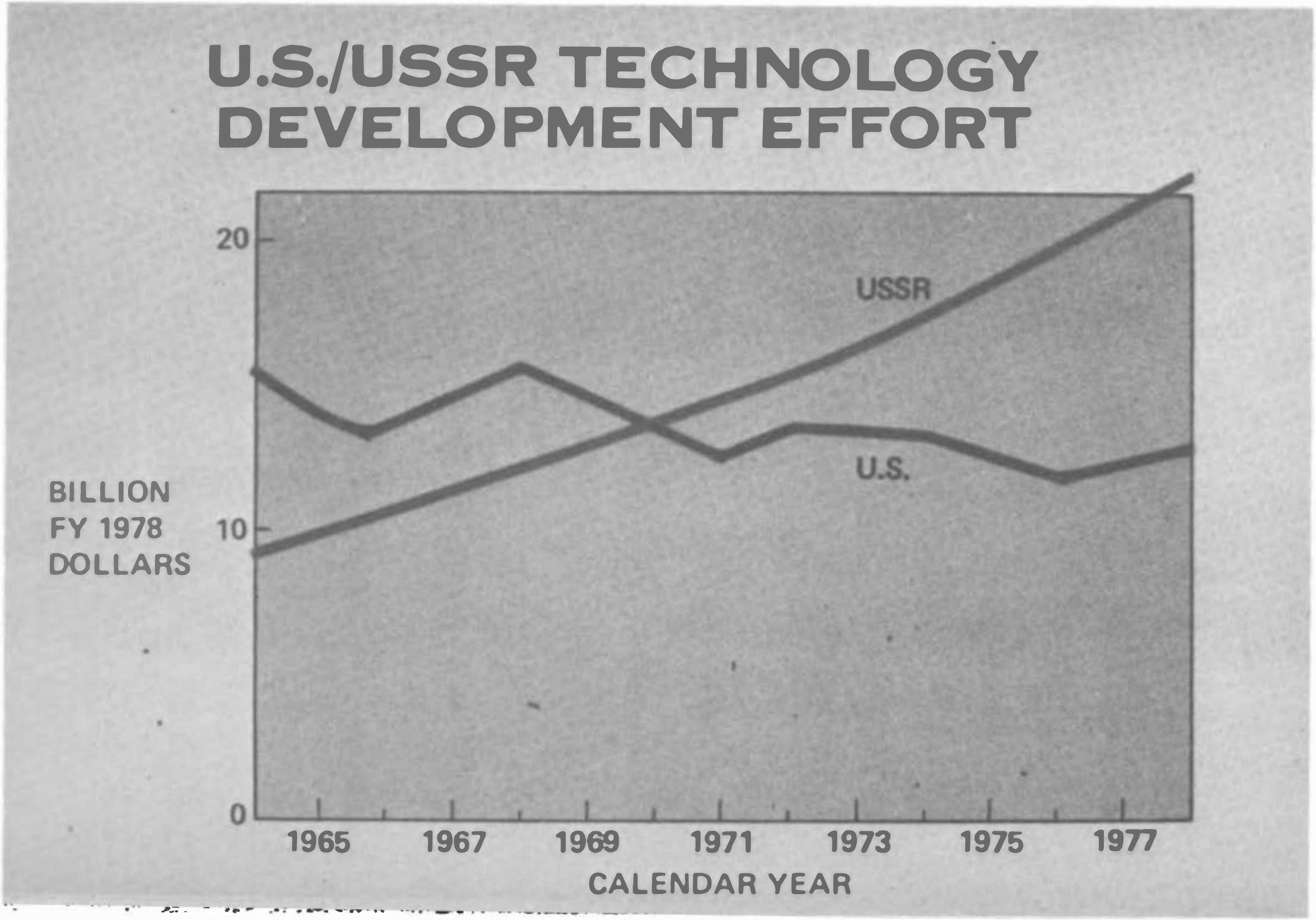

U.S./USSR TECHNOLOGY DEVELOPMENT EFFORT
20
10
0
BILLION FY 1978 DOLLARS
USSR
U.S.
1965
1967
1969
1971
1973
1975
1977
CALENDAR YEAR

FIGURE 5

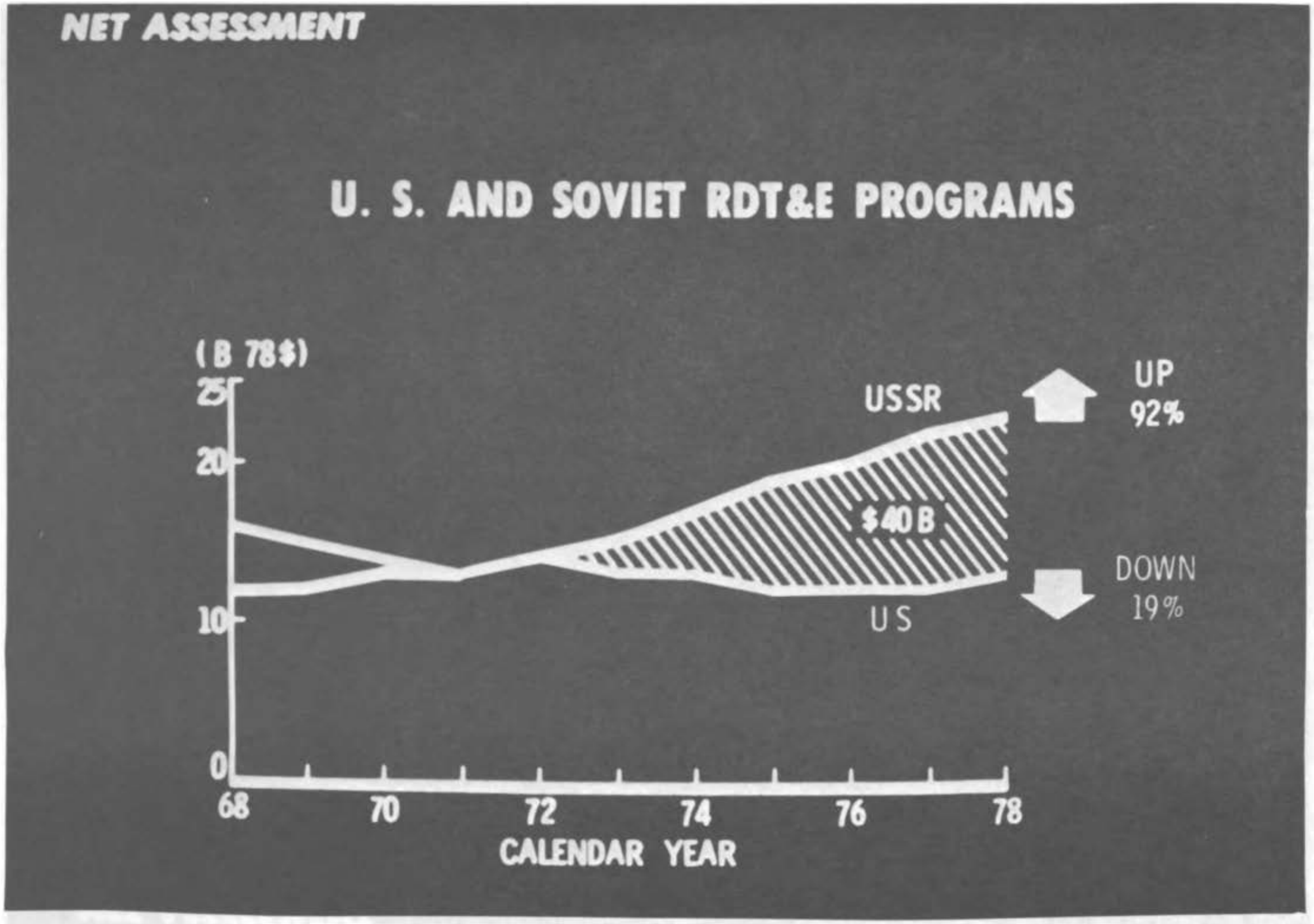

NET ASSESSMENT
U. S. AND SOVIET RDT&E PROGRAMS
(B 78$)
25
20
10
0
USSR
$40 B
US
UP
92%
DOWN
19%
68
70
72
74
76
78
CALENDAR YEAR

FIGURE 6

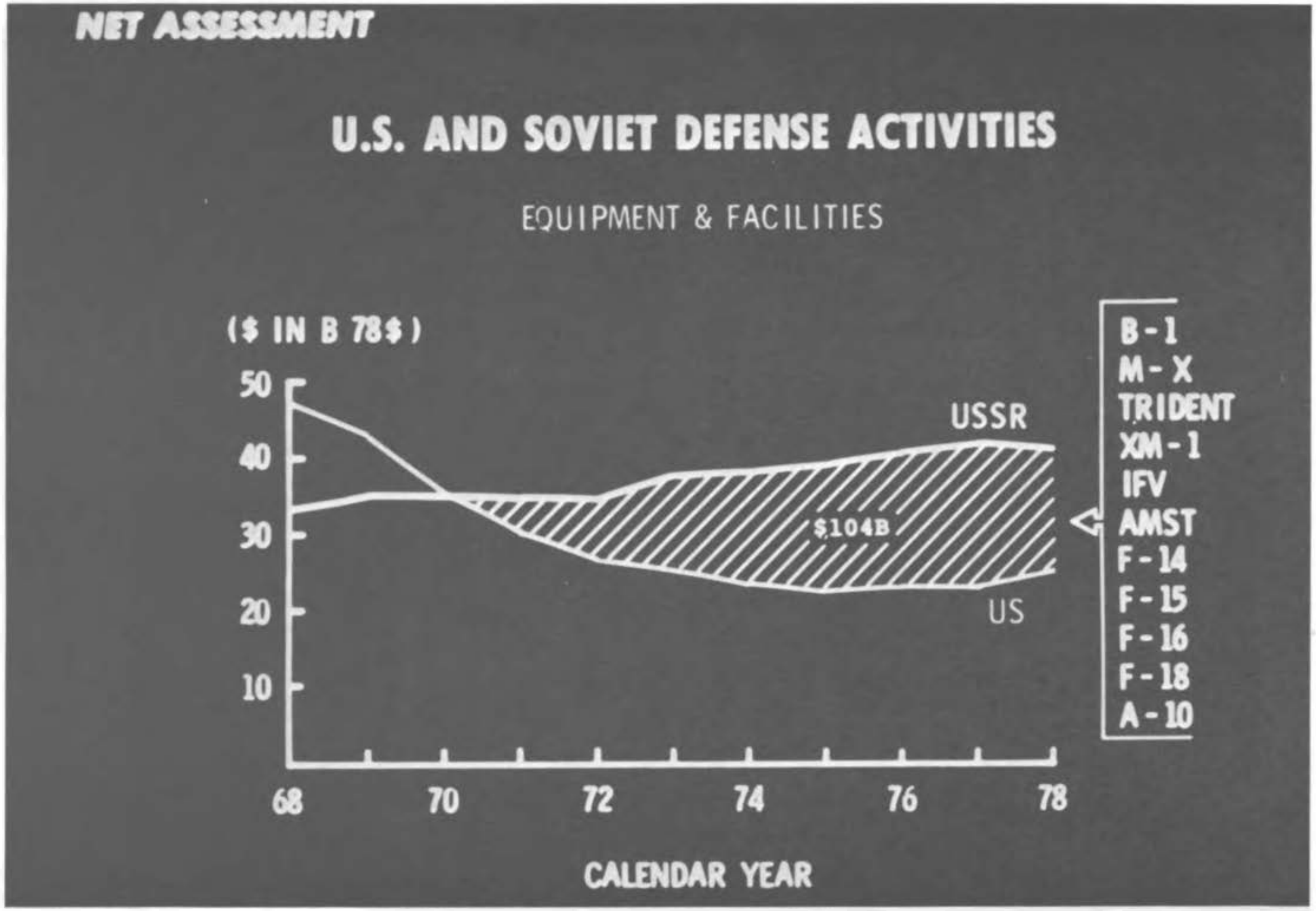

NET ASSESSMENT
U.S. AND SOVIET DEFENSE ACTIVITIES
EQUIPMENT & FACILITIES
($ IN B 78$)
50
40
30
20
10
68
70
72
74
76
78
CALENDAR YEAR
USSR
US
$104B
B-1
M-X
TRIDENT
XM-1
IFV
AMST
F-14
F-15
F-16
F-18
A-10

FIGURE 7

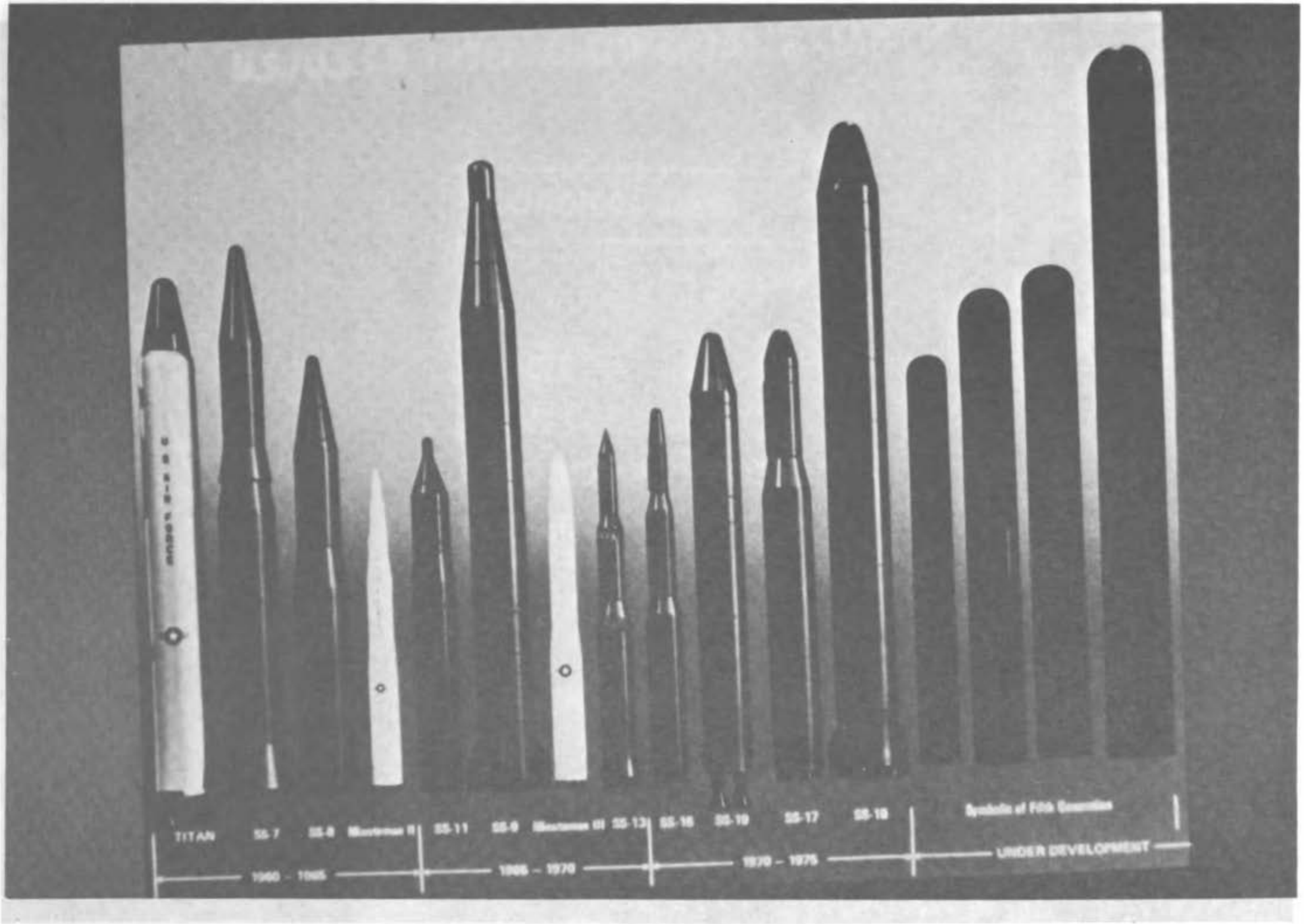
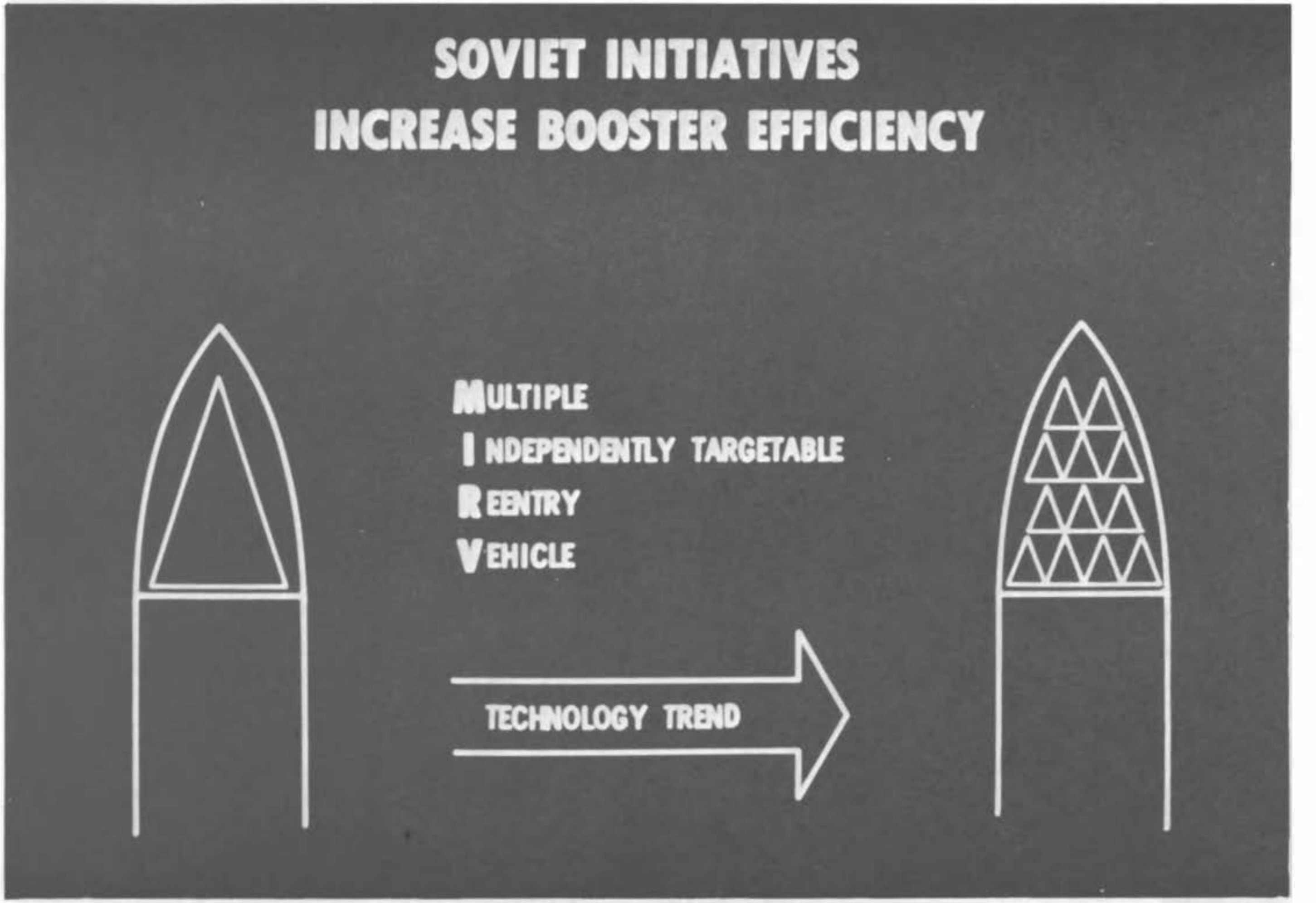

TITAN
SS-7
SS-8
Minuteman II
SS-11
SS-9
Minuteman III
SS-13
SS-16
SS-19
SS-17
SS-18
Symbols of Fifth Generation
1960 - 1965
1966 - 1970
1970 - 1975
UNDER DEVELOPMENT

FIGURE 8

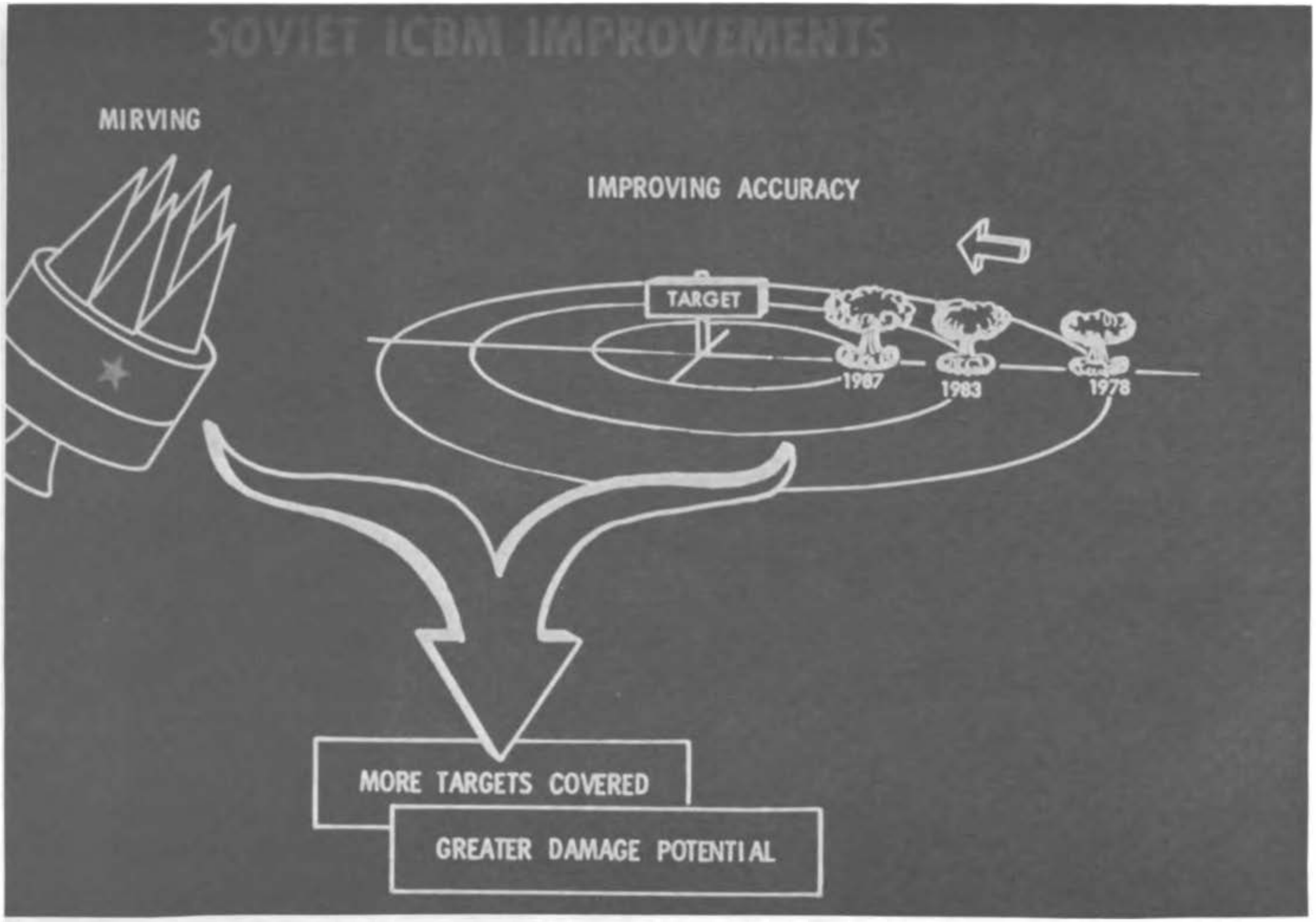


SOVIET INITIATIVES
INCREASE BOOSTER EFFICIENCY

MULTIPLE
INDEPENDENTLY TARGETABLE
REENTRY
VEHICLE

TECHNOLOGY TREND

FIGURE 9



SOVIET ICBM IMPROVEMENTS

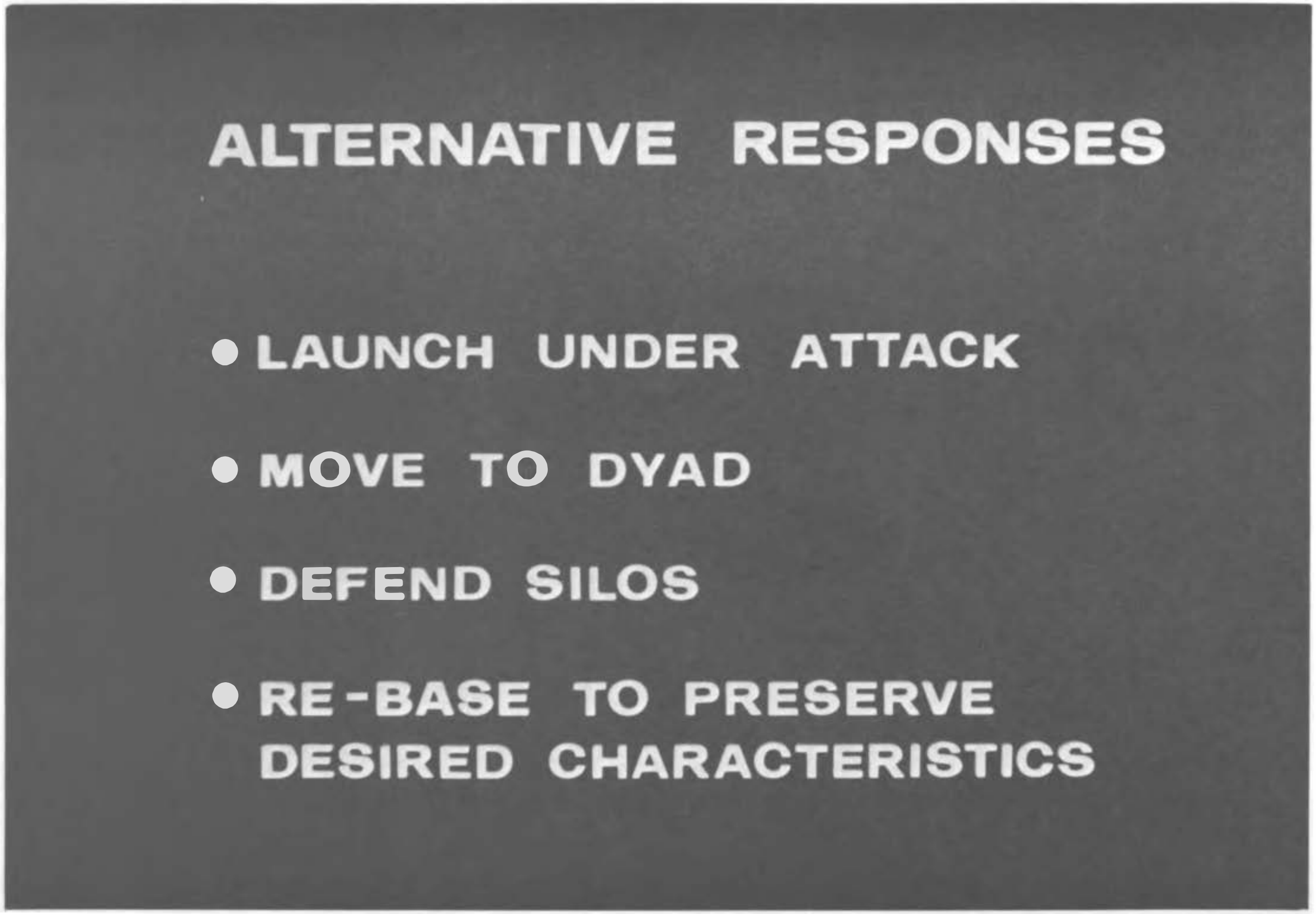
MIRVING

IMPROVING ACCURACY

MORE TARGETS COVERED

GREATER DAMAGE POTENTIAL

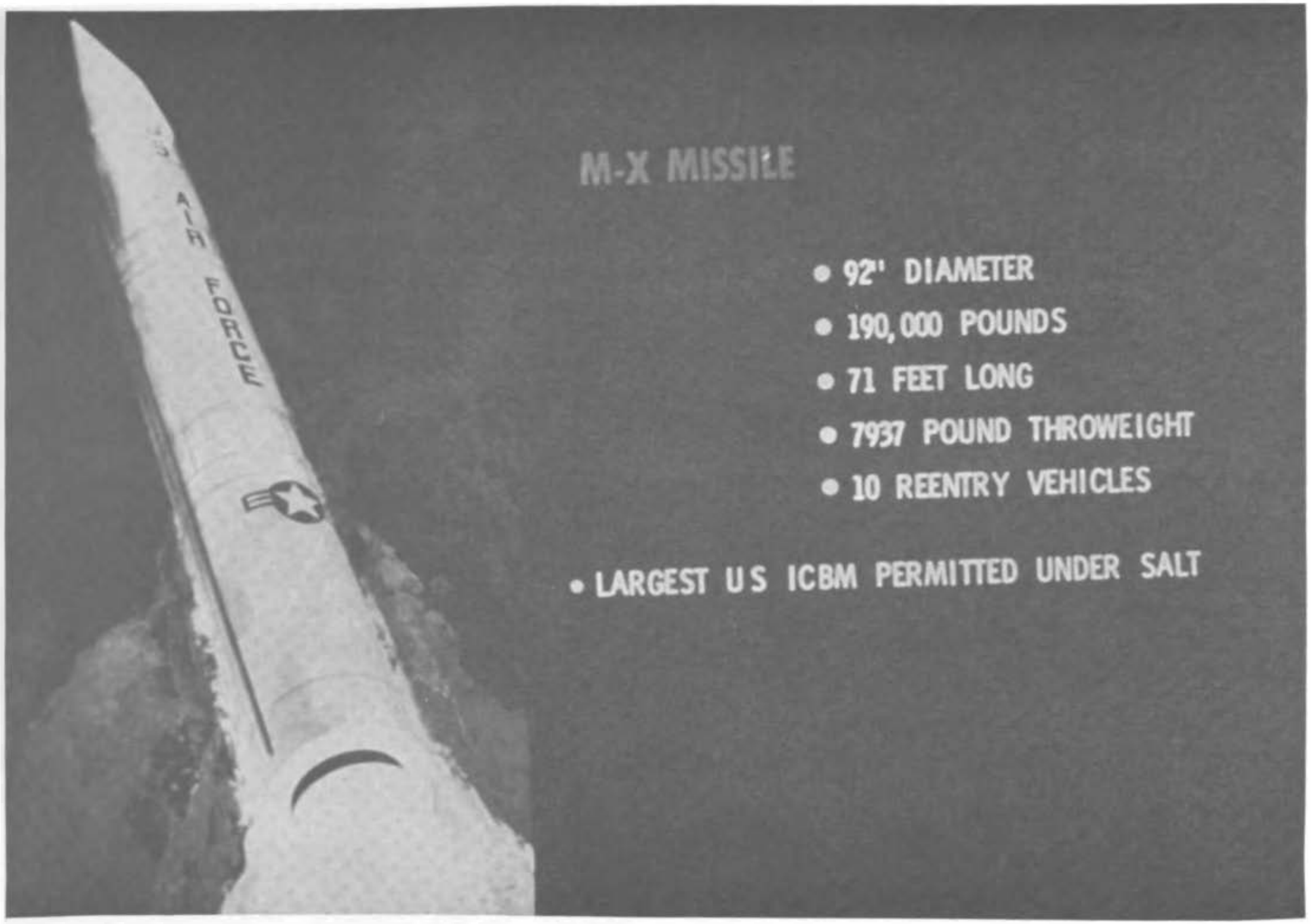
FIGURE 10



ALTERNATIVE RESPONSES

- LAUNCH UNDER ATTACK
- MOVE TO DYAD
- DEFEND SILOS
- RE-BASE TO PRESERVE DESIRED CHARACTERISTICS

FIGURE 11

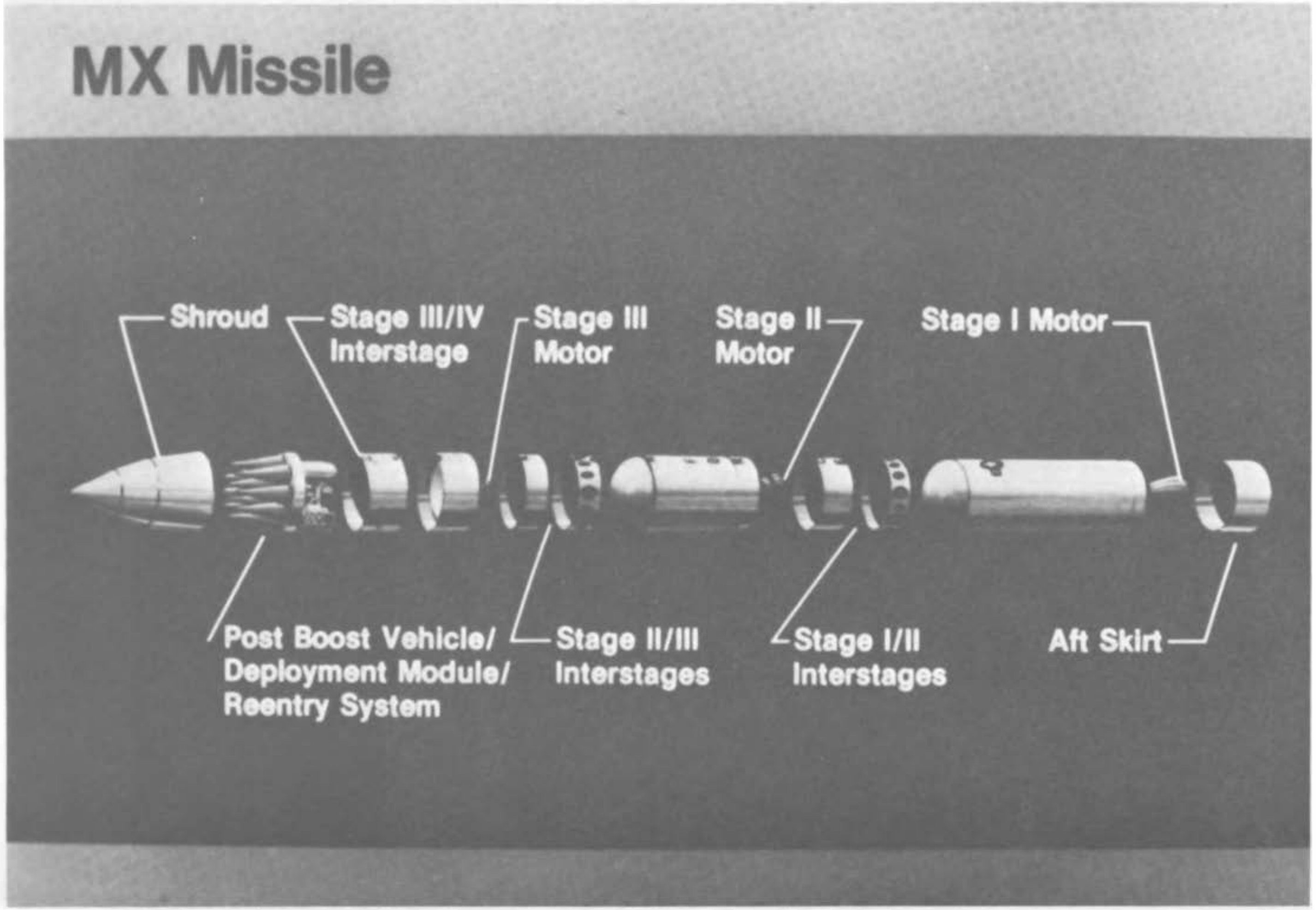


M-X MISSILE

- 92' DIAMETER
- 190,000 POUNDS
- 71 FEET LONG
- 7937 POUND THROWEIGHT
- 10 REENTRY VEHICLES

- LARGEST US ICBM PERMITTED UNDER SALT

FIGURE 12



MX Missile

FIGURE 13

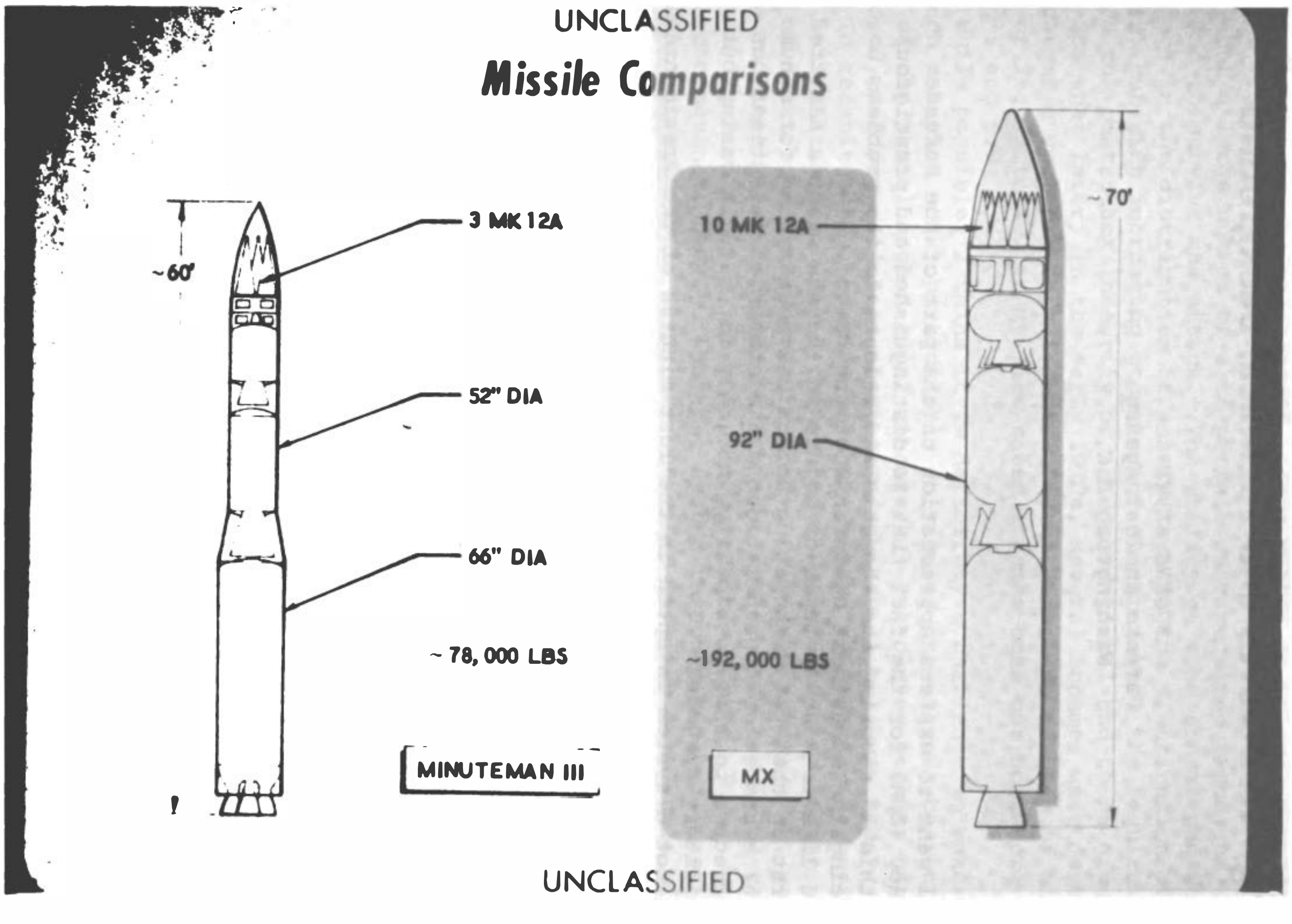

UNCLASSIFIED
Missile Comparisons
~60'
3 MK 12A
52" DIA
66" DIA
~ 78, 000 LBS
MINUTEMAN III
~70'
10 MK 12A
92" DIA
~192, 000 LBS
MX
UNCLASSIFIED

FIGURE 14

Basing Alternatives and Technical Background

EUGENE SEVIN
Defense Nuclear Agency
Washington, D.C.

Gentlemen, I want to express appreciation on the part of the Defense Nuclear Agency (DNA) for the fact that so distinguished and prestigious a group as this is devoting its thoughts and talents to the problems that are facing the Department of Defense at the moment.

I would like to make a couple of points in the few minutes allotted me. The first is that the deep basing option has been around for a number of years; a number of considerations and a number of investigations have been directed to this possibility, not only for missile basing but for other military purposes.

It was not a system invented in the last minutes of the Presidential decision. If there is a window of vulnerability at the moment, I would like to believe there is, also, a window of opportunity, so that by 1984, if the decision does not favor the schemes we are thinking about now, at least we have left some legacy to the engineering profession and we know a bit more about things than we do at the moment, and there will be at least a better basis on which to make intelligent engineering decisions in the future.

So, I think we have an opportunity. Over the past 20 years we have gotten to a point where we believe that there are certain essential attributes of deep underground basing. So here is a mini-course in the evolution—my view of the evolution—of deep basing (Figure 1). Things started about the early to middle 1960s, with a view toward concentrating resources deeply underground and requiring proliferation of surface portals to get out. There were two essential problems. First, this was a high-value target, and encouraged an enemy to direct a substantial attack toward it, and as the threat went up, the depth of burial went down, and pretty soon it went down to a point where economically, at least at that point in time, it did not seem feasible. So, the concentration of assets underground was deemed not a good idea. The second objection was that the means of egress depended on there being some portal or portals remaining undamaged; that is, after attack they had to have the same capability as they had before attack, and with the increase in accuracy that was mentioned by Colonel Berry, and the limited number of portals which could be afforded, each one could be targeted, and there was no way to get out.

During the so-called "Strat X study" in the later 1960s, the thought was to distribute the underground assets within an interconnected tunnel system. The depth of burial was to be reduced by finding a hard rock site, but a large number of exit portals were required since, as before, some had to survive the attack. The utility of this scheme was found to lie more in the distribution of assets than in the distribution of attack points, but with increasing accuracy of the attacker, the requirement to ensure the postattack integrity of an egress portal had to be given up.

Somewhat later, in the early 1970s, several schemes were developed to restore a vertical egress shaft after attack. On a scale of bizarreness of from 1 to 10, in my view these schemes came out somewhere between 5 and 9.9.

While possible, I think it is definitely a challenge to make systems of such a nature work, particularly in view of the unknown characteristics of the portal region after an attack. But clever schemes have been proposed, and you will hear about some of them, I believe, today.

To recapitulate, our view is that we need to distribute assets at some substantial depth below the ground. We need to give up the notion that at least some egress portals must survive the attack. So, we have to be completely self-sufficient from the inside out, and if we cannot do that, then we probably do not have a credible scheme. There is an obvious consequence; namely, that the system response time will not be as immediate as some would like, and therefore that the attributes of a deep underground system, which are more or less constrained, have got to be entirely consistent with the mission and roles that are expected of a missile force based in this manner.

Okay, so I guess my first point is that we have come a way. We have a reasonable idea, not a single concept, not a baseline concept today, but the general characteristics and general attributes of a deep underground system are fairly well understood. I think we have to be careful to do something useful in the relatively short time we have been given by this Administration, and not to go too far afield from things that have been properly discarded in the past. On the other hand, we should not be dogmatic about rejecting past ideas.

My second point has to do with uncertainties. In developing and deciding to deploy a deep basing system, we are going to have to learn to live with uncertainties to a degree beyond which perhaps we, as engineers, have been willing to admit heretofore. Figure 2 illustrates something of what is known about the shock environments at depth introduced by nuclear weapons detonated at the surface. I have suggested a porous rock, perhaps a tuff that we might find at the Nevada test site, and I show depth contours at which one could expect 0.5 kilobar of stress from a large megaton-size weapon (in fact a 100-megaton weapon, which is a larger weapon than presently is in anybody's arsenal). So, to talk in terms of facilities intended to survive these kinds of yields already is to stress an attacker, and probably cause him to aggregate smaller weapons and set them off simultaneously.

I have suggested an uncertainty in the data base that, expressed in range, is roughly a factor of two, and is a consequence of several things, I believe. First of all, there is the essential uncertainty, or randomness of behavior, associated with shock propagation in geologic media. Secondly, we suffer from the fact that the data base that we have, while it is fairly substantial with regard to tamped bursts (i.e., nuclear bursts that are fully contained), has no relevant data on modern, high-yield weapons detonated at the surface of the ground. Therefore, the basis that we have for inferring relationships between yield, stress, and depth of burial such as those shown in the figure is indeed inferential. That has been done in the past by simulating a free surface burst underground—setting off a small weapon in a small cavity—and so the data also is subject to uncertainties of a systematic or bias nature. We may be wrong in the key that we have chosen to use in unlocking the tamp data and relating it to surface burst conditions. Although we think we have related the tamp data to surface burst conditions in a design conservative way, we may be wrong. We plan to conduct an underground test involving a cavity of 40 meters or larger that would allow us to study the nature of the energy coupling of the bomb to the surface, the early stages of crater formation, and shock propagation into the ground. This would be a very major undertaking, but we plan to do it.

I have talked so far about free field stresses or free field conditions. Let me turn now to response of the buried facilities. A third element of uncertainty has to do with survivability of underground openings. In a hard rock—perhaps a granitic rock, which is less dissipative and more elastic in its wave transmission characteristics—one would find that these kinds of environments would occur at greater depths than in soft rock. At the same time, one could expect a cavity or a tunnel to survive at higher stress levels. So there is a trade between the depth at which one would like to put the facility and the costs associated with hardening or making the cavity survivable. The point, of course, is that the selection of a site from the point of view of survivability is something that has to interact very strongly with site selection from the point of view of constructibility, maintenance, and public acceptability.

From a survivability point of view, there is such a thing as a beneficial site; that is a porous over hard layered site, perhaps with cap rock at the surface to discourage penetrating-type weapons. One would utilize the porous overburden for its dissipative (shock attenuating) properties, and then utilize the stronger, more competent material below in which facilities could survive at greater stress levels (or require a lesser amount of hardening).

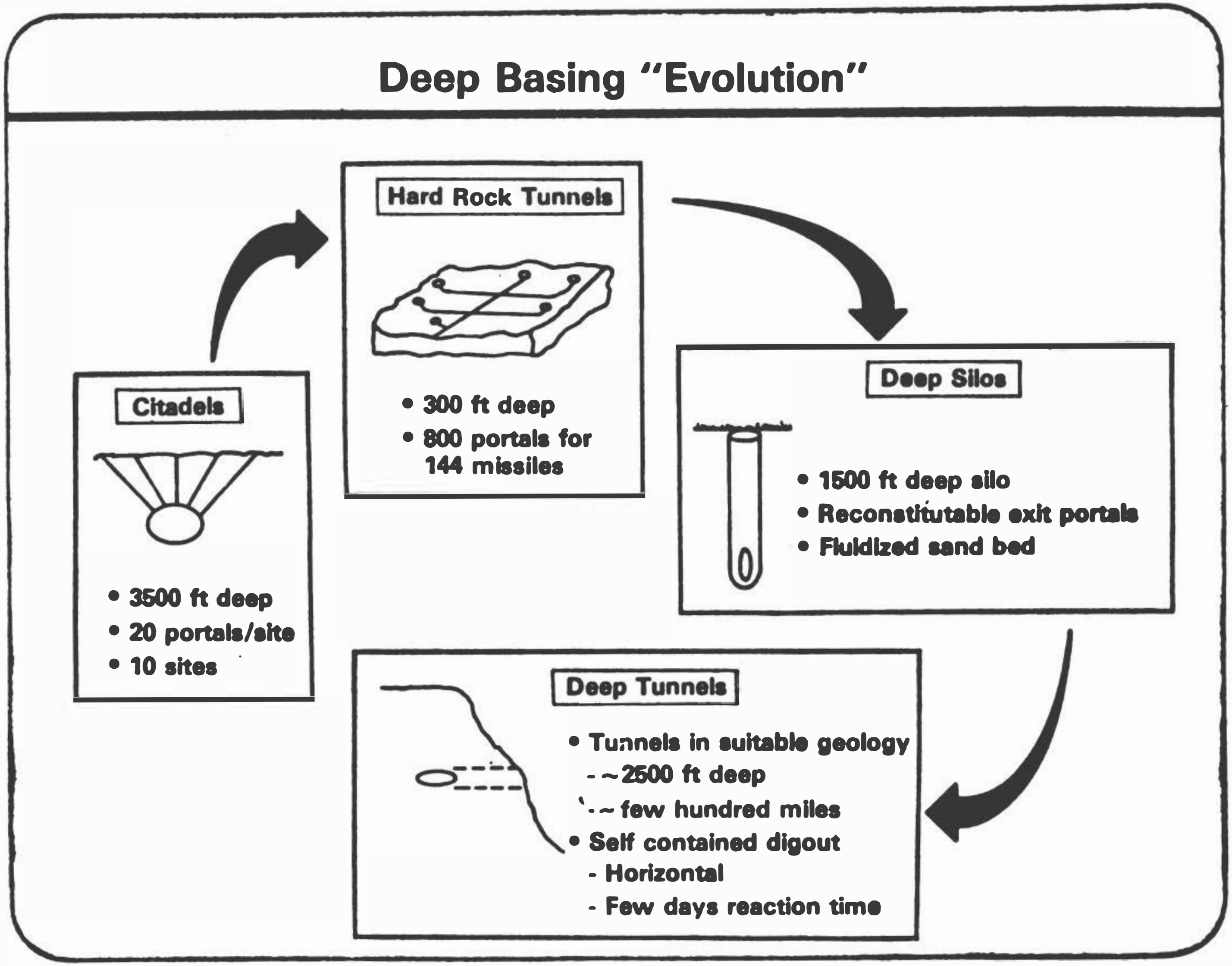
Finally, this chart also carries an implication from an attacker's point of view, since uncertainties in burial depth of a factor of two are really quite bothersome. Pressure-range relations scale as the cube root of weapon yield. Thus, for an attacker to be sure that he has imposed, say, 0.5 kilobar stress on a facility at known depth of burial, he would have to increase the yields shown here by a factor of eight. Where we may have designed a facility to survive a 100-megaton attack, he may look upon it as a target requiring at least 800 megatons to ensure acceptable (to him) levels of damage. Also, the attacker is going to have a difficult time understanding what, in fact, he did accomplish. However, let me emphasize that this view of uncertainty, which may be favorable from our perception of the attacker's problem, is not all that helpful when we are planning an enormously expensive engineering undertaking and are expected to quantify, to the extent possible, the notion of risk.

In summary, let me say that we think the required technology exists (Figure 3) in the sense that the work of the past years, much of which you will hear about today, provides an existence proof, a proof of engineering principle. There is a substantial amount of engineering data that is not in hand, and, before the Air Force and the Department of Defense could go forward with an acquisition program, risks would have to be reduced to a point compatible with the way the Department of Defense goes about its business and makes its decisions. We are entering into a concept validation program in which we have to expand our consideration of admissible deep basing concepts, so that we have a fair set from among which to make a best choice. We have to document very well not only why we have made the choice from among that set, but also that other concepts were excluded for good and sufficient reasons. So, we have to document not only what we recommend to do but also what we have chosen not to do, and we have to carry out those sorts of technology and engineering demonstration activities that, indeed, will provide sufficient data for an informative and intelligent engineering decision.

Over the past years, and most notably since 1976, we have tried to address deep underground basing technology in a very systematic and relatively exhaustive fashion, trying to identify which aspects of design, construction and operation were in hand from an engineering point of view, and which, in fact, were technology issues around which we either could not pass or for which proposed solutions simply lacked credibility. In those latter areas is where we have concentrated our resources and efforts. I trust that we will convey to you during the course of this meeting where we think we are, and the basis for our proposed efforts.

There is a great deal that needs to be done and we are appreciative of the fact that the U.S. National Committee has chosen to address itself to this problem which, to the Department of Defense, the Air Force, DNA, at the moment is of really very significant importance.

Deep Basing "Evolution"



Citadels

- 3500 ft deep
- 20 portals/site
- 10 sites

Hard Rock Tunnels

- 300 ft deep
- 800 portals for 144 missiles

Deep Silos

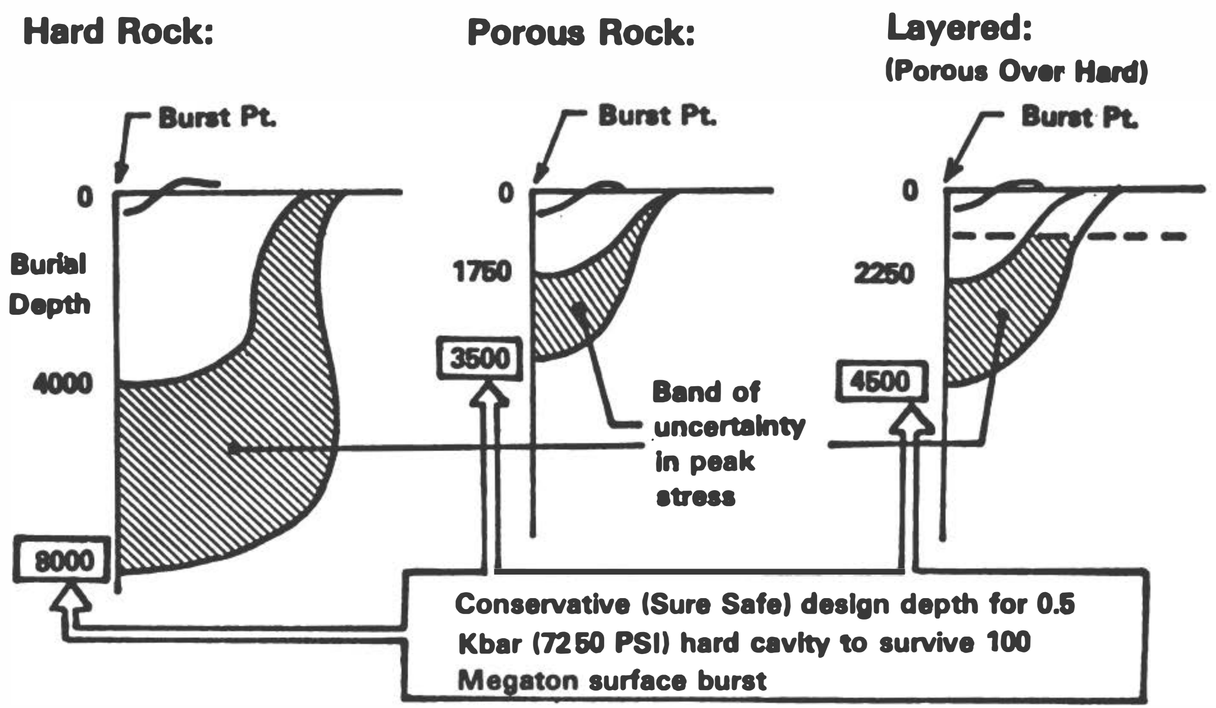
- 1500 ft deep silo
- Reconstitutable exit portals
- Fluidized sand bed

Deep Tunnels

- Tunnels in suitable geology
  - ~2500 ft deep
  - ~ few hundred miles
- Self contained digout
  - Horizontal
  - Few days reaction time

FIGURE 1

Geology vs. Required Depth
Range of depth for ½ Kbar, 100 MT surface burst



Conservative (Sure Safe) design depth for 0.5 Kbar (7250 PSI) hard cavity to survive 100 Megaton surface burst

Attacker's Viewpoint:

- 800 Megaton surface burst required for sure kill of 0.5 Kbar cavity at these depths

FIGURE 2

Required Technology Exists

Requirement	Experience
Major underground excavation & construction	Mines; subways; aqueducts; hwy.& rail tunnels; hydro power plants; NTS UGT complexes; Chicago storm water sys; NORAD CMCC;site R
Routine underground crew activity	Mines; submarines; hydro power plants; underground offices & factories & warehouses; NORAD; Site R'
Prolonged crew confinement	Submarines, space vehicles
Control of toxic contaminants in air	Mines; submarines; space vehicles
Waste heat disposal	NORAD CMCC; site R; safeguard

Requirement	Experience
Muck handling & disposal	Mines; civil/comm'l tunneling
Megawatt size fuel cells	DOE/EPRI/CON ED/ UTC demo in NYC
Definition of attack environ	Underground nuclear tests
Survivable rock openings	Underground nuclear tests
Shock isolation	Minuteman; ships; submarines
Through-earth communication	Mine rescue; UGT data telem (Discus Thrower, Husky Pup, Mighty Epic); Sanguine

FIGURE 3

Nuclear Weapons Effects and Results of Previous Tests

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SUMMARY: The damage done at a given distance from ground zero at Hiroshima and Nagasaki would be inflicted by modern weapons at distances perhaps ten times as great. Also, dramatic improvements in the accuracy of delivery systems for missiles make it probable that a near-surface target (such as an egress portal) would be within the crater produced by any weapons used to attack it. Furthermore, the numbers of potential attacking weapons are such that using proliferation of targets (such as egress portals) as a means of protection is not economically feasible.

Protection, however, can be afforded in a deep basing facility by burying the facility deep enough to provide a suitable distance between the burst point of the attacking weapons and the facility. The weapons effect of most concern is the stress induced in the rock, propagating to the deeply buried facility. Results of tests in rock, from which these stresses can be inferred, indicate that such an approach may be feasible.

The structural damage observed in several completely contained nuclear events (namely, events "Hard Hat," "Pile Driver," Mighty Epic," and "Diablo Hawk") yields data useful for planning the design and construction of deep basing facilities. Although much of it was inflicted on sophisticated, super-hard structures at high stress levels, some unlined and rock-bolted structures survived impressive stresses in the rock. The rock types included granite and tuff with a wide range of unconfined strengths and angles of internal friction, as measured by tests of conventional cores.

I have been asked to summarize our experience over the last thirty-five to forty years in weapons effects, and particularly weapons effects on deep underground structures. I must do so in an unclassified nature. The experiences I shall cover, or at least touch upon, are our experiences in Hiroshima and Nagasaki. The attack on those two cities involved so-called "nominal" bombs, a nominal bomb being 20 kilotons of explosive energy. (The Texas City ship explosion in 1944, incidentally, was estimated to be the equivalent of two to four kilotons of explosive energy.) I will then go into, in an unclassified way, a discussion of the nuclear weapons effects, emphasizing cratering, stress with depth, and what we know about the stress with depth. Finally, I shall very briefly go over what we learned from a series of experiments entitled "Hard Hat" in 1963, "Pile Driver" in 1966, and—more recently—"Dining Car," "Mighty Epic," and "Diablo Hawk" beginning in 1975.

I mentioned the Hiroshima and Nagasaki experiences. Figure 1 is from a book entitled *Effects of Nuclear Weapons*, the first edition of which was produced in 1946; there have been several editions since then, the most recent being in the 1970s. These photographs show what happened at 0.5 mile from ground zero at Nagasaki (Figure 5.34a) and what happened 0.3 mile from ground zero at Hiroshima (Figure 5.34b); there was total destruction at those points. I mentioned this is a 20-kiloton nominal bomb. The yields of the bombs we are talking about today are in the neighborhood of 20 megatons, a thousandfold as great. To a reasonable degree of approximation, what happened at Hiroshima and Nagasaki at about 0.5 mile would occur at 5 miles from our current weapons. It is an awesome amount of energy and an awesome amount of damage that can be created by that energy.

Colonel Berry has already mentioned CEP (circular error probable). Dr. Sevin has mentioned stress with depth. Figure 2 is a cartoon which I borrowed from *Air Force Systems Command Manual 500-8*, published in 1967. I have added some rough outlines to emphasize some of the points that we need to at least touch on. The most important point is the crater created by a surface or near-surface burst of a nuclear weapon. If that burst should occur at or near the surface of a very competent rock —granite or basalt, as an example—the radius of that crater* is about 500 feet for a 1-megaton device. If you take that up to current operational sizes, we could multiply that by a factor of three. So, instead of 500 feet in radius, we are talking some 1,500 feet in radius, about 0.25 mile for the radius of the crater. The depth of the crater, again, for 1 megaton for scaling purposes is something on the order of 100 to 120 feet. You scale that up to, let us say, a 27-megaton device, it becomes 300 to 360 feet in depth. The accuracy of the weapon is such that if an enemy aims at a target, he can almost certainly place that target within the crater. For soils, to jump to another extreme while not attempting to imply any solution in terms of siting, the crater, instead of being some 1,500 feet, could be on the order of 3,000 feet in radius.

I marked also on the figure "EMP" and "prompt radiation." I will not go into any depth on those. Suffice it to say that EMP (electromagnetic pulse) is the most awesome lightning strike that you could imagine multiplied by many, many-fold. The prompt radiation is also a significant item and could create significant damage to anything on the surface. As the stress waves propagate downward from the crater, we have the directly induced ground shock, which Dr. Sevin has already touched upon.

Figure 3 shows our experience in hard rock on the left. The first four are granitic sites. The French data is in granite for weapon yields of 3.6 kilotons to 117 kilotons. Hard Hat, in 1963, was conducted in granite at the Nevada Test Site (Climax Stock granite) with a yield of 5.9 kilotons; "Shoal," north in Nevada, was again at a granite site with

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*Here we are referring to the apparent crater, that which exists after fallback has occurred. The true crater and the associated rupture zone may be much larger.

a yield of 12.5 kilotons; Pile Driver, 59 to 61 kilotons in 1966; and the last three on this chart are for andesite at Amchitka, Alaska, ranging from 81 kilotons for the "Longshot" event up to a 5-megaton device for the "Canikin" event. Plotted within the two bars is the summary of all the measurements of particle velocity in those particular shots and then, using an acoustic impedance to relate particle velocity in feet per second to stress in kilobars, we have a separate bar on the ordinate for the stress in kilobars. The 0.5 kilobar used by Dr. Sevin would correspond to a scaled distance below a contained event on the order of 700 feet for a total confined explosion. The preponderance of experiments that we have conducted in the United States have been in the hard rock and the tuff at the Nevada Test Site. Most of the tuff is at Area 12, Nevada Test Site.

On the right-hand panel of Figure 3 we show the scatter bands of data from the left-hand panel. Superimposed on the right-hand panel is the measured particle velocity from experiments in tuff. You can see that the lower bound of the data for hard rock becomes essentially the mean for the data in the softer rock, specifically tuff. Again using an acoustic impedance to convert particle velocity to stress, you find a lower stress in tuff as compared to granite. Dr. Sevin has already mentioned the coupling. I would emphasize that the data shown in the figure are strictly from contained bursts. We have to convert from contained bursts to the conditions of a surface burst by use of the coupling factor mentioned by Dr. Sevin.

We made up Figure 4 in cartoon form to summarize our data base for behavior of lined and unlined openings in rock in the United States. The underground explosion test series conducted in 1948 to 1953, logistically supported out of Dugway Proving Ground, Utah, included granite, limestone, and sandstone, with a tunnel below the burst point. The burst point was a buried burst; much of the data were gathered by documenting the behavior of those tunnels following the detonation. They were all chemical explosives, ranging in size from 320 to 320,000 pounds. The sizes of the tunnels went from 6 feet in nominal size for a modified horseshoe up to 30 feet in size. The 30-foot tunnel was subjected to the effects of a 320,000-pound burst. The 6-foot tunnels were subjected to the effects of a 2,560-pound charge or, in a few instances, a 320-pound charge. I have flagged the test sites that I have already mentioned and the sizes of weapons: 8 pounds to 160 tons for the UET (underground explosive test) series; the nuclear events go from 55 tons to 5 megatons, 5 megatons being for the Amchitka shot. The series of experiments have involved Hard Hat and Pile Driver, as already mentioned. First is a cartoon of these events which I will discuss in greater detail a bit later. Next is a cartoon of the Mighty Epic/Diablo Hawk events that were conducted in the middle to late 1970s.

Finally, we summarize the peak stress of up to a kilobar (a kilobar is 14,500 psi) for unlined cases. For lined cases we have experienced all the way up to 5 kilobars (or 72,500 psi) stress in the rock. Finally, in the table we summarize the types of linings, the environments, and the materials in which we have conducted experiments. The basalt, mentioned at the bottom of the chart, incidentally, was at the Nevada

Test Site; the salt is located in two places. We have done free-field experiments in those media also.

Let us move to the Hard Hat event (Figure 5). The Hard Hat event was reached through a shaft 785 feet deep to the muck pocket; the muck pocket went an additional 35 feet below the intersection with the nearly horizontal drift. There were 3 experimental stations and some 43 test structures in these 3 areas. The device was emplaced in a 36-inch cased drill hole some 943 feet below the surface; as already indicated, it was a 5.9-kiloton device. The working point, as we call it, or the zero point, was depressed below the structure's drifts to get rid of the shadowing that might occur from one drift to another if they happened to be at the same elevation.

The plan view of those three drifts, A, B, and C, is shown in Figure 6. "A" drift was some 250 feet from the zero point. "B" drift was 340 feet and "C" 460 feet from the zero point. The 5.9-kiloton device was to the left, off the figure in this sketch. There were 10 structures in A drift, 18 in B drift, and 15 in C drift. The basic design was for the conditions estimated to occur in B drift, and then the structures were arrayed at three different locations in order to give a spectrum of damage. Stress levels inferred from measured particle velocities at A drift were 2 to 4 kilobars, and at C drift, 0.5 to 1 kilobar. A series of mainly cylindrical structures were involved, ranging from the strongest structure, a reinforced concrete structure 8 inches thick surrounded by 20 inches of polyurethane foam, to the weakest of the structures, a horseshoe shape with 4-inch, 13 pound-per-foot steel shapes with 2-inch lagging between the shapes. I will not have time to go into any great detail on Hard Hat, but I think from the slides I shall show on Pile Driver, subsequently, we can infer some of the conditions that occurred in the Hard Hat experiment.

Now, moving to the Pile Driver experiment (Figure 7), I shall show a perspective with the access shaft some 1,367 feet deep, extending to a muck pocket 89 feet deep, and then some 1,400 feet along the access drift to a winze. The winze goes down some 104 feet; the device was placed at the bottom of it. The device was planned to have a 50-kiloton yield. It actually turned out to be a 59-kiloton yield and in some references it has been noted as a 61-kiloton yield. The test structures were located in X drift, at 320 feet from the zero point, on out to C drift at some 940 feet from the working point. Measured particle velocity at X drift was sufficiently high that it corresponds to about 30 kilobars—about 500,000 psi—in the rock, on out to about 10,000-20,000 psi, or 0.66-1.33 kilobars, at the most remote range.

From the perspective, you should note that we varied the size of excavation from 44 to 7 feet in size. We also varied configuration: X intersections, T intersections and complete structures, capsules at the bottoms of the X intersections. The structural types included rock bolts, unlined openings, and various types of sophisticated lining, but before we touch briefly on the construction methods and the results of that particular experiment, I would like to note some of the major features of the geology at Area 15 of the Nevada Test Site.

In Figure 8, the plan is just reversed over the preceding perspective. The lines are the surface maps of the various major joints encountered throughout the workings. The joints were mapped at the tunnel level, some 1,400 feet below the surface. At that level, the contact between a quartz monzonite and a granodiorite was as shown. The physical properties of the rock types were almost identical, but one was a much more quickly cooled material than the other. Also at tunnel level, we had a horsetail fault that we picked up a definite expression of at the base of the shaft and near C drift, but we did not pick it up clearly in B drift. The granite was a jointed rock and it did have some faulting and discontinuities in it.

Some damage along natural joints can be seen in Figure 9. The darker areas in the roof in the foreground represent regions where small blocks of rock fell.

Figure 10 is a post-test picture of a more sophisticated structure. This one is seven feet in internal diameter. It is 6 inches thick, has nominally 0.5 percent reinforcement on each face in the circumferential direction and 0.25 percent reinforcement on each face in the longitudinal direction. The "flex duct" used to provide air was installed after the reentry; during the event itself the opening was completely free of materials. The power line was also brought in for electric power after the event. The only things that existed within this structure at the time of the event were the signal cables, which were strapped to the wall with airplane cable in one case and with bungee cord in the other case. You can see the bungee cord in place. Surrounding this seven-foot structure was some four feet of material, frequently referred to as Merlcrete. It is a foamed neat cement that has a flat-top stress-strain curve. That structure survived somewhere between 0.66 and 1.33 kilobars. Other structures actually survived at a level of two to four kilobars, as I shall show in this next slide.

Figure 11 shows a steel structure, but there is a concrete structure very similar to the one we just saw in the background in this particular view. This figure is in B drift. B drift saw a measured particle velocity of about 110 feet per second, which, depending on how you want to convert that into stress, is somewhere between 2 and 4 kilobars. The concrete structure in the background survived. The steel structure in the foreground used corrugated steel of two thicknesses. It was surrounded by four feet of the foamed neat cement. It also survived two to four kilobars. Again, there was a power line and a "flex duct" that were put in after the event to give us ventilation and power. On the left rib of the structure are the cables for getting the instrumentation signals out. They were held down with bungee cord or with airplance cable. They were covered with spray-in-place foam to further protect them.

I mentioned a rock bolted section. Figure 12 shows a heavily rock bolted section. The rock bolts are some two feet on centers. There are at least two layers of chain link fence on the surface. The rock bolts are size number 11; they are 16 feet long. The opening is 16 feet in diameter. This picture was taken after the event, and there is no evidence of any distress whatever in that particular structure. I would hasten to add several things, however. First, this is an end-on configuration. (The stress wave propagated in the direction of the longitudinal axis.) The working point, if you eye down the rock bolt with the white painted bearing plate, is some 846 feet ahead of that. The best estimate of the stress level at that particular point is about 1.5 kilobars, about 20,000 psi, in the rock. Also, I would emphasize that these rock bolts are very closely spaced. These rock bolts were also tensioned to 60,000 pounds force in each of the bolts after they were in place, so that there was a fairly high confining stress intentionally put on the rock.

Finally, in my last five minutes I shall try to bring us up-to-date with the recent series of tests and, because I am running out of time, let me try to expedite this by first quickly indicating in plan view the Mighty Epic event (Figure 13). The Mighty Epic event was originally planned as a line-of-site (LOS) pipe experiment, as they are called, with test chambers off the view on the right side to test other effects of the device. Of course, that device creates a stress wave that propagates outward and we took advantage of that stress wave and added a series of structures in the Mighty Epic event.

Mighty Epic had as its main thrust looking at so-called super-hard construction. The Diablo Hawk event following it reloaded that super-hard construction in a second loading. In passing, let me briefly comment on the result of a reloading of a structure where it first saw one kilobar propagating in a direction perpendicular to the longitudinal axis (side-on) in Mighty Epic; and axially in Diablo Hawk with stress levels, depending where you were in the drift, anywhere from one kilobar to about three-eighths kilobar range. There was some distortion of the interior steel ring resulting from the second loading, but the actual measured distortion was on the order of one-half inch.

The Mighty Epic working point appears on the left. In Diablo Hawk, we not only reloaded the structures that you saw in the previous case, but we added a number of other experiments. One was a sand-filled tunnel to determine the behavior of potential underground reservoirs and finally, there was a series of size-effects experiments at 0.6, 0.3, and 0.15 kilobar. The size of the last set of structures ranged from 9 inches to 18 feet.

Construction of the horseshoe-shaped drifts for size effects was with a roadheader in a single pass for the 9-foot and 13-foot openings. Two passes were required for the 18-foot excavation. The completed structure was some 54 feet long. The openings were largely unlined. There were rock bolts between the various unlined segments, so that in the event that one of them failed, it did not propagate to the next segment. There was some dislocation of the rock from the back in several places in the unlined openings, but probably nothing to cause any great concern about moving personnel and equipment through that tunnel subsequently at the lowest stress level.

In closing, I would like to emphasize that high-speed photography, taken in those types of drifts, which you will see later today, shows what appears to be an awfully hostile environment, but there was no serious damage in many drifts. Assuming, of course, that one has provided secondary protection for anything that might have been housed in the drifts, I would not be concerned about surviving the environment shown in the high-speed photograph. So, my time is doubtless up; I shall close at this point.

* * * * *

SPEAKER: Jay, what is the stress level for that unlined tunnel?

DR. MERRITT: The unlined tunnel shown in the last slide saw 2,400 psi. We had two other drifts of similar size that saw 4,000 psi and 8,000 psi. The 8,000 psi one was very heavily damaged. The one at 4,000 psi was moderately damaged. This one was lightly damaged.

SPEAKER: On a scale of one to ten, at the present time, what is our reliability on the test related to instrumentation cabling, etc.? Where would we stand in analyzing where we go from here on that reliability?

DR. MERRITT: Gosh, I am not quite sure how to answer that because, as you are probably aware, we are actively considering the development of new gauges to allow us to go into still higher stress levels than we have looked at there. There is a lot of work in being able to do that. The instrumentation for most of the things I have shown here, up to one kilobar in tuff, has survived quite well, with some exceptions. There is some faulting in this particular rock, and we did have one case, and I emphasize one case, in which a fault did guillotine our instrumentation system.

SPEAKER: In our time span of collectively analyzing and going into a basing mode, do you think that between now and 1984 there is enough research and development being done in this field that should bring us to a better percentage of reliability? What I am referring to is one of our discussions has to be what is coming out of new technology, and is it sufficient?

DR. LINGER: I think, in answer to that question, the instrumentation technology has improved probably two orders of magnitude since these tests were conducted, and I think that we will see a high-speed photograph of this tunnel during the shot, and the man that is going to do that is the manager of the Construction Division at Nevada Test Site, and I think he has tremendous reliability built into his instrumentation, more so now than ever before.

SPEAKER: What was that rock, the last one we were looking at, the unlined tunnel?

DR. MERRITT: The unlined tunnel there is a tuff at N tunnel, approximately 1,400 feet below the local surface. The unconfined compressive strength of that particular rock, using NX cores, is in the neighborhood of 3,000 to 4,000 psi. If you want to characterize it as a Mohr-Coulomb material, it probably has an angle of internal friction in the range of 10 to 15 degrees. Its specific gravity is right around two. Its seismic velocity is about 8,000 feet per second.

INDUSTRIAL STRUCTURES 167

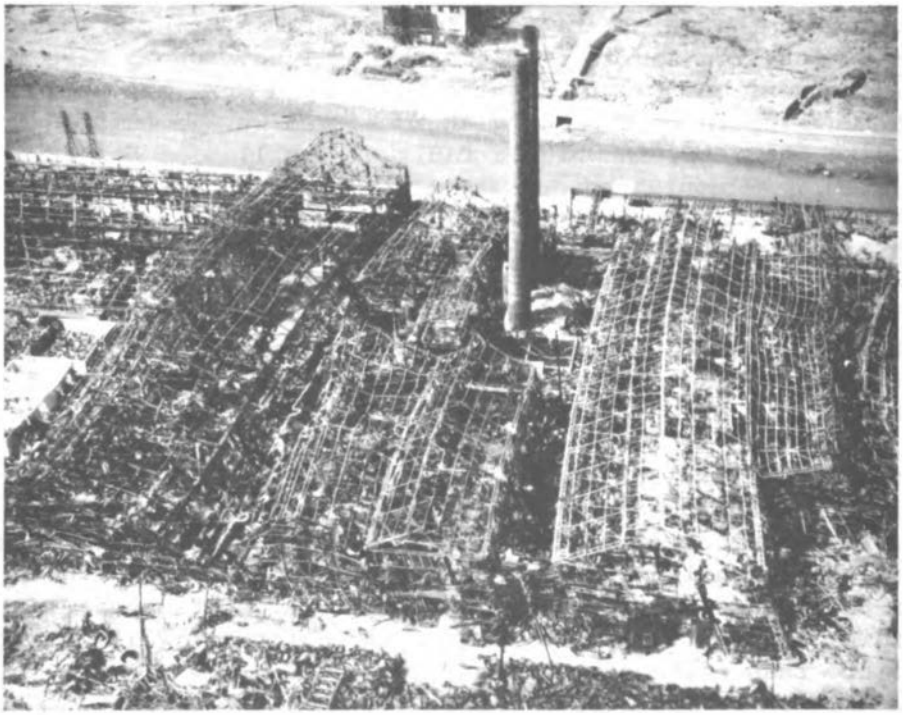


FIGURE 1 (5.34a) Destroyed industrial area showing smoke-stacks still standing at 0.51 mile from ground zero at Nagasaki (from *The Effects of Nuclear Weapons*, 1977).

FIGURE 1 (5.34b) A circular, 60 feet high, reinforced-concrete stack at 0.34 mile from ground zero at Hiroshima (from *The Effects of Nuclear Weapons*, 1977).

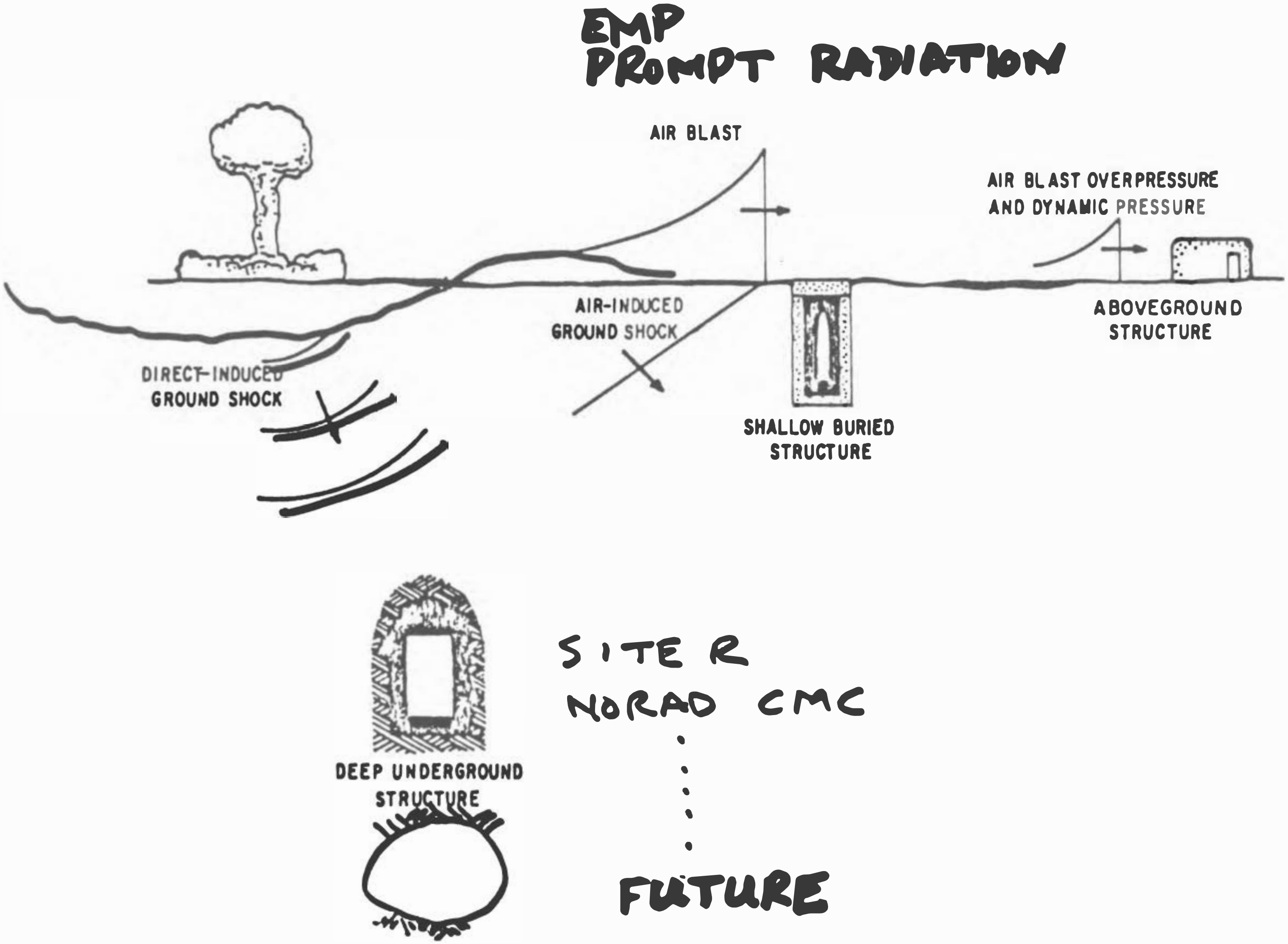


FIGURE 2 Types of air blast and ground shock effects associated with permanent-type structures.

DEEP BASED
FSRF

Scaled Ground Motion from Tamped Underground Nuclear Explosions

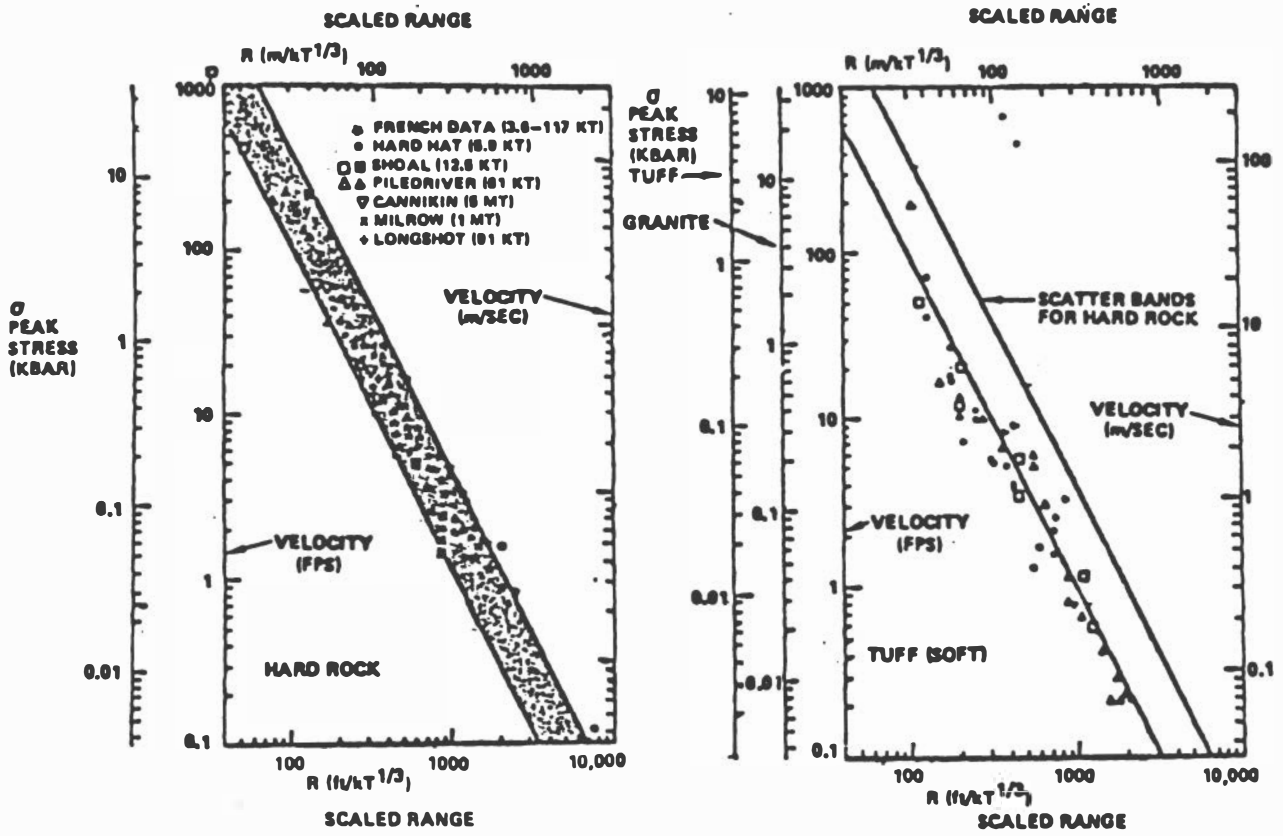


FIGURE 3

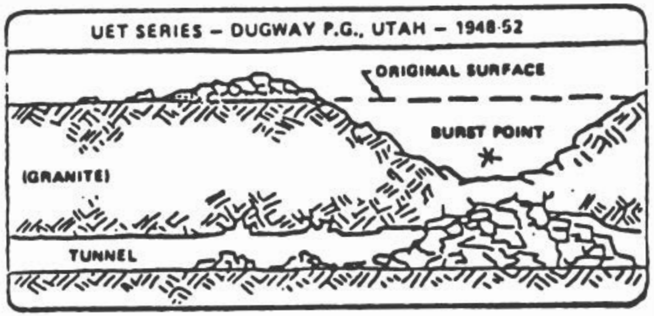
DEEP BASED
FSRF

Experimental Data Base
Ground Shock Environment & Rock Opening Reinforcement

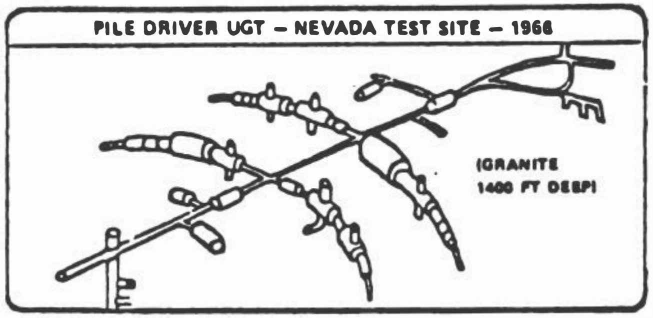
- 1948 TO TODAY
- TEST SITES:
  - DUGWAY PROVING GROUND, UTAH
  - NEVADA TEST SITE
  - CARLSBAD, NEW MEXICO
  - HATTIESBURG, MISSISSIPPI
  - AMCHITKA, ALASKA
- YIELD
  - CHEMICAL: 8 LB – 160 TONS
  - NUCLEAR: 55 TONS – 5 MT
- PEAK STRESS
  - (FREE-FIELD, AT STRUCTURE LOC)
  - UNLINED: 0 – 1 KBAR (14,500 PSI)
  - LINED: 0.2 – 5 KBAR (72,500 PSI)
- ROCK TYPES

	UNLINED OPENINGS	LINED OPENINGS	FREE-FIELD ENVIRONMENT
GRANITE	▨	▨	▨
SANDSTONE	▨		▨
LIMESTONE	▨		▨
TUFF	▨	▨	▨
ANDESITE, SALT & BASALT			▨

UET SERIES – DUGWAY P.G., UTAH – 1948-52



PILE DRIVER UGT – NEVADA TEST SITE – 1966



MIGHTY EPIC/DIABLO HAWK UGT'S – NTS – 1976 & 78

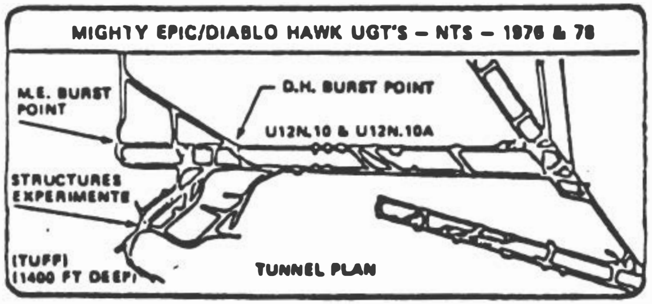
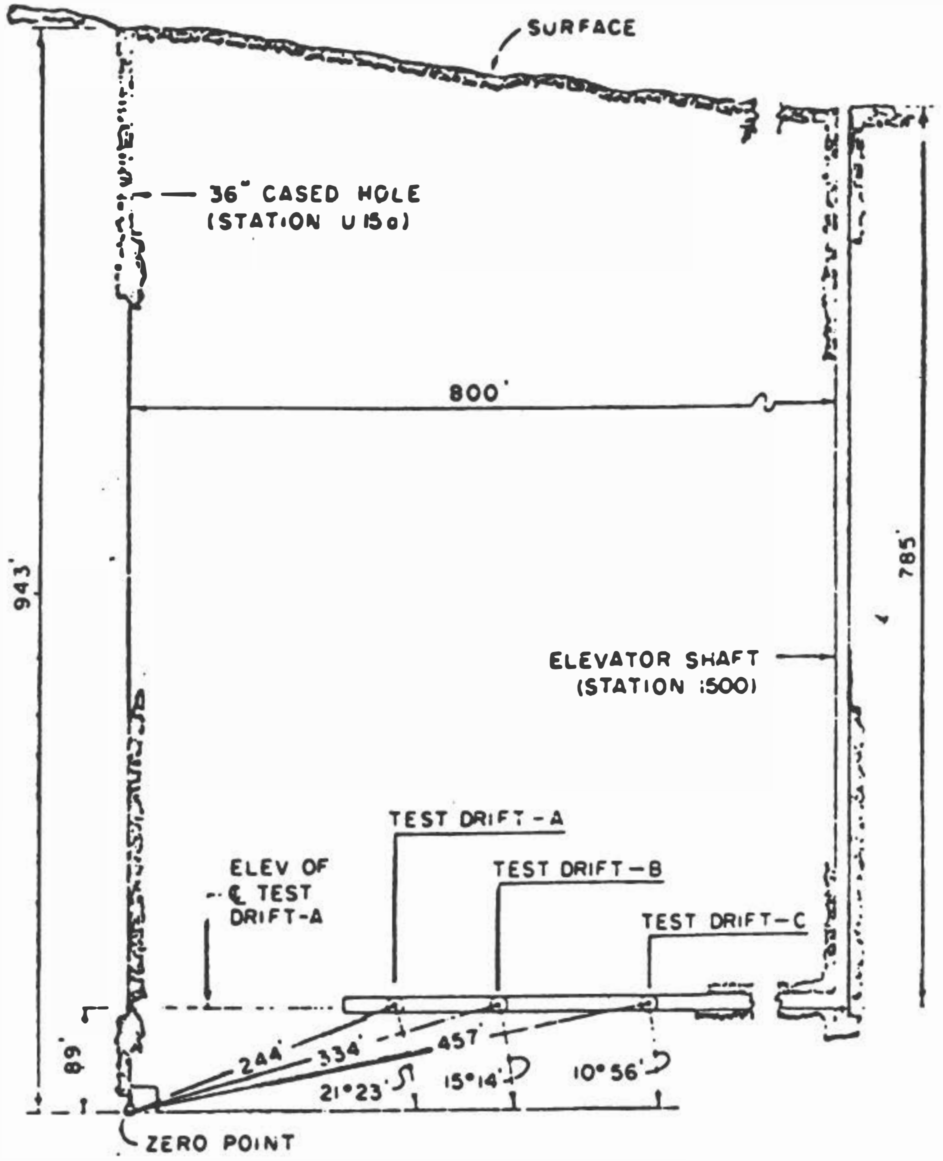
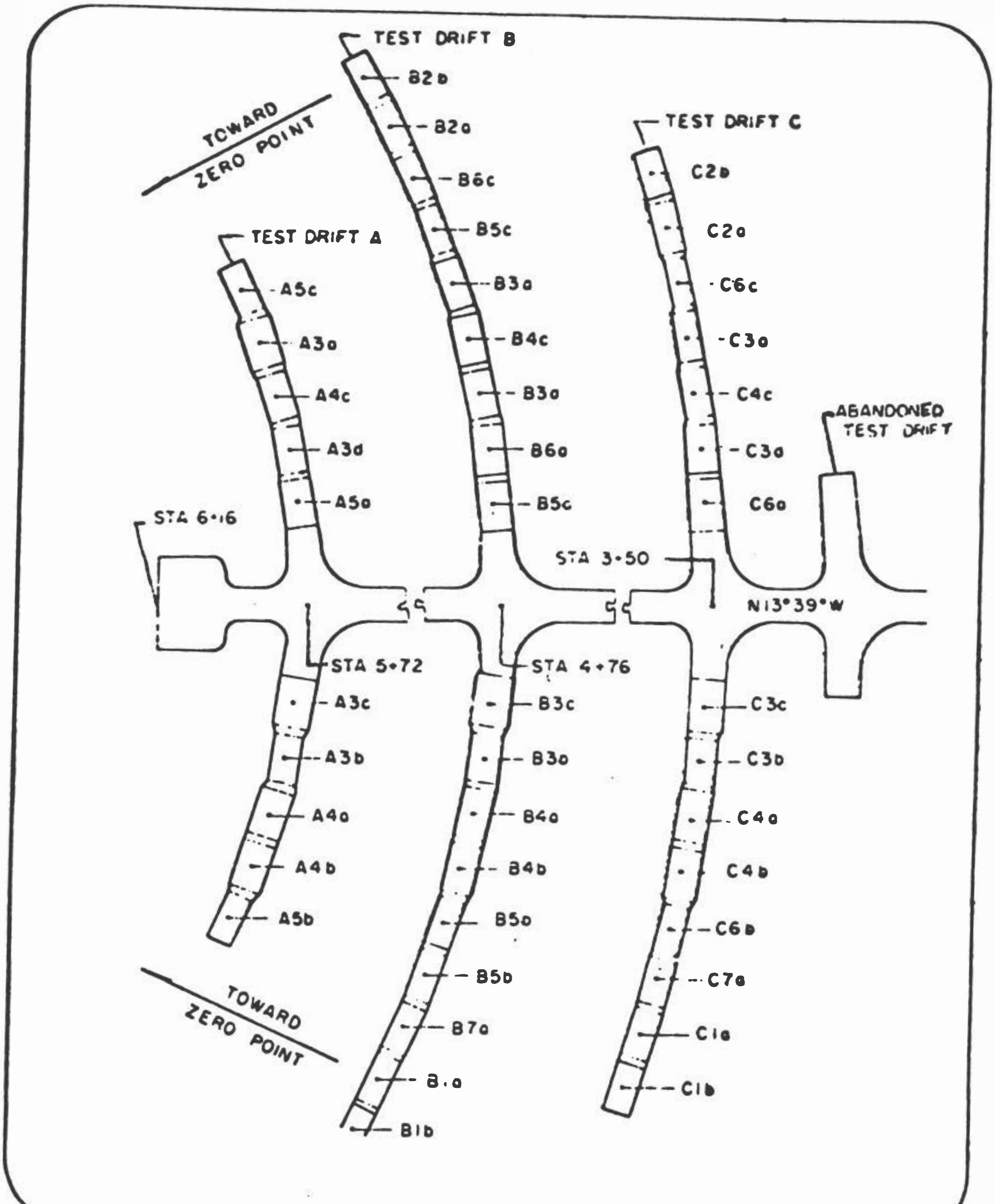


FIGURE 4



- Vertical Section, Event Hard Hat

FIGURE 5



- Plan View of Test Sections, Event Hard Hat

FIGURE 6

UNCLASSIFIED

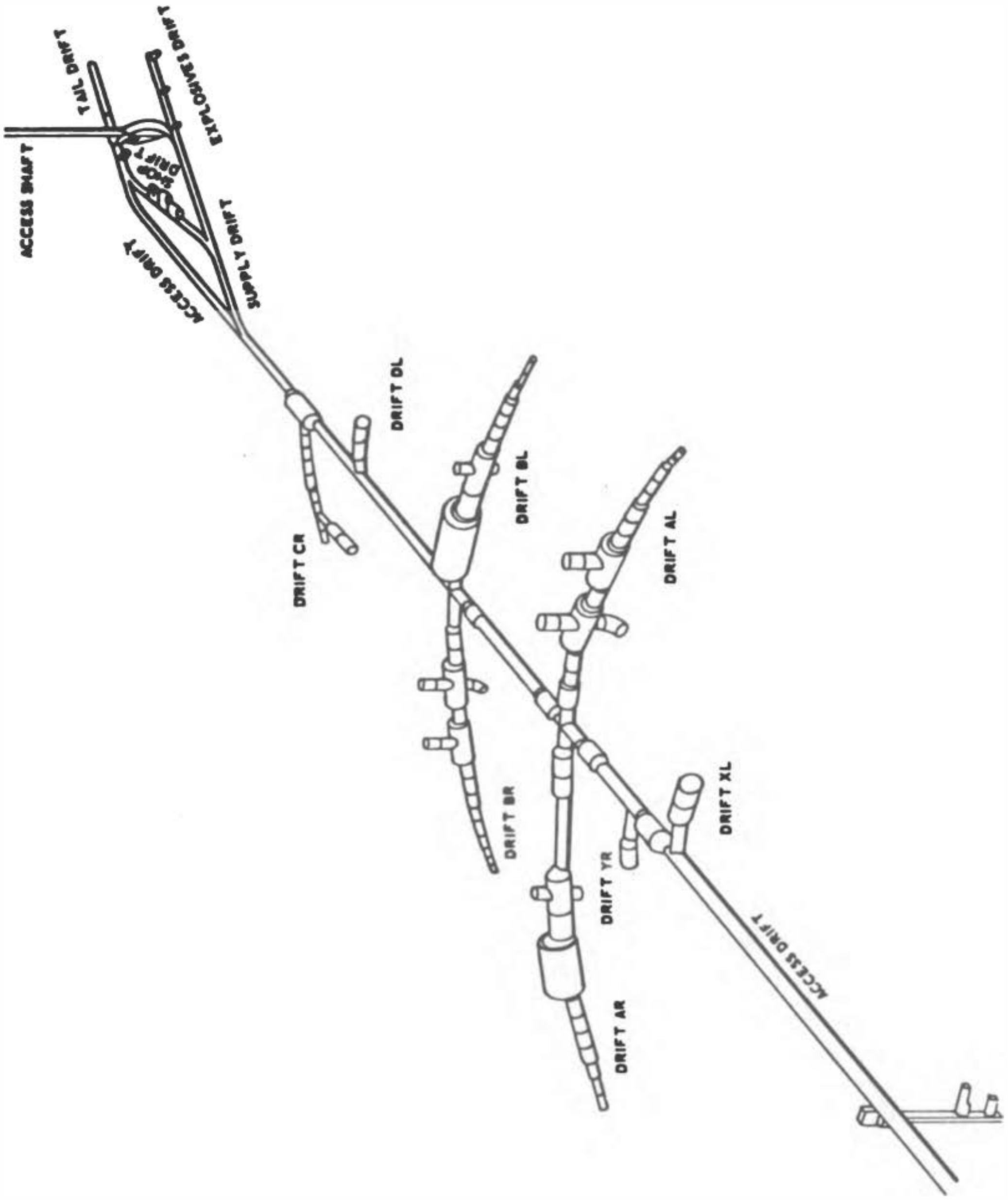


FIGURE 7

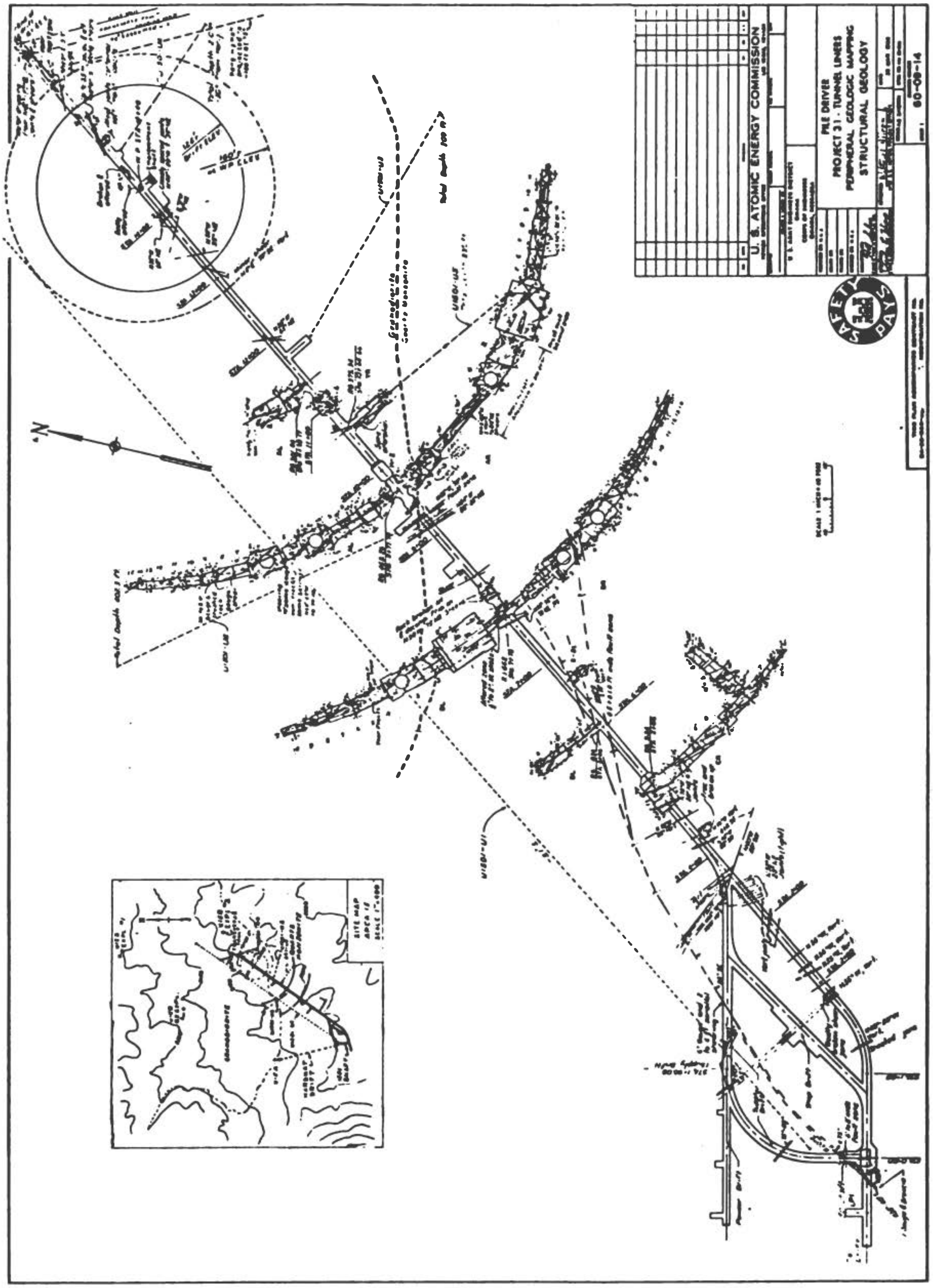

U. S. ATOMIC ENERGY COMMISSION
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
PILE DRIVER
PROJECT 31 - TUNNEL LINERS
PERIPHERAL GEOLOGIC MAPPING
STRUCTURAL GEOLOGY
60-08-14
SAFETY PAYS
SITE MAP
AREA 15
N

FIGURE 8

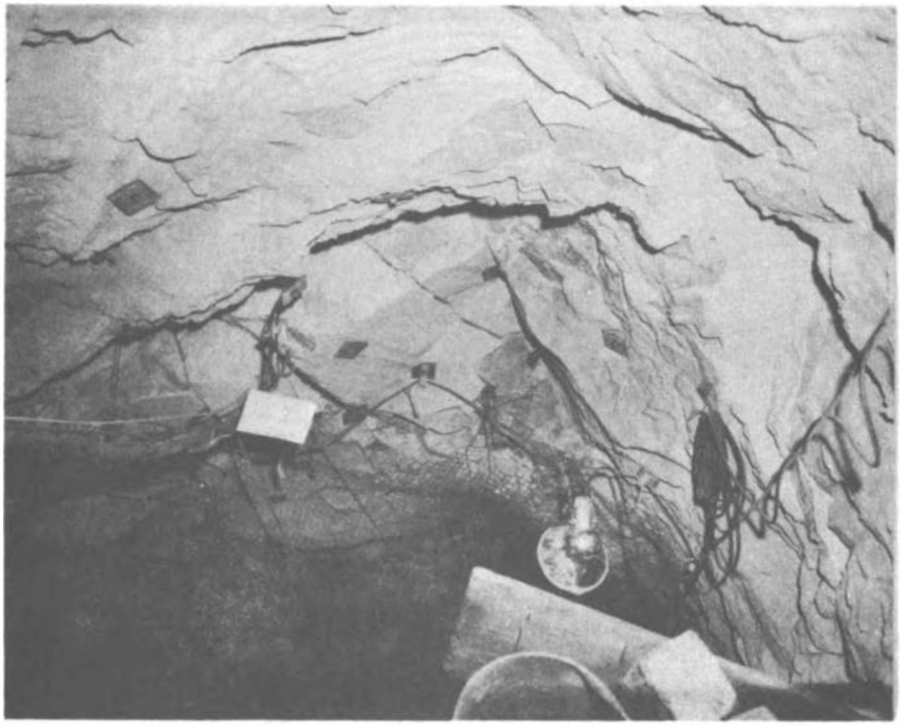


FIGURE 9 Failure along natural joints, Shop Drift (event Pile Driver).

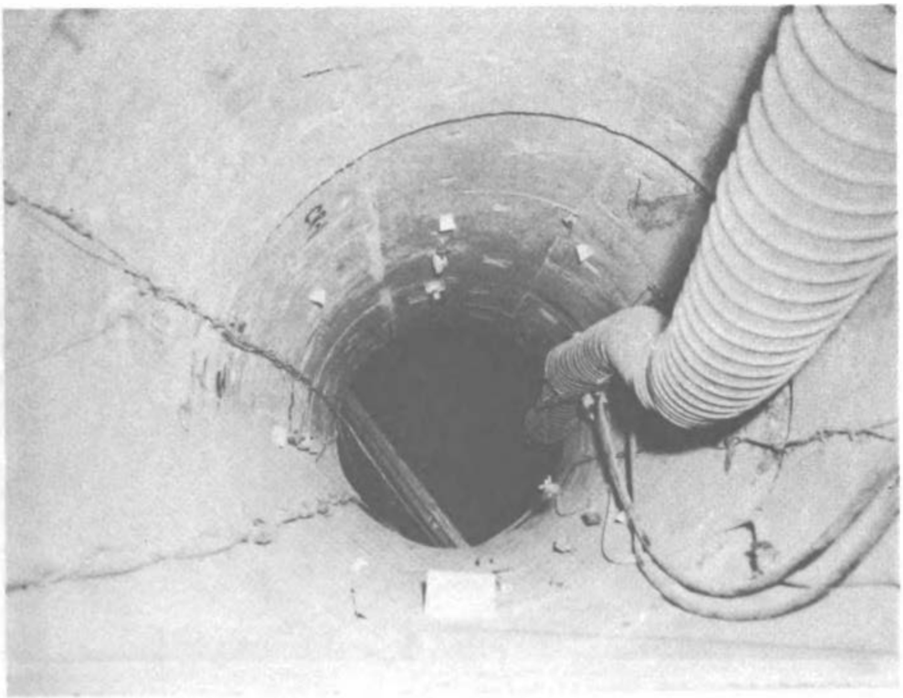


FIGURE 10 Structures with packing, sections CR1 and CR1a (event Pile Driver).

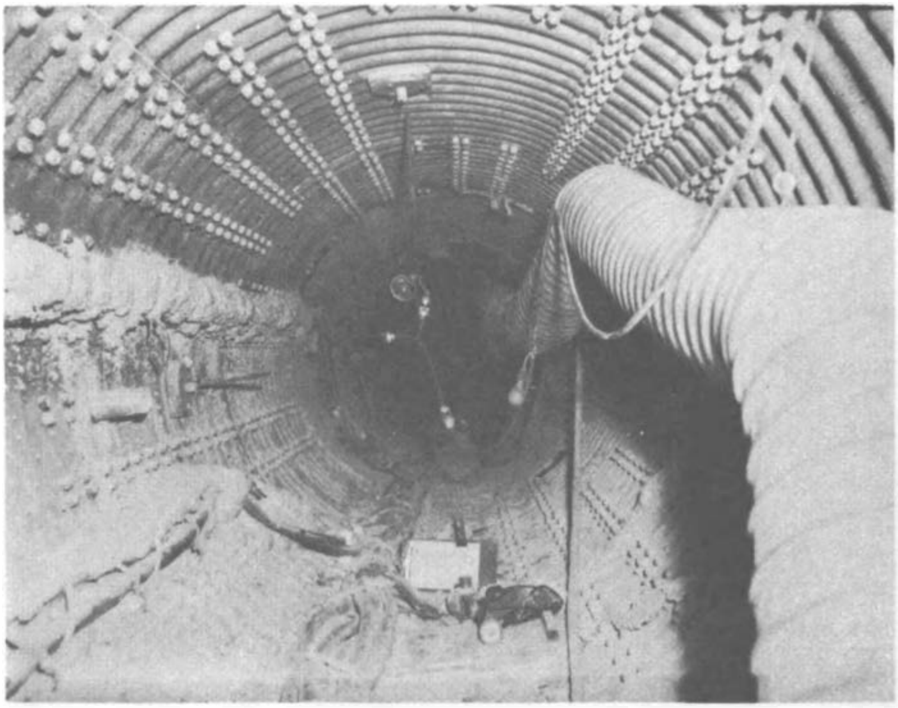


FIGURE 11 Structure with packing, section BR9 (event Pile Driver).

FIGURE 12 Structure with rock bolts and mesh—end-on loading, sections CR5 and CR6 (event Pile Driver).

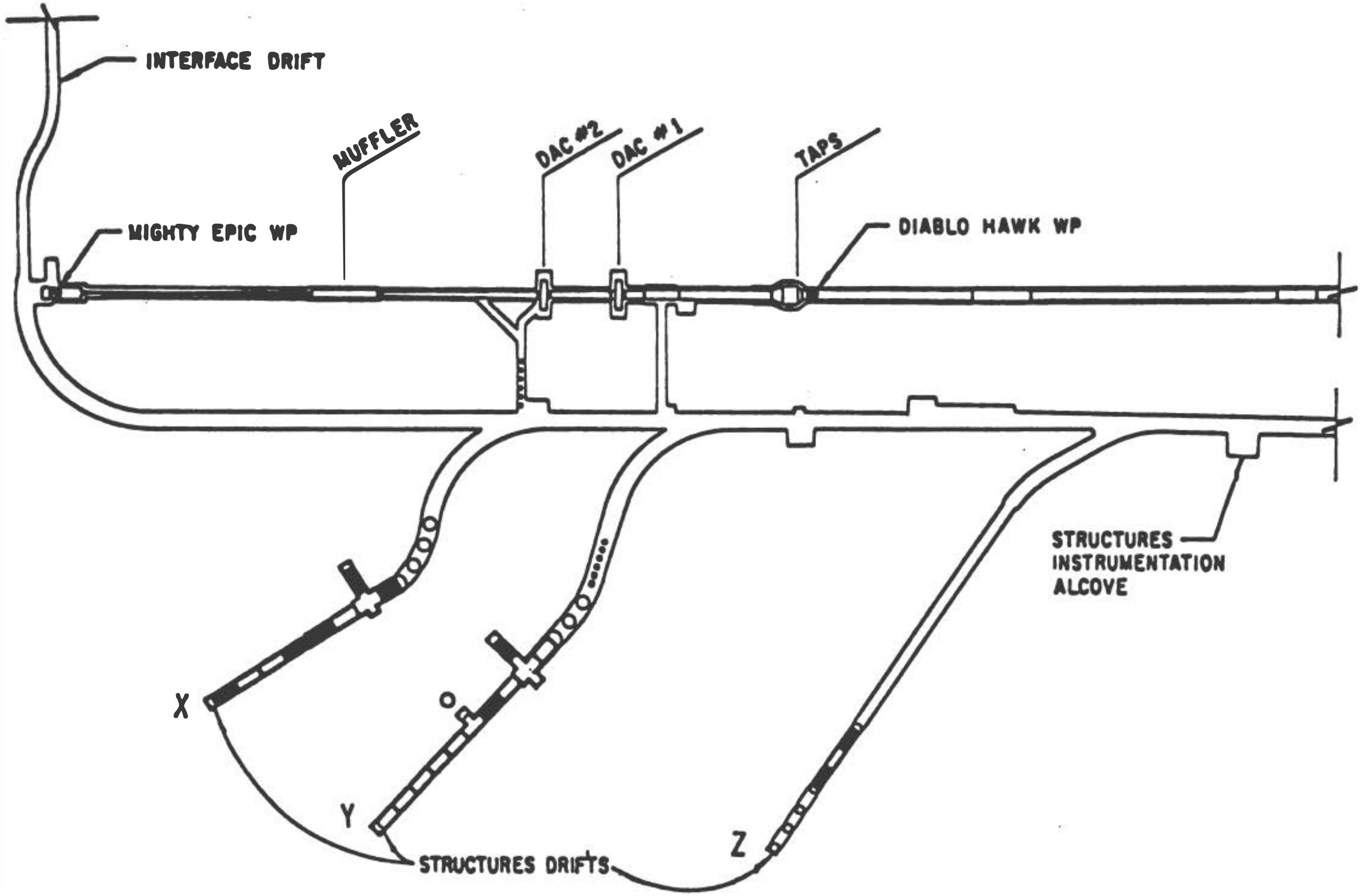

INTERFACE DRIFT
MUFFLER
DAC #2
DAC #1
TAPS
MIGHTY EPIC WP
DIABLO HAWK WP
STRUCTURES INSTRUMENTATION ALCOVE
X
Y
Z
STRUCTURES DRIFTS

FIGURE 13

Deep Basing Concept (Horizontal Egress)

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Boeing Aerospace Company
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SUMMARY: Recent developments and observed trends in the intercontinental nuclear threat against potential strategic targets in the United States have caused much interest in new concepts for survivable basing of this nation's own high-value military systems. President Reagan's October 2, 1981, announcement initiated the current investigation of deep basing as one of three possible long-term basing modes for the MX intercontinental ballistic missile (ICBM). The same threat trends (primarily for increasing accuracy, increasing numbers of large delivery vehicles, and increasing numbers of individual nuclear weapons) that engendered today's ICBM rebasing activity also affect our approach to the design of deep basing systems. Most importantly, we should avoid (a) any dependence on fixed surface elements to perform mission-critical functions and (b) the temptation to concentrate a great deal of target "value" in one or a few deep underground cavities. In other words, we are driven to underground system concepts that can operate relatively independent of surface support after attack, and that spatially distribute target value to make a nuclear attack on the system as unrewarding as possible to the attacker. For a combination of reasons, both technical and nontechnical, we also should avoid dependence on deception of the potential attacker regarding the exact underground locations of critical fixed system assets.

Recognizing the foregoing constraints, Boeing engineers in recent years have studied a series of concepts for deep basing of an ICBM force. Their efforts led to the description, in some detail, of a particular example of a deep basing system concept, and to some parametric investigations of the anticipated cost and survivability of such a system. The example is an interconnected network of horizontal tunnels, excavated deep under a mesa or mountain ridge composed primarily of unsaturated porous rock. Access tunnels are horizontal, but passageways for postattack egress may involve slopes anywhere between horizontal and vertical. Provisions are made for critical subsystem equipment, personnel, and materials to be distributed among many separate locations within the tunnel network. Preliminary evaluation of this type of system concept indicates that satisfactory nuclear survivability probably is achievable at depths that appear to provide a reasonable number of candidate sites in the United States.

Those of you who have an agenda will notice that this slot on the agenda is entitled "Horizontal Egress Systems." I want to take the liberty now of expanding that title a little bit. I will try to speak in basically two categories. First I'll identify some of the overall system architectural design options that we believe are available to designers of potential deep based systems. Then I would like to go into a specific example that we have worked out in more detail than the others and that gives a reasonable outline, I believe, of two things. One is a system with near horizontal egress capability, and the other is some of the critical subsystems that must be involved in just about any deep based system (particularly a manned system) that might be considered.

Just before we start, I would like to recall several things that speakers have said today. First of all, Colonel Berry's presentation on the evolution of the threat is pertinent because it tells us that as the attacker's accuracy increases we cannot count on anything on the surface to survive an attack. As the attacker's ability to deliver very large amounts of yield to the target increases, we also are driven, as Dr. Sevin pointed out, away from concepts that tend to concentrate high-value assets in one place, regardless of their depth. Thus we are driven to distributed systems by those two trends in the threat.

Finally, some of the material that Dr. Merritt just presented in the way of weapon effects testing, and particularly vulnerability testing, of various cavity lining systems and that sort of thing gives us some basis for constructing analytical models of deep basing system vulnerability in the gross structural sense.

What I will show you, I believe, will illustrate how that type of information can be used in at least the very preliminary stages of a system design. I would also point out that in an attempt to meet my time schedule I am going to be walking through these charts at a speed of about one per minute. I won't be able to elaborate on everything, but I want to give you some ideas as to approaches that might be possible.

An obvious one, I suppose, with which to start (and with which, indeed, we did start) is the idea of distributing a system in the sense of providing many self-sufficient deep shafts, as illustrated in Figure 1. In other words, just very deep silos that are capable of protecting the missile from attack and provide the capability, also, for self-sufficient digout and all the other functions that must be provided to support the missile. In the plan view, because of nuclear attack considerations, you are driven to some sort of a hexagonally packed layout to avoid the attacker's being able to get "bonus kills." In the elevation view you must consider some possible nonideal geologic conditions. At this stage of the game, about as far as we went in that direction was to consider two-layer systems.

At the time when this was being done there was a temptation to bring in the idea of deception—in other words, having more deep shafts than you actually have missiles. Recent events in this type of business, I think, would convince us all that deception is not a very viable approach to design. Deceptive basing schemes have a lot of ugly aspects as regards public acceptability and cost, but nevertheless we tried various approaches.

You can try to shuffle missiles on the surface, as indicated in Figure 2. You could try to do it in a shallow tunnel, as shown in Figure 3, to help conceal your activities in operating the system. Or, as illustrated in Figure 4, you could provide a shallow tunnel for missile shuffling and a deeper tunnel for less mechanically intensive operations, such as minor maintenance.

We eventually came to the conclusion that, at least conceptually, this sort of a design approach would lead us to a deep tunnel system where the interconnecting tunnels are as hard as the cavities that protect the high-value assets. (Such a concept is shown in Figure 5.) Although we can't be certain this is the ideal solution, at least it is a very attractive one. I want to be careful I don't say anything is an ideal solution, because I think before I am through here you will see that the work we have done barely scratches the surface as to the preliminary system design activity that we are facing in the next two years.

Returning to the question of postattack egress, we believe the uncertainties (primarily in the nature of crater-related damage to such a site) tend to drive you to consider the idea of creating entirely new egress paths after attack and avoiding the immediate locale that was attacked. Such an approach seems superior to attempting to dig through or otherwise pass through an environment of very disrupted material the mechanical nature of which, or even the extent of which, you are unable to predict prior to the actual attack. This crater-rupture environment uncertainty makes design of a digout system (particularly an automated one) an almost intractable engineering problem. Figure 6 illustrates the foregoing issues.

There are also reasons for looking at the variation on that theme of providing prestarted exit pathways that are not completed all the way to the surface. This approach to system design has two attractions. One is that if any of the exits are not attacked or happen to survive for whatever reason, they provide you potentially with a much shorter egress time, and that is militarily a very attractive feature.

Referring to Figure 7, another attractive thing about pre-established exits is that we believe they complicate the targeting problem for the attacker. If he sees a system like this or believes that the system is designed like this (actually he would know it) he then must make a choice. He must decide either to target the high-value assets at great depth, which are well protected and thus require large amounts of his deliverable yield, or he can decide to use that yield in another way and attack your prestarted egress pathways. An attack against prestarted egress passageways requires him to use up a significant fraction of the yield that he might allocate against the entire system and thus leave large numbers or a large percentage of the higher value assets, such as missiles, power plants, crews, etc., undamaged at the greater depth. If so, they would still remain a long-term threat to him, although perhaps not as immediate a threat.

Although this is probably an obvious point, I want to mention briefly in passing that the basing of digout capability in such a system also clearly provides the capability (at least conceptually) of repairing some of the damage sustained during an attack. This idea is illustrated in Figure 8. It gives the system flexibility, particularly, we believe, if it is a manned system. It would have flexibility that an unmanned system without this capability could not exhibit.

I will apologize for the cartoonish nature of Figure 9, but if you think about the problem of creating new egress pathways after attack and avoiding damaged areas, we believe you will be drawn to the idea that perhaps vertical egress paths may not have all the attractiveness that steeply or even shallowly angled egress paths might have.

In particular, if you are capable of finding a site that allows some surface relief, the task of tunneling or otherwise excavating an egress path, we believe, might be accomplished with less of a demand on technological development. In other words, it takes more advantage of existing underground excavation technology.

So, with that as background on the preliminary search for a system to examine in greater detail, I will proceed now to the system that we have recently given some attention to. Please understand, however, that our elaboration of this concept was done only as an example. The motivation for doing so was (a) to convince ourselves that we understand all the parts of such a system and how they must play together and (b) to provide a framework for the planning of required research, particularly research in nuclear hardness and survivability as they relate to mission-critical subsystems.

Now, I have a series of four or five illustrative charts here which tend to start, as you see in Figure 10, with an external view of an idealized site. The surface relief shown here probably is physically unrealizable, but the point is that a base such as you will see described would have very little observable signature on the surface. You would see a system of access roads and a system of access tunnel portals from the outside leading into whatever escarpment was used as a host for the system.

As we see in Figure 11, if it were possible to cut away and see what is inside that ridge or mesa or mountain, whatever you want to call it, we propose that a tunnel system be excavated in that escarpment which basically consists of, first of all, a peripheral tunnel that essentially follows the lay of the land, the outside periphery of the ridge. For reasons which I probably don't have time to go into in detail, we believe that you would, also, be driven to have essentially enough additional underground space to provide a redundant tunnel (shown there in a zigzag shape) that connects with the basic peripheral tunnel.

We have shown the idea of providing prestarted exit tunnels sloping up nominally at a 20-percent slope. This concept for prestarted exits is one that we chose rather arbitrarily for purposes of this exercise. Figure 11 shows that for some distance (which would have to be determined by our estimates of cratering weapon effects, etc.) that exit tunnel would not be completed all the way to the surface.

The access tunnels are shown again here in Figure 11. They would have to be provided at intervals, probably something on the order of every 10 miles around this system, for two reasons. One is that, as you people are more aware than I, access tunnels would be necessary for construction purposes during the deployment of the system, and finally, of course, it is required to have some way to get crews, equipment, etc., in and out of the system during peacetime operation.

In Figure 12 we have made an attempt to show a closer view of what is in that internal tunnel arrangement. This is a view that at least tries to give a conceptual idea of what that system would look like from a closer vantage point and what sort of equipment is required in it during the period of postattack egress operation.

We have shown that the machine to be used would be a tunnel boring machine (TBM). I don't think that we need to select a particular device at this time, and we realize that a standard TBM is probably not a good choice, given the uncertainty about the type of material you will be going through. However, some sort of excavating capability has to be provided along with some means of handling the spoils, a place to dispose of them within the system, and of course all the other critical items. They include accommodations for the crew (in other words, the life support systems), shops for maintenance of the equipment being used, transporter-launchers which house and protect the environment of the missile while it is being stored and, also, serve the function of bringing it to the surface for launch after digout has been accomplished, plus some sort of survivable electric power system.

We chose to look at large-capacity hydrocarbon fuel cells as a candidate for that system and, of course, recognized the need for a very important and very elaborate environmental control system which provides ventilation and disposal of waste heat in this system.

Before I proceed to a short discussion of some critical subsystems besides the ones that you see there, I want to make a few points about assumptions that were made.

First of all, we made assumptions which I believe are critical. One is that nothing in the layout of this system will be unknown to the attacker, that he will have perfect pre-attack knowledge of the location of everything underground. It is very difficult, we believe, to convince ourselves that we could keep that information secret or even significantly uncertain.

Secondly, we also believe that by the time the full range of threats against such a system has been considered it will be a requirement that the system have maximum autonomy in the sense of not requiring exchange of air or coolant fluids with the external surface environment after attack. In other words, it truly must be a self-contained, buttoned-up, sealed operation after attack. For that reason, as many of you are well aware, the problem of thermal efficiency of all the equipment involved, and particularly energy storage and energy conversion systems, is extremely important. The problem of disposing of waste heat in a fully sealed system that is housed in rock (particularly the types of rock that we believe would be attractive, which tends to be a rather good insulator and not the most ideal medium for disposing of waste heat) will have to be given significant attention in the design of deep underground survivable basing systems.

The previous figures have shown you a few of the critical subsystems, and I particularly want to point out that, as we are all aware, the post-attack egress issue is the first one that people will ask about in considering this type of concept. It is my belief that perhaps the second question that will be asked has to do with the survival of communications. If this system is to have any utility to the nation, some means of communicating with it after attack must be provided. As you noticed in the previous pictures, no designs were chosen for that particular subsystem. The reason is that we don't believe it has been worked out, or that the technology in general has developed to the point at which a particular design can be chosen. Thus, although there are a number of promising technologies from military applications, oil exploration programs, mining safety research, and that sort of thing, that lead us to believe that some sort of through-the-earth communications link would serve well as a last-ditch survivable link to outside authority, we did not believe that we could identify a particular design as being even a reasonable candidate for an example.

Now, clearly you must have some criteria on which to judge the benefits of such a system of deep based strategic missiles. Our aerospace discipline in this area tends to concentrate on these two criteria: how well does it survive an attack of the type that we think might be mounted against it, and how much is it going to cost?

At that point, particularly with the last word, "cost," ringing in your ears, I would like to caution everyone that the amounts of resources that have been devoted thus far to this type of conceptual system design are by no means adequate to provide a lot of confidence in cost estimates. I think that before we are through here you will understand that all the confidence that we place in the estimated cost numbers that we have come up with for this one particular example is to convince us that it is not an order of magnitude cheaper than alternative basing schemes, and neither is it an order of magnitude more expensive. It is in the same ballpark.

I mentioned the capability of creating survivability models, given some rather arbitrarily chosen parameters at the outset about the type of site that you will be in. In Figure 13 we show at least one model of the survivability of tunnels of about the size that we are talking about in dry, soft (that is, unsaturated and porous) rock.

You can see that an analytical model (which is a lot fuzzier than that nice crisp line of Figure 13 would tend to make you believe) can be created which, for example, shows that, from the facility designer's viewpoint, 100 megatons of attacking yield are required to irreparably damage a single point on a tunnel at a depth of 3000 feet in the type of material we are talking about. In other words, trying to provide a system that we believe with great confidence could survive a given attack, we would say at that depth one point on the tunnel would require something like 100 megatons of attacking yield in a surface burst to create a severe enough destructive environment to render that point or a few tens of feet along the tunnel inoperable.

As Dr. Sevin mentioned in his presentation, the tunnel system designer's viewpoint is not the only one that counts. The attacker's viewpoint, also, has to be taken into account. The attack planner has a lot of uncertainty about every step in the process of predicting how much damaging environment he can produce at this system's depth. Even conservatively speaking, we believe that when those uncertainties are folded in (as you will see) there is probably something like a factor of eight between the two points of view. If, for example, the designer felt he had a system that was reasonably survivable against 100 megatons detonated on a particular surface aim point, the attacker (at least if he uses targeting philosophies that we believe he would) would be convinced that he had to put 800 megatons on that aim point to ensure a high confidence in destroying the deep tunnel target location. Such a calculation of target hardness would, in our opinion, tend to make any potential attacker look very hard at other ways of neutralizing that target.

Now, given a model like that and some knowledge of other nuclear weapon effects, you can come to some rough conclusions about some of the parametric variations of such system designs as a function of depth for a given set of other postulated constraints. Some sort of a threat estimate must be obtained. Some requirement must be specified for how many missiles out of the original number deployed must survive. Also necessary are some specification of the type of site and an agreement as to what the proper kill mechanism is; that is, that combination of weapon-induced environments which will render the system inoperable.

We have done a little bit of this kind of thing, and in Figure 14 we can see a couple of curves that are important for the type of system I have just described. As you can see, as you go deeper, you require fewer missiles to be deployed. Also as you go deeper, fewer miles of tunnel have to be constructed to interconnect those deployed missiles.

As you can see, these curves do not have a definite optimum point. However, they tend to tell us that if we are interested in fielding a system that looks reasonable in terms of number of missiles and if all of our other assumptions about the threat, the nuclear weapon effects, and the survivability of tunnels are correct, then you want to be somewhere down in the neighborhood of at least 2000 feet deep, probably closer to 3000 feet.

Again, I don't want to give the impression that there is a lot of confidence in these exact numbers. We did this type of analysis primarily to show trends, to see if there were any obvious optimal depth points, and exactly what were the trends of system requirements as you go deeper. Doing that and having some idea of how much it costs to dig tunnels and shafts, provide various pieces of equipment, etc., you can make an estimate of how cost varies as a function of depth. Here we are going to get into some Defense Department cost terms.

We see a few of these terms in Figure 15. Life cycle cost, for example, is the total cost of doing research, developing the system, deploying the system, and operating the system for a given period of years. Research and development cost, acquisition cost, and operating and support costs are depicted individually in Figure 15.

Acquisition costs are just the costs of actually producing and installing all the necessary equipment, plus providing the necessary base facilities, including underground cavities. Out of acquisition costs, just for curiosity, we display how much of that in our estimate was occupied by the cost of excavating tunnels and other cavities.

As you can see, depending on the system depth, it is a relatively small fraction of the total. Figure 16 is a display of the same data for a particular system depth in pie charts. Please keep in mind that in developing this estimate we employed techniques good within plus a factor of two and minus considerably less than that. We can see, however, the division between research and development, acquisition, and operations costs. Keep in mind, also, that in the research and development cost category we charged the development of the missile itself against this system. In acquisition we also charged the acquistion of the missile against this system, in developing a number which comes out into the few tens of billions.

What we are probably more concerned about now, having been charged by President Reagan with comparing three competing long-term MX basing options, is just the cost of the basing system itself. To do that you have to take out the cost of missiles in both acquisition and R&D. However, the remainder of this acquisition pie (which is about two-thirds of it) is split about equally between equipment and other items and excavation. These costs must be charged against the cost of the basing system. Again, if you look at system acquisition costs for basing only, then tunnels, at least in this particular example, loom as a larger fraction of the total (about half the total basing cost).

Again, I want to offer the caution that this exercise was not done with the intent or the claim that it produced a system that we could go out and build tomorrow, or a system that we could even stand up and say today is the optimal system. We clearly cannot say that. We have not done sufficient research to identify an optimal system. We have not exercised all the possible deep basing options in this way. However, we feel that this example was useful, at least as a starter, in portraying to the community the type of considerations that have to be included in an R&D program such as we are facing right now.

With that, I will close with a couple of minutes to spare.

* * * * *

SPEAKER: It went a little fast, but what cost per linear foot of tunnel are you talking about in those estimates?

MR. WOOSTER: The estimate, which was done in 1978 dollars, I think came out to something like $1,800 a foot, at the most.

SPEAKER: What size tunnels were they?

MR. WOOSTER: They varied. Different parts of the system had different tunnel diameters, but the access tunnels were of about 18-foot diameter, and most of the rest of the tunnels we estimated would be 15 feet in diameter.

SPEAKER: You passed over the shell game of the old silos very quickly. What disadvantage did you see in those?

MR. WOOSTER: I will cite two primary disadvantages which we feel were a great hindrance to the MX surface shelter deceptive system. The first one is that producing redundant shelters in which to house missiles, particularly in this deep based example, would be extremely expensive. While it might enhance survivability, the costs quickly get out of hand, and just from an economic standpoint we feel it would hinder feasibility of the idea.

The second one is that in this country, with the society as we have it set up, maintaining deception in any system like that (with the possible exception of one where everything is at great depth and fully concealed) is very difficult. I believe we would be unable to assure ourselves that we could maintain deception and be confident that we were indeed still creating enough uncertainty in the eyes of the attacker. So, since both of those things were looked upon as close to being "show-stoppers" on the previous concept, it would be nice to avoid them here.

SPEAKER: It might save us a little money, but what are the Russians doing? What are they going to do to base their missiles?

MR. WOOSTER: I am not even briefed into that activity, but we ought to be concerned with two aspects of what they will do. One of them, as you said, is looked at from the defensive point of view. Would they mirror-image a development like this if we started it? That is an interesting question. Perhaps it would be a good thing.

The second question is, "How would they perhaps modify the forces they have in order to attack a system like this effectively?" I think in that area lies one of the primary advantages of deep basing. I say so because I believe that the nuclear survivability of a properly designed deep underground system will not be sensitive to changes in the enemy's threat, or even to some very substantial changes in his threat.

SPEAKER: Your presentation was based on a prototype site. Would the system have multiple sites?

MR. WOOSTER: I don't think that issue has been even addressed yet. There are some considerations that I think would drive you to wanting to have multiple sites, among them threats in the non-nuclear category.

SPEAKER: Which means you have not eliminated the possibility of the silos; you have not totally eliminated anything that you started in the beginning. You are still going to have another look?

MR. WOOSTER: That is right, if we are permitted to look.

SPEAKER: So you have not done our job?

MR. WOOSTER: That is right. I certainly don't mean to imply that any options have been foreclosed. We have some reasons for believing that some of the 15- to 20-year-old approaches no longer are viable because of recent developments in the threat, but there is still quite a wide spectrum of design approaches that we believe are still valid for investigation against today's and tomorrow's threat.

SPEAKER: Does your scheme depend on these 5 percent and 20 percent tunnel slopes, which are pretty tough to build?

MR. WOOSTER: No, it does not. I think there are two main penalties for going to shallower slopes. One of them is that shallower slopes make acceptable sites harder to find. So, site availability from a topographic point of view is much enhanced if you can go out at a steeper angle. Perhaps you don't even need any surface relief, if you can convince yourself you can dig out at a sufficiently steep angle.

SPEAKER: Conversely, talking about a postattack excavation, I would think you might want to keep it simple, and you might want to make it horizontal, and that would limit your geographical sites.

MR. WOOSTER: Yes, it would.

SPEAKER: What digout times are being considered? How long do you have to get out?

MR. WOOSTER: The answer, as far as I know, is no.

SPEAKER: The answer is no. There is no constraint, but obviously faster is better.

MR. WOOSTER: That is right. Through the several years that our organization has been looking at this particular problem there has been a distinct paucity of specific requirements. We have had to postulate what that system might be required to do, and it appears that in this program there is going to be a deliberate approach which says that we want to see what is possible before we start laying any specific requirements on the system.

There is a wide variety of opinion as to what is desirable. There are some people in the Air Force who believe that if such a system cannot launch instantaneously it has no credibility as a deterrent. There is another variety of opinion, perhaps in the "strategic thinker" category, of people who say that as long as you can create enough uncertainty in the attacker's mind that he cannot actually destroy the missiles, even if they cannot dig out at all, he still has to consider them in his calculations of threat against himself. That point of view is not terribly appealing to me either. It does not constitute a very credible threat against an attacker who otherwise could bottle you up.

SPEAKER: What is to prevent the observations of rubble after the attack and the immediate "zap" when you break through before you have the time to get your missile up? It is obviously going to be a long period of time.

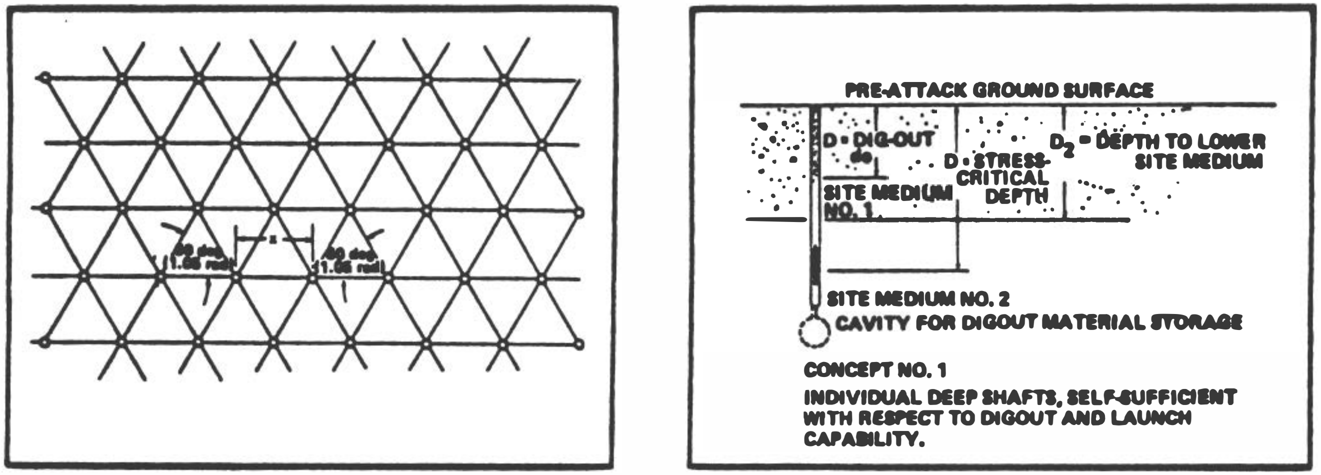
MR. WOOSTER: Yes. That question has not been addressed, and it will be a key part of the R&D program, I would predict. However, I think that one of the answers that is going to come out is that even a system such as we are talking about, which has a high degree of self-sufficiency postattack, is not entirely independent of outside help. For example, one common thing that is said is that we must retain the capability to deny enemy occupation of the site. Working that problem even further, then, perhaps denial of surveillance or at least interference with post-attack surveillance on the part of the adversary may also be a requirement for systems like this.

DR. LINGER: That is one reason why there is a task force whose objective is egress. Egress is the big problem.

SPEAKER: I thought maybe they solved it already.

DR. LINGER: No, as a matter of fact, I think there might be some words that will come out here that would help. Are there any other questions for Jim? Super. Well, thank you, Jim, for an excellent presentation.

Self-Sufficient Deep Shafts

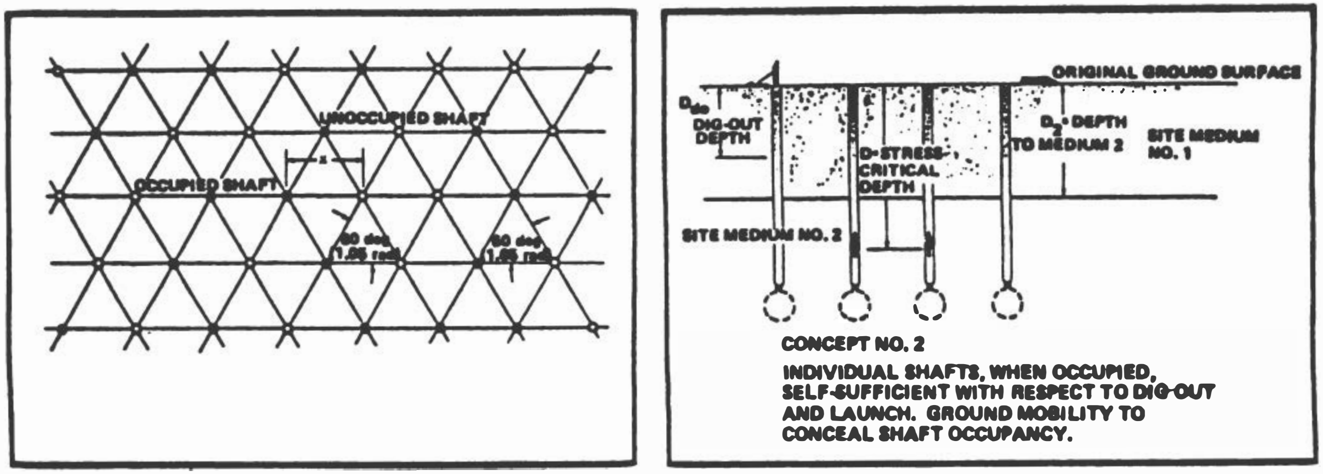


PLAN VIEW **ELEVATION**

FIGURE 1

**DEEP
BASED
SRF**

Self-Sufficient Deep Shafts (Deceptive)



CONCEPT NO. 2

INDIVIDUAL SHAFTS, WHEN OCCUPIED, SELF-SUFFICIENT WITH RESPECT TO DIG-OUT AND LAUNCH. GROUND MOBILITY TO CONCEAL SHAFT OCCUPANCY.

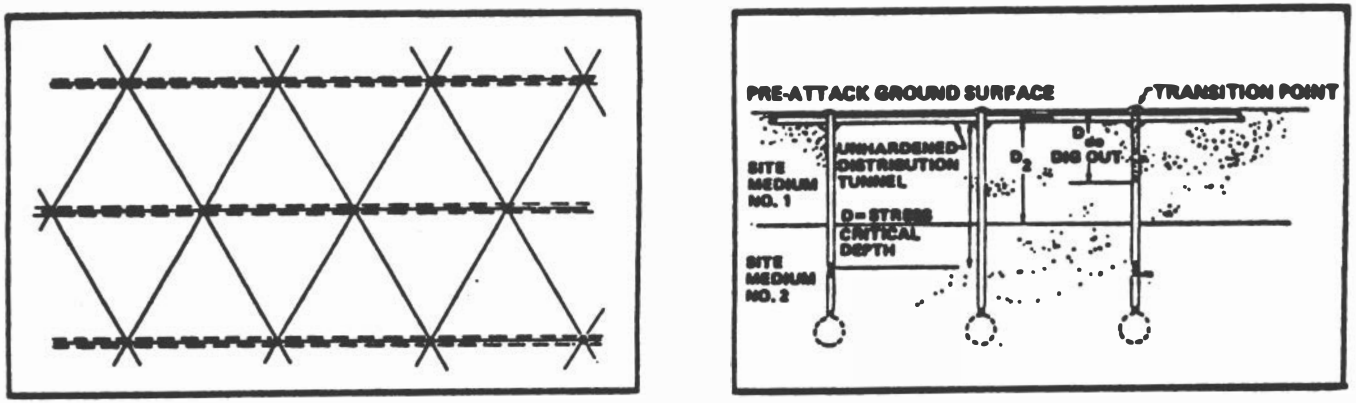
PLAN VIEW

ELEVATION

FIGURE 2

DEEP
BASED
SRF

Deep Shafts, Shallow Connecting Tunnels (Deceptive)



PLAN VIEW

ELEVATION

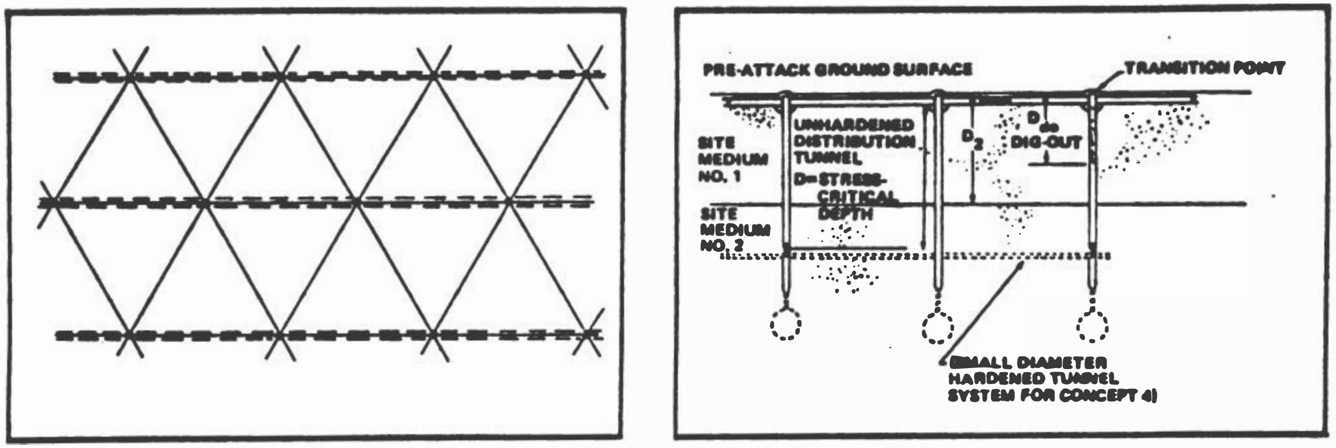
CONCEPT NO. 3

VARIATION OF CONCEPT NO. 2
WITH UNDERGROUND SYSTEM FOR
DEPLOYMENT AND MAINTENANCE.
SYSTEM ELEMENTS SELF-SUFFICIENT
FOR DIGOUT AND LAUNCH.

FIGURE 3

**DEEP
BASED
SRF**

Deep Shafts, Both Deep and Shallow Connecting Tunnels (Deceptive)



PLAN VIEW

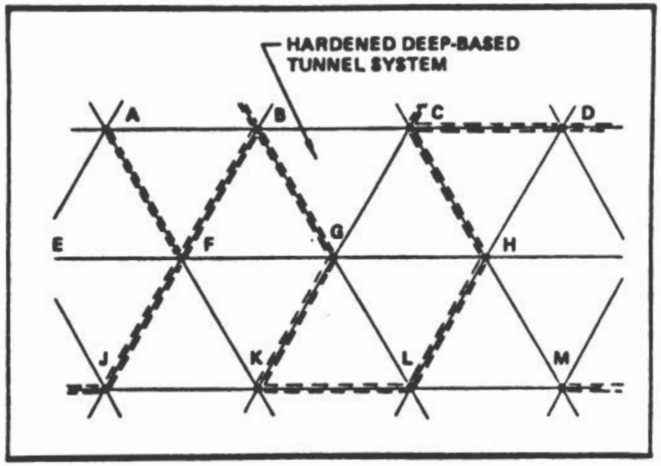
ELEVATION

CONCEPT NO. 4
VARIATION OF CONCEPT NO. 2
WITH UNDERGROUND SYSTEM FOR
DEPLOYMENT AND MAINTENANCE.
SYSTEM ELEMENTS SELF-SUFFICIENT
FOR DIGOUT AND LAUNCH.

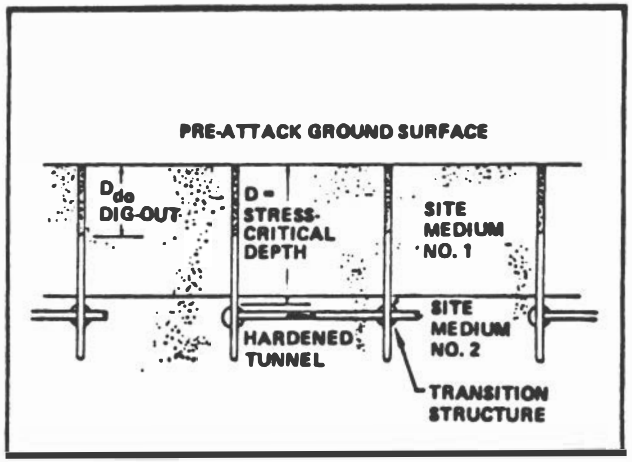
FIGURE 4

**DEEP
BASED
SRF**

Deep Shafts, Survivable Interconnecting Tunnel at Depth (Deceptive)



PLAN VIEW



ELEVATION

CONCEPT NO. 5

INDIVIDUAL SHAFTS WITH DEEP-BASED HARDENED TUNNEL SYSTEM FOR PRE-ATTACK DECEPTION AND POST-ATTACK LAUNCH EGRESS FROM SURVIVING SHAFTS.

FIGURE 5

DEEP
BASED
SRF

Deep Tunnel, Digout Via Shafts Raised Post-Attack

SAMPLE DESIGN POSSIBILITY:
POST-ATTACK DIGOUT CAPABILITY THROUGH UNDISTURBED SITE MATERIAL = D
OR, THROUGH OVERSTRESSED AND RUPTURED MATERIAL = D/2
OR, COMBINED, IF X + 2Y = LESS THAN D

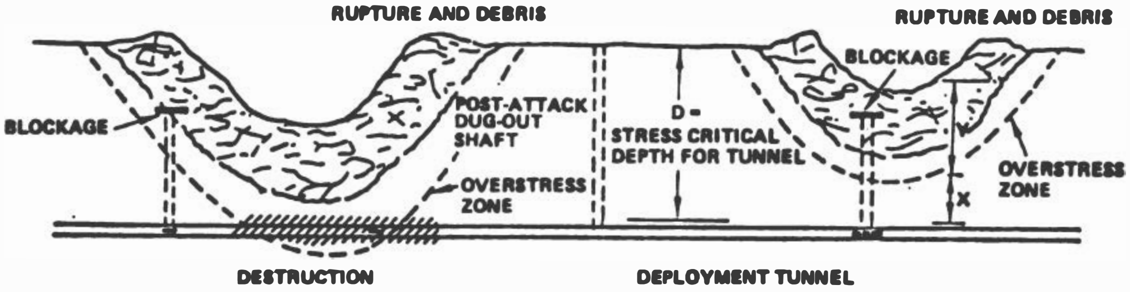
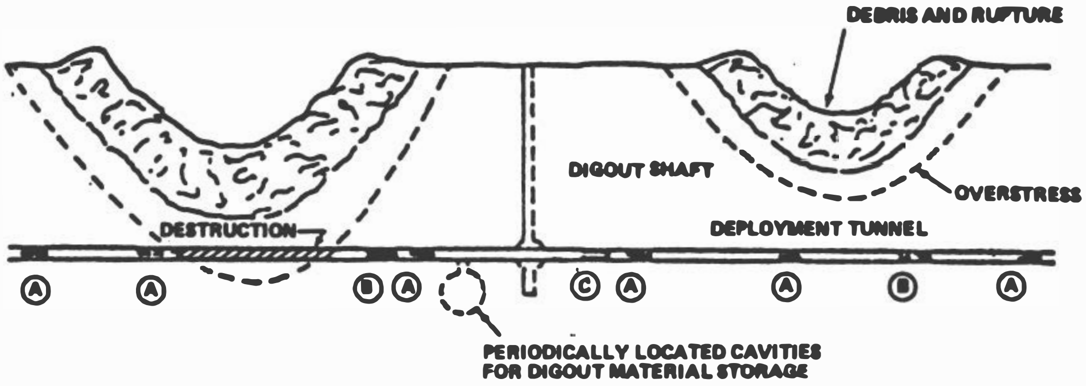


FIGURE 6

**DEEP
BASED
SRF**

Potential for Tunnel Damage Repair After Attack



POST-ATTACK, SURVIVING TUNNELING EQUIPMENT, Ⓑ, RE-ESTABLISHED TUNNEL TO A DIGOUT SHAFT CREATED BY A SURVIVING DIGOUT DEVICE, Ⓒ, PERMITTING MISSILE-LAUNCHERS, Ⓐ, TO REACH THAT DIGOUT SHAFT FOR EXIT AND LAUNCH..

FIGURE 8

**DEEP
BASED
SRF**

Deep Tunnel, Digout Post-Attack, Prestarted Exits

SAMPLE DESIGN POSSIBILITY:
POST-ATTACK DIGOUT CAPABILITY THROUGH UNDISTURBED SITE MATERIAL = D
OR, THROUGH OVERSTRESSED AND RUPTURED MATERIAL - D/2
OR, COMBINED, IF X + 2Y = LESS THAN D

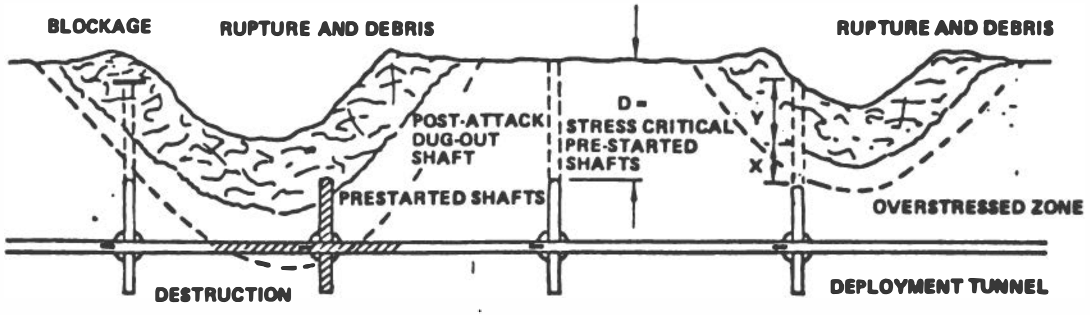


FIGURE 7

**DEEP
BASED
SRF**

Deep Tunnel, Non-Vertical Post-Attack Egress

TUNNELING EGRESS CAN BE SUBSTITUTED FOR THE SHAFT EGRESS ASSUMED IN CONCEPT NO. 6 WITH RESULTING CIRCUMVENTION OF THE TRANSITION PROBLEM OF MOVING FROM HORIZONTAL TUNNEL INTO VERTICAL SHAFT. SLOPED START OF EGRESS TUNNEL CAN BE ACHIEVED WITH MINIMAL UNDERCUTTING OF THE TUNNEL FLOOR. THIS COULD BE PROVIDED PERIODICALLY ALONG THE TUNNEL PRIOR TO ATTACK. TUNNEL EGRESS ANGLE, Θ, WILL DETERMINE EGRESS TUNNEL LENGTH, RELATIVE TO ALTERNATIVE DIGOUT SHAFT LENGTH, l/sin Θ.

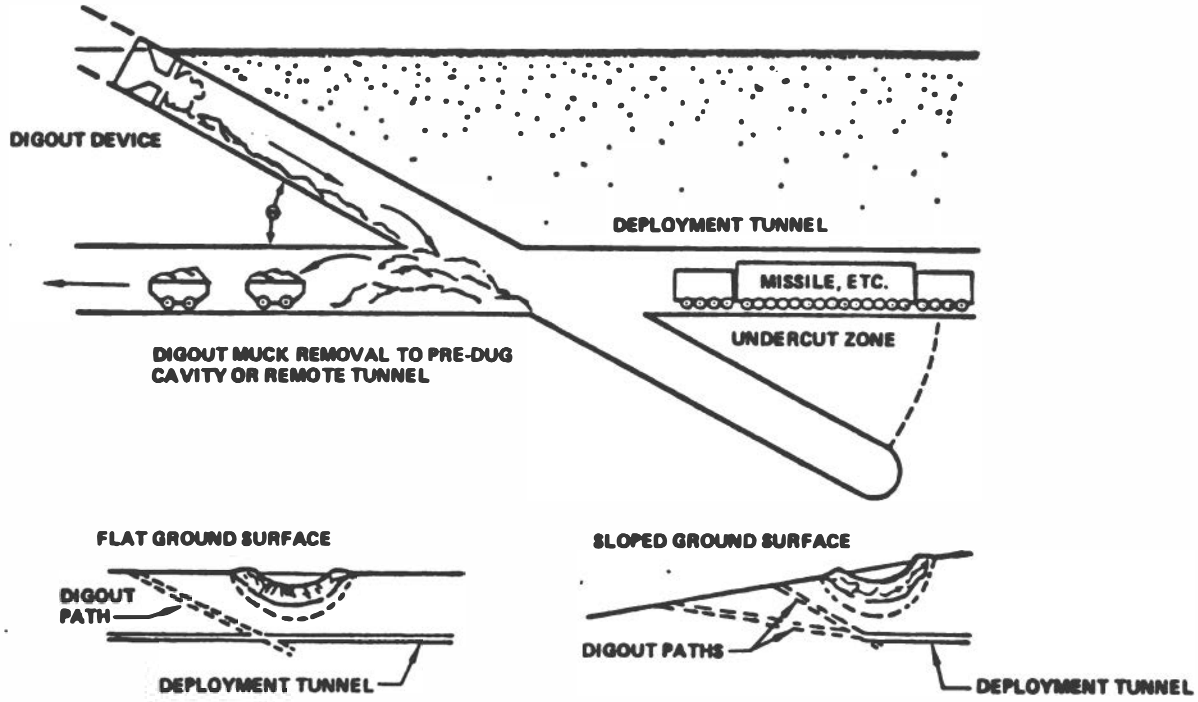


FIGURE 9

DEEP BASED
FSRF

External View - Deep Underground Base

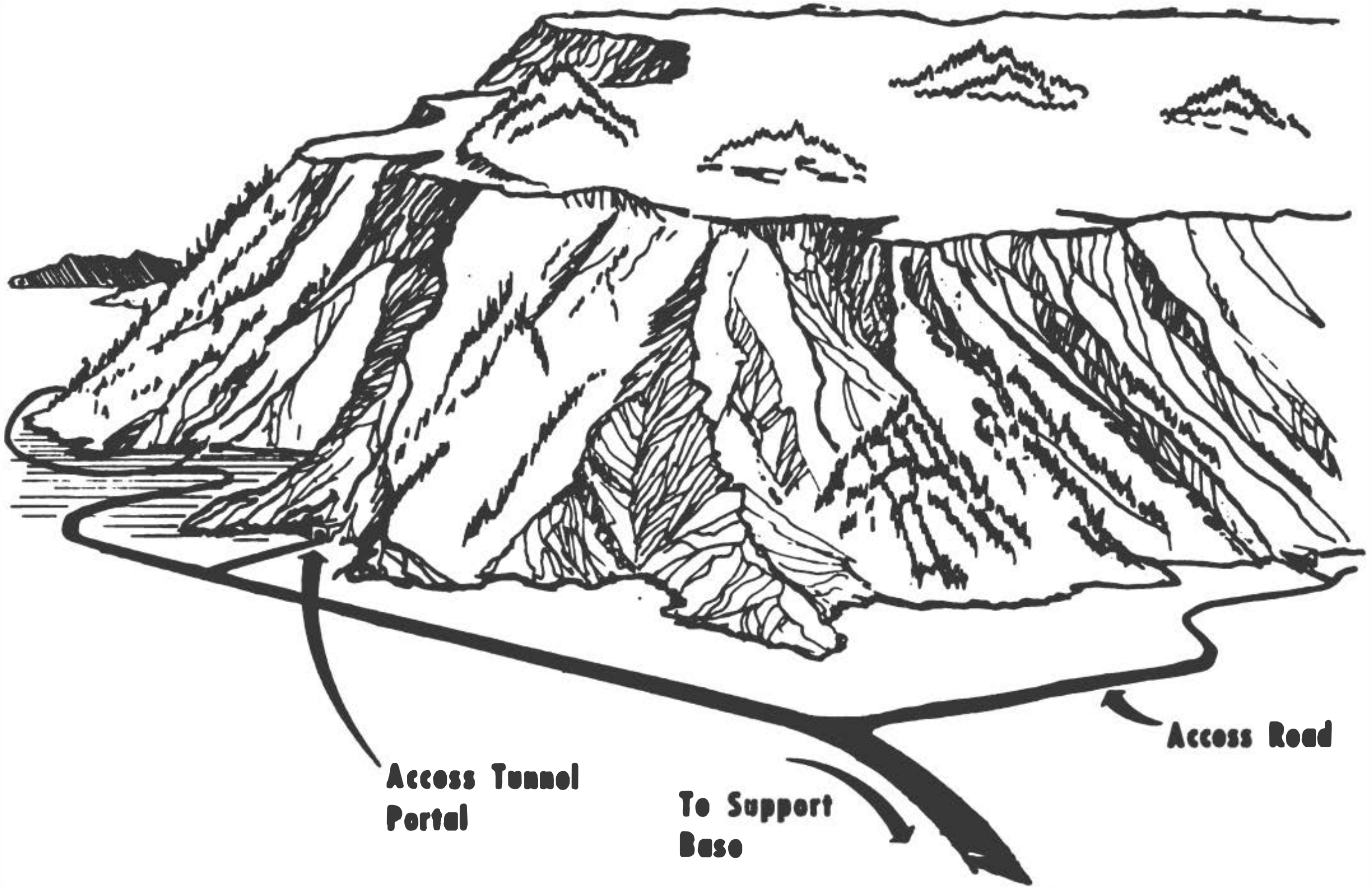


FIGURE 10

DEEP BASED
FSRF

Cutaway View - Deep Underground Base

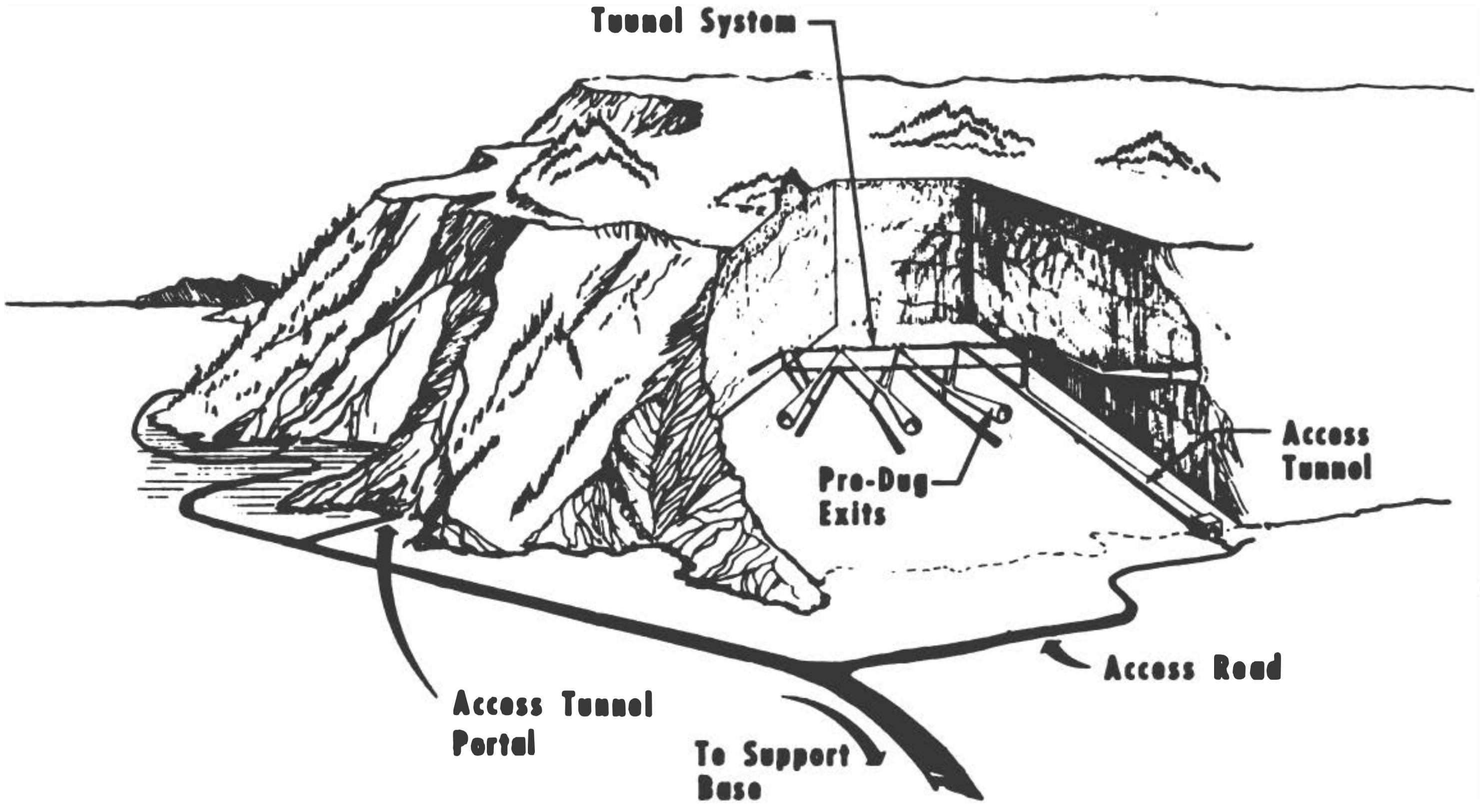


FIGURE 11

DEEP BASED
FSRF

Internal Arrangement of Deep Underground Base - During Post-Attack Digout Operation

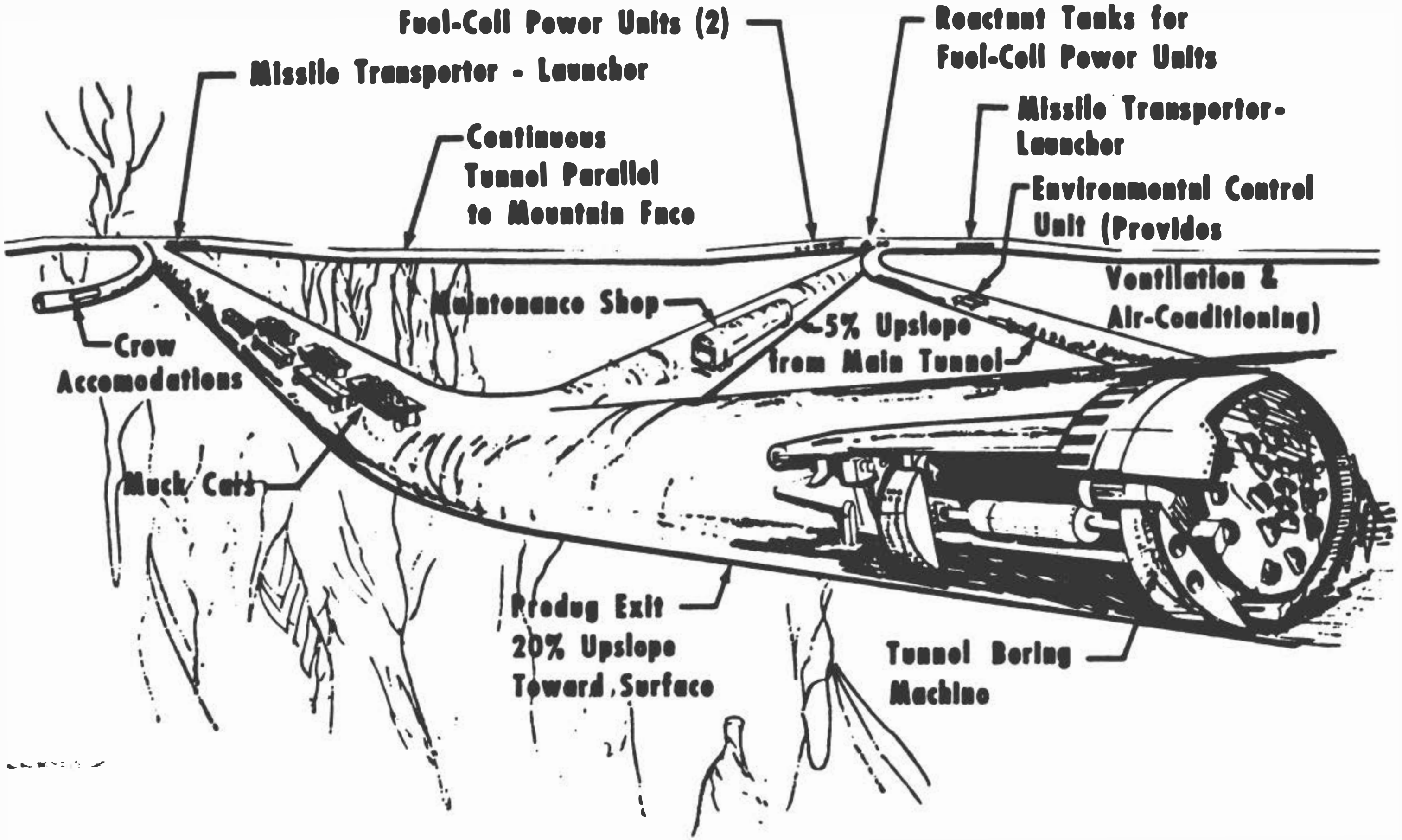


FIGURE 12

DEEP BASED
FSRF

Tunnel Survivability in Dry Soft Rock

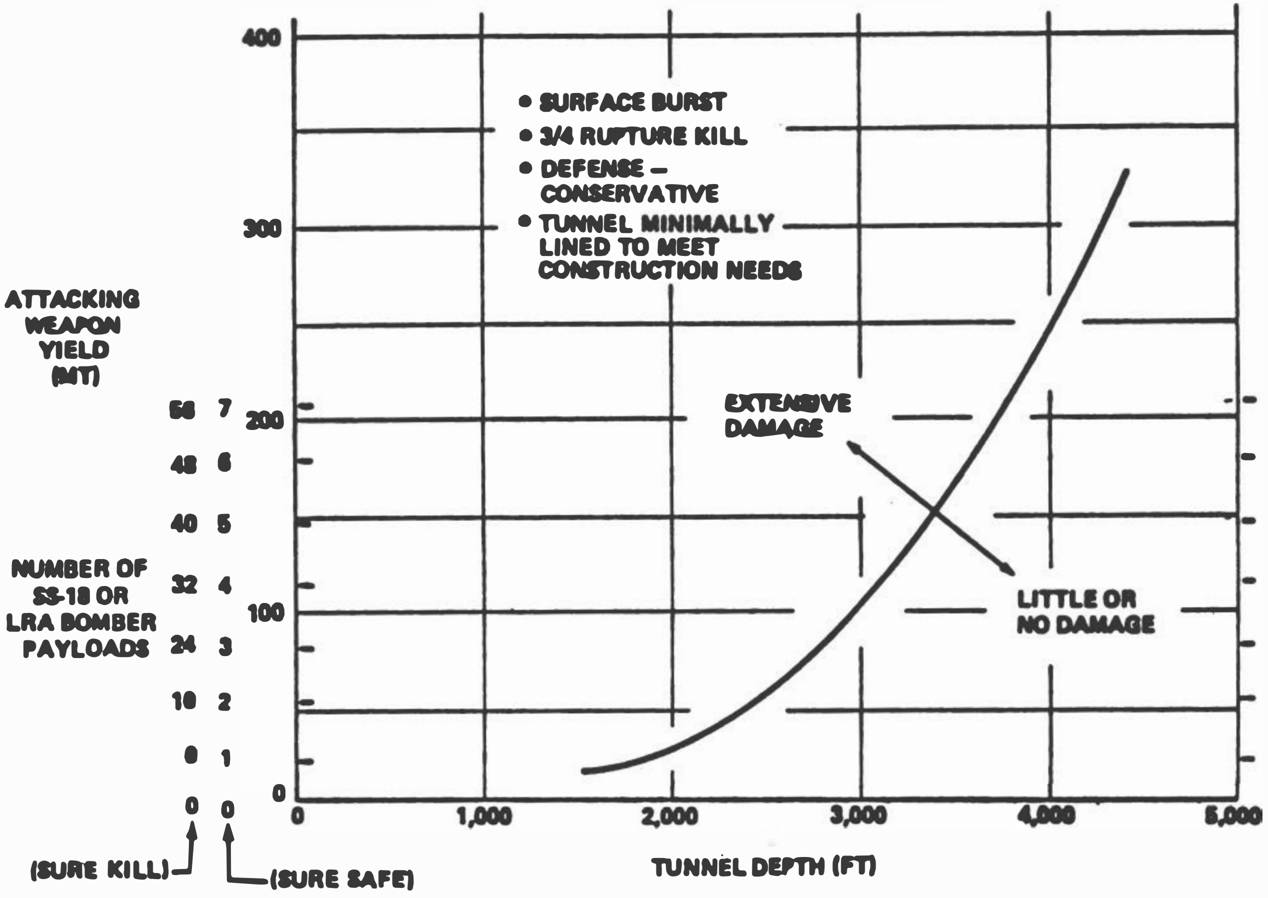


FIGURE 13

DEEP BASED FSRF

Required Force Size & Tunnel Length
Change with Depth

POSTULATED CONSTRAINTS:

- THREAT = 260 DELIVERED LRA BOMBER LOADS
- 50 SURVIVING MISSILES
- DRY, POROUS ROCK
- KILL CRITERION (DEF. CONSERVATIVE)
  - 3/4 RUPTURE ZONE (~ 0.2 – 0.25 KBAR STRESS)

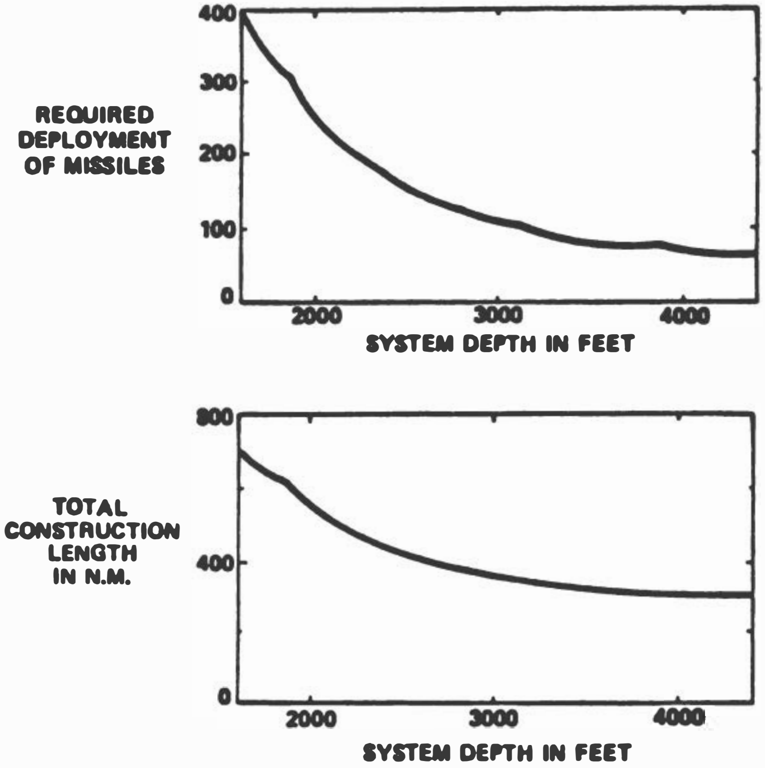


FIGURE 14

DEEP BASED
FSRF

Cost Breakdown

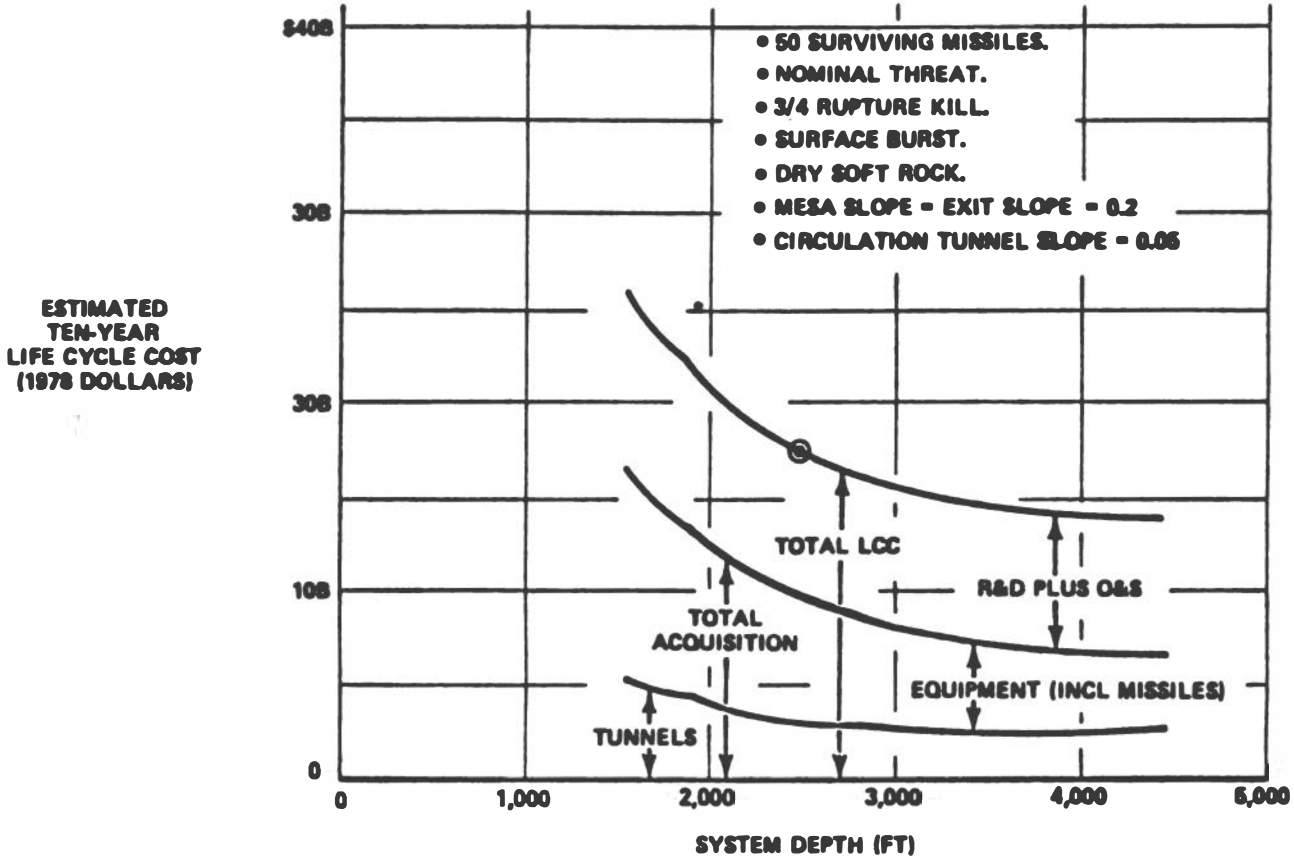


FIGURE 15

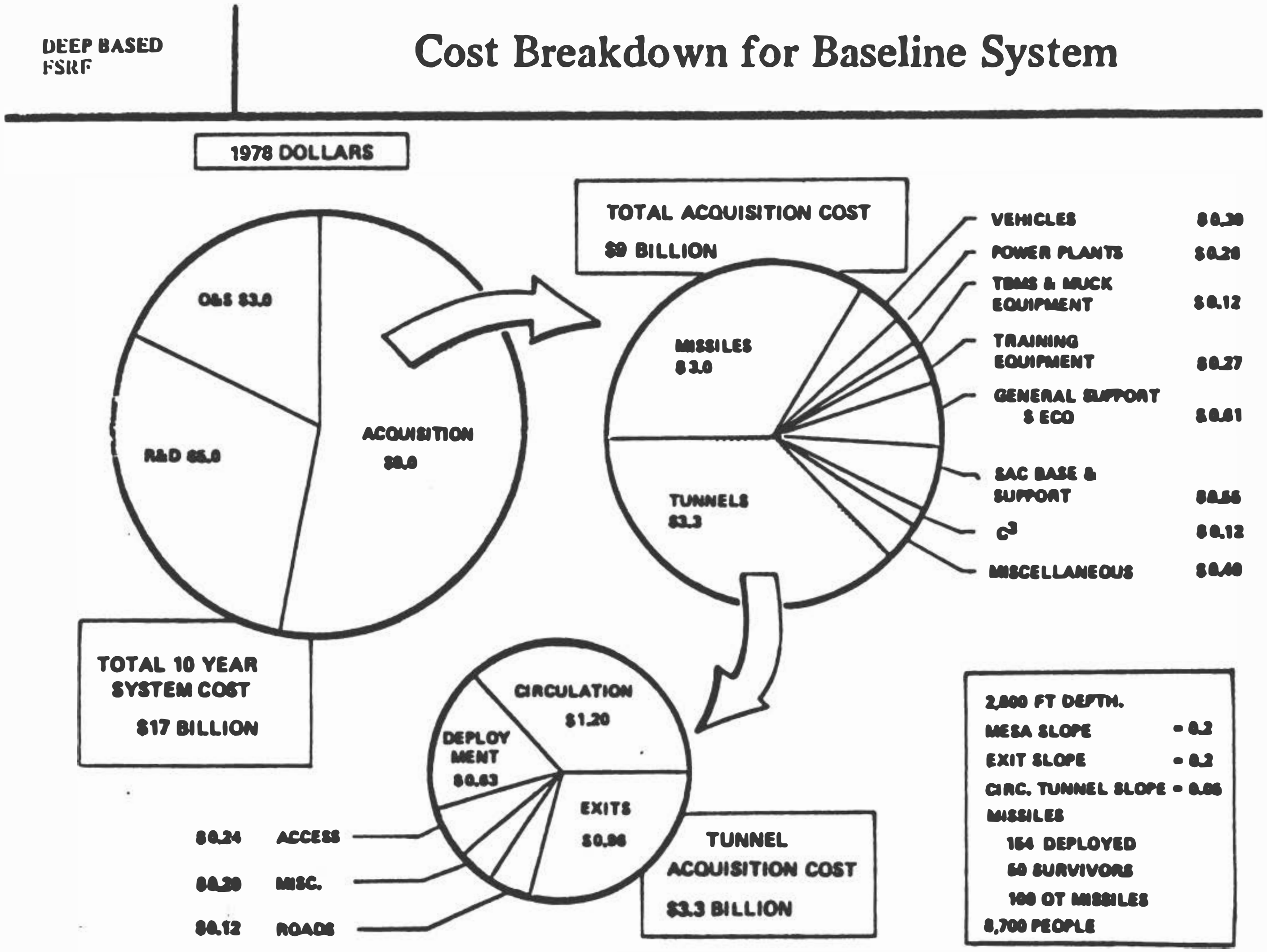

DEEP BASED
FSRF
Cost Breakdown for Baseline System
1978 DOLLARS
O&S $3.0
R&D $5.0
ACQUISITION
$9.0
TOTAL 10 YEAR
SYSTEM COST
$17 BILLION
TOTAL ACQUISITION COST
$9 BILLION
MISSILES
$3.0
TUNNELS
$3.3
VEHICLES $0.30
POWER PLANTS $0.28
TBMS & MUCK EQUIPMENT $0.12
TRAINING EQUIPMENT $0.27
GENERAL SUPPORT $ ECO $0.81
SAC BASE & SUPPORT $0.56
C3 $0.12
MISCELLANEOUS $0.40
CIRCULATION
$1.20
DEPLOY MENT
$0.63
EXITS
$0.86
$0.24 ACCESS
$0.20 MISC.
$0.12 ROADS
TUNNEL
ACQUISITION COST
$3.3 BILLION
2,800 FT DEPTH.
MESA SLOPE = 0.2
EXIT SLOPE = 0.2
CIRC. TUNNEL SLOPE = 0.06
MISSILES
154 DEPLOYED
50 SURVIVORS
100 OT MISSILES
8,700 PEOPLE

FIGURE 16

Deep Silo Basing Systems

FRANK PARRY
R & D Associates
Marina Del Ray, California

SUMMARY: An alternative to the horizontal tunnel basing mode (i.e., the "Mesa" concept or any of its derivatives) is the system of deep vertical silos. These are typified by two main types, the "Sand Silo" and the "Pencil Pusher."

Unlike the horizontal systems, the vertical systems are unmanned and would tend to be operated very much like current Minuteman silo systems, with the exception that the deep silos might also be for "dormant" missile storage. In this mode the missile would be essentially "turned off" and would not be activated until egress and launch were required. The vertical systems would accommodate similar threats to the horizontal systems, but in some conceptions might be based at a greater depth than the horizontal systems with an attendant increase in hardness. One possible disadvantage is that the vertical system must have fixed and known exits, whereas in the horizontal concepts the exit points could be unknown until egress. In general, designs have been made to accommodate surface bursts of up to 100 megatons.

The "Pencil Pusher" (see Figure 3) was originated by the Lawrence Livermore National Laboratory in 1980. The MX-sized missile canister is placed near the bottom of a 3,000-foot hollow steel tube open at the bottom and terminating at the top in a conical raise borer. The steel tube is the "pencil," and the whole is sited below the water table, which is at a depth of 2,000 feet. Thus, silos containing this system are some 5,000 feet deep. The required siting is for 2,000 feet of soft overburden over 3,000 feet of hard rock with the water table no lower than the interface. A capsule of propellant for egress actuation is stored below the missile canister. In the storage position the pencil is full of water, and the buoyant missile and propellant canisters are anchored at the bottom of the pencil. For egress the missile and propellant canisters, both of which are buoyant in water, are released and floated to the top of the pencil and there anchored. The propellant is then ignited. This propellant, possibly hydrazine, is designed to burn slowly in a controlled manner and expels water out of the pencil. This makes the whole pencil assembly very buoyant in the lower water-filled 3,000 feet of the silo, giving an upthrust of several million pounds. This raises the whole assembly to the ground level either by simply forcing it through a prepared upper fill or by using the raise borer. An alternative to the buoyancy concept (see Figure 7) is the hydraulic ram concept (see Figure 8). In the latter case, the lower 3,000-foot silo is pressurized by a reservoir and pump system, thus sliding the pencil through a seal system and forcing it through the upper fill as shown. The ram concept can produce over twice the force of the buoyancy concept.

The "Sand Silo" concept (see Figure 13) was originated by Boeing about 1974. The MX-sized missile is encapsulated and placed at the bottom of a deep silo some 30 feet in diameter and 1,500 feet deep. The silo shaft above the missile capsule is filled with prepared sand. For capsule emplacement or egress the sand is "fluidized" by introducing a fairly uniform water content throughout the sand. The capsule is operated somewhat like a submarine; for emplacement the capsule can be made heavy by

filling ballast spaces with water and thus making the capsule sink through the fluidized sand, with the latter behaving like quicksand. For egress, the reverse of this process takes place; the capsule is made buoyant by "blowing" the ballast spaces. This method of operation allows ready emplacement and also egress from an undisturbed silo. If, however, the silo has been subject to a nuclear attack the upper silo could be greatly disrupted and no longer have a prepared fill of known characteristics. It is therefore desirable that the capsule carry a raise boring machine so that in this worst-case condition egress can be achieved by boring out the upper portion of the silo.

In general, the deep silo systems are capable of more rapid egress than the Mesa systems—perhaps hours instead of days. After attack, where egress requires operation of the raise borer machine, the silo systems would have the advantage of providing a steady force on the rock face by virtue of their inherent upthrusts, whereas the horizontal exit requires use of a conventional tunnel boring machine with a repetitive "grab and thrust" mechanism.

The above is an abbreviated description of the vertical silo deep basing systems. Details of associated system requirements, such as siting; operations and maintenance; command, control, and communications; security; and cost are included in the briefing charts.

It has been a long morning, and we are talking about tunnels. I always think of tunnels as horizontal. I am going to talk about something different. I am not going to promise you a light at the end of the tunnel, but at least I am going to turn them upside down and talk about vertical systems.

I am going to talk briefly about the generic deep basing concepts and then the very pressing question: what are the threat and the environment that one must design to? I have been involved in designs in a number of these systems, and it is always very difficult getting the nuclear community to tell me what to design to.

Somehow we need some unified threat to compare all these systems by. I am going to talk first about the "Pencil Pusher," a concept originated at Lawrence Livermore Laboratory on which we have done some very preliminary engineering work. (As Jim Wooster said, all these things are very, very preliminary.) Then I am going to talk about one of Jim Wooster's systems, the vertical "Sand Silo." Finally, I will address some of the issues at the end.

The problem, as has been explained, is to provide a land-based ICBM either as a secure reserve force or as an alternative primary basing mode (Figure 1). The potential solutions for the deep underground are the vertical, which tend to be unmanned, and the horizontal, which tend to be manned.

I am going to talk about, as I said, the Sand Silo and the Pencil Pusher in terms of the system technology issues and survivability; what actually is the threat you want to design to, and what is the environment at depth? Then the big thing we are all talking about here is egress: How feasible is it? How long does it take? What powers does it want? And so on. The endurance and communications, which Jim briefly addressed, but which have not been properly dealt with yet, and siting are some of the other issues.

Why vertical deep underground basing? Well, it is said—and let me say here that I am not in a position of advocacy here but am just trying to present some things that have been developed and postulated—vertical egress might require only tens of hours, for the simple reason that the vertical shaft does ease the muck disposal problem provided you make proper preparations for a muck pit underneath.

The cost per unit employed (UE) is comparable with those of all the other systems; they all cost around about $100 to $200 million per missile for acquisition. The MX multiple aim point (MAP) concept had the same estimated costs.

Combined concepts are also possible. For example, if you make a vertical deep silo, one could have a quick-response shallow silo at the top.

Also, the egress system developed for the vertical silo might be applicable to the Mesa concept, and we believe at this time that these types of concepts should be included in the Air Force deep underground program. Don't throw them out yet. They may have some value.

The two things I am going to be talking about, the Sand Silo and the Pencil Pusher, were conceived as responses to different threats (Figure 2). The Sand Silo has a 5-megaton threat, with the shock spectrum as shown. Boeing did a point design. R & D Associates looked at their environment, and sure enough the Boeing points lay within that environment. If you extend the threat to 25 megatons, the chart shows the uncertainty bounds—this is actually the same chart that Dr. Sevin showed you—and for the Pencil Pusher we are using this environment, a soft rock over a hard rock, with basing at 5,000-foot depths.

Because I am showing the Pencil Pusher (Figure 3) first does not mean that it is either preferred over the Sand Silo or not. It just happens that I have recently worked on this, so it is a little easier for me to talk about it.

The principle of the Pencil Pusher, originated in 1980 by Livermore, was that one would dig a deep hole in this layered medium with alluvium on top and competent rock below. In the bottom 3,000 feet, one would have a hollow steel pencil-like object. One would require the water table to be somewhere at the 2,000-foot level. In the bottom end of the pencil is the missile canister. Below that is the canister containing "propellant," or some material that can be burned to expel the water in the canister.

For egress, first of all these two canisters are raised to the top of the pencil, and then the propellant canister is fired—under control, of course—so it can force the water out of the inside of the pencil, and the whole thing then becomes very buoyant and can force its way up through the upper prepared fill. Of course, the problem is that after an attack you may not have prepared fill anymore. Maybe you have 2,000 feet of prepared fill; the top 1,000 feet is gone or is badly disrupted. So, in all cases—and this applies to the Sand Silo as well—I think one has to have a raise borer of some sort on top. One advantage of this type of concept, which uses buoyancy for pushing up, is that the raise borer has automatically got its force on the rock face. So you don't have to keep grabbing and pushing, grabbing and pushing.

That is the principle. The summary (Figure 4) is that for this limited study, a first-cut summary, it appears feasible with compatible costs and possible egress advantages, but a number of issues require clarification. However, we did not uncover any obvious showstoppers.

Now, as a matter of interest, we normally draw it exaggerated like the left-hand diagram so you can see it; a true perspective view is more like the right-hand diagram.

General system considerations are shown in Figure 5. The sure kill/ sure safe limits are untestable. That is a common deep underground (DUG) problem, but for a 100-megaton burst in a layered medium and 2,000 feet of porous overburden where we have the equipment below in the 3,000 feet of the Pencil Pusher, the environment is benign compared to that of the MX shelter MAP system. The size we used for preliminary engineering based on that type of environment was, for block motion, 1 meter at 2,000 feet (which gave us a 13.5-foot lower shaft) and 3 meters at 1,000 feet, with a 20-foot upper shaft and rubblizing to a 500-foot depth.

Siting would require 2,000 feet of soft overburden, 3,000 feet of competent lower medium, and a water table that would enable us to keep the bottom silo filled. There are quite a number of areas that satisfy these conditions.

The egress uncertainties (until determined otherwise, and I am sure it is always going to be the case) require some kind of raise borer cutters on the pencil top, to get through the material you are not sure about. If you have a fill that you know about, I am sure you can get out very quickly.

When we started this we were using the buoyancy concept (Figure 6), but this troubled us, largely because of the control. If you fire the propellant, how do you control it after you have fired all of the propellant? However, this is the type of force we can generate for such a system if we measure the tip depth. If the tip is 2,000 feet down to start with, it comes up, and it will go about 500 feet above. The figure shows the sorts of forces we can get by buoyancy, depending on the initial water table depth. We are talking of 5 to 10 million pounds of upthrust in such a system.

It occurred to us that if we could do this hydraulically we would have more control over it; as we changed pump speed and so forth we could change pressure. So, we looked at a system whereby we pump water into this lower cavity and force this whole thing up, filled with water again. Everything else is the same as before. So, if we forced this up through a set of seals (a unique problem in itself), we can then talk about as much as 20 million pounds or even for moderate pressure we can keep 10 to 15 million pounds upthrust all through egress, and that, of course, we can control.

We can work anywhere on the force diagram at any particular depth. There are pumps, not of this capacity, but I point out that in the North Sea some of the pumps are at 10,000-foot depths, and they have as many as 200 stages, pumping water and oil up from that depth. Figures 7 and 8 depict some of the features of the two concepts.

In the hard copies there are a number of detailed designs. I have not time to go through all those, but let us have a look at the energy required in this system for egress (Figure 9).

Before attack, all of the energy needed would be supplied by land line or an on-site powerhouse. There is no need to worry about that;

that is straightforward. For after attack, we just looked at a case in which we stored all of the energy in lithium sulfur batteries. These batteries were sized and priced on the basis of some work that Boeing did some five or six years ago, when it was looking at a semidormant system that could be stored for a long time. We based our sizes and costs on that study, updating it, of course, for inflation.

The digout penetration, we assume, requires about 10 megawatt-hours. That is assuming a worst case, in which we have to dig through soft alluvium. If we go through our filler medium—a formed concrete something like Jay Merritt talked about in those shafts that were lined—which we believe we can dig through fairly quickly, we could get through very quickly. However, we cannot allow ourselves that luxury. The whole shaft may shift over, and we may have to dig through straight alluvium. So, 20 megawatt-hours has a safety factor of two in it.

The lifting energy is also of interest. In one case it is by buoyancy, and here we have to fire a gas generator with 840 kilopounds of hydrazine in it. In the other case we have pumps which have to keep this pencil pressing up by pumping a large volume of water under high pressure. For that we want about 20 megawatt-hours, and we double that for safety and allow for 40 megawatt-hours.

For postattack egress, we believe we can get up in 40 hours if it were all alluvium; 20 hours if we had 1,000 feet of undisturbed foam-type or vermiculite concrete—something of that nature—plus 1,000 feet of earth destructive crater; and 10 hours if it were all undisturbed. Again, there is great uncertainty here. That is a guess, extrapolating data from smaller sizes and so forth.

We estimated the cost of both systems (Figure 10). The buoyancy concept would cost about $86 million per missile. Now, this is acquisition only, no O & M (operation and maintenance), none of the outside facilities. This is just the shaft, the digging machines, the casings, the bottom tunnel lined with quarter-inch steel, the pencil, the missile and all those sorts of things, and the power systems. Of that $86 million, the civil engineering (the digging of the tunnels, etc.) is about $50 million (Figure 11).

For the hydraulic concept the cost of the shaft is about the same—a little bit more because you have to dig cavities for pumps and so forth—but the mechanical systems cost much more (Figure 12). You have to provide all those pumps and you also have to provide a much thicker-walled pencil, because you are talking about a 3,000-psi pressure differential; much higher than in the buoyancy concept.

In the buoyancy case we are talking about 1.5-inch walls on the pencil, as compared with the hydraulic ram case of 3- or 4-inch walls. So, it is a lot of steel, and that comes out to about $120 million. The costs of MX turned out to be about $70 or $80 million per missile. That is the 23 shelters and all the associated costs.

Now, for the Sand Silo (Figure 13). This was originated by Boeing around about 1974, and most of these are Boeing charts with some charts from a critique that R & D Associates did at that time.

This was planned at that time to be about 1,500 feet deep. It had a wide shaft filled with sand, and the idea behind this concept is that you can get out very quickly if you make that sand fluid. In other words, you make it quicksand, and buoyancy gets you up rather than your weight pushing it down. That is what it really is, quicksand.

To do that you have to have a manifold with survivable water, and you have to pump that into the sand, and then the canister being buoyant will rise up, and we made a few models of this. We did not use water. We used air, and indeed, you put a canister in there and without putting air in you could not drag it out. So, you pumped air into the sand and out it came. The problems, of course, are somewhat different at depth. How do you get the water uniformly dispersed in the sand? In any case, I think the same problem occurs for all these concepts.

What do you do about disruption (Figure 14)? It is all right if nothing is disturbed and you have a nice, straight silo, but the sort of thing that happens is that the earth gets shifted and you may get 250 feet for a 5-megaton blast, or for a 100-megaton blast even more.

So, it is our feeling that for all these vertical concepts you must have a digger at the top.

The ground rules that were used for Boeing's design of the Sand Silo prescribed an objective mission the same as the Minuteman's. The missiles were to be sited in hardened and dispersed facilities deep underground, colocated with Minutemen so that they could use Minuteman facilities. The numbers assumed to be used were 150 to 300 MX missiles. The facilities were expected to be able to survive direct hits by 5-megaton surface bursts. Operation and maintenance were to be roughly the same as for the Minuteman missile. The question of command, control, and communications (C^3) has not been addressed in detail, as Jim pointed out.

Now, there is one big advantage the Sand Silo has over the Pencil Pusher, and that is maintenance (Figure 15). With the Sand Silo, maintenance, if required, will be before any disruption so you can fluidize that sand and get the missile out fairly quickly for maintenance. In the Pencil Pusher, especially if you have a fill at the top of foamed concrete, it is more difficult to get through that stuff if you have to dig it out.

So, in all our Pencil Pusher costing, we assumed an auxiliary shaft going down with side drifts so that one could get to the guidance and the interstages for maintenance if you wanted. That complicated the design, but the cost of those shafts was included in that overall cost.

However, as I said before, maybe this sort of a system is unmanned, and egress is the only problem. Maintenance may be a problem, but it may be also an opportunity to get the Air Force to go fully dormant on these systems. If they cannot get out in a hurry, why not go fully dormant? Then maintenance costs should go way down. That is something to think about. I am not advocating it particularly.

For the Sand Silo, here is an active egress concept (Figure 16). You can see how complicated it gets to dig out of something like this. There are a number of arms which grab the side and gradually telescope this thing out. None of this was costed in the Boeing study, which is probably why we get a slightly different answer in cost. Jim was asked questions about tunnel costs; Figure 17 is his old curve of what the costs of tunnels were. This was done in 1974, and one has to double these, roughly, for 1981 costs.

We are talking about 20- or 30-foot tunnels, which at that time had costs of around a thousand dollars a foot. In our digging for the Pencil Pusher I used four thousand dollars a foot for the upper shaft and five thousand dollars a foot for the lower shaft, just for digging. That does not include the linings. So, I tried to make that cost fairly conservative.

For the Sand Silo cost summary, I doubled the Boeing estimate (1974) to get 1981 dollars, and that came out to be about $26 billion for 300 units employed (including R&D, acquisition, military construction, and O&M). Acquisition plus construction costs (to compare it with the Pencil Pusher, which was $80 million in one case and $116 million in the other case) came out to be $54 million. It wasn't as deep, and there was no digging machinery included in that.

Now, I would like to finish up by addressing some of the issues listed in Figure 18. Again, as somebody who gets into designing concepts for some of these things, I think ground motions versus depth really want defining so that these systems can be truly compared. For egress—especially for the vertical systems—the question is what is the disruption zone and what are its characteristics. How do you design your machines to get through it?

We did not have a lot of time or a lot of money to do very deep studies of egress and upper filler trade-offs, but we lighted on vermiculite concrete, which is kind of a foam concrete, as a suitable medium for the upper fill. There are lots of other things one could do there. You could fill it with water. You could fill it with air, and add blast doors. That would make maintenance very easy, but somehow it seems like you really want to seal it off for other reasons and it seemed to us at the time that the vermiculite concrete was pretty good. Egress mechanics (forces, times, and control) are also issues.

The raise borer design that goes along with these systems needs to be defined.

The water systems are obviously vital; both Pencil Pusher and Sand Silo have water systems. The Pencil Pusher needs seals, pumps, and a water supply. It would be deep enough to be well below the water table, so maybe supply is not a problem, but at least it should be looked at. When you are pumping this water, how do you make sure that you keep your pump supplied? For the Sand Silo, fluidization is a peculiar problem. How do you make sure that the sand doesn't go into a slugging mode, so that you get slugs of sand and slugs of water and things like that?

As Jim said, the auxiliary disciplines have not been defined, and yet they have a very important effect on the system as a whole and on its acceptability, maintenance, C^3, and security.

Then for this system there are some perturbations and options. One of the things that we have addressed is an MX system, but one option which may be suitable, say, to secure reserve forces is a small missile. Does going to a small missile, or a missile with a single reentry vehicle (RV) make any difference to these systems? Probably not, but it has not been addressed.

Then I talked about the dual missile, the shallow silo plus the deep silo, and multimissile. If these systems are so good, why can't you put several missiles in one silo, if you could do the mechanics?

Now, a few words about some of the advantages of all deep underground systems. We lost the MX MAP system for three basic reasons. One, it cost too much. I am not putting them in any particular order, but the final cost of the MX system was about $3.7, say, $4 million per shelter times 23 shelters per missile. It was not accepted by the public with all those shelters all over the place, and I think that deep underground basing removes that public interface. It really is just like the ordinary silos, which are accepted. Whether it is Mesa or anything else, it is out of view, so from that point of view it is acceptable. The other thing that happened to the MX MAP system was that the argument was made that if shelters cost $3 to $4 million each you get threated to death. It is easier for the enemy to put one more RV on his big missile than it is for you to build one more shelter. This does not apply to deep basing, which requires the enemy to go the other way. It requires him to put very large-yield weapons on his missiles, which is very difficult to do. In other words, if he has started fractionating, he has to go back again.

So there are three thoughts, I think, which are worth bearing in mind in considering these things, and one of the primary ones is cost. If it costs too much, it will never be funded.

* * * * *

SPEAKER: Mr. Parry, you used the term "dormant." I am not familiar with that.

MR. PARRY: Missiles like the Minuteman are called "active." In other words, their guidance is turned on, and they are running all the time. So, they are ready to go as soon as the button is pushed. It takes guidance and things time to warm up. Something like an MX missile would require 10 to 15 kilowatts to keep it running. That is a lot of power. But there are systems which are not quite here, but on the horizon, whereby one could have missiles shut down and get them started up fairly quickly, and people are beginning to talk about that as a way to go dormant. That is dormant. Partially dormant is where you keep something warm and when required get it fully running quickly.

However, in these underground systems it is going to take you hours to get out. So, what is the point of keeping the missile running down below? You really have a good opportunity to go truly dormant. In fact, you really have no choice. So it is not a problem; it is an opportunity.

SPEAKER: I did not quite understand the egress problem. You were going to have a shaft in the upper 2,000 feet of alluvium?

MR. PARRY: Yes.

SPEAKER: Is that shaft going to actually be filled by vermiculite?

MR. PARRY: Yes. Vermiculite concrete.

SPEAKER: And so you have to drill through that even if there is no destruction?

MR. PARRY: Yes, but that is very easy to drill through. In fact, some calculations that we did, which I have got here, suggest that you could almost push your way through that. It disintegrates, especially if you put a fairly fine point on the front and push. It will disintegrate and powder, and you can push your way through. Now, clearly some trade-offs have to be done there. How survivable is it? In the nuclear environment how much of it will survive? I did not say there were no problems. There are a lot of problems.

SPEAKER: You have not addressed shock mounting of any of this equipment. What is the reliability of this equipment sitting out there dormant year after year and day after day?

MR. PARRY: It is shock mounted.

SPEAKER: Everything is shock mounted?

MR. PARRY: Oh, yes. The missile has to be. It is really fairly fragile. Most of the missiles cannot take more than about 5 g, and that is a good missile. Shelf life more than anything else is the critical dormancy problem.

DEEP UNDERGROUND BASING (DUG)

PROBLEM

TO PROVIDE A LAND BASED ICBM

- SECURE RESERVE FORCE

OR

- ALTERNATE PRIMARY BASING

POTENTIAL SOLUTIONS

- **VERTICAL (UNMANNED)**
  - SAND SILO
  - PENCIL PUSHER
- **HORIZONTAL (MANNED)**
  - MESA
  - BRIMSTONE

SYSTEM/TECHNOLOGY ISSUES

- SURVIVABILITY
  - THREAT
  - ENVIRONMENT AT DEPTH
- EGRESS
- ENDURANCE
- COMMUNICATIONS
- SITING

FIGURE 1

THREAT/ENVIRONMENT ASSUMPTIONS

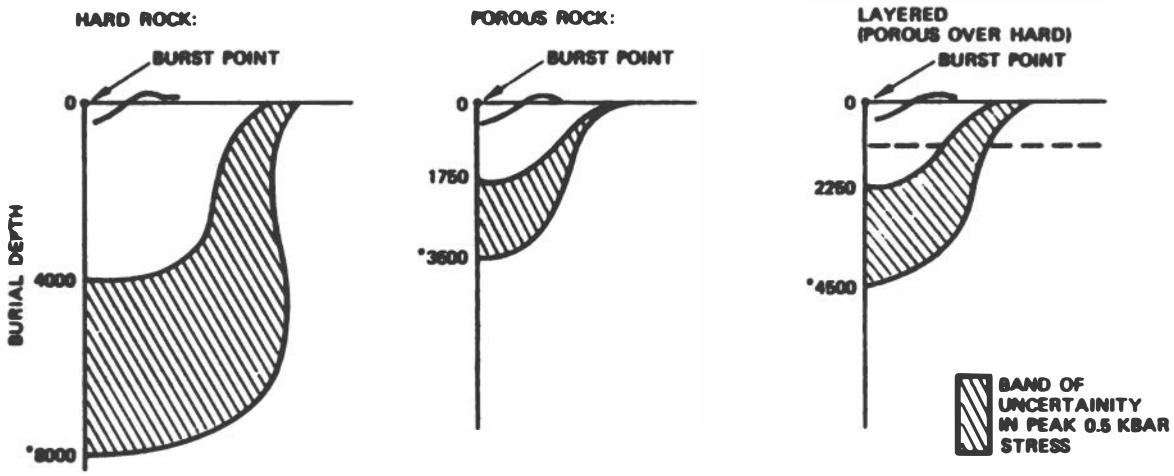
- **SAND SILO**

		5 MT		25 MT
		BOEING	RDA*	RDA*
SHOCK SPECTRA	PEAK STRESS (KBAR)	0.8	0.325-3.25	1-10
	PEAK DISPLACEMENT (IN)	5.0	6-60	25-300
	PEAK PARTICLE VELOCITY (IPS)	326.0	170-1700	510-5100
	PEAK ACCELERATION (G)	220.0		

*RDA (COOPER, KNOWLES, BRODE – 1973)

- **PENCIL PUSHER**

100 MT SURFACE BURST



*CONSERVATIVE (SURE SAFE) DESIGN DEPTH FOR 0.5 KBAR
≈ 800 MT (SURE KILL)

FIGURE 2

PENCIL PUSHER CONCEPT

- ORIGINATED BY LLNL (1980)

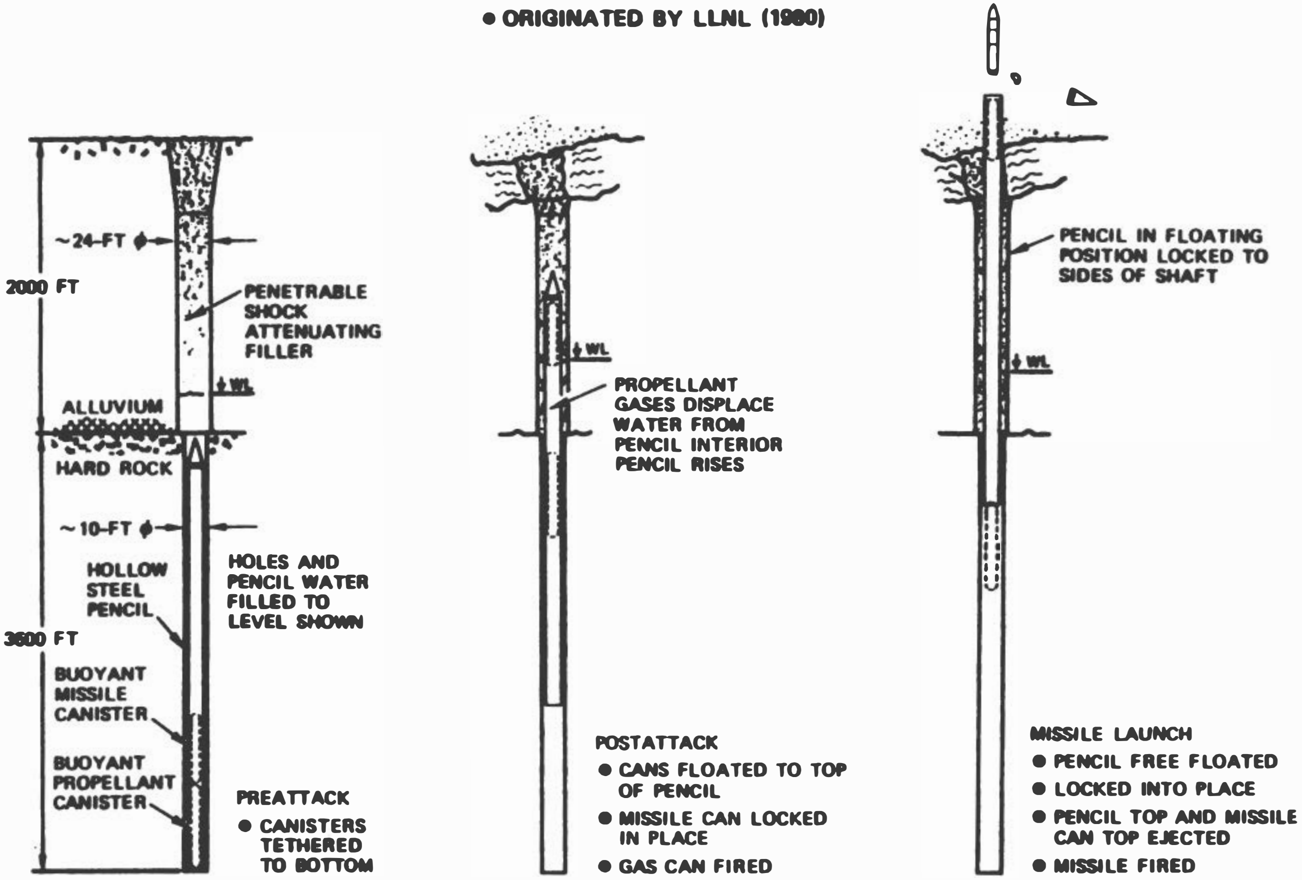


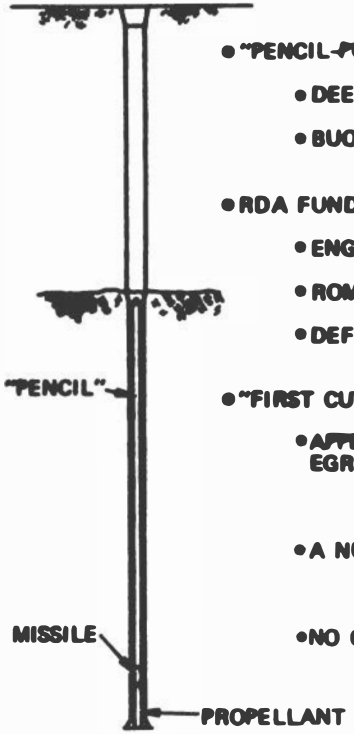
FIGURE 3

PENCIL PUSHER SUMMARY

- "PENCIL-PUSHER" CONCEPT SUGGESTED BY LLNL
  - DEEP SILO BASING (5000 FT WITH WATER TABLE NOT BELOW 2000 FT)
  - BUOYANCY FORCES USED FOR EGRESS
- RDA FUNDED FOR LIMITED STUDY
  - ENGINEERING FEASIBILITY/ALTERNATE SOLUTIONS
  - ROM COSTS
  - DEFINE ISSUES
- "FIRST CUT" SUMMARY
  - APPEARS FEASIBLE WITH COMPATIBLE COSTS AND POSSIBLE EGRESS ADVANTAGES

    BUT
  - A NUMBER OF ISSUES REQUIRE CLARIFICATION

    HOWEVER
  - NO OBVIOUS "SHOW-STOPPERS"



BOUYANCY CONCEPT
(NOT TO SCALE)

FIGURE 4

GENERAL SYSTEM CONSIDERATIONS

- THREAT
  - KILL/SAFE LIMITS UNTESTABLE (COMMON DUG PROBLEM)

    BUT FOR 100 MT IN LAYERED MEDIUM (2000 FT POROUS OVERBURDEN)
    BELIEVE EQUIPMENT BELOW ~ 3000 FT IN ENVIRONMENT BENIGN C.F. MX MAP
  - SIZING FOR PRELIMINARY ENGINEERING
  - BLOCK MOTION — 1 M AT 2000 FT (13 ½ FT LOWER SHAFT)
  - SHIFTING SOIL — 3 M AT 1000 FT (20 FT UPPER SHAFT)
  - RUBBELIZING — 500 FT
- SITING (~2000 FT SOFT OVERBURDEN, 3000 FT COMPETENT LOWER MEDIUM)
  - DEEP DESERT VALLEYS

	AREA (NMI^2)	WATER TABLE (FT)
YUCCA (NTS - NV)	80	1500/2000
HUALAPI (AZ)	120	1000
PHOENIX, PICACHO, BULLARD WASH (AZ)	200	1000/2000
DRY LAKE (NV)	100	200
● DEEP VOLCANIC SINKS (NTS - NV)	>300	1500/2300
● LAYERED ROCK SITES (AZ, CO)	>400	500/1500

- EGRESS UNCERTAINTIES
  - UNTIL DETERMINED OTHERWISE "RAISE BORING" CUTTERS MUST BE ASSUMED FOR EGRESS

FIGURE 5

BUOYANCY vs HYDRAULIC RAM CONCEPTS

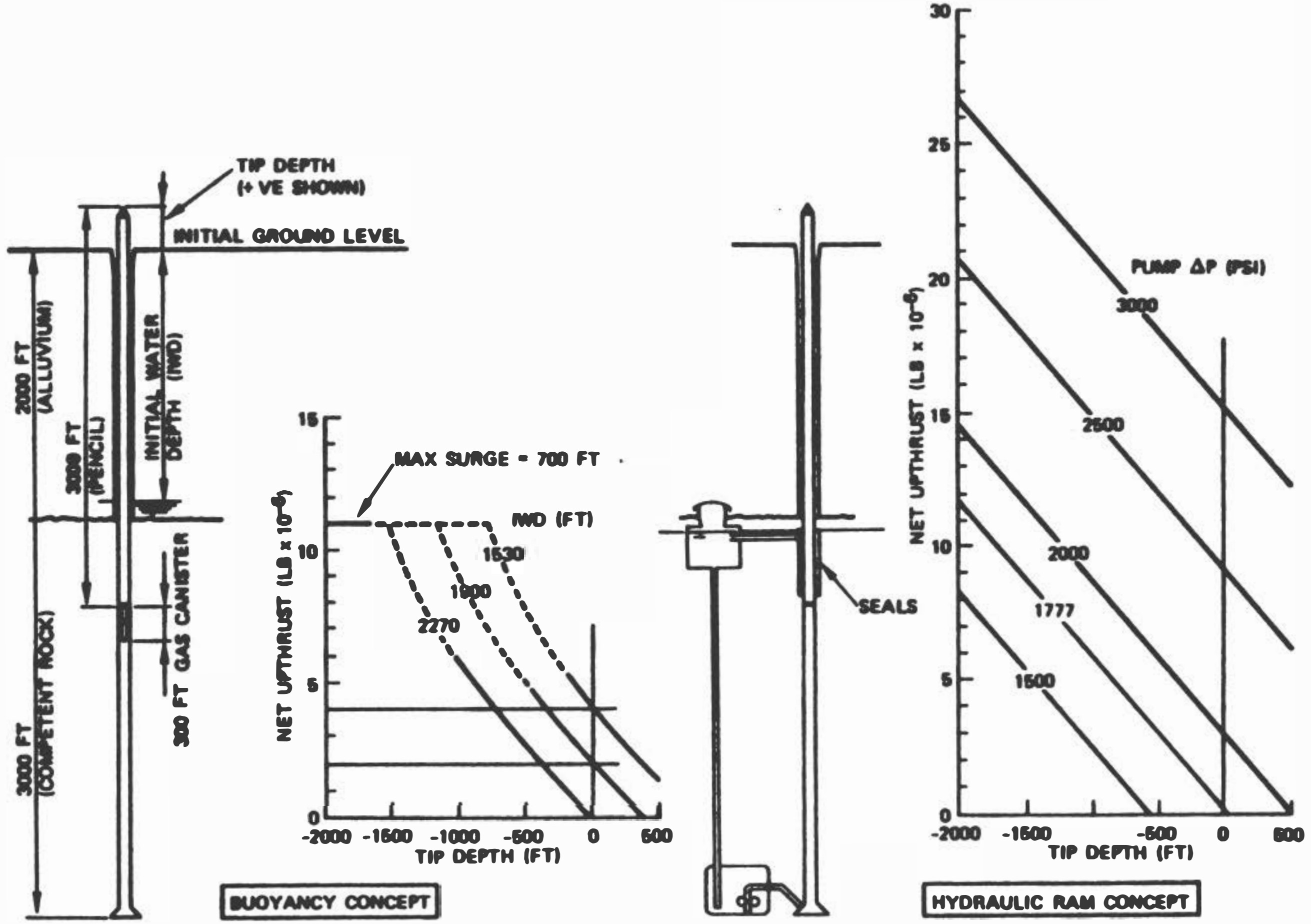


FIGURE 6

BUOYANCY CONCEPT

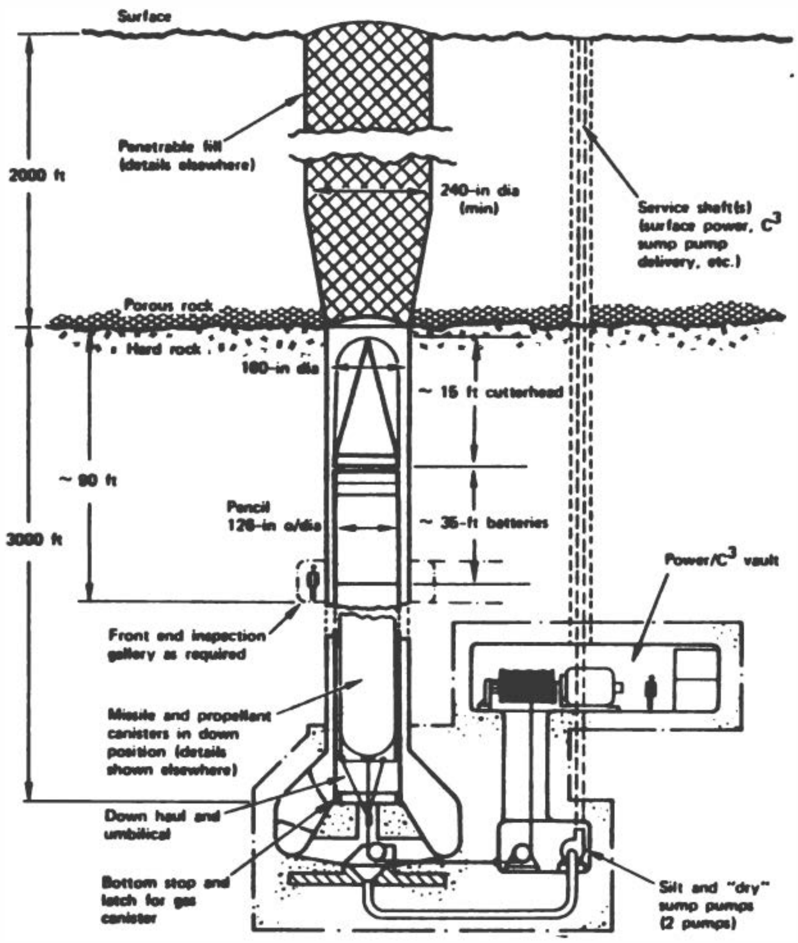


FIGURE 7

HYDRAULIC RAM CONCEPT

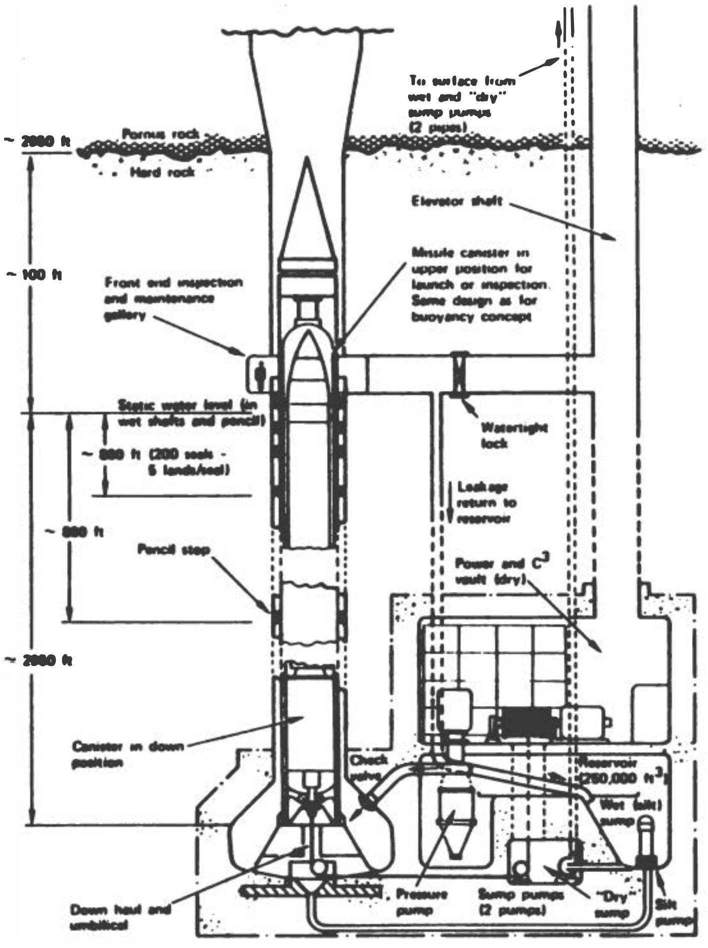


FIGURE 8

EGRESS – ENERGY AND TIMELINES

ENERGY

- PREATTACK (INCLUDING MAINTENANCE) - ALL ENERGY SUPPLIED BY LANDLINE AND/OR ON-SITE POWERHOUSE
- POSTATTACK - ALL ENERGY STORED IN $LiSO_2$ BATTERIES

REQUIREMENTS	BUOYANCY CONCEPT			HYDRAULIC RAM CONCEPT		
	MWH	FT^3	MLB	MWH	FT^3	MLB
C^3 AND WINDING ENGINE	1	150	0.01	1	150	0.01
DIG OUT (PENETRATION)	20	3000	0.2	20	3000	0.2
LIFTING ENERGY	*	19,800	1.1	40	6000	0.4

*GAS GENERATOR CANISTER CONTAINING ~840 KLB OF HYDRAZINE

TIMELINE

- PREATTACK
  - MOST MAINTENANCE DOWN HOLE (SERVICE SHAFT)
  - MISSILE CHANGEOUT (10-20 HOURS DRILL OUT, $3 M)
- POST ATTACK EGRESS
  - 40 HOURS ALL ALLUVIUM
  - 20 HOURS (1000 FT UNDISTURBED PLUS 1000 FT DISRUPTED/CRATER)
  - 10 HOURS (2000 FT UNDISTURBED)

FIGURE 9

COST SUMMARY

- COSTS PER U. E. ($M 1981)
- NO O AND M INCLUDED

	BUOYANCY CONCEPT	HYDRAULIC RAM CONCEPT
CIVIL ENGINEERING	50	55
MECHANICAL	17	42
DIG OUT SYSTEM	4	4
MISSILE	15	15
	86	116

NOTE: 100 U.E. ASSUMED FOR DEEP SILO

FIGURE 10

CIVIL ENGINEERING COST ESTIMATE

1981 $M

- FOR BOTH BUOYANCY AND HYDRAULIC RAM CONCEPTS

SITE SELECTION, 5000 FT x 3 IN TEST BORE	0.5
SURFACE PREPARATION	0.3
ASSOCIATED ROADS (4 MI AT $250 K/MI)	1.0
EXCAVATION (SEE NOTE1):	
UPPER HOLE (2000 FT x 20FT) SOFT ROCK)	10.0
LOWER HOLE (3000 FT x 13 1/2 FT HARD ROCK)	18.0
BOTTOM CAVITY (20 FT x 30 FT DIA)	2.0
POWER VAULT (20 FT x 40 FT x 15 FT)	2.0
ELEVATOR SHAFT (5000 FT x 5 FT AT $1000/FT)	5.0
INSPECTION GALLERY (7 FT x 20 FT DIA)	0.5
ACCESS TUNNEL (8 FT DIA x 3 FT LONG)	0.2
LINING (SEE NOTE 2):	
UPPER HOLE (GUNNITE AT $2.5/FT^2)	0.3
LOWER HOLE (640 T x 1/4 IN STEEL PLATE)	1.5
ELEVATOR SHAFT (60 T x 1/8 IN STEEL PLATE)	0.2
BOTTOM CAVITY (125 CY R.C., 1 FT THICK)	0.1
POWER VAULT (125 CY R.C., 1 FT THICK)	0.1
INSPECTION GALLERY ACCESS TUNNEL } (125 CY R.C., 1 FT THICK)	0.1
	41.8
VERMICULITE CONCRETE FILLING AT $100/CY (30,000 CY)	3.0
SURFACE BUILDINGS	1.0
CONTINGENCY (~ 10%)	4.2
	50.0
ADDITIONAL PUMP HOUSE, CAVITIES AND SPILL WAYS FOR HYDRAULIC RAM	5.0

NOTE 1: EXCAVATION COSTS PER J. SPERRY, MINING AND DRILLING ENGINEER:
UPPER SOFT ROCK $5000/FT, LOWER HARD ROCK $6000/FT

NOTE 2: STEEL PLATE $1/LB (U.S. STEEL EQUIVALENT ≈ $0.65/LB FOR MX SHELTER)
CONCRETE (REINFORCED REBAR AND ROCK BOLTS) $800/CY INSTALLED

FIGURE 11

BUOYANCY CONCEPT ESTIMATE

MECHANICAL (LESS MISSILE AND DIG OUT EQUIPMENT)	
STEEL PENCIL (3000 FT x 126 IN OD x 1.2 IN MEAN T, 4.7×10^6 LB AT $2/LB)	9.4
PROPELLANT (837 KLB TOTAL AT $1.20/LB AVERAGE)	1.0
PROPELLANT CANISTER (280 KLB STEEL AT $3/LB, 38 KLB EPOXY/GLASS AT $2/LB)	0.9
MISSILE CANISTER (140 KLB STEEL AT $3/LB)	0.4
OSE (60 KLB – PER MX)	0.6
WINDING ENGINE AND CABLE	0.3
C^3 AND ANTENNA	0.3
SUBSURFACE POWER (1.0 MWH, 0.10 MLB, 100 C.F.)	0.1
SUMP PUMP AND PLUMBING	0.1
SURFACE EQUIPMENT (POWER, CRANES, ELEVATOR, etc.)	2.5
SURFACE C^3	0.2
	15.8
CONTINGENCY (≈ 8%)	1.2
	17.0

HYDRAULIC RAM CONCEPT ESTIMATE

MECHANICAL (LESS MISSILE AND DIG OUT EQUIPMENT)	
STEEL PENCIL (3000 FT x 126 IN OD x 3.5 IN MEAN T, 15×10^6 LB AT $2/LB)	30.0
CANISTER/MISSILE (140 KLB STEEL AT $3/LB)	0.4
OSE (50 KLB – PER MX)	0.6
WINDING ENGINE AND CABLE	0.3
C^3 AND ANTENNA	0.3
SUBSURFACE POWER (40 MWH, 0.40 MLB, 6000 C.F.)	3.5
PENCIL SEAL SYSTEM	0.4
SUMP PUMP/PLUMBING	0.1
SURFACE EQUIPMENT (POWER, CRANES, ELEVATOR, etc.)	2.5
SURFACE C^3	0.2
	38.3
CONTINGENCY (≈ 8%)	3.7
	42.0

FIGURE 12

SAND SILO CONCEPT

- ORIGINATED BY BOEING (1974)

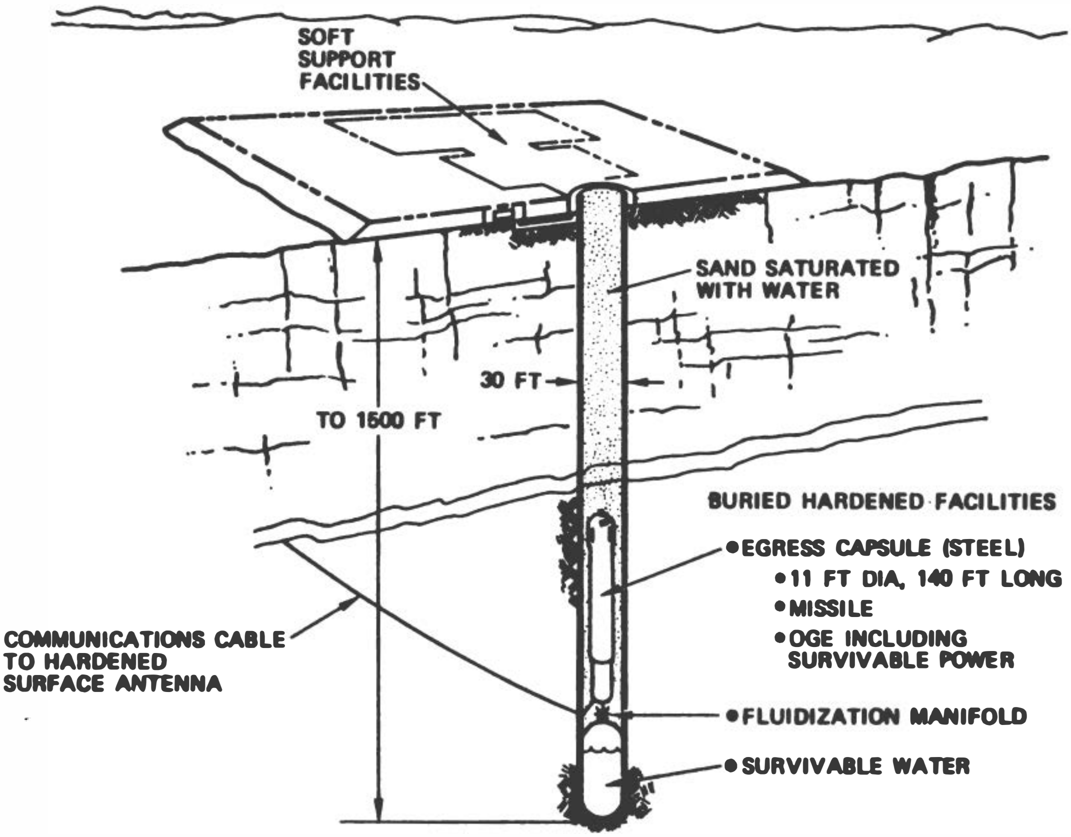


FIGURE 13

CLOSE-IN NUCLEAR ENVIRONMENTS

5 MT SURFACE BURST - MEDIUM TO HARD ROCK

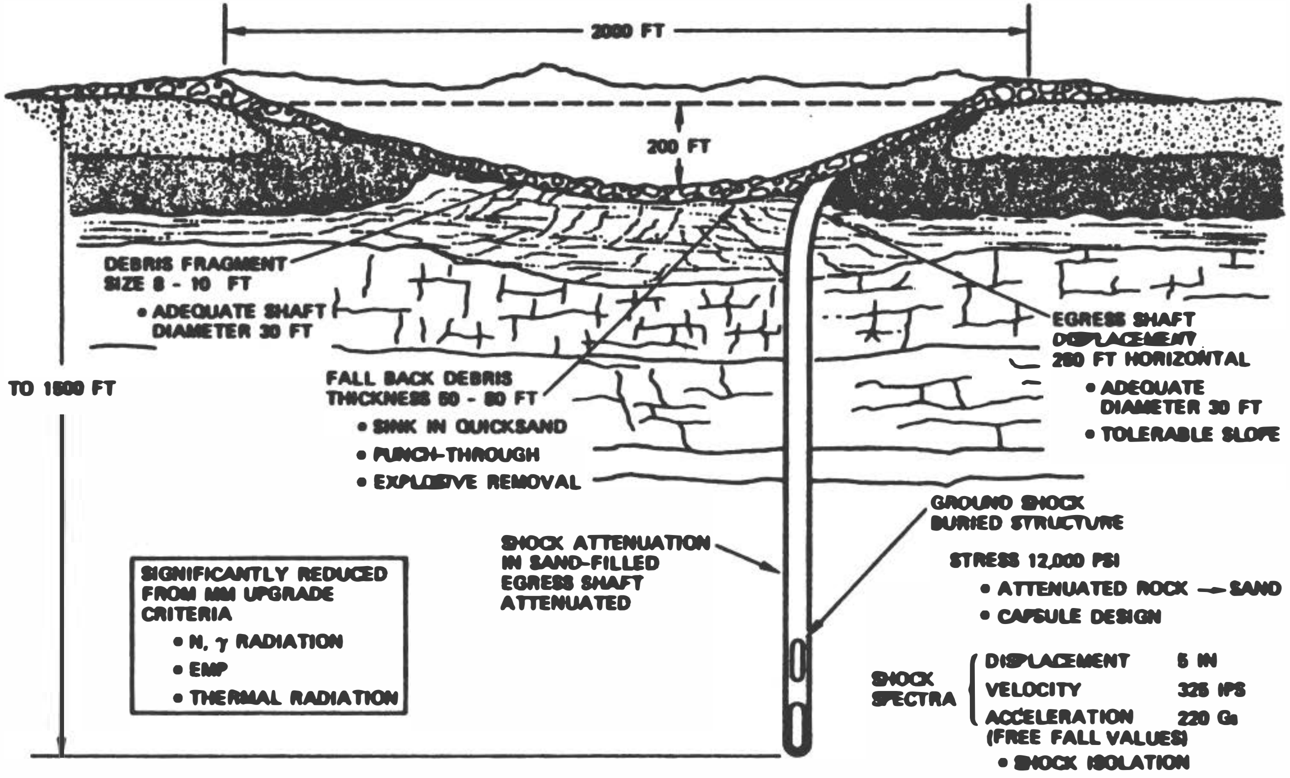
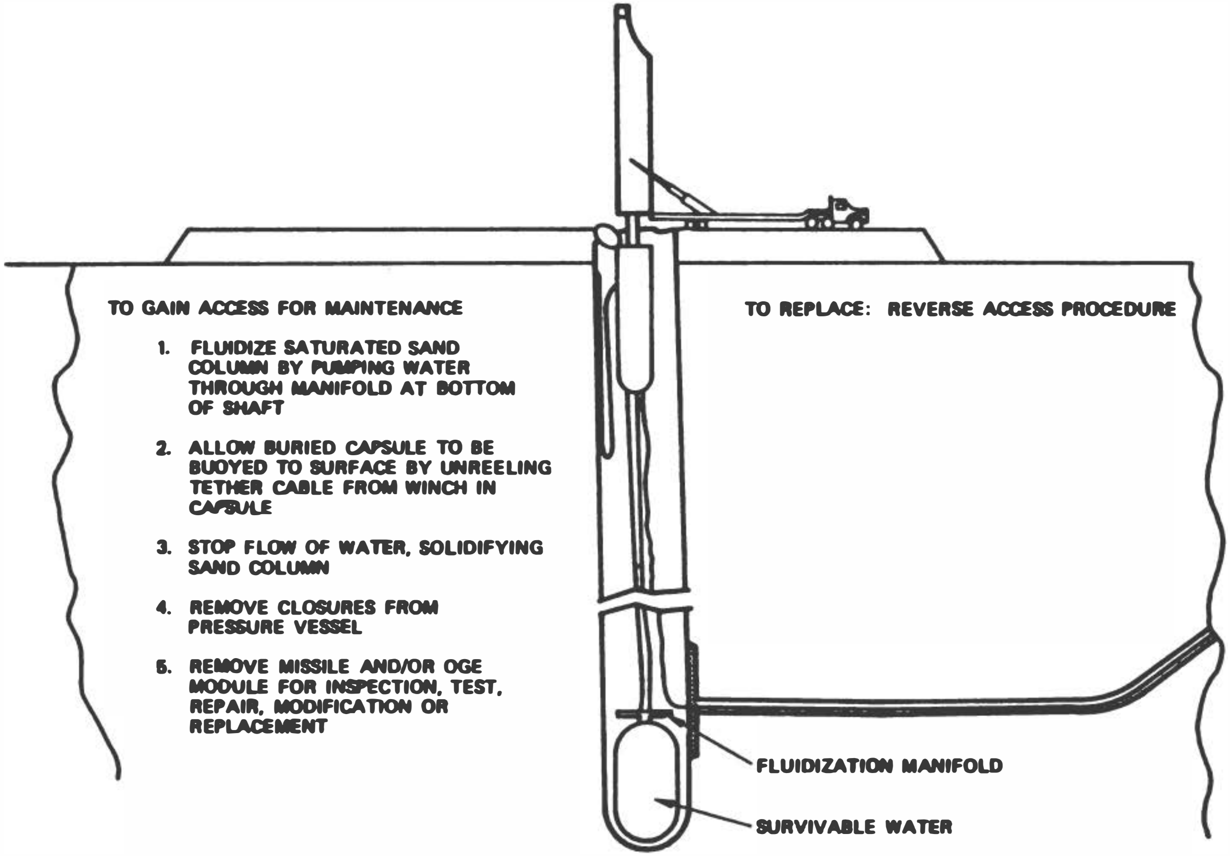


FIGURE 14

MAJOR MAINTENANCE MODE



TO GAIN ACCESS FOR MAINTENANCE

1. FLUIDIZE SATURATED SAND COLUMN BY PUMPING WATER THROUGH MANIFOLD AT BOTTOM OF SHAFT
2. ALLOW BURIED CAPSULE TO BE BUOYED TO SURFACE BY UNREELING TETHER CABLE FROM WINCH IN CAPSULE
3. STOP FLOW OF WATER, SOLIDIFYING SAND COLUMN
4. REMOVE CLOSURES FROM PRESSURE VESSEL
5. REMOVE MISSILE AND/OR OGE MODULE FOR INSPECTION, TEST, REPAIR, MODIFICATION OR REPLACEMENT

TO REPLACE: REVERSE ACCESS PROCEDURE

FIGURE 15

ACTIVE EGRESS CONCEPT

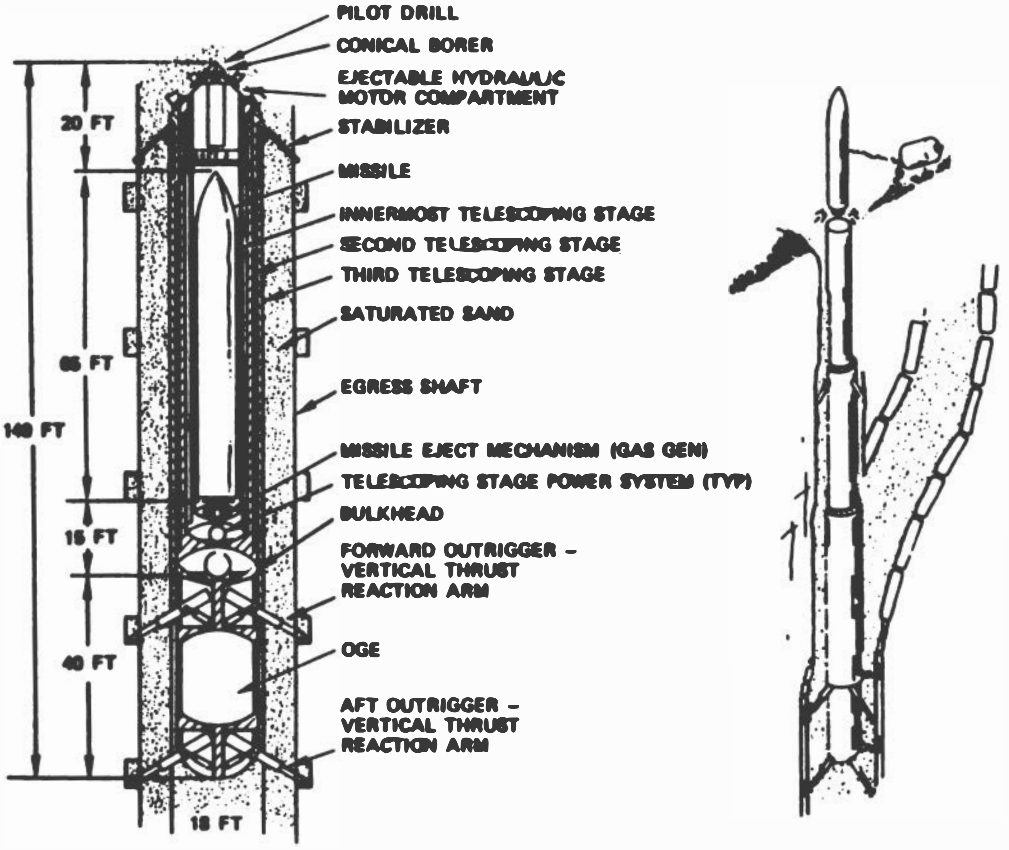


FIGURE 16

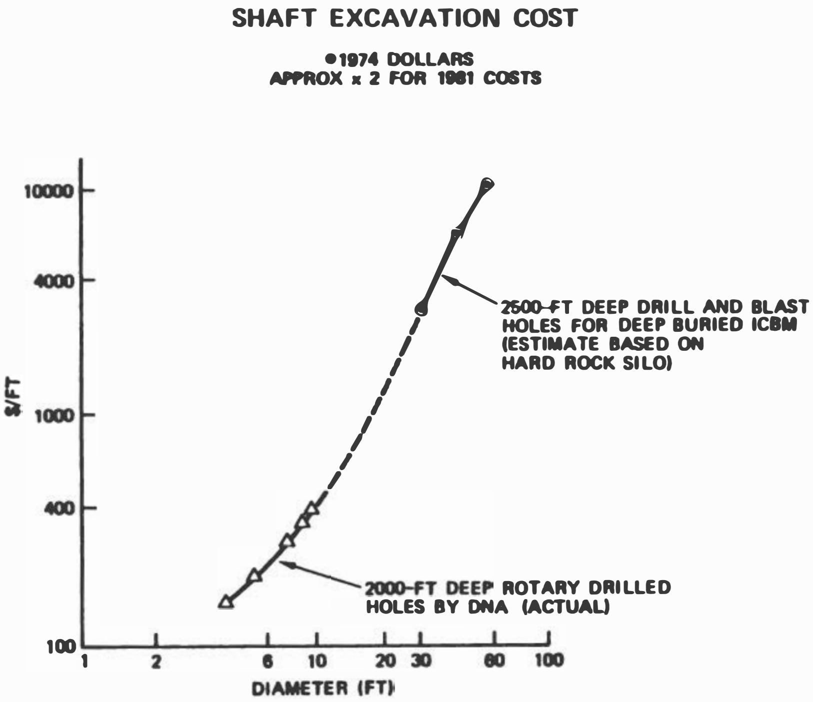


FIGURE 15

ISSUES

- THREAT DEFINITION
  - GROUND MOTION vs DEPTH
  - DISRUPTION ZONE DEFINITION
- EGRESS
  - UPPER FILLER TRADEOFFS
  - EGRESS MECHANICS (FORCES, TIME, CONTROL)
- RAISE BORER DESIGN
- WATER SYSTEMS
  - SEALS, PUMPS, SUPPLY (PP)
  - FLUIDIZATION (SS)
- AUXILIARY DISCIPLINES DEFINITION
  - MAINTENANCE
  - C^3
  - SECURITY
- SYSTEM PERTURBATIONS/OPTIONS
  - SMALL MISSILE
  - DUAL MISSILE (SHALLOW + DEEP)
  - MULTI MISSILE

FIGURE 16

System Requirements

LT. COL. CARL W. RULE
Ballistic Missile Office (AFSC)
Norton Air Force Base, California

SUMMARY: Since the President's announcement on October 2, 1981, the Air Force has redirected its efforts toward near-term and long-term basing modes for the MX missile. This briefing addresses the deep basing alternatives and preliminary plans being formulated at this time. Main topics include details of the President's announcement, initial guidance from higher headquarters, various concepts under consideration, issues to be resolved, the organization of the Ballistic Missile Office, contractual requirements, work in progress, future efforts, and ways in which the U.S. National Committee on Tunneling Technology could help the Air Force.

Underground complexes are not new or revolutionary ideas. At least a dozen major studies have been completed since the late 1950s. Various concepts for deep basing have included horizontal tunnels, vertical shafts, and various forms of manned or automated egress. At this time no single concept is preferred by the Air Force; careful evaluation over the next year will have to be completed before the Air Force will have an official recommendation to offer.

Most of the technology required for a deep basing system exists; however, several feasibility or "proof of concept" tests may have to be performed in areas such as egress through cratered or ruptured zones, communications through the earth, power generation, and heat dissipation. Another key factor is siting, because site-specific geology affects survivability, cost, schedule, and environmental impact.

The deep basing program is in the early stage of definition. The Air Force is very serious about long-term basing programs and knows that extraordinary management skill will be required to meet objectives in the next year or two. The Air Force is evaluating conceptual and location alternatives with the intent of making recommendations to the Secretary of Defense in 1984 or sooner.

Deep basing is an opportunity for the application of existing, emerging, and new tunneling, shafting, and mining technology. Knowledge gained will contribute to a critical national defense program; in addition, reapplication of the new technology could help civil works throughout the world.

I feel very honored to be able to participate in today's program. I am from the Ballistic Missile Office out at San Bernardino, in California. As you might be aware, there are many other people here from California. That is the place where houses periodically change zip codes, and I think it may be partially in response to some of Joe LaComb's activity after looking at those movies here this morning.

The Air Force is really an exciting career and for me every assignment has been interesting. The program that I am now embarked upon, the deep basing program, is perhaps going to be the most interesting of my Air Force career. It is an important job. It has technical challenges that indeed are going to be very large. We do recognize that we need help in order to achieve these goals, and we hope that you share the same enthusiasm that we have and help meet some of the national defense needs, as well as in the process to reapply some of the technology that we come up with to perhaps help civil works.

This presentation has been advertised as being a systems requirement type of briefing. What I intend for it to offer is really an Air Force perspective of some of the preliminary planning that we have done with the deep basing program ever since the announcement was made by the President on the second of October. Figure 1 lists some of the key points that I would like to address during this short presentation. Col. Berry has already addressed the President's announcement (Figure 2). Just to recapitulate some of the high points, it was back on the second of October. Indeed, one of the three long-term options that we are going to be concerned with is going to be the deep basing mode, and that has not yet been defined very well, as we will find out.

We will initiate an intensive program so that the Department of Defense and the President and Congress can make the decision as to which of those three basing modes—or perhaps a combination of those basing modes—is to go into full-scale development in the 1984 time frame (Figure 3).

The deep basing concepts are really nothing new. We see from Figure 4 that when we go back into time, into the late 1950s, early 1960s, at least one dozen of these different concepts have been looked at.

For one reason or another, due to cost uncertainty or evolution of the threat or one or more of these reasons, these have not really been deployed, save for the control centers that we might have at the Cheyenne Mountain complex, or the command and control centers that we have back here on the East Coast. But due to the threat evolution and due to technology that has come about in the past years with the increased yield of Soviet weapons, as well as the accuracy that they are now going to experience or are projected to experience, deep basing is being looked at in a new light and has indeed very much promise to provide us a very survivable intercontinental ballistic missile (ICBM) force.

Also in the figure is a conceptual depiction of what that underground complex might look like. It need not necessarily be vertical because we have not made that decision at this time.

Some of the things following the Presidential announcement: we have received some guidance (Figure 5), none of which has been written up to this point, but we are taking this as basic assumptions for the program, that we will initiate a concept validation program for 50 to 100 MXs or the equivalent. That means that we will be doing parametric studies for different size missiles for a deep basing system. Postattack endurance of at least a year will certainly present some challenges. Other systems have started out with a goal to have survivability of at least a year and have reduced that goal because it was very difficult to achieve. We mentioned the rapid egress before; there is no firm requirement that has been specified as of this point. Rapid egress is very desirable, but right now we don't have a quantitative requirement against which to measure that.

"Milestone II," for those who might not be familiar with the acquisition process in the Department of Defense, is the decision point where key leaders within the Department review the program, the cost, the schedule, and the performance risk to see if it is worthy to go into full-scale development. This is now scheduled to be in fiscal year 1984, and of course that depends on the funding levels that we do obtain. Of course, 1984 being an election year, we sense that we would like to have that fiscal year 1984 date moved forward, and this was indeed brought out by the President himself in the announcement.

The Initial Operational Capability (IOC) has not been defined. Traditionally we, for ICBM systems, define IOC as having 10 missiles on alert or having that capability. For the deep basing we have not defined that. It could very well be one. It could be just the completion of the command and control center, or it will be perhaps a different definition than that. A detailed program plan is due to the Department of Defense in January 1982, and at this time we are busily preparing that.

The purpose of Figure 6 is to show that we are concerned not only with the underground complex but also with all the various other elements of a deep basing system. Here we see the underground complex which has been represented. This is very much like the one Jim Wooster presented —Mesa concept—but we also want to keep aware of the transportation network, the road network, as well as the main operating base. As we found in the MX multiple protected shelters (MPS) system, the main operating base was, indeed, the thing that caused the most environmental impact.

We have already looked a little bit at the deep basing history (Figure 7). I won't belabor this—Dr. Sevin went through that this morning—but it goes back to the Brimstone concept, back in the 1970 time frame, and the Strat-X deep tunnel in the 1972 time frame, and we did have a briefing by Mr. Parry on the Sand Silo and, of course, the Boeing presentation on the Mesa.

None of these has been adopted officially as the system concept *per se*. We are reviewing all the concepts that have been presented and trying to be objective in a system definition.

Jim Wooster earlier described the "Mesa" base concept, with a perimeter tunnel going all the way around the mesa, horizontal tunnels spaced approximately 10 miles apart, and predug egress portals that approach a steep slope ideally, and are approximately 4,000 feet apart. Again, the entire system, as I recall, was approximately 2,600 feet beneath the surface.

Figure 8 is a cross section of that, and as Jim corrected us this morning, this is not purely a horizontal system, but it is a nearly horizontal system. Here you can see the egress portals that are spaced every mile or so apart, again 2,600 feet beneath the surface. These egress portals come very close to the surface, but you still have some distance to tunnel in order to egress when the time comes to launch. Of course, you have a place in the back to handle all the muck when it comes time to egress, and on the right hand side we show there are some vertical shafts for communication antennas.

Tunnel boring machines conceivably would be used for the initial construction of the project. We understand that these take about 1,000 horsepower—perhaps 4,600 volts nominally—and the world record rate of tunneling, I recall, is about 400 feet in a day, but we do experience, I guess, in practical application such as Metro or in Chicago, rates much lower than that—perhaps 30 to maybe 70 feet per day—and this is one of the big areas of concern.

The cost of being able to construct these tunnels is an uncertainty. Before, at one of the previous subpanel meetings, we heard that depending on geology we could have tunneling costs from on the order of $200 a foot all the way up to maybe as much as $2,500 a foot. With that band of uncertainty it certainly has to be one of the key points of our validation program to find out what those costs indeed would be. The purpose of Figure 9 is to illustrate the fact that we are not locked into any form of egress or tunnel configuration. These are some of the ideas that are available and the ones that we are evaluating at this particular time. In fact, it can be a combination of horizontal, as well as vertical, or we can even have systems, as Mr. Parry had mentioned, like the Pencil Pusher concept (Figure 10), being completely vertical.

Now, going deep down in order to achieve survivability, one might say, "How deep do you have to go?" Our understanding of this particular problem is the fact that it depends very much on the medium that you are located in, whether it is igneous rock such as granite or perhaps limestone or unsaturated porous rock (Figure 11). Of course, in the latter case—on the right-hand side—this does have better shock attenuating features.

Depending on the hardness that we are able to achieve, we have already seen concepts before in tests that were conducted with tunnels to the half-kilobar level. We also heard of some that were to the 1-kilobar level, but it shows on Figure 11 here these are not exactly the projected threats. What was done is to take the theoretical data that exists and, assuming that it was just going to be a one-time surface burst, for instance, the 240-megaton case could be really a combination of 24 10-megaton weapons that go off simultaneously.

We have done a rough calculation, and the concepts that we have looked at really fall in the range between 2,000 feet and, in the case of the Pencil Pusher concept, about 5,000 feet, and we can see the function of how deep do we really have to go. The real point is that geology is very, very important to how hard these actual tunnels are going to be, and if we can make them ½ kilobar is a very big question or if we can make them 1 kilobar in granite. Do they have to be lined? What type of backing material is needed? These are questions that are very pertinent.

From the existing literature we were able to review in the past couple of weeks, we located a number of sites that appear to be reasonable for the types of concepts that were discussed this morning (Figure 12). I would caution you to not take this as being an Air Force position that we have narrowed in and that these are the only candidates. That is not the case at all. What we are doing right now is trying to establish a set of criteria that we can apply to the entire United States, including Alaska, Hawaii, and the possessions, so as not to overlook any reasonable alternative. We have to consider such things as underground railroads. I think that we should also consider the fact that there may be abandoned mines on the East Coast that may be equally suitable. But for right now, using geotechnical criteria that have been established so far, these appear to be some of the reasonable areas.

Figure 13 was explained also by Dr. Sevin this morning. I did change one particular word, and that is in the title. We say that most of the required technology exists. I think that in each one of the areas we have demonstrated some form of the technology that would be applicable to the deep basing system. However, there are other things that have to be tailored very carefully for application to the configuration that we come up with.

Some of the things on Figures 14 and 15 are very much on our minds. They are not listed in any particular order of priority, but of course we have seen various underground configurations this morning.

We, the Air Force, will have to go ahead and consider all these configurations and come up with a concept or perhaps several concepts for additional testing and for environmental analysis and costing.

Hardness and vulnerability is, indeed, a very important question as to the existing simulations; are they adequate? We are working very carefully with the Defense Nuclear Agency (DNA), as well as the Air Force Weapons Laboratory, to find out how hard we can actually make these tunnels and whether they can withstand the current threat as well as responsive threats.

Egress. Once you have a buried system that has hardened, how do you get out? In fact, once you are down in the depths, if it does take you a long time to get out, as you approach the surface you may, indeed, become very vulnerable. That is why preservation of location uncertainty (PLU) was so very important in the MPS system. It may be very important, in fact, if we have long egress times for the deep basing system. With quick egress the PLU problem tends to be diminished, but until we can demonstrate that, we have to be very careful with the signatures that we would be giving off as we egress so that we don't make ourselves vulnerable to a second-wave attack.

Power. We would have to look at the potential use of nuclear reactors and fuel cells. What type of power are we going to be using for at least one year's endurance? How are we going to power those particular machines when it comes time to egress—perhaps the entire force—in a very short span of time?

Crew endurance. Again, we have many problems there, with medical and simple life-support systems.

For launch control and communications, how do we communicate with the system that is located 2,600 feet beneath the surface? That, we think, is solvable, but it has yet to be demonstrated. Some work has been done as far as emergency rescue missions with mining operations over the years, but we think that we will need something particularly adaptable, so that we can communicate with the complex down within the mountain to the external world.

Heat dissipation becomes very important with heat gradients that increase as you go beneath the surface, conceivably 10 or 15 degrees higher below the surface than at sea level and during the button-up condition—during that one-year time frame—we could have considerable problems, particularly during egress when a lot of heat would be generated.

Security, of course.

The operational concepts—how do you logistically support this?

Manned versus automated types of features, particularly in the egress area.

Among the other issues that we have is siting (Figure 15). I think that this is very, very important to determine where we want to conduct our tests. Does it have to be in the type of geology that is actually going to be in the deployment area, or can we just use representative ground? Where, in fact, do we want to deploy the system? I will come back to this on the next chart.

Constructibility. By that we mean what types of scenarios; how many men are required to do this; how much do we expect this to cost; how long would it take? Those types of considerations.

We know that there are going to be some feasibility demonstrations. The two most likely, of course, would be egress and the attendant problems with egress. Communications comes a very close second there. Power and heat dissipation are also possibilities.

The cost is very uncertain, as I mentioned, due to the wide range of possibilities in constructing this system.

The environmental impact analysis process. We are currently going through a process to narrow down all the concepts into one that we consider to be a baseline and, also, to come down and look at the possible locations for the system, look at these alternatives. Those two in combination we would be able to use for environmental impact analysis, as well as the technical feasibility and cost estimates. We have a base comprehensive plan that would be closely related to the environmental impact work. That would be related to the external support facility. Those are very time-consuming efforts, and a little later I will show you the time lines.

On siting (Figure 16), I promised that I would come back to this. This is one of the critical factors because the geology does determine how survivable the system may be. The type of geology affects the cost of construction, affects how fast it can be done, and affects what type of environmental impact we experience. Some of these important considerations might be considered by the Siting Work Group; we heard about having steep escarpments as being desirable. We already know that porous, unsaturated rock is desirable. We would like to have water to support the people. However, water could be detrimental as far as construction is concerned. The temperature gradient I mentioned before, as I did the other items, which I think are pretty self-evident.

Now for the people that are doing this (Figure 17). I mentioned before that the Ballistic Missile Office does have charge of the deep basing team, and that at Norton we have both the Ballistic Missile Office and the Air Force Regional Civil Engineer. Colonel Berry is located in the top command section. Beneath him we have Colonel Carl Case, who recently became the Director of Advanced Strategic Missile Systems (ASMS). This would be me (pointing to Deputy Director for Deep Basing), and then of course we have the entire BMO organization and the Air Force Regional Civil Engineer (AFRCE) associated with the Corps of Engineers to support us with construction plans, costs, the environmental impact analysis process, the siting work and the base comprehensive plans.

In order to address the issues that I mentioned before, these are the types of contracts (Figure 18) that we are considering very, very strongly for fiscal years 1982 through 1984. System support would deal with the integration of all the technology, such as the power, the life support, the heat sink, the communications, and egress. But egress we broke out as a separate item of that system support that is especially important. We think that a system definition as well as a demonstration will be called for. Construction validation is principally an effort to go ahead and identify the cost in the scenarios, as I mentioned. The site screening is a narrowing process to, again, do a literature survey followed up by a site characterization study that would actually go out and do core borings to find out if Mother Nature is exactly as predicted in the literature. Of course, the environmental impact and base comprehensive plans would, also, be under contract.

This is how it looks when you put it together (Figure 19). We have got our direction. We are currently undergoing a concept screening, looking at all the viable concepts, trying to take the best features of all of those. We are developing the program plan that is due to the Secretary of Defense. We are developing our screening criteria, with TRW doing an awful lot of that work. We plan to have a contract that would start later, possibly next spring to summer, on the site characterization. We have recently put out *Commerce Business Daily* (CBD) announcements for sources sought in each of three critical areas: system support, egress, and construction validation. About 47 different agencies or companies have responded, including 30 in the system support. We have 30 companies in egress, and we have 19 in construction validation. With respect to survivability, we are working with the Air Force Weapons Laboratory, as well as the Defense Nuclear Agency. Of course, we have to have all of our cost data before the Defense Systems Acquisition Review Council (DSARC) II meeting that I mentioned, which would be toward the end of 1984. Once we have the concept evaluated and we have the tentative locations, those two items combined go into a description of the proposed action and the alternatives. That is the real kickoff point or a key item in the environmental analysis process. That process takes 18 to 20 months, and the final environmental impact statement (FEIS) is required by law to be prepared before a decision is made.

Figure 20 lists the work in progress. This includes looking at the organization. We are also very busily engaged in program acquisition, mostly contract work, getting our strategy approved, getting our statements of work written, and preparing to review those particular proposals when they come back and to award those contracts. The POM, or Program Objective Memorandum, is an Air Force programming document that we have to use to justify the outyear funding. As for the public affairs package, on the second of November you may have seen the *Aviation Week* article by Clarence Robinson, which has an awful lot on deep basing. Of course, we expect to receive an awful lot of input and questions from the public, and therefore we have to have a public affairs package. We are working very carefully with DNA and AFWL for the survivability program, working on that program management draft (PMD) with Headquarters USAF and the program plan.

Figure 21 lists some of the upcoming events that we see. Of course, first on the list is our meeting here today. Next week we expect to have a briefing at Norton Air Force Base for potential bidders, those that responded to the *Commerce Business Daily* (CBD), as well as other invited contractors. We expect to have our strategy briefed to our Headquarters on the 17th, and if they approve that strategy, our plans would call for release of the request for proposal (RFP) at the end of this month. We have some survivability management steering groups (SMSG) that are planned here. I think they are in error. Right now these dates are now going to be toward the end of the month. Our program plan for the Office of the Secretary of Defense (OSD) is another thing that we cannot forget. The contract awards, if our strategy is approved, would be in the springtime, April or (hopefully) sooner. Of course, you know that, with the government procurement process, normally that takes about 10 months to do. We are working very diligently to reduce that and take as little time as possible.

As Figure 22 says, we are in the very early stage of development of this project. The Air Force is, indeed, as serious as can be about this particular program. Our schedule is very, very compressed. We are looking at various concepts, as we saw today, and location alternatives. This we view as a very golden opportunity for the application of the existing technologies as well as those that are emerging and new.

Figure 23 is to say that your help, I think, is not only helpful; I think that it is going to be essential. Any feedback that we can get on our preliminary program plans to see if we have emphasized the right things or if we have neglected some things would be very, very useful. Your thoughts on contract approaches, as to how the industry as well as government can share the risk, would be useful, and I know that there are some thoughts within the community regarding this matter. Cost estimating is also very much on our mind. We have to have a good handle on that before we get to DSARC II.

The siting criteria, again, is in my judgment one of the most important of all. In that regard I mentioned the fact that we would like to look at the use of existing underground spaces, to see if they would be applicable to our purposes. Egress keeps coming up on everybody's list of things that have to be done; the mechanized mining, whether we have machines that can deal not only with construction but with egress through rubble. The construction validation.

Some of these thoughts as to what can be done as far as the future involvement. We don't see this as being the end. We see this as really the beginning. We know that there are newsletters that are put out by the community. There are magazine articles that we can use to help keep everybody informed. There is a possibility that this group can serve as an advisory group or perhaps it would be better to go with specialized consultants that you may know of. Your thoughts on how the NRC (National Research Council) could be involved in the future would be appreciated.

* * * * *

SPEAKER: In terms of construction validation, what are your thoughts in that area?

LT. COL. RULE: Construction validation, I think, is one of the initial activities that the Air Force Regional Civil Engineer and the Corps of Engineers will be involved in. This would be an opportunity to review the scenario as to what type of machines are available; how many people are required; what are the types of shift requirements that would be needed; and how much would it cost. The latter is probably the most important thing. It is like an independent assessment of cost estimates. There may be an option within the contract, if needed, if there is considerable uncertainty in the costs. We may have to conduct an actual construction demonstration, but that at this point appears to be an option. We have made no final decision along those lines.

SPEAKER: You had on your last illustration contract approaches, and we heard a lot about this technology and the different approaches being contemplated. What do you contemplate on contracting approaches?

LT. COL. RULE: Do you refer to the type of contract, whether it is cost plus incentive fee (CPIF) or fixed price or——

SPEAKER: That would be an issue, also, if you have systems as opposed to breaking out contract approaches. You have the question of whether you are going to do things in house or contract them out. You have questions about phasing from concept R&D to construction, and so forth. What are your present initial thoughts?

LT. COL. RULE: We are going to do a little bit of everything. TRW is our systems engineering and technical advice contractor. They will be there to help in all facets of the program, but there may be opportunities for an extension of that staff where we might have to get other Systems Engineering-Technical Advisor types of contractors to augment TRW.

As far as the contracting is concerned, we would like to make it competitive. In fact, that is our goal. We view system support as being a major type of an effort to coordinate all the technologies that go into system definition and for the costing of that particular thing. We are looking at, providing that the funding levels are sufficiently high, having multiple types of contracts for the key areas, such as system support, such as egress——those two in particular. Construction validation is a third example. Those key things have been advertised in *Commerce Business Daily*.

With these contracts we would envision that there would be opportunities —after the first year or two after the system is defined and we start to go into a feasibility demonstration—for option points where the multiple contracts might reduce down to just one in each of those respective areas, but right now we are planning to have a minimum of one in each of those key areas.

As far as being a research and development and having the uncertainties involved with the program, I think that most of the contracts would, indeed, in the early phases have to be cost plus, but this is a strategy that really has not been officially approved—that is my own personal judgment. We would have to work that up the line and get approval, as I mentioned. The 17th of November is when we will get guidance as to which contracting method, what will be basic and what will be options.

I am maybe just nibbling around your question.

SPEAKER: What about beyond that point, after you get beyond the R&D phase and start talking about constructing these facilities?

LT. COL. RULE: That would be another series. You are jumping to construction. There would actually be a full-scale development phase. That would come after 1984.

SPEAKER: Would that involve a prototype tunnel or tunnels?

LT. COL. RULE: Those types of things—yes, sir—flight testing just as we have with the MX. You actually build things to full scale to iron out all the bugs that you can during the full-scale development and to prepare yourself for construction.

Construction would conceivably be in the mid-1980s, perhaps in the 1984-85 time frame, but even that schedule has not been defined. The initial operational capability date of 1989 will give you some measure as to when we have to begin the construction. Some of these concepts that we have looked at take on the order of maybe six or seven years to construct, normally.

SPEAKER: Has the Air Force ruled out the use of Titan II and Minuteman for the first 100 MXs?

LT. COL. RULE: In the President's guidelines we were told that we would produce 100 and that they would be placed in existing silos, not being specific as to whether they would be Minuteman or Titan, but I would presume that they would be one or possibly a combination of both. The likelihood of actually deploying 100 in silos is really not very great. It would probably be some lower number, perhaps half that many before we eventually deploy the deep basing system or start to deploy it.

SPEAKER: Deep basing would come after that?

LT. COL. RULE: Yes, sir. The interim solution to the strategic problem happens to be putting MX missiles into existing silos. The long-term solution—for 1989 and beyond—is going to be deep basing, the ballistic missile defense, the continuous-patrol aircraft, or in some mixture. It could be one or the other. I don't know what combination. It is unlikely that all three would be selected to go into full-scale development, due to the sheer cost of each of the programs.

SPEAKER: One thing I think the Air Force needs to look at is the contracting procedures of your contract. They just don't work out. The risks and liabilities are not shared properly. We have all been looking at this; it is something you need to start now because it is going to take many years to straighten it out.

LT. COL. RULE: Yes, sir.

SPEAKER: And in something like this, with the magnitude of tax money being spent, I think it is about time we straighten it out.

LT. COL. RULE: It is a golden opportunity, sir, and we would look to your thoughts, and I know that various members—and I hesitate to point anybody out, but I recognize Mr. A. A. Mathews as being one of the foremost people that has thoughts along these lines, and we would be very anxious to get those thoughts.

SPEAKER: I just gather that it is implied and it is almost policy there will be an egress after attack, vertical, horizontal, or sloping, but—

LT. COL. RULE: We have to have the capability to egress after an attack. Yes, sir. Whether it is actually a requirement that we will do it in order to make the system survive has yet to be defined, but once you do egress we have problems of how do you button it back up again, you know, to protect the equipment and people that are within the complex. But we must look at that given the fact that we egress: How do we protect the remaining portion of the system and keep it survivable?

Deep Basing

- PRESIDENTIAL ANNOUNCEMENT
- CONCEPTS
- ISSUES
- ORGANIZATION
- CONTRACTUAL REQUIREMENTS/SCHEDULE
- WORK IN PROGRESS
- UPCOMING EVENTS

FIGURE 1

President Reagan's Announcement

2 OCT 1981

- DEVELOP AND PRODUCE 100 MX MISSILES
- DEPLOY SOME MISSILES INITIALLY IN SILOS
- PURSUE LONG-TERM OPTIONS
  - AIR MOBILE
  - BALLISTIC MISSILE DEFENSE
  - DEEP UNDERGROUND BASING
- SELECT LONG-TERM BASING MODE(S) IN 1984

FIGURE 2

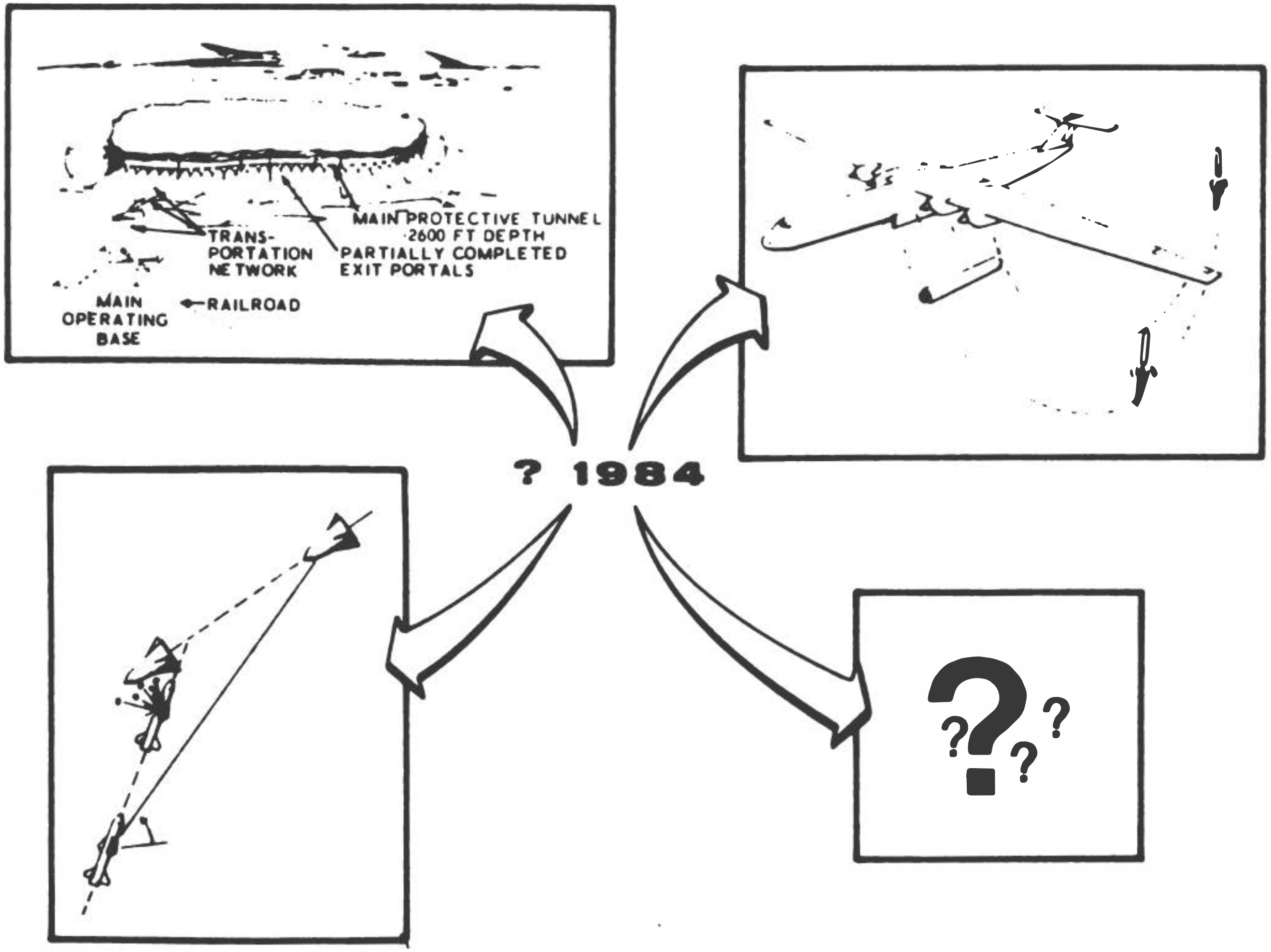
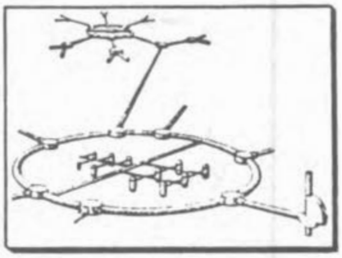

? 1984
MAIN PROTECTIVE TUNNEL
2600 FT DEPTH
TRANS-PORTATION NETWORK
PARTIALLY COMPLETED EXIT PORTALS
MAIN OPERATING BASE
RAILROAD
?
?
?
?

FIGURE 3

Planned Installations - Never Constructed

	CONCEPT												
	PRAIRIE DOG	LARGE PAYLOAD BASING	DEEP UNDERGROUND COMM CENTER (DUCC)	SUBT. LAUNCH ENVIRON (SUBTLE)	BRIMSTONE	COUNTERPUNCH	STRAT-X TUNNEL	DEEP UNDERGROUND SANGUINE SYS (DUSS)	QUICK EGRESS	SHUCCS	UMMS (MESA)	WWMCCS	DEEP BASE FSRF
DATES:													
FROM	59	64	67	68	69	64	68	67	72	74	76	76	76
TO	60	65	67	69	70	66	72	68	74	75	77	77	79
PRIMARY FUNCTION													
C^3								●					
ICBM	●	●		●	●	●	●		●		●		●
C^3I			●							●		●	
ROCK TYPE:													
HARD		●	●	●		●	●	●		●		●	
SOFT											●		●
VARIED	●		●				(SHALLOW, ~100M)		●				
EXIST. MINES					●								
FACILITY TYPE													
ARSENAL		●				●							
DISTRIBUTED	●			●	●		●				●		●
COMM POST			●							●		●	
DEEP SILO									●				
COMM SYS								●					
COMMENTS	NATIONAL NEED FOR ADDITIONAL (TO NORAD & SITE R) DEEP BASED FACILITIES NOT YET ESTABLISHED TECHNOLOGY NOW AVAILABLE FOR LARGE UNDERGROUND FACILITY CONSTRUCTION AND OPERATION COST AND POTENTIAL BENEFITS SIGNIFICANT												



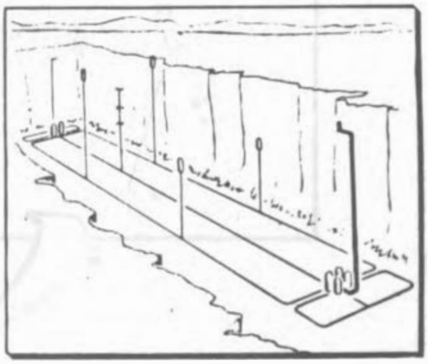


FIGURE 4

Initial OSD Guidance

- **INITIATE CONCEPT DEFINITION/VALIDATION**
  - **SIZE FOR 50 -100 MX OR EQUIVALENT**
  - **POST ATTACK ENDURANCE OF AT LEAST ONE YEAR**
  - **RAPID EGRESS DESIRABLE BUT NOT MANDATORY**
- **MILESTONE II FY 84**
- **IOC 1989**
- **PROGRAM PLAN JAN 82**

FIGURE 5

A Deep Basing Conceptual Configuration

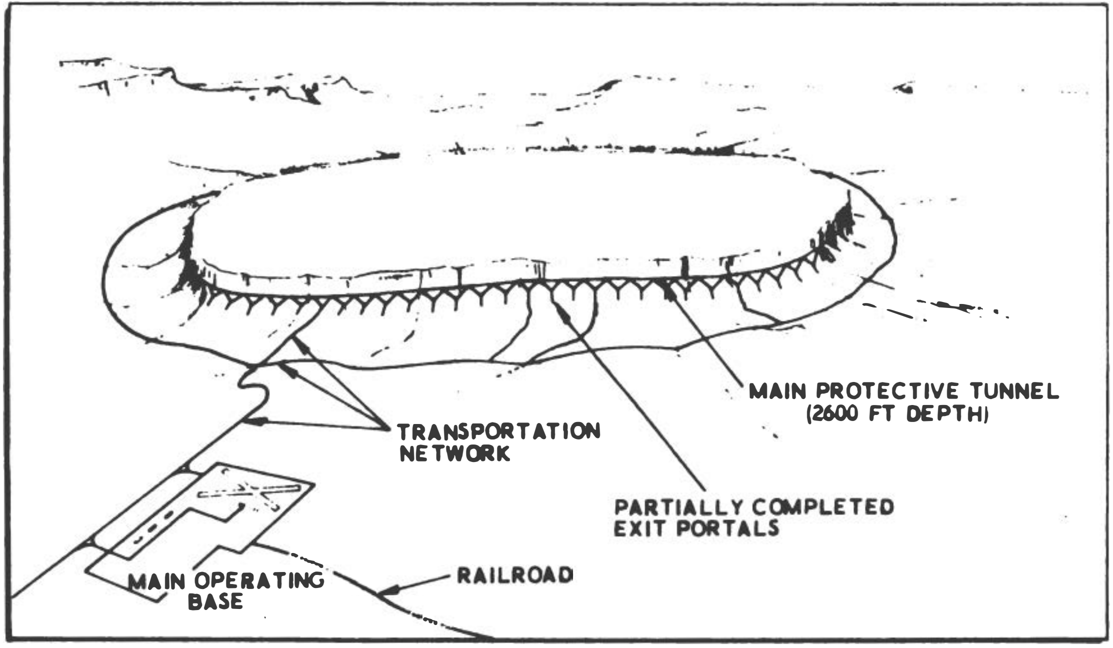


FIGURE 6

Deep Basing "History"

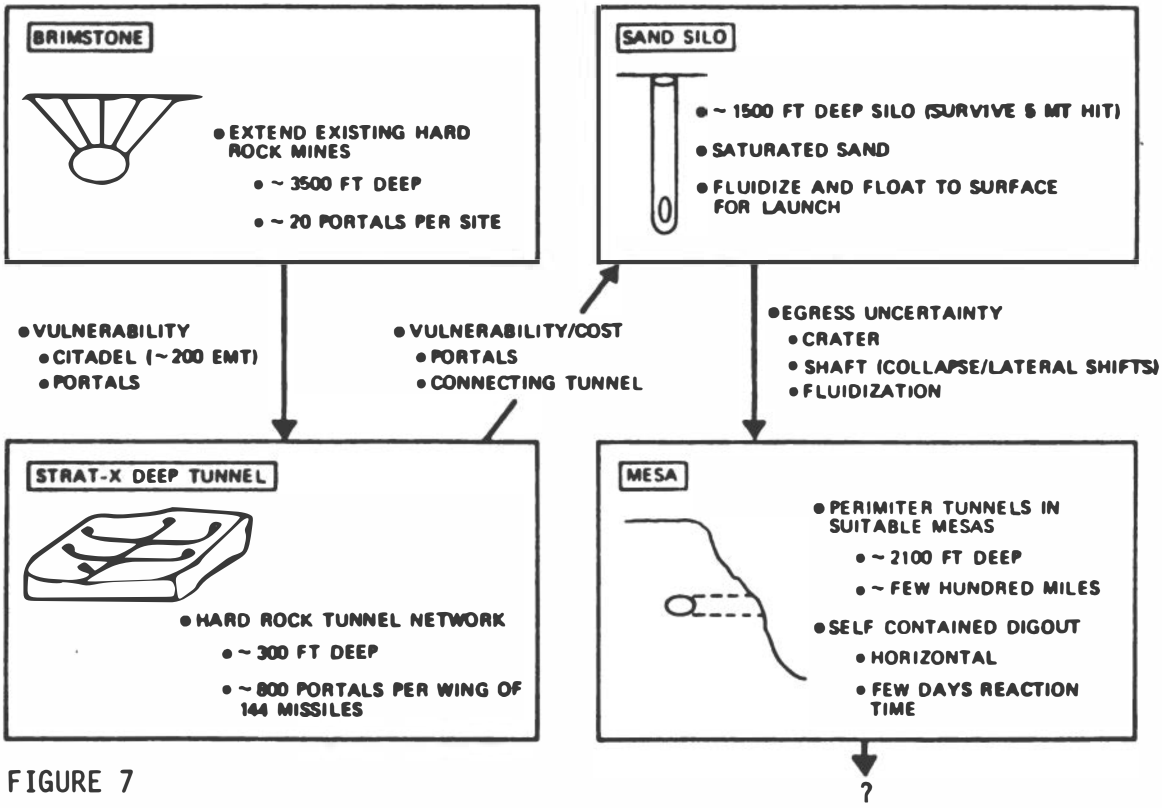
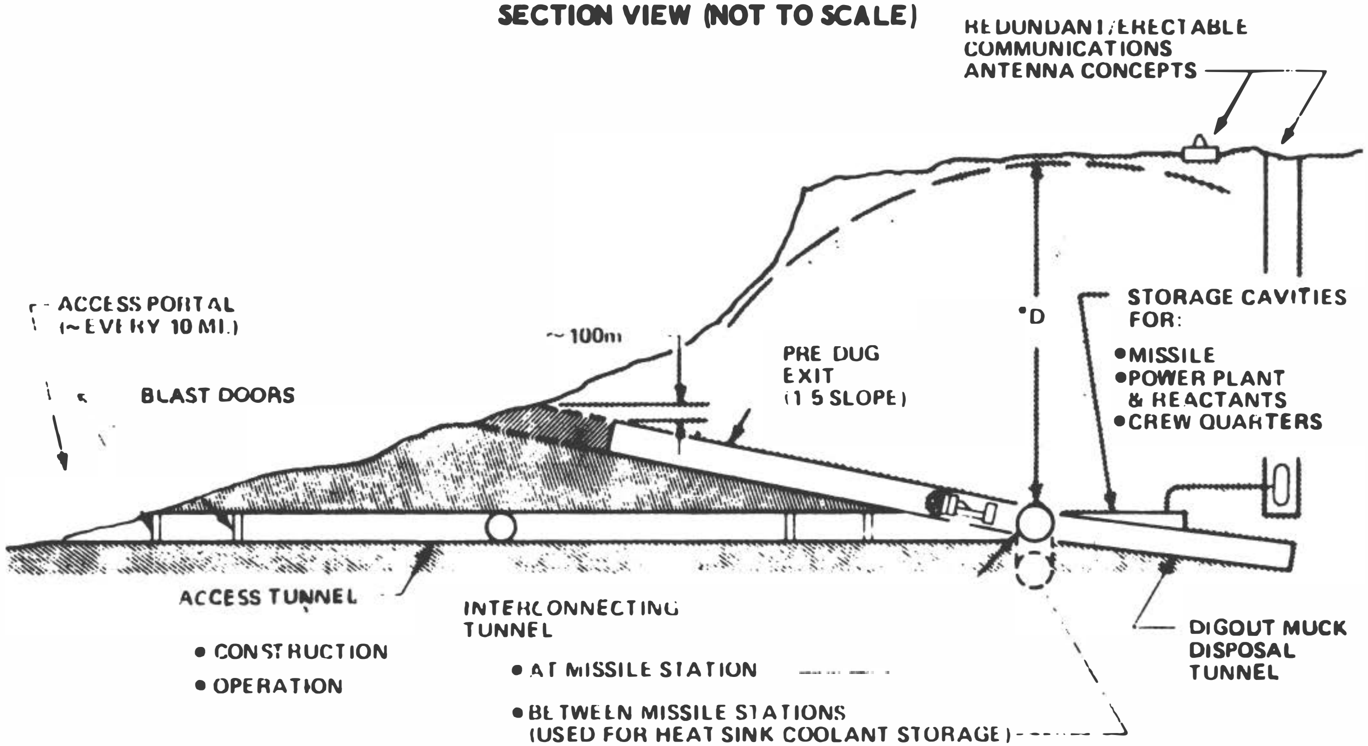


FIGURE 7

Mesa/Tunnel Concept

SECTION VIEW (NOT TO SCALE)



* FOR A PARTICULAR THREAT ESTIMATE SITING DEPTH D SELECTED FOR MIN. COST, TRADING WITH TUNNEL LENGTH & PROLIFERATION OF MISSILES AND RELATED ASSETS

FIGURE 8

Deep Tunnel Sand Dump Concept

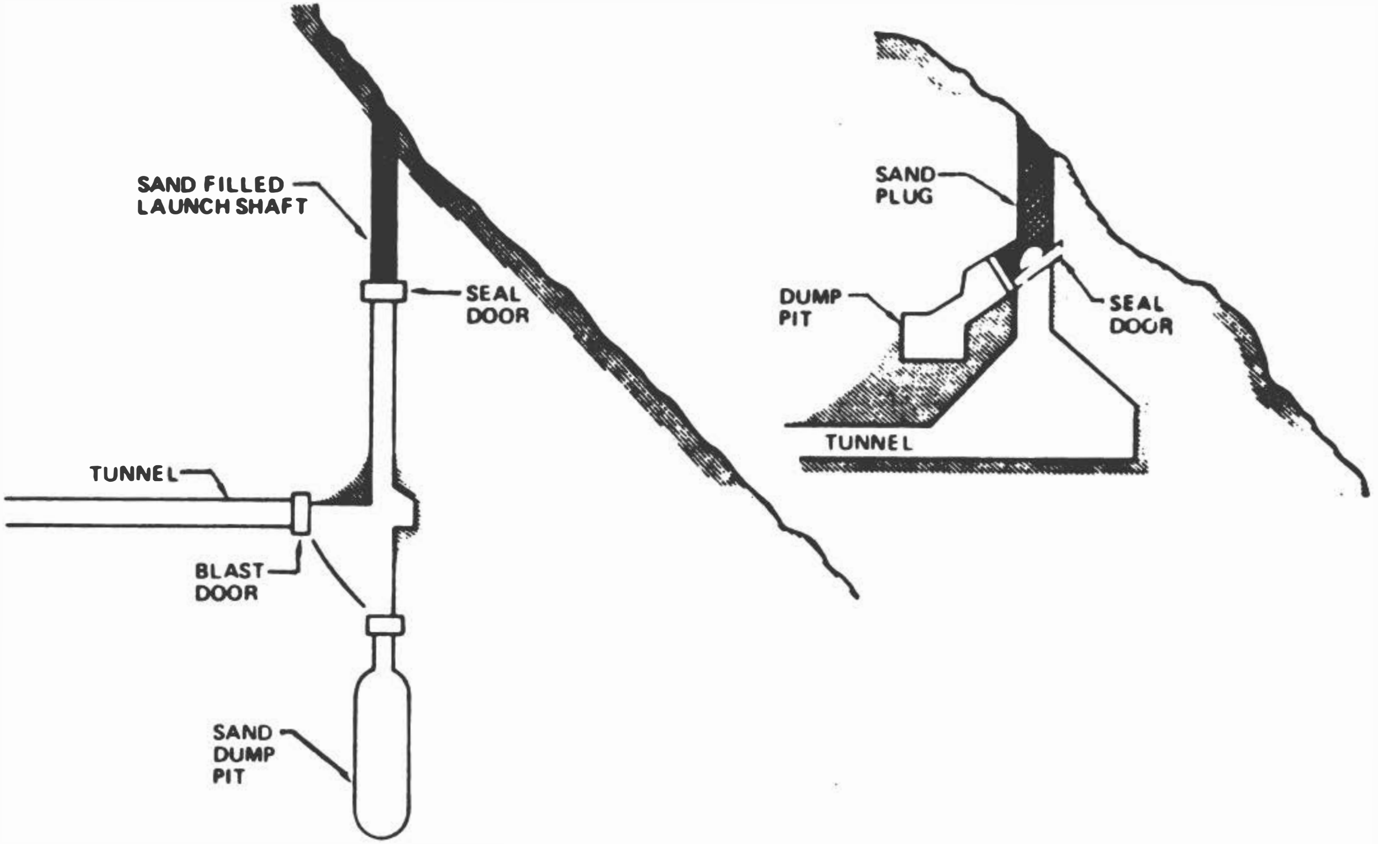


FIGURE 9

"Pencil-Pusher" Egress Concept

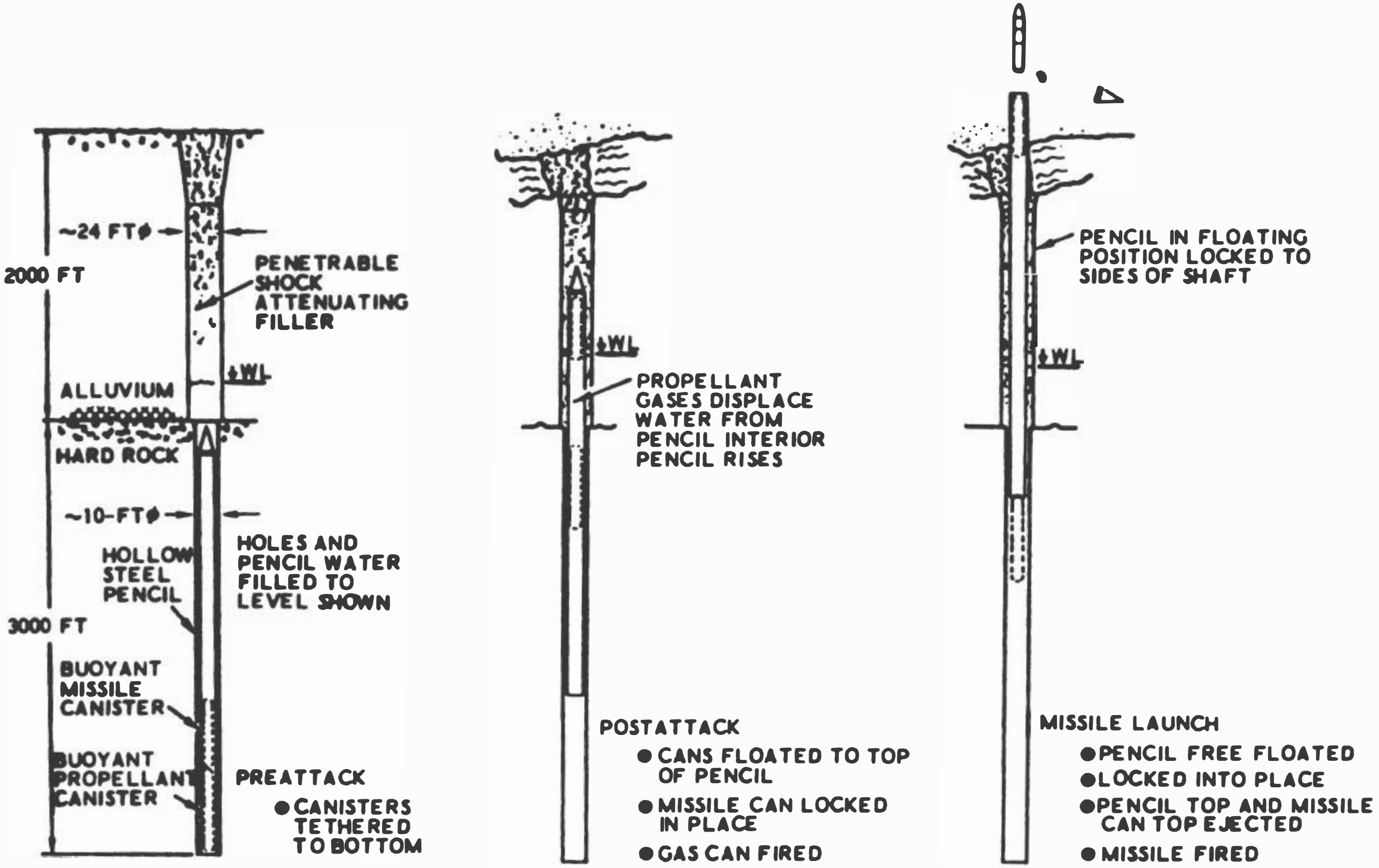


FIGURE 10

Deep Basing

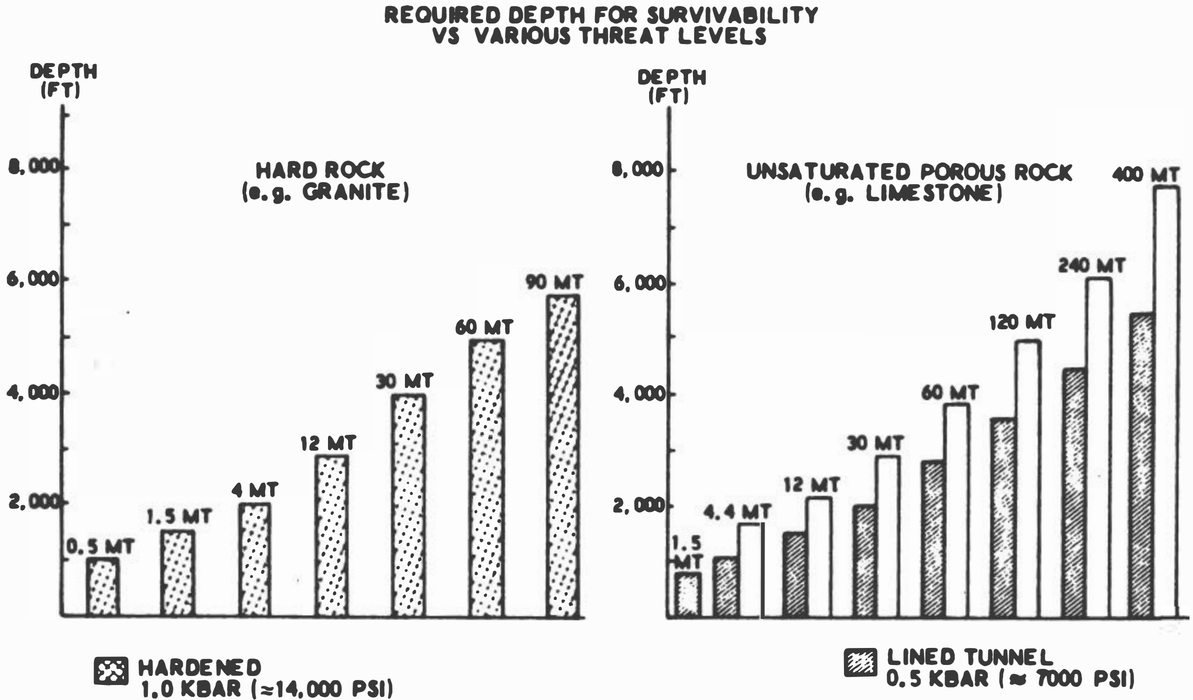


FIGURE 11

Potential Geologically Suitable Areas

FIGURE 12

Most Required Technology Exists

REQUIREMENT	EXPERIENCE
MAJOR UNDERGROUND EXCAVATION & CONSTRUCTION	MINES; SUBWAYS; AQUEDUCTS, HWY. & RAIL TUNNELS; HYDRO POWER PLANTS, NTS UGT COMPLEXES, CHICAGO STORM WATER SYS; NORAD CMCC; SITE R
ROUTINE UNDERGROUND CREW ACTIVITY	MINES; SUBMARINES, HYDRO POWER PLANTS, UNDERGROUND OFFICES & FACTORIES & WAREHOUSES; NORAD; SITE R
PROLONGED CREW CONFINEMENT	SUBMARINES, SPACE VEHICLES
CONTROL OF TOXIC CONTAMINANTS IN AIR	MINES; SUBMARINES; SPACE VEHICLES
WASTE HEAT DISPOSAL	NORAD CMCC; SITE R; SAFEGUARD

REQUIREMENT	EXPERIENCE
MUCK HANDLING & DISPOSAL	MINES, CIVIL/COMM'L TUNNELING
MEGAWATT SIZE FUEL CELLS	DOE/EPRI/CON ED/ UTC DEMO IN NYC
DEFINITION OF ATTACK ENVIRON	UNDERGROUND NUCLEAR TESTS
SURVIVABLE ROCK OPENINGS	UNDERGROUND NUCLEAR TESTS
SHOCK ISOLATION	MINUTEMAN, SHIPS, SUBMARINES
THROUGH EARTH COMMUNICATION	MINE RESCUE; UGT DATA TELEM (DISCUS THROWER, HUSKY PUP, MIGHTY EPIC); SANGUINE

FIGURE 13

Major Issues

- SYSTEM DEFINITION
    - UNDERGROUND CONFIGURATION
    - HARDNESS/VULNERABILITY
    - EGRESS/PLU
    - POWER
    - LIFE SUPPORT - CREW ENDURANCE
    - LAUNCH CONTROL, COMMUNICATIONS
    - HEAT DISSIPATION
    - SECURITY
    - OPS CONCEPT
    - LOGISTICS
    - MANNED VS AUTOMATED

FIGURE 14

Major Issues (Cont'd)

- SITING
    - TEST BED(S)
    - DEPLOYMENT AREA
- CONSTRUCTABILITY
- POSSIBLE FEASIBILITY TESTS
    - EGRESS
    - COMMUNICATIONS
    - POWER
    - HEAT SINK
- COST UNCERTAINTY
- ENVIRONMENTAL IMPACT ANALYSIS PROCESS
    - CONCEPT
    - LOCATION ALTERNATIVES
    - BASE COMPREHENSIVE PLAN

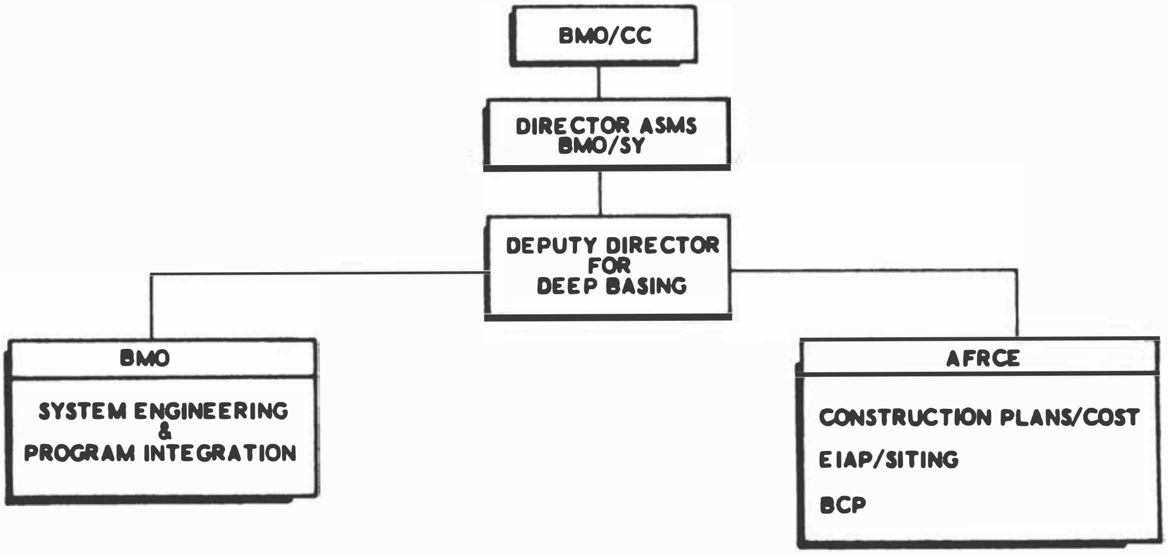
FIGURE 15

Deep Basing - Siting

- CRITICAL FACTOR
  - SURVIVABILITY
  - COST
  - SCHEDULE
  - ENVIRONMENTAL IMPACT
- IMPORTANT CONSIDERATIONS
  - GEOLOGICAL/TOPOGRAPHIC CHARACTERISTICS
  - WATER
  - TEMPERATURE GRADIENT
  - MUCK DISPOSAL
  - DEPTH REQUIREMENTS
  - PUBLIC VS PRIVATE LAND
  - PROXIMITY TO MILITARY BASES
  - ENVIRONMENTAL IMPACT
  - LEGAL, POLICY CONSTRAINTS

FIGURE 16

Deep Basing Team



OTHER PARTICIPANTS & INPUTS

HQ USAF --- POLICY GUIDANCE/DIRECTION
HQ AFSC --- POLICY GUIDANCE/DIRECTION
DNA ----- NUCLEAR EFFECTS & SURVIVABILITY
AFWL ----- SITING REQUIREMENTS, HARDNESS
SAC ----- OPERATIONAL CONCEPT
AFLC ----- LOGISTICS

FIGURE 17

Deep Basing - Preliminary Estimate

CONTRACT REQUIREMENTS FY82 – FY84

- SYSTEM SUPPORT
  - POWER
  - HEAT SINK
  - COMMUNICATIONS
- EGRESS STUDY & DEMO
- CONSTRUCTION VALIDATION
- SITE SCREENING
- SITE CHARACTERIZATION
- ENVIRONMENTAL IMPACT
- BASE COMPREHENSIVE PLAN

FIGURE 18

Advanced Development Program

MAJOR MILESTONE SCHEDULE

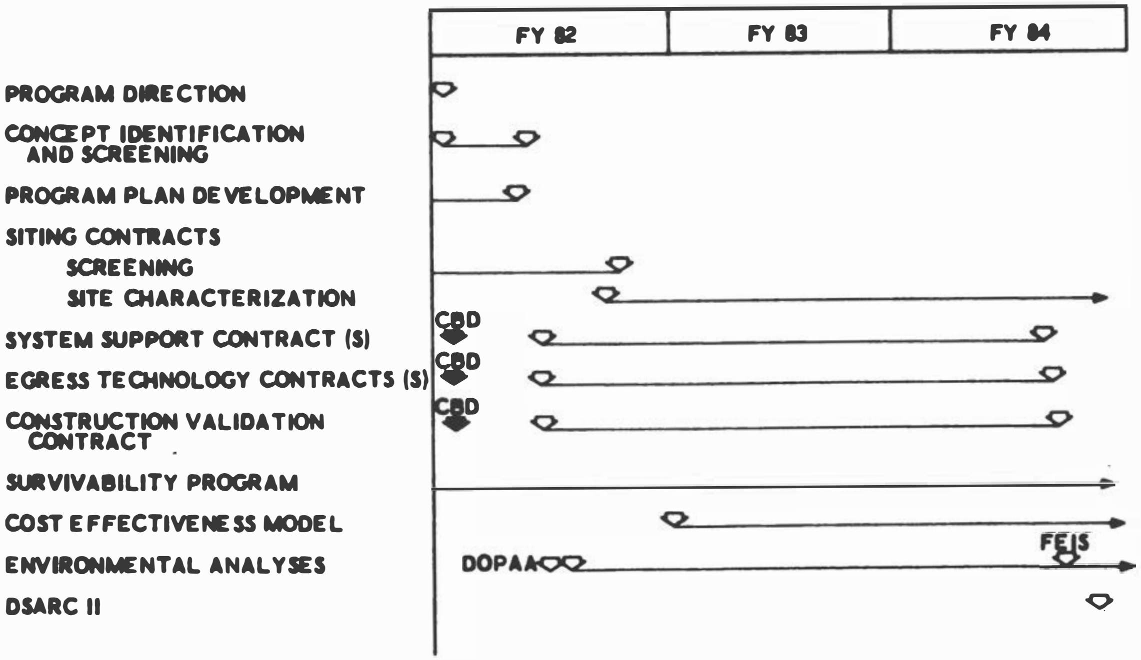


FIGURE 19

Work in Progress

- ORGANIZATION
- PROGRAM ACQUISITION
  - CONTRACT STRATEGY PAPERS
  - SOURCE SELECTION PLAN
  - BUSINESS STRATEGY PANEL
  - BIDDERS CONFERENCE
  - STATEMENTS OF WORK
  - RFP'S/TECH REQUIREMENTS DOC
  - PROPOSAL REVIEW TEAMS
  - ACQUISITION PLAN MODS
  - D&F
- FY 84 - 88 POM IMPUT
- PUBLIC AFFAIRS PACKAGE
- LIAISON WITH DNA & AFWL
- PMD DRAFT
- PROGRAM PLAN

FIGURE 20

Upcoming Events

5 - 6 NOV	U.S. NATIONAL COMMITTEE ON TUNNELING TECHNOLOGY
12 NOV	BRIEFING TO POTENTIAL BIDDERS
17 NOV	BUSINESS STRATEGY PANEL
30 NOV	RFP RELEASE
23 - 25 NOV	SMSG WORKING GROUPS
30 JAN 82	PROGRAM PLAN DUE TO OSD
APRIL 82	COMPETITIVE CONTRACT AWARD

FIGURE 21

Deep Basing - Summary

- EARLY STAGE OF DEVELOPMENT
  - SERIOUS PROGRAM
  - COMPRESSED SCHEDULE
- AIR FORCE NOW EVALUATING CONCEPT AND LOCATION ALTERNATIVES
- OPPORTUNITY FOR APPLICATION OF EXISTING, EMERGING AND NEW TUNNELING/MINING TECHNOLOGY

FIGURE 22

Deep Basing - What Next ?

- YOUR THOUGHTS WOULD BE HELPFUL
  - PRELIMINARY PROGRAM PLAN
  - CONTRACT APPROACHES
  - COST ESTIMATES
  - SITING CRITERIA/SCREENING
  - USE OF EXISTING UNDERGROUND SPACE
  - EGRESS
  - MECHANIZED MINING
  - CONSTRUCTION VALIDATION
- FUTURE INVOLVEMENT POSSIBILITIES
  - NEWSLETTER
  - MAGAZINE
  - ADVISORY GROUP
  - SPECIALIZED CONSULTING

FIGURE 23

Summary of Issues from TUCWG Meeting

JOSHUA L. MERRITT
Merritt CASES, Inc.
Redlands, California

SUMMARY: The meeting of the Tunneling and Underground Construction Working Group (TUCWG), which was held on 15 and 16 October at the Defense Nuclear Agency, was a precursor to look at some of the more critical problems and issues. Construction and siting were the major issues discussed.

The typical reaction voiced by most members of the group was that if we were required to, we could proceed now with construction of a facility at approximately 2,600 feet in depth in a sandstone, for example. The major considerations confronting us in that case would be the following:

- Schedule
- Cost
- Other key issues to be expected and how the may best be resolved by a program beginning now.

A feeling common among the members was that "digout," or egress, as it has been called, will have to occur at least in concept; we have to be prepared to egress after an attack.

The urgent needs and recommendations discussed included the following:

- Management organization
- Adequate staffing
- Definition of promising sites
- Configuration compatible with chosen site.

A small group had studied earlier the possibility of using underground space already in existence. The results of that study are included in this presentation. It was not an exhaustive study, but just a preliminary look at what may be available and useful.

During the meeting of the Siting Subgroup, the issue of digout, or egress, was discussed at length. A major outcome of this subgroup meeting was a preliminary basis for applying decision analysis techniques to the siting problem.

Several siting concept alternatives were discussed: mesas, ridges, and plains. Concepts were solicited for generally desirable site characteristics in terms of vertical relief, talus slopes, and other conditions.

Some possible schemes for solving the egress problem are discussed in this presentation, including methods for vertical, horizontal, and inclined egress.

In summary, it is important to point out that the problem of egress is not by any means solved. Inputs in this area are urgently needed.

We have given to your chairman, Dr. Cording, about 20 copies of the reports that were received as a result of the meeting on October 15 and 16. They will be available to you for consideration in your further deliberations.

The meeting on October 15 and 16 was merely a precursor to begin to look at some of the more critical problems and issues, and I would emphasize at the outset that it was only a two-day meeting. The first three-quarters of the first day was spent on construction. The rest of that day and the following day were spent on siting issues. Obviously, it has been a very brief consideration and certainly deserves a lot more consideration.

I should finally emphasize that the reports that you will receive, the 20 copies or so that we have, are listed as draft reports of the individual members of the working groups. Please look at them as drafts. Again, an awful lot of work needs yet to be done. I would emphasize, again, that this meeting is unclassified. Our meeting on October 15 and 16 was also unclassified, so that there is no classified information in any of those reports which will be available for your perusal.

Figure 1 lists the group that convened on October 15. The working group members are listed at the top, and there were a number of other attendees. The meeting was held at the Defense Nuclear Agency.

Figure 2 lists some of the meeting's conclusions. Perhaps I was a little too strong in calling this a "consensus." There are perhaps some items of consensus here. There are probably some items that might be further debated; I apologize for using the word "consensus." I think, however, it is important to note the typical reaction. I merely quoted Al Mathews in the typical reaction, but this reaction was also voiced by the other members that have provided a report. The reaction is that if we were required to proceed with the construction of a facility at, let us say, 2,600 feet in depth in (for example) a sandstone, there is no question that we could go do it. As Colonel Rule has indicated, the big issues are how quickly can it be done, what is the cost of doing it, and what are some of the other issues that might be resolved in the process?

Another item that was common among all of the written reports is that digout, or egress as it has been called here several times today, is something that needs to have a great deal of work, and as one of the persons on the committee has indicated, egress, as a matter of policy, will have to occur at least in concept. We have to be prepared to egress after an attack.

Some of the "urgent needs and recommendations" (Figure 3) are my paraphrases of the various reports that were received following the three-quarter day meeting. We touched on one of the questions that has been raised before, and that is the management organization and the adequate staffing of this very important program of tremendous magnitude. Other questions are also shown in the figure, and the final one is to define the properties of promising sites and then configure, or optimize a configuration, to be compatible with that site.

In response to a request of the Under Secretary of Defense for Research and Development back in early August, we convened a small group to look at what underground space existed and what the possible use of that space might be. Figure 4 shows some of the highlights of the conclusion. Some 80 mineral mines were identified from a preliminary inventory, and 35 of them had overburdens greater than 1,500 ft. Of that 35, 26 are currently operating, and there might be a problem of acquisition or perhaps, instead of acquisition, parallel use of the space. The four operating mines with vertical egress are indicated. The "8' × 10'" noted in the figure is the typical size of the opening; the 1,600 or 3,160 feet is the depth. Of the remaining nine existing openings, seven nonoperating mines are flooded, and the actual conditions of the underground space there are unknown. Two nonoperating mines are dry, as indicated.

The group looking at this problem—over a brief period of only two or three days—identified the fact that, of course, several other government agencies (one highlighted in the figure, the Nuclear Regulatory Commission) have investigated existing space for possible use for nuclear waste disposal. A third item from that particular study was that there are abandoned railroad tunnels that have the characteristics indicated; four in particular might be attractive in that they are in government-controlled public areas.

The final area that was identified was limestone mines. There was no effort to look at natural limestone caves within this very abbreviated study, but there are limestone mines in existence. There are a large number with numerous sizes of openings and naturally dry conditions. They may be weak, due to the room-and-pillar excavation that was used in these limestone and dolomite areas.

The recommended additional work to develop these data is indicated. I would emphasize again that this was primarily three people working for two to three days; it is certainly not an exhaustive study by any means. It was merely the first cut at what might be available and what might be useful. There is a potential for a lot more consideration in that area.

The Siting Subgroup of the Tunneling and Underground Construction Working Group (Figure 5) met on Thursday afternoon and then continued on Friday, October 16. The subgroup members are as indicated, and the other attendees of the October 16 meeting are listed at the bottom.

Obviously I lost my courage in calling the material in Figure 6 a consensus at this point. Again, the items of digout were of paramount concern, and the figure lists some of the things that Ron Heuer had to say about digout. I would emphasize that he indicates that obviously if we can go through soil or alluvium we certainly simplify one of the problems; there are machines that might go through that. At the same time, of course, because we would have to carry along continuous support for such a medium, we do not solve the entire problem by going through alluvium.

Jim Gould had an important item for consideration, particularly in view of the so-called "SUMS" involving the placing of missiles on small submarines which came up as part of the multiple protective shelter (MPS) considerations (Figure 7). He indicated that we might want to look at some of the Continental Shelf areas (possibly the United States territories under the Great Lakes could be looked at as potential siting areas as well). Although at the same time I must note that penetrating devices can more readily go into water than they can into rock, there may be some other advantages of locating off the Continental Shelf or under the Great Lakes.

Finally, from the Siting Subgroup (Figure 8), I am remiss in not identifying the source of this information: it was suggested by Gene Waggoner as a potential means of siting decision analysis techniques in a simplified way. In his report he gives a more complete decision analysis approach to looking at siting. He noted in his letter transmitting this material that Item 2 may immediately throw out a site if it is determined that the particular characteristics of that site make its ability to survive attack very doubtful. Even though one might go through a weighing of important parameters, one might single out an item, such as survivability. Since survivability is the name of the game regardless of how the site turns out otherwise, obviously if it cannot survive it would be eliminated from further consideration.

Now, to move to a different subject. The one perhaps that we are here for is to look at siting concept alternatives. I had the staff put together a complicated cartoon of things that you might wish to consider. We have heard a lot about mesas because mesas provide horizontal egress into the area both for construction as well as possibly for mining out after an attack. Figure 9 is intended merely to flag the fact that there are mesas. One example is Grand Mesa, Colorado. We have indicated in the figure that we wish to stand off somewhere between 2,000 and 3,500 feet, depending upon the type of rock that we might be in as well as the trade-offs of hardness with depth. We recognize that there may be several levels of talus slopes that might exist against the mesa, not only at different geographical locations, but even at the same mesa.

Configuration was intentionally left as a blob in Figure 9 because it could be vertical, it could be horizontal, or it could be a hybrid of horizontal and vertical. It could also involve a situation where we might have certain assets at a greater depth than other assets. Depending on the criticality and required hardness of those assets, we might want to put them at a greater depth and thereby provide them greater survivability.

Figure 9 gives one example of a ridge site: either side of Forty-Mile Canyon in Nevada. There is a fairly significant vertical relief there. There are many others throughout the country that might be possibilities; again, a blob is indicated for the configuration. We might have to go deeper into a ridge to make sure that we get our 2,000 to 3,500 feet of standoff distance between the nearest point on the surface and the facility, so that it may actually be, say, 4,000 feet below the local ridgeline. Dotted lines are used to indicate the possibility of various levels of talus slopes and alluvial fans adjacent to such a ridge.

The third possibility, of course, is to go into a plain, such as the basalt at the Columbia River Basin. We have indicated Washington near Fairchild Air Force Base, but, of course, the basalt extends further. As shown in Colonel Rule's earlier chart, it is also in Oregon. If located under a plain, we would have to have vertical egress systems as well as vertical shafts in order to mount the construction. Finally, we solicit your ideas or your concepts for what is a desirable site in terms of vertical relief, talus slopes, and other conditions.

Finally, I have a very complicated chart (Figure 10) that was put together just as we were rushing out. I should start with the punch line of "your concept": we really want your concept and ideas; what we are merely trying to highlight here are some off-the-top-of-the-head kinds of things that one might consider, and certainly by no means is it exhaustive. It suggests some thoughts that one might want to consider as you go into your deliberations on possible schemes for solving the egress problem.

First, we started with vertical egress, where we assumed that we mine out after an attack using a raise climber and using the main tunnel for muck disposal. The main tunnel for muck disposal may not be the most attractive thing, but that perhaps is a point of departure.

I should have mentioned the dashed line on the figure. The dashed line is to indicate that in this particular case, of course, we could be under a plain where we do not have any major vertical relief and would have to go into a vertical egress system.

The missile would have to carry with it everything that is required to take it out of the hole, assemble itself, get its initial alignment, and take off. There would have to be some sort of a chamber back into the plain or out into the plain that allows you to make the transition of that 70- to 100-foot missile.

As Figure 10 shows, in cartoon form, we could partially or completely predig the tunnel and backfill it with several alternative materials. The plug at the top would probably have to be significantly deeper than shown. As Dr. Linger has pointed out, if they actually knew the location of the egress point (we certainly must assume that they would know), it would then become a target. Consequently, the crater would come to perhaps a 300-foot depth and the plug shown might have to be more than 300 feet deep to ensure that it avoided the crater. With some of the materials with which one might backfill a predug egress way, you would still have to use a raise climber or a raise borer in order to get rid of the material.

Another possibility would be to use preset charges, not only to break up the plug at the top and possibly the bottom, but also the backfill, to break up the natural arches that are going to form as we try to have 2,000 feet of muck fall through the shaft; in this case, of course, we would not need a raise climber. I would hasten to add, however, due to electromagnetic pulse (EMP) effects—equivalent to the worst lightning storm you could imagine increased manyfold—protecting the charges from that sort of electrical transient may be difficult, but certainly it is something that could be investigated.

Also, there is the possibility of having a predug muck pocket at the base; in that case, of course, one could eliminate any need for providing conveying systems to get rid of the muck as it falls.

Finally, of course, is a possibility of using an offset vertical egress system.

Another consideration for egress is proliferation. Proliferation, however, is not very attractive because, as indicated this morning, we are talking about thousands of potential warheads to attack the triad;

thus we would need thousands of such openings, which is not cost-effective. Additionally, we could have a defense overlay to protect some openings.

Now, let me very quickly walk through the same sort of thing for inclined egress (Figure 11). Inclined egress would require a slope, of course, that would depend on the talus configuration. It does not appear as attractive to go out on the incline if you have to go all the way to the upper surface. The angle is a variable depending on the site, as well as perhaps some of the mechanization. Recognizing this, we can discuss the same sorts of possibilities as we did for vertical egress. I shall not comment further except to point out that one needs, of course, some sort of a door to assure that the muck goes into the muck pocket and then drop the door in order to get access to take the missile out.

For inclined egress, I would emphasize another possibility. If we can prove that we can get preset charges to survive EMP and other near surface effects, we could have preset charges on the slope providing there was no major talus slope. Preset charges could remove the top of the slope and other charges could remove the final plug such that we would get access passively to the surface.

Finally, Figure 12 shows horizontal or nearly horizontal egress. The cross-hatching which now appears on the talus slope indicates that the final opening would have to come out on a clean surface, not through the talus, although one could certainly come up with a scheme with a shield and full lining to go through the talus. We shall merely walk through the several possibilities for near horizontal egress.

In this case, blast doors might be an attractive addition, and I would mention that the Defense Nuclear Agency for years has used first a structure called a tunnel and pipe seal (TAPS) at the Nevada Test Site, which is designed for rather impressive overpressures and temperatures. More recently, they have used DACS (DNA Auxiliary Closure System) and variations of the DACS, which is a very rapidly closing blast door that can take very high temperatures and pressures. For near horizontal egress, we would excavate probably with a tunnel boring machine (TBM) or some variant of a TBM.

In summary, I would come back to my initial point: the three complicated figures (Figures 10, 11, and 12) merely lead up to the fact that the problem has not been solved by any means. We need your inputs very urgently in this area.

TUNNELING AND UNDERGROUND CONSTRUCTION WORKING GROUP
15 OCTOBER 1981 MEETING

WORKING GROUP MEMBERS:

E. J. CORDING, UNIVERSITY OF ILLINOIS
J. P. GOULD, MUESER, RUTLEDGE
R. E. HEUER, CONSULTANT
DON A. LINGER, HQ, DNA
A. A. MATHEWS, CONSTRUCTION ENGINEERING CONSULTANT
T. G. McCUSKER, TUNNEL CONSULTANT
J. L. MERRITT, MERRITT CASES, INC.
EUGENE B. WAGGONER, CONSULTING ENGINEERING GEOLOGIST
S. P. WIMPFEN, CONSULTANT

OTHER ATTENDEES;

K. N. BAKER, ANSER
J. K. BEATTY, TRW
LT. JOHN A. CALLAHAN, AFWL
CDR. T. J. DEEVY, HQ, DNA
JAMES F. DEVINE, USGS
MAJ. JOHN ELLEN, HQ/AF RD-M
JAMES W. FAY, TRW
PAUL R. FISHER, HQ, USACE
COL. E. D. FRANKHOUSER, HQ, DNA
MAJ. MICHAEL HAVEY, HQ/AF RD-M
K. B. MORRILL, MERRITT CASES, INC.
LTC JAMES K. MORROW, HQ, AFESC/RDX
PAUL P. ORKILD, USGS
MARK J. OSTROWER, NMERI
GENE PATTEN, USGS
LTC D. D. PIEPENBURG, HQ, DNA
M. A. PLAMONDON, AFWL
EUGENE C. ROBERTSON, USGS
R. ROHR, ANSER
LTC. C. RULE, BMO/EN
MAJ. RICHARD SADLER
AFRCE-MX/DEES
E. SEVIN, HQ, DNA
J. W. SEELIG, ANSER
MICHAEL J. SHORE
OUSDRE/S&TNF (O&SS)
ALAN J. SILVER, TRW
LEONARD B. STEPHENS
AFRCE-MX/DEEC
J. A. WOOSTER, BOEING
(OBSERVER)

FIGURE 1

CONSENSUS

FIRST MEETING OF TUNNELING AND UNDERGROUND CONSTRUCTION WORKING GROUP

15 OCTOBER 1981

TYPICAL REACTION (QUOTE FROM A. A. MATHEWS):

> EXISTING TECHNOLOGY IS ADEQUATE TO ASSURE THE SATISFACTORY COMPLETION OF ALL UNDERGROUND CONSTRUCTION NECESSARY FOR THE COMMISSIONING OF AN ACCEPTABLE DEEP BASING SYSTEM IN A SUITABLE GEOLOGIC SETTING.

HIGHLY PROMISING AREAS FOR IMPROVEMENT OF TECHNOLOGY (QUOTE FROM A. A. MATHEWS):

- CONTINUOUS CONCRETE LINING PLACEMENT BEHIND TBM
- AUTOMATIC APPLICATION OF SHOTCRETE
- VERY HIGH SPEED RAIL HAULAGE
- HIGH PRESSURE, PRE-COOLED VENTILATION AIR
- FRANGIBLE BACKING FOR SUPPORT ELEMENTS

DIG-OUT, ESPECIALLY THROUGH RUBBLE, NEEDS DEVELOPMENT/DEMONSTRATION, CONSIDER AS EXAMPLES (QUOTE FROM R. E. HEUER):

> DIG OUT THROUGH CRATER RUBBLE AT RATES OF 100 FT/DAY MAY BE POSSIBLE IF:
>
> I. DONE AT SLOPES OF LESS THAN 20%
> II. CRATER RUBBLE IS SOIL OR LOW STRENGTH ROCK
> III. CRATER RUBBLE IS ABOVE THE WATER TABLE
>
> CURRENTLY AVAILABLE TUNNEL BORING MACHINES (SUCH AS THE LOVAT MACHINE, FULL SHIELDED WITH DRAG BIT CUTTERS) AND TUNNEL LINING SYSTEMS (PRECAST CONCRETE OR STEEL RIBS WITH WOOD LAGGING) ARE LIKELY TO PROVE ADEQUATE FOR THESE CONDITIONS.

FIGURE 2

URGENT NEEDS/RECOMMENDATIONS

FIRST MEETING OF TUNNELING AND UNDERGROUND CONSTRUCTION WORKING GROUP

15 OCTOBER 1981

PROCEED WITH HIGHLY PROMISING AREAS FOR IMPROVEMENTS IN TECHNOLOGY

ESTABLISH A MANAGEMENT ORGANIZATION AND PROVIDE ADEQUATE STAFF NOW

STRUCTURE INNOVATIVE APPROACHES TO DEFINITION OF WORK AREAS AND CONTRACTING

DEFINE PROPERTIES OF PROMISING SITES AND CONFIGURE (OPTIMIZE) A SPECIFIC FACILITY FOR SITE

FIGURE 3

EXISTING UNDERGROUND SPACE FOR MISSILE OPERATIONS

PRELIMINARY INVENTORY OF 80 MINERAL MINES OF WHICH:

- 35 HAVE OVERBURDEN OF GREATER THAN 1500 FT.
  - 26 OF THESE ARE OPERATING: PROBLEM WITH ACQUISION?
    - 4 OPERATING MINES ARE DRY:
      - GREEN RIVER (WYOMING) - 8′ x 10′ AT 1600′
      - SAN MANUAL (ARIZONA) - 10′ x 12′ AT 3160′
      - SAFFORD (ARIZONA) - UNKNOWN AT 2300′
      - WHITE PINE (MICHIGAN) - 8′ x 14′ AT 1500′

      VERTICAL ACCESS
  - 7 NON-OPERATING MINES ARE FLOODED
  - 2 NON-OPERATING MINES ARE DRY:
    - LAKE SHORE (ARIZONA) - 8′ x 12′ AT 1800′
    - TUNGSTEN QUEEN (NORTH CAROLINA) - 10′ x 12′ AT 1700′

INVENTORIES BY OTHER GOVERNMENT AGENCIES:

- NUCLEAR REGULATORY COMMISSION INVESTIGATION FOR NUCLEAR WASTE DISPOSAL

ABANDONED RAILROAD TUNNELS:

- HORIZONTAL ACCESS
- EXISTING TUNNEL SUPPORT
- 4 LOCATED WITHIN GOVERNMENT CONTROLLED PUBLIC AREAS:
  - CASCADE TUNNEL (WASHINGTON)
  - ALPINE TUNNEL (COLORADO)
  - HAGERMAN TUNNEL (COLORADO)
  - ATLANTIC-PACIFIC TUNNEL (COLORADO)

LIMESTONE MINES:

- LARGE NUMBER AND NUMEROUS SIZES OF OPENINGS WITH NATURALLY DRY CONDITIONS
- WEAK DUE TO ROOM AND PILLAR TYPE EXCAVATION METHODS

RECOMMENDED ADDITIONAL WORK TO DEVELOP THESE DATA FURTHER:

- EVALUATE HARDNESS OF OPENINGS
- INVESTIGATE ABANDONED RAILROAD TUNNELS
- INVESTIGATE WORK DONE BY OTHER AGENCIES

FIGURE 4

SITING SUB-GROUP
TUNNELING AND UNDERGROUND CONSTRUCTION WORKING GROUP
16 OCTOBER 1981 MEETING

SUB-GROUP MEMBERS:

PAUL R. FISHER, HQ, USACE
J. P. GOULD, MUESER, RUTLEDGE
DELON HAMPTON, DELON HAMPTON & ASSOCIATES
R. E. HEUER, CONSULTANT
DON A. LINGER, HQ, DNA
J. L. MERRITT, MERRITT CASES, INC.
EUGENE C. ROBERTSON, USGS
EUGENE B. WAGGONER, CONSULTING ENGINEERING GEOLOGIST

OTHER ATTENDEES:

J. K. BEATTY, TRW
LT. JOHN A. CALLAHAN, AFWL
JAMES W. FAY, TRW
WES MANN, TRW
K. B. MORRILL, MERRITT CASES, INC.
LTC JAMES K. MORROW, HQ, AFESC/RDX
PAUL P. ORKILD, USGS
MARK J. OSTROWER, NMERI

LTC D. D. PIEPENBERG, HQ, DNA
M. A. PLAMONDON, AFWL
LTC C. RULE, BMO/EN
MAJ. RICHARD SADLER, AFRCE-MX/DEES
MICHAEL J. SHORE, OUSDRE/S&TNF (O&SS)
ALAN J. SILVER, TRW
LEONARD B. STEPHENS, AFRCE-MX/DEEC
J. A. WOOSTER, BOEING (OBSERVER)

FIGURE 5

QUOTE FROM R. HEUER

DIG OUT.

SELECT SITE SO THAT POTENTIAL CRATER RUBBLE TO BE PENETRATED DURING DIG OUT IS:

I. THROUGH LOW STRENGTH ROCK (2000 PSI OR LESS) OR SOIL (SUCH AS DESERT ALLUVIUM).
II. ABOVE WATER TABLE (WANT LOOSE PERMEABLE, RUBBLE TO BE DRY, NOT FULL OF WATER).
III. LOCATED TO PERMIT DIG OUT AT RELATIVELY FLAT INCLINATION:
  (A) PREFERABLY LESS THAN 3%, AMENABLE TO RAIL HAULAGE
  (B) POSSIBLY UP TO 20%, USING RUBBER TIRED VEHICLES WITH PROBABLE RESULTING SLOWER ADVANCE, HIGHER ENERGY REQUIREMENTS, GREATER PROBLEMS WITH POLLUTION OF BASE ATMOSPHERE, ETC.
IV. LOCATED TO PERMIT DIGOUT INTO STEEP SLOPE
  (A) LESS RUBBLE ACCUMULATION.
  (B) GREATER LIKELIHOOD OF FAVORABLE GROUNDWATER TABLE.
  (C) REDUCED DIG OUT DISTANCE.

QUOTE FROM A. A. MATHEWS:

SITING NEEDS.

DESIRABLE GEOLOGIC, TOPOGRAPHIC AND GEOGRAPHIC CRITERIA SHOULD BE IDENTIFIED AND ALL POSSIBLE SITES MEETING THE MINIMUM STANDARDS SHOULD BE LOCATED. THESE SELECTIONS CAN THEN BE CLASSIFIED IN ORDER OF PREFERENCE.

FIGURE 6

QUOTE FROM T. McCUSKER:

EFFECT OF GROUND TYPE:

PRODUCTIVITY -- POTENTIAL RANKING: TUFF, LIMESTONE (MASSIVE, NO GYPSUM), SCHIST/GNEISS, BASALT, GRANITE, METAVOLCANICS WITH HIGH HORNBLENDE CONTENT

BEHAVIOR UNDER BLAST EFFECTS

SHOCK ISOLATION

CONSTRUCTION METHODS

QUOTE FROM J. GOULD:

A SCHEME THAT COULD BE CONSIDERED IS BASING ON THE CONTINENTAL SHELF WITH APPROACH TUNNELS FROM LAND ACCESS POINTS. COASTAL PLAIN SEDIMENTS ALONG THE MID-ATLANTIC BETWEEN THE HUDSON RIVER CANYON AND SOUTH GEORGIA COULD PROVE FAVORABLE. THEY INCLUDE HARD CLAYS AND CALCAREOUS SEDIMENTS WITH VARIOUS DEGREES OF CEMENTATION. IT IS POSSIBLE THAT LAYERS IN THE COASTAL PLAIN THAT WOULD PRESENT DISTINCTLY FAVORABLE SOFT GROUND TUNNELING CONDITIONS COULD BE SELECTED. FOR EXAMPLE, IN COOPER MARL IN CHARLESTON, S.D., TUNNELS 8 FEET IN DIAMETER WERE EXCAVATED BY A LOVATT MACHINE ADVANCING AT THE RATE OF ABOUT 160 FEET IN AN 8 HOUR SHIFT WITHOUT TEMPORARY OR PERMANENT SUPPORT. OBVIOUSLY, EGRESS FOR A DEEP BASE IN THE CONTINENTAL SHELF WOULD REQUIRE SPECIAL FACILITIES, INCLUDING INSTALLING A COMPRESSED AIR LOCK AND THE LAUNCHING OF MISSILES IN SOME FASHION SIMILAR TO THAT FROM A TRIDENT SUBMARINE. WE, OF COURSE, HAVE NO IDEA IF SUCH AN ARRANGEMENT COULD DEVELOP INTO A PRACTICAL REALITY, BUT AN UNDERWATER HARDENED SITE COULD ELIMINATE MANY OF THE PUBLIC PROBLEMS OF LAND SITES.

FIGURE 7

DRAFT

Figure 1. Example of Objectives and Attributes

Objectives	Subobjectives	Attributes	Weight	Score for Site X on Attribute a_i
1. Provide quick egress	Maximize speed of tunneling in competent rock	a_1 (specific rock properties)	w_1	s_{x_1}
	Minimize amount of rubble to be penetrated	a_2 depth available and angle of cliffs	w_2	s_{x_2}
2. Survive the attack	Minimize penetration of surface	a_3 thickness of cap rock	w_3	s_{x_3}
	Maximize rate of shock attenuation	a_4 thickness of dry porous rock or alluvium	w_4	s_{x_4}
3. Endure while waiting	⋮	⋮	⋮	⋮
4. Maximize ease of construction	⋮	⋮	⋮	⋮
5. Provide locations acceptable to the public	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮
n		a_n	w_n	s_{x_n}

Overall score for Site X = sum of (score times weight) for each criteria

FIGURE 8

SITING/CONCEPT ALTERNATIVES

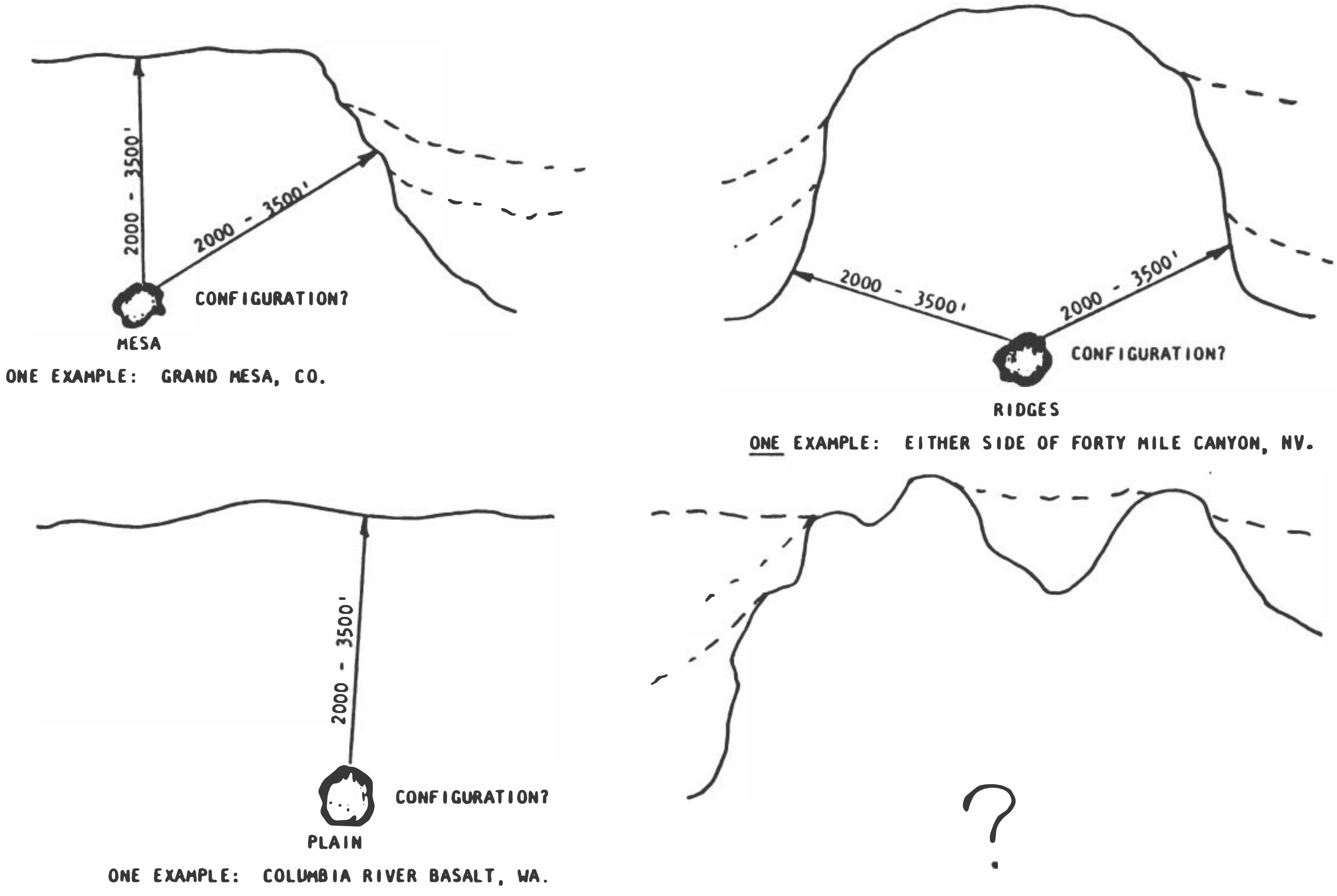


FIGURE 9

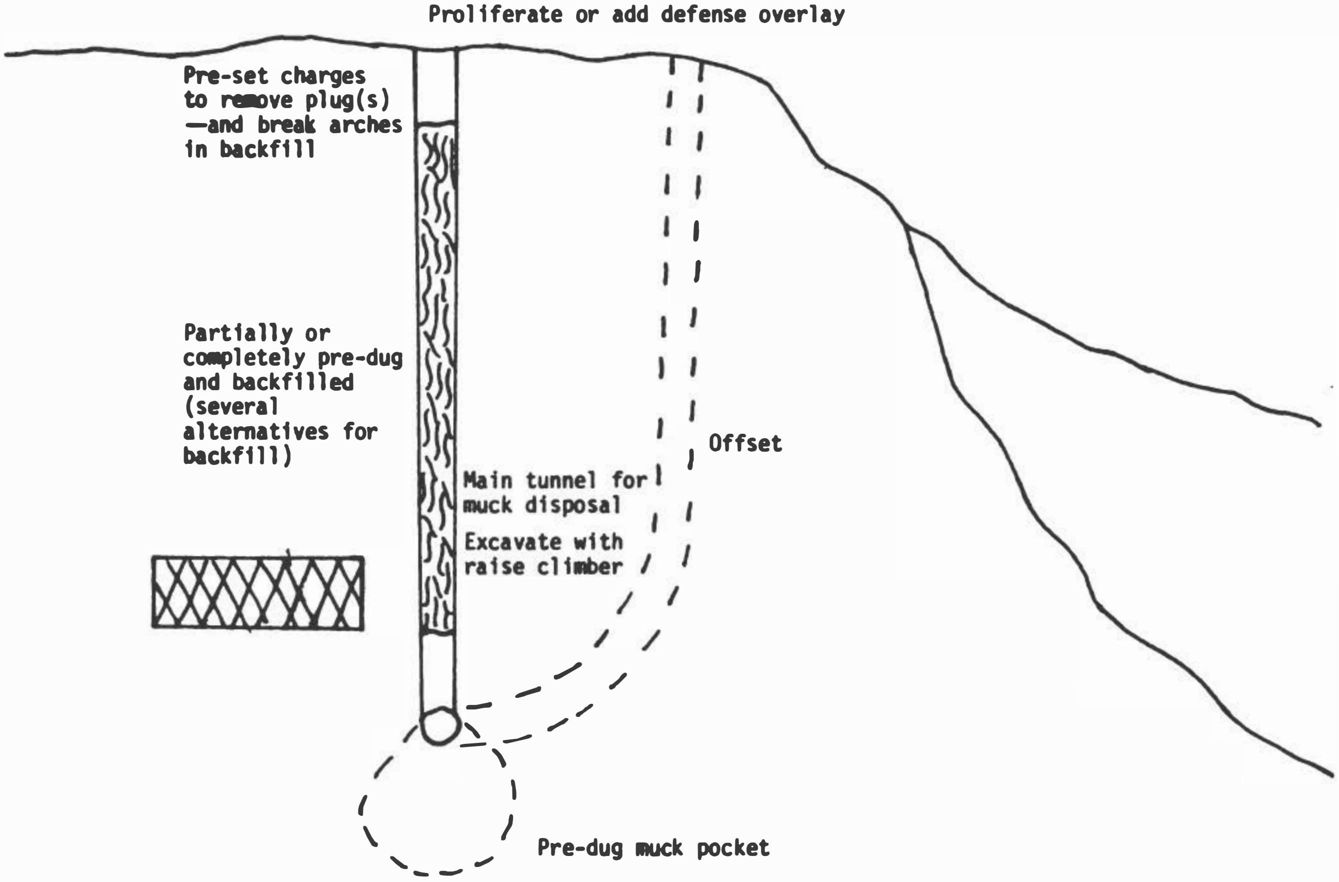


FIGURE 10 Possible scheme for vertical egress (composite of individual overlays).

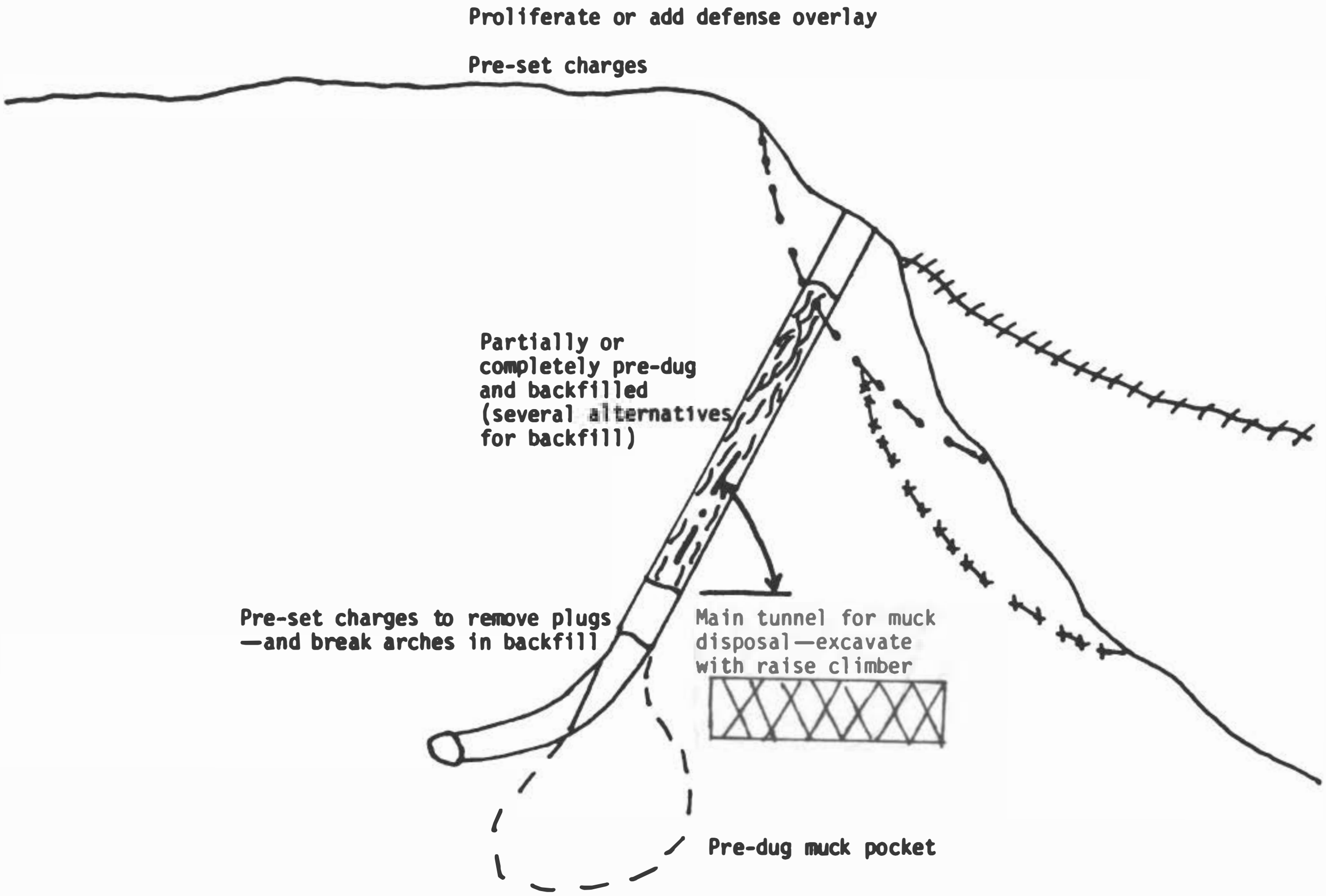


FIGURE 11 Possible scheme for inclined egress (composite of individual overlays).

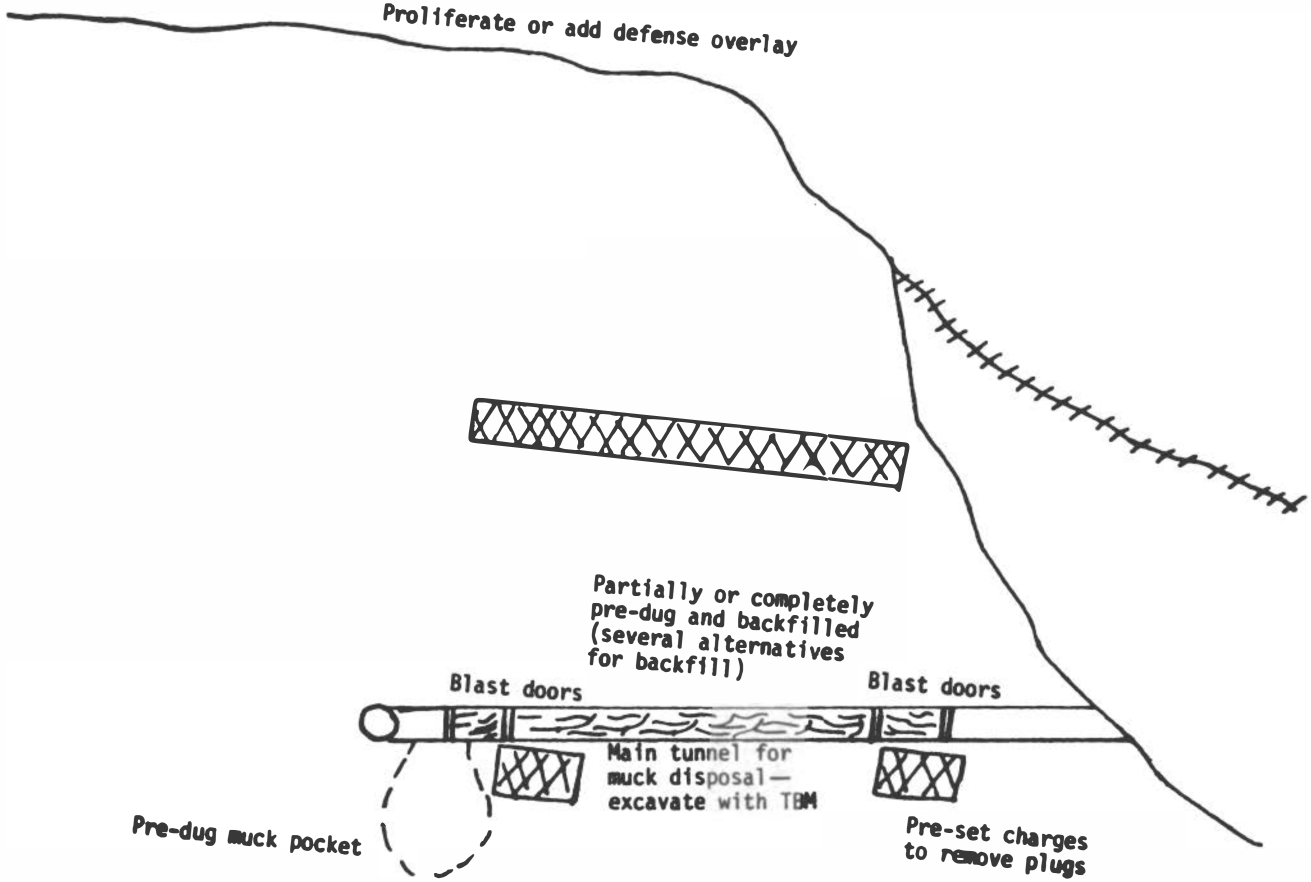


FIGURE 12 Possible scheme for horizontal, or nearly horizontal, egress (composite of individual overlays).

General Discussion of Egress Issues

SPEAKER: Is it a given here that in considering the egress alternatives we will have knowledge of what has happened on the surface, in other words the extent and depth of craters?

DR. LINGER: That is one of the things that has been proposed. There are a number of rubble zones and craters at the Nevada Test Site. We could go out, presumably within the next six weeks, two months, five months, or whatever is required, and view remote detection schemes for finding out just where is a rubble zone and what is its extent.

SPEAKER: We will assume that we will know where when we are planning direction of egress?

DR. LINGER: Not necessarily, because we could only assume that if what I just outlined proved to be a viable technique, that is if we could reliably predict where the crater was and—

SPEAKER: I am addressing myself to something else. After the attack will you know where the—

DR. LINGER: I think what you are saying is which egress to come out because of what happened on the outside, and I don't think that you can really assume that you will know. I don't know.

SPEAKER: Can we assume that you can talk to the outside and they can talk back?

DR. LINGER: That is right. I think that is something that you can assume.

SPEAKER: This 70-foot long missile is—

DR. LINGER: It is 100 feet long. Diameter is what you—

SPEAKER: At any rate you lay it down horizontally, and then does it fire off or do you walk it out to the end of the mountain and then it fires off?

DR. LINGER: It will come out and erect and fire itself or it would come out and fire. I don't think it would fire in the tunnel. It would have to come to the end.

SPEAKER: How do you walk it out? Are you going to lay a rail in this tunnel?

DR. LINGER: Therein lies a problem. How does one get it out? I don't really know. I am not sure that anybody does. Carl will lend some light to this.

LT. COL. RULE: With the multiple protective shelter system the means of launches is kind of like in submarines. We have a canister—a metallic canister or some form of hard structure in which the missile is in place. That, in the old concept, would move outside of the shelter area and erect up to a vertical position, and then there would be a gas that would form—either steam or a hot gas—to eject the missile from the canister. The missile would ignite once it was clear of the canister, but we would have to worry about putting that canister on wheels or transport of some type in its underground complex, to get through the egress, to break the ground, and then to be able to get to a kind of near-vertical attitude and launch.

SPEAKER: Does that have a firm foundation? When you get it out, you have to tip it up, and it has got to not tilt?

LT. COL. RULE: You would like to have it stable, yes, sir.

SPEAKER: So all the supports and everything you erect have to be outside the limits of that canister and still be capable of supporting the weight of the canister?

LT. COL. RULE: That is correct. You have a tremendous moment arm, you know, getting from the horizontal to the vertical, but that has been worked up. It is an engineering problem that has been worked out for the multiple protective shelter system.

SPEAKER: That would have to be done in the rubble zone?

LT. COL. RULE: You have to get through the rubble zone and then be able to erect it after you have egressed.

SPEAKER: Before the Russians spot you on the ground.

SPEAKER: Jay, can it then guide itself from either side of the mountain? If you go out either way it takes it from there; you just get it up in the air?

DR. MERRITT: Conceivably, of course, if one went through the rubble zone with some sort of aligning system the canister could be anchored within that lining system. It would not have to actually expose itself on the surface and erect itself from the rubble zone. It could be directed from the lining and ejected by steam or otherwise.

One other point. This is not my field, but I have been told by those in missile design that the interstages and the pressures implied by hot launch within a tunnel are such that you don't want to try to tackle that problem. You have to canisterize the missile such that it is a cold launch up to some point and then hot launch outside of that environment.

DR. LINGER: Good question. As Colonel Rule said, the MX is designed to come out, erect itself, cold launch, and then fire.

SPEAKER: I had a question on the Mesa concept. You know everything seems to be the attenuation of the tunnels of the central control system for all of this underground, based on numbers we will use like one direct hit. But if you have a Mesa system with five or six tunnels then this whole thing has to be able to withstand—what?—half a dozen direct or indirect hits over a two-day period?

DR. LINGER: I would go back to Dr. Sevin's chart which showed the depth to which you had to go to survive, was it half a kilobar or one kilobar? Did you see at the bottom what he had for the threat? Did he have 800 megatons which would have to be delivered? You would have to deliver those in packages and have them all go off at the same time.

SPEAKER: Is there any return, either repeatedly hitting the same place?

DR. LINGER: The Colonel just mentioned that, and it may apply to what you are asking: whether or not somebody would keep repeatedly hitting the rubble zone to try to dig you out and—

SPEAKER: No, that is not my question. We saw the experiments of half a kilobar from one side, and what I am thinking of is that those tunnels may have to withstand one or two blasts from different directions over a period of time?

DR. LINGER: Yes, and a rather large weapon yield altogether.

SPEAKER: It seems that the chamber to tilt this thing down or turn it around is going to be crucial. You would have to build that with skilled miners before the shooting starts because you are just going to have soldiers in there to do the rest of it.

DR. LINGER: This would be complete in itself. That is, this system would be complete with the necessary radius and size to maneuver the missile for each of the egress and each of the maintenance and operation locations. As each section is completed, it would be complete in itself.

SPEAKER: A variation of Wayne's question this morning about what are the Russians doing. On the basis of a feat being better than a theory, the Swiss and the Swedish have long been involved in the psychology of burying everything and going deeper. Do we have knowledge or is that not even worth looking at or is that none of our business at all?

DR. LINGER: I don't think we could discuss it at this security level. All I can say is Dick Robbins is coming in tomorrow and just ask him about his two machines which are over there. Five years ago he gave them the plans for his machine, and they went right back home and built one, and they have not got one of their machines to work yet. So, anyway, I don't know what they are doing. All I know is I think they have got bigger problems than we do.

SPEAKER: I think we are all assuming something here that has not been said so far, and that is that the people in the tunnel will not be deafened so they will be unable to hear orders and that they won't be injured by the shock. Is that a viable assumption?

DR. LINGER: Yes, and one thing that Joe LaComb said when he showed his movie was that the tunnel survived, but it indicated that it would of necessity have to be further protected inside for personnel and equipment, and I think he made that statement, and I think that is a very good statement.

SPEAKER: I am concerned about the noise levels as well as the physical injury.

DR. LINGER: I am sure that the noise level problem has got to be addressed.

SPEAKER: I have one other question somewhat in that same line. There was some discussion about heat dissipation at certain depths after the blast, but I heard nothing here about radiation when you remove this rubble. What occurs at that point?

DR. LINGER: I think the radiation problem, because of the automation of the missile as it comes out and erects and cold launches, is not a problem. I mean it is a solvable problem. I think it is a solved problem.

SPEAKER: Then those people that remove the rubble are expendable, right?

DR. LINGER: No. That is one reason why I think that all of the discussion has focused on TBMs, you know, that it is assumed that egress or mining out would be as automated as possible.

MR. LA COMB: I don't believe the radiation will be a real problem because it would simply be, even if we had a horizontal surface, it would be tied up mostly in blast funnels, which might be two, three, to four feet thick that you could handle by shielding it out. I don't think it would be a significant problem.

SPEAKER: You still have to dispose of it. You would be hauling your muck or your radiation muck down into the heart of the system.

DR. LINGER: You mean the egress? You are making an assumption that you are going to haul the muck back down and not drop it in a pit.

SPEAKER: Even if you drop it in the pit, it will go into the pit but it is still going down into the mountain.

DR. LINGER: Yes, but I think that is after the attack.

SPEAKER: The missile will egress, erect, and fire off. You know you are going to have to have a hardened slab therefore to do that. Then the egress takes place, you are going to have a lot of muck lying around on that slab, too. You may not be able to do it without some actual manpower out there to facilitate actual firing. Once it comes out you have some of the radioactive muck that is bound to come back inside or fall around it. It will get back into the hole it came out of.

DR. LINGER: As Joe LaComb said, I don't think the activity in that material that is going to come back down is going to be that hazardous, and I think that that is one of the drivers in trying to get the egress out at a slope where it can fall away on the outside, where you don't have to dig through what is otherwise deposited broken rubble. One of the advantages of the horizontal or near-horizontal egress out through a rock slope is the fact that you won't have this rubble lying there to worry about handling manually.

SPEAKER: The problems of egress due to rubble, radiation, and other things that have been cited lead me to harbor the idea that the storage of a single missile should be in a corkscrew, convoluted type of opening where you could have it on rail and of a diameter so that the missile could be lowered to whatever point you want and a multiplicity of openings going out so that if one gets rubblized you have got four or five others.

DR. LINGER: That is exactly the point of this kind of system, that the egress can be chosen. You mightn't know exactly what the situation was outside at this egress point but you would have an opportunity to go out through multiple egress points, all of which would be unknown to the enemy and all of which would be far enough apart so that in fact it would be impossible for him to cover that entire area with the kind of rubble that we are worried about.

SPEAKER: It would seem to me that the military had better make it policy that these guys are constantly digging tunnels, because even with trained tunnelmen we cannot always achieve the kinds of rates that these policies are—so they had just better dig holes in that mountain all the time.

DR. LINGER: Actually what you are saying, and what I am sure all the mining contractors like Traylor will reemphasize, is that once you get them going you might as well keep them going because that is when you get your production. I think that a point that should be made is that starting with a relatively small system and constantly expanding is ideal for getting the ultimate system you want and absolutely necessary for the operational capacity of the machine and men. That is what you are saying. You have got to keep them going to keep them tuned to that.

SPEAKER: They have got to know how to repair that TBM. They have got to know all this stuff.

DR. LINGER: That is a damn good point, and it is a point that should be made because what it says is don't build the whole thing and have the machines sitting down there. Keep building it. Those are the kinds of points, I think, that are important.

SPEAKER: I have heard comments about retaining communications, through-rock communications, and so forth. Have any thoughts been given at this point to maintaining ventilation? If the main tunnel is blasted shut—

DR. LINGER: Yes, you have got a problem. You don't want to mine in the wet area and yet on the other hand you are going to have to have water, and you are going to have to have some heat dissipation medium. Obviously water would be the best. So, you are between a rock and a hard spot, and the best siting is probably that that in fact has perched aquifers that do replenish themselves and can be used as heat sinks, and that has got to be a driver in the siting.

SPEAKER: Why is it we have to leave so much material between the point of egress and where the missile is going to be if we are going to have to do some sort of mining? Isn't it possible to have some sort of mechanical stopper system so that one of them might be hit and damaged, but there would be so many horizontal points of egress that you have lots of options to follow? What you are really trying to do is prevent damage to the entire system by a hit on one of these points of horizontal egress, and you have other options open for firing missiles.

DR. LINGER: So you have a lot of potential egresses all of which go closer to the face than you would go for secured hardness, some of which you may get wiped out, and that is an alternative, and that is an alternative I am sure that will be considered, because it gives you the multiple egresses and it gives you a quicker out, than if you are at 2,000 feet to bore out.

SPEAKER: It, also, cuts down on a lot of the mining that might be required in circumstances like that.

DR. LINGER: Yes, but they cannot go close enough so that the Russians can identify where they are.

SPEAKER: But that is a parameter of the system, according to some of the people I heard talk, that we have to assume that they know everything about the system to start with.

DR. LINGER: That I think was stated at the onset. Whether they would know the exact location of the egress, these blind egresses, I don't think that was intended to cover that. I am not sure.

SPEAKER: Could we get clarification of that? It can affect the whole concept.

DR. LINGER: The egress won't go to the surface. They would go some distance from the surface, and in the discussions I have been in on, it is assumed that in fact they will not know where those egresses are. They may know where the ingress is, you know, where you are taking things in. They will certainly know where you are bringing the muck out because there are going to have to be multiple egresses for the muck, but they probably would not know. I think you could assume they would not know.

SPEAKER: I think it is fair to comment that the multiple-aim-point concept of digging the tunnels near the surface or all the way out, regardless if you try to harden them or put blast doors or something to shut them up, has been shown to be really not the right way to go because for every tunnel we dig all they have to do is add one more MIRV and it becomes cheaper for them to add a MIRV than for us to dig a tunnel, and that has been the downfall of the current shelter program in the past. That is why we tried to go to a totally benign environment until we have to start showing our hand and at the same time protect ourselves.

DR. LINGER: And to translate—"No, they won't know where those egresses are."

SPEAKER: I suggest that one way in which you can preserve the locational uncertainty of the egress stub tunnels, if you don't take them all the way to surface, is simply to set them in random directions without any survey work ever being done.

DR. LINGER: From some of the tunnels I have been in I am not sure even if you told them that there was a survey and gave it to them that they would know where they were coming out.