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Archaeological Data as a Basis for Repository Marker Design

Technical Report

October 1982

Maureen F. Kaplan

The Analytic Sciences Corporation
One Jacob Way
Reading, MA 01867

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ABSTRACT

This report concerns the development of a marking system for a nuclear waste repository which is very likely to survive for 10,000 years. In order to provide a background on the subject, and for the preliminary design presented in this report, a discussion is presented about the issues involved in human interference with the repository system and the communication of information. A separate chapter summarizes six ancient man-made monuments including: materials, effects of associated textual information on our understanding of the monument, and other features of the ancient monument relevant to marking a repository site. The information presented in the two chapters is used to provide the basis and rationale for a preliminary marker system design presented in a final chapter.

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1 INTRODUCTION

The Office of Nuclear Waste Isolation (ONWI) has established the Human Interference Task Force (HITF) to respond to the issues of human interference activities in nuclear waste isolation. The purpose of the HITF is to develop an approach to reducing the likelihood of future human interference with the nuclear waste repository system. The HITF has focused on the development of effective, long-term communication systems as being important for minimizing the likelihood of human interference. Thus, the HITF is concerned with communicating information about nuclear waste repository locations, contents, and associated risks, both at the repository site itself and at numerous places away from the site. The time frame of interest for the marking system is 10,000 years after repository closure; this is consistent with draft EPA waste management criteria.(1)

This report is written in support of, and is consistent with, the work of the HITF. It primarily addresses the problem of marking the repository site by designing a marker system based on a study of ancient man-made monuments, some of which have survived for up to 5,000 years. The marker system design entails both the physical marking of the site and the communication of information about the site by the markers. In order to delineate the general premises upon which the design is based, Chapter 2 presents a discussion of the issues involved in human interference and the communication of information. Chapter 3 contains information about six ancient man-made markers, including their relevance to marking repository sites. The section delineates, by case histories, the factors which result in a comprehensible long-lasting marker. The information presented in Chapters 2 and 3 is utilized in Chapter 4, where a preliminary marker system design is proposed.

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2 HUMAN INTERFERENCE

The safe disposal of high-level radioactive waste is a subject of much interest to the general public and the scientific community. One method of disposal calls for the waste to be buried in a deep mined repository with a series of barriers between the waste and the environment. These barriers include, but are not limited to, transformation of the waste into a long-lasting material, enclosure of this material in a durable container, filling the repository with a material which reduces the access of ground water and retards the transport of radionuclides, finding a suitable rock type for the repository, and locating the disposal site in a remote area. Much effort has been expended to develop these barriers between the waste and the environment. Human interference could perturb this system of barriers and reduce its effectiveness. For example, the system could be breached by intercepting the waste through mining or drilling. Or, inadvertent intrusion into the repository system could become a possibility in the future if records are lost, or memory of site locations and contents becomes hazy. Thus it appears important that nuclear waste repository sites be marked, and that these markers survive for an extended period of time. The period of interest used in this study (10,000 years) is based on draft EPA waste management criteria (10 CFR 191)(1). The logic and discussions which follow were derived from preliminary work of the Human Interference Task Force (HITF) modified by this author's perspective. However, those modifications are consistent with the overall logic used by the HITF.

There are three basic approaches to the issue of how to prevent human interference with a nuclear waste repository. The first is not to draw attention to the site and to leave it unmarked, relying upon the site requirements of remote location and minimum resources to make it unlikely that the site would be disturbed in the future.(2) Since we can neither predict what will be considered a resource at a remote location in the future, nor leave the site unmarked (with any sense of responsibility towards posterity), this approach is not suitable.

A second method is to dispose of the waste in such a manner that it could not be interfered with or recovered. This is not acceptable for two reasons. First, the disposal of nuclear waste in such a manner would preclude its possible future recovery, an approach which is inconsistent with the views held

by the EPA.(1,3) Second, it is unlikely that one disposal option, a repository system with disposal in a deep mine, could be designed which could not be breached by techniques developed by future technologists.(3)

The third and final approach is to mark the site and attempt to convey information about the repository location, contents, and associated risks to future generations. This section discusses the general logic followed in deducing what might be required by such a system, and it presents the underlying reasoning which was followed when designing the system presented in Chapter 4. An analytical framework for ascertaining the means by which this information can be conveyed is given in Figure 2-1. The first three points to consider are that the message must exist, be detected, and be understood in order to be effective. Each of these points is further discussed in separate sections.

It should be noted that the objective of this work is to have the message understood. The Department of Energy has taken the position that this generation bears no responsibility if a later generation decides to do something which would affect the repository behavior (e.g., retrieve the waste) if that generation is fully cognizant of the hazards and consequences of that action.(3)

Figure 2-1 Main Logic Diagram for Warning Messages

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2.1 MESSAGE EXISTENCE

The decision to mark the repository site means that it has been decided that a message to future generations should exist. The next level of decision (cf., Figure 2.1-1) involves what should exist (message definition), where it should exist (message location), and how long it should exist (message survivability). Each of these factors is discussed below in separate sections.

2.1.1 Message Definition

In order that a message may be conveyed to future generations, we must first define what that message is and the audience to whom it is addressed. Although this report speaks of "a message", i.e., in the singular, there may actually be several possible levels of information which can be conveyed. For example, the message can be classified into four levels:⁽⁴⁾

- Level I: Attention-getter, i.e., something is here.
- Level II: Attention-getter and warning, i.e., something is here and it is dangerous.
- Level III: Basic information, i.e., what, who, when, why, what actions to avoid, and where to find information.
- Level IV: Full record of information, i.e., plans, drawings, environmental impact statements, etc.

It is apparent that the utility of a Level I message without any association with a higher level message may be dubious. Indeed, such an approach is likely to spur interest in, and investigation of, the site, possibly resulting in actions the marking system was designed to avoid. The amount of effort which some people are willing to spend in investigating man-made phenomena may be seen in the work performed in the field of archaeology.

The medium of the message may determine the level of information the marker can convey. For example, if the site is to be marked in an obvious manner, an earthwork may be a suitable marker. An earthwork, however, is limited by its very nature in the amount and type of information it can convey. It can call attention to the site regardless of its form (Level I). If made in the form of a hazardous material warning symbol, it can convey Level II information. If it rings the site, it can convey one facet of Level III

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Figure 2.1-1 Logic Diagram for Message Existence

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information, but the Level II information is lost. The different levels of information, therefore, may require different media and methods of presentation in order to be effective.

Another aspect of message definition is the identification of the audience to whom it is addressed. For the purpose of repository marking, the technological level of the audience may affect how the message is structured. In particular, the technological level may affect what is mentioned as actions to avoid in the Level III and IV messages.

It therefore follows that an initial step in identifying the technological level of the audience is the identification of undesirable actions so that warnings against them may be made. These generally fall into two categories: direct intrusion into the site itself, and near-site activities. Direct intrusion is exemplified by drilling into the repository. Near-site activities, though not at the site itself, could diminish the effectiveness of the repository system. An example of near-site activities is injection of substances into the overlying aquifer which would reduce the ability of the aquifer to retard the transport of radiolotopes.

The boundaries of the first category of undesirable actions (direct intrusion) are well defined, since they are set by the areal extent and depth of the repository. It is unlikely that these will change radically within the time frame of interest due to site selection factors. A repository marking system can then be designed to delineate the site and its potential hazards.

In contrast, the boundaries of the second category of undesirable actions (near-site activities) are not well-defined. It is not immediately evident how far away the action must take place for it not to have an effect on the repository system. In addition, it may be difficult to predict whether and where potentially undesirable activities may take place in the future, e.g., dam building or large scale irrigation projects. Both these factors make it very difficult to decide where to place the near-site markers. Finally, there is the difficulty in relating the presence of these scattered markers and actions to be avoided to a possibly remote repository site.

It should be noted that there are very different technological levels associated with on-site and near-site interference. The Romans were quite capable of building dams and water systems;⁽⁵⁾ however, it is only recently that the technological level has been reached which would allow deep drilling (the repository will be located at a depth of 2000-3000 ft), which would constitute on-site interference.

The site-specific safety analysis which would be undertaken at a repository site could be utilized here. First, the analysis would consider those actions and their consequences which would be detrimental to the repository system. This work may also facilitate the identification of a buffer zone around the repository to protect against actions such as drilling. If this can be done, then the repository site, plus buffer zone area, would be the area to mark. This still leaves action which may take place at some further distance from the site, e.g., dam building, to consider. The safety analysis could determine the severity of the consequences if actions such as dam building were taken. Given the potential difficulty in marking such a near-site area and determining the actions to be avoided, the results could be used as part of the site selection process, i.e., to judge whether a repository should be placed at that site. Finally, this information would be suitable to include in the Level IV message so that future generations could make an informed decision on whether to take a certain action.

2.1.2 Message Location

All four message levels should be located on the repository site, in order to physically connect the concepts of "nuclear waste burial" and "burial at this place". As mentioned in the introduction, this report is primarily concerned with the on-site marking of the repository and so shall only briefly discuss the off-site conveyance of information. The off-site information should be located in numerous places, preferably world-wide, to increase the likelihood of the survival of some copies even if local information blackouts occur. The off-site messages may be carried by both physical and non-physical means, e.g., oral tradition and archival material. Level III information can be conveyed by such means as having the site location denoted by the hazardous warning symbol on maps. The off-site archival material, with its ability to carry the more complex levels of information, should include information about the hazards of near-site activities, but as mentioned above, near-site marking for all undesirable actions may not be appropriate or feasible.

2.1.3 Message Survivability

The Human Interference Task Force has chosen a 10,000 year time frame as the period for which the markers need to survive, based on EPA draft

criteria.⁽¹⁾ There is a distinction drawn here between the durability of a message and the ability of that message to survive. Durability refers to the longevity of a material if it is left undisturbed after placement. Survivability takes into account not only the durability of a material, but its likelihood to withstand human actions as well. As such, survivability reflects a combination of factors, each of which is described below.

Archaeological evidence indicates that human actions are a prime factor to consider when assessing the potential survivability of the marker system. This factor can affect the choice of materials; metals may not be suitable because of their ability to be recycled (cf. Sections 3.2 and 4.1 for examples and further discussion). Removal, defacement, and vandalism are all possibilities to be considered. Chapter 3 contains examples of what has happened to some notable monuments at the hands of man. The reasons for removing or destroying monuments are varied, ranging from iconoclasm to museum acquisition, and the marker system must be designed to make removal and/or destruction undesirable or difficult to do.

Human actions can also indirectly affect the durability of markers. For example, industrialization has led to acid rain, which is having an adverse effect on many ancient monuments (Section 3.1.3 discusses its effect on the monuments of the Acropolis, Greece). The marker components must be chosen with this phenomenon in mind.

The marker system should also be able to withstand the natural events and processes which might occur at the repository site during the time period of interest. However, in some cases, this may not be feasible. For example, it is unlikely that any on-site marking system could withstand the onslaught of a glacier. It is also unlikely that the repository would be intruded upon while it was under glaciation. This restricts the situations which need consideration to those where a glacier could advance, retreat, and have time after the retreat for site exploration, all within the time frame of interest. Such a case can be eliminated because of its low likelihood of occurrence. In any case, for any such extreme scenarios, it is the off-site messages which will continue to convey the information.

In many cases, the site selection criteria for the repository would exclude many sites which could present a problem for long-term marking on the basis of other considerations.⁽²⁾ For example, it is unlikely that a repository would be located in an area in which lake formation, severe flooding, or river formation would occur within the time frame of interest. Other features

of the marking system, e.g., height of the markers, or whether they should be placed on platforms, could be chosen with consideration of site-specific factors such as soil erosion or deposition rates.

Finally, the marker system must require no active maintenance. Such maintenance cannot be guaranteed and to require it would be contradictory to the idea that the generation which receives the benefit of nuclear power should place no burdens on future generations for its disposal.

2.2 MESSAGE DETECTABILITY

The message must be noticed in order for it to be effective (Figure 2.2.1). This brings us to the questions of the distance at which the message should be detectable and the means by which it should be detectable. (As stated earlier, this discussion is concerned with the message at the repository site itself. It does not consider off-site information such as warning symbols on maps or reports stored in libraries.)

Figure 2.2-1 Logic Diagram for Message Detectability

The distance at which the message is detectable may be determined, in part, by whether it is desirable to actively call attention to the site or to warn people once they have decided to investigate the area. For example, if it is desirable to call attention to the site and have it be detectable by remote methods (e.g., aerial or satellite detection), it is possible to take such measures as creating a magnetic anomaly or changing the vegetation at the site. Such an approach could carry Level I or Level II information (if the unusual feature takes the form of the hazardous material warning symbol), but no higher levels. This approach, however, may trigger further investigations of the area where none had been previously planned. It may also be a superfluous level of redundancy in the marker system design, since whether the repository is known or noticed at this distance will not affect the behavior of the repository system. Interference can only begin through ground level activities by man or machine. (It is beyond the scope of this report to speculate on the possibility of the development of drilling or excavating techniques which would originate at a distance from the ground level.)

The second option, detectability on the ground level, is an obviously necessary part of repository system design. (Here, "ground level" includes up to human height above the ground as well.) Nearly all of mankind's previous markers have been designed on this basis. In addition, any action taken on or near the repository site which might disrupt the repository system would almost certainly take place with part or all of the personnel and equipment located on ground level. Such actions would not occur in a vacuum; that is, it is very unlikely that those performing or affected by the actions would be unaware of an unusual feature in the vicinity. The primary focus of the repository design, then, should be on ground-level detectability.

It may also be suggested that the repository marking system includes features located between the ground level and the repository, e.g., a buried mesh net to entrap a drill bit, or the inclusion of an odoriferous or unusually colored material to catch the attention of the drillers. These suggestions may not be practical for several reasons. First, these features come into use only after the intrusion has begun. The marking system should prevent the investigators from reaching this stage. Second, it may be difficult to design features which would survive for the period of time in which we are interested. Third, these features might intrigue the investigator and provide an incentive for more exploration, not less.

There are two general means of message detection: by humans or by machine. In either case, the means of communicating the message cannot be hazardous or require an energy supply in order to function. The human means of detection, the five senses, provide us with a baseline for the design, since these are not expected to change over the time period of interest. It is difficult to conceive of a message and/or warning which could be conveyed to the senses of hearing, tasting, smelling, or touching which would be practical, non-hazardous, and passive. Quite the opposite is true for the sense of sight; the ancient monuments and markers which have survived appeal to this sense. It is for this reason that the primary emphasis of the design presented in Chapter 4 is based upon detection by human sight.

Detection by machines can occur by the interception of various types of signals, e.g., electrical, magnetic, chemical, and so forth. This approach may not be practical for several reasons. It is not possible to predict what type of signal may be searched for by future technologies; it may be one which has not yet been developed. Some signals, e.g., gravimetric, may be extremely difficult to implement, while others, e.g., chemical, may be hazardous. The remaining possibilities, such as creating a magnetic or soil resistivity anomaly, can carry only the first two levels of information. For these reasons, the primary emphasis in the marker system design should be on detection by sight.

2.3 MESSAGE COMPREHENSIBILITY

As mentioned above, the objective of the repository marking system is to convey a warning and information about the site to future generations. This project differs from what was generally undertaken in the ancient world on two points.

First, when earlier cultures proclaimed messages to posterity, they appear to have pictured that culture as not differing substantially from their own. However, this project is being undertaken with the idea that societies, cultures, and languages may change drastically within the time period of interest. In spite of their failure to consider future culture change, the success of the earlier markers is evidence that messages can be conveyed to future generations with great disparities in technological levels and languages without overt efforts in this direction. It is suggested, therefore, that the repository marking system has a higher probability of survival

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and understandability since it is being designed with culture change in mind. And, since we cannot predict the changes which will occur, we can use our present languages as part of the message and know we have done no worse than the ancients.

The message must not only be understandable, but believable. This is a second difference between previously made messages and the ones designed for the repository system. The ancients placed warnings and impediments in the way of intruders because there was something (or the intruder had reason to think there was something) of value stored in that place. The builders designed a curse or threat to frighten off persons who sought the wealth. That their curses failed to drive off tomb robbers can be seen in the wide extent of this type of intrusion. The excavation of the tomb of Tutankhamun created such a stir because it had been rifled only in a minor way. An example of a warning against intrusion is the text given below; needless to say, the inscription was found over an empty tomb.

I, Tabnit, priest of Astarte, king of Sidon, the son of Eshmun'azar, priest of Astarte, king of Sidon, am lying in this sarcophagus.

Whoever you are who might find this sarcophagus, don't, don't open it and don't disturb me, for no silver has been given me, no gold, and no jewelry whatever has been given me! Only I (myself) am lying in this sarcophagus.

Don't, don't open it, and don't disturb me, for such a thing would be an abomination to Astarte! But if you do open it and if you do disturb me, may (you) not have any seed among the living under the sun or resting-place together with the shades! (?)

In contrast, the intent of the NITF is to prevent accidental or uninformed interference with a repository system which is designed to separate people from a hazardous material. Because of this difference in initial circumstances, i.e., desirable versus undesirable contents, the repository is in a very different category concerning human reactions to the message. The warning given in the above text was probably ignored because prior experience indicated that high-ranking people were often buried with valuable grave goods and the graves were therefore worth investigating. Such would not be the case with the repository and its contents. In other words, prior ancient warnings

were to protect the tomb, and its contents, i.e., its owner, while the repository system warnings are to protect the intruder. To this writer's knowledge, the intent to mark a hazardous waste site for such an extended period of time for the purpose of protecting the potential intruder is unprecedented. It cannot be guaranteed that the investigator will heed the warning even if it is understood. An analogous situation is the warning placed on cigarette packages. In either situation, the individual or investigator bears the responsibility of his or her actions because the decision to act was taken with knowledge of the potential consequences.⁽⁴⁾

The emphasis in this report, therefore, is to make the message as comprehensible as possible over the time frame of interest. The message may be conveyed by three different means -- symbols, pictures, and by languages (Figure 2.3-1).

Figure 2.3-1 Logic Chart for Message Comprehensibility

Symbols can be used to convey Level II information on the site itself and on such items as maps. Examples of two such symbols denoting atomic materials are given in Figure 2.3-2. The one on the left is standardly done in magenta against a yellow background. Given the wide-spread public interest in radioactive materials and their disposal, the symbol on the left is now recognized by a reasonably large segment of the population. Since symbols do not rely on language, they may be more adaptable for pancultural uses such as this, although they must be learned by the public.

Figure 2.3-2 Example Symbols Used With Atomic Materials

Pictures are an obvious means of communicating information without written language. For example, Figure 2.3-3 shows a statue being dragged by many people, something which is discernible even though most readers of this report cannot read Egyptian hieroglyphs.(8) (Since this scene comes from a 3,800 year old tomb, it is an excellent illustration of the potential for communication to future generations.) Although it is outside the scope of this report to develop a pictorial representation of the repository system, such a representation should be included in the marker system.

Figure 2.3-3 Scene From Tomb of Djehutyhotep
Transporting Statue to Shrine

Language is the third option for conveying information. Given the time frame involved for repository markers, it is extremely unlikely that English will not evolve significantly from its present form. For example, most native speakers of English can read Shakespeare (c. 1600 A.D.), a few can muddle through the original Chaucer (c. 1400 A.D.), but most could not read the original Beowulf (c. 700 A.D.). Yet it should not be overlooked that the latter two literary works exist in modern translations and are therefore available to a wider audience. A similar phenomenon may be seen in the translations of the Greek and Egyptian myths and histories, as well as the burial inscription quoted above. There are two points to be noted from this phenomenon. First, it appears that if the message is of sufficient interest, it will be translated or "re-encoded" into the languages used at that time. If the level of interest in the disposal of nuclear waste is indicative of future interest, the message is likely to be re-encoded. Second, the message need not be immediately readable by all members of the general public in order to have the information survive and be disseminated to that public. As long as some people can read ancient languages, the message can be translated for the general public.

In other words, we should neither overlook nor downplay the potential for language to carry information about the repository. Language also has the potential for conveying finer levels of information than is possible by the other two means. For example, we can say that Figure 2.3-3 shows a statue being moved, but to be able to say it is a statue of Djehutyhetep, governor of the Hare nome, and that it is being moved from the quarries to a shrine, requires the use of language. The effect of accompanying texts on our understanding of ancient markers is further discussed in Section 3.2.

The preceding paragraphs refer to the use of written languages. It is also possible that language may take the form of oral tradition. There are several factors which weigh against the reliance on oral tradition in the repository marking system. The most apparent is that such an approach requires a generation-by-generation update and renewal of the information (or, at most, an update every other generation). This contradicts the previously stated premise that no responsibility must be placed on later generations for the marking of the repository site.

The second factor is more subtle and requires familiarity with oral traditions. The examples discussed here are the well known compositions of

Homer, the Iliad and the Odyssey. There is little doubt that these were originally oral compositions. There were many versions of the Homeric epics when they were first written down, c. fifth century B.C. There were attempts to collate, reconcile, and edit the various versions by the third century B.C. Even after the outstanding work of a Homeric critic in the second century B.C., there were still "wild" texts (i.e., those which differ in length or in substantial wording of the text), though these now were more the exception than the rule.⁽⁹⁾ But once they were written out, it was the literary tradition, not the oral, which preserved Homer's epics to our time.

Research and studies of modern "singers of tales", primarily those in the Balkans, are the work of Parry and Lord, and it is useful to quote some of the latter's comments:

If the singer of oral epic tradition always sang a song in exactly the same words, it would be possible, of course, to ask him to repeat the performance a number of times but bards never repeat a song exactly

Those singers who accept the idea of a fixed text are lost to oral traditional processes.⁽¹⁰⁾

Oral tradition is an inherently vibrant and mutable phenomenon. Like language itself we cannot control the ways in which it will mutate, nor how it will change with each generation of transmission.

Moreover, Lord indicates that the oral and literary traditions are mutually exclusive for an individual; once there is a concept of a set text, the oral tradition is destroyed.⁽¹⁰⁾ In other words, the literary tradition supplants oral tradition; the latter is most often affiliated with an illiterate society and dies out when writing is introduced. To rely upon oral tradition as a primary facet of the repository marking system is to overlook the fact that those who build the repository are part of a millennia-old tradition -- a literary tradition. It is on this tradition that the primary emphasis of the repository marking system should be based.

There are several guidelines which it may prove useful to follow in designing a message, since we cannot predict the precise direction in which languages will evolve:

- o Use several languages. This enhances the probability that at least one of them will be recognizable and decipherable.

- Use languages currently in widespread use. There are more speakers of English or Spanish than there are of Esperanto, although the latter is an artificial language designed for international use.
- Try to avoid jargon since it has a limited audience and linguistic lifetime.

The use of language, in conjunction with symbols and pictorial representations, should provide the means for conveying different levels of information about the repository. This redundancy in the design will enhance the possibility that the information will be comprehensible to future investigators.

2.4 SUMMARY

In the discussion of the potential problems of human interference, there are several aspects of repository marker system design which rest upon factors determined outside of this report, e.g., technological level of the audience, and distance of detectability. Several guidelines, however, become apparent. Given the difficulty of correlating the repository with near-site features and detrimental actions, the main emphasis should be placed on marking the repository site itself (possibly incorporating a buffer zone). The on-site marking system should incorporate all four levels of information (i.e., from an attention-getter to the full record of information) utilizing symbolic, pictorial, and textual forms. It should delineate the areal extent of the repository, be primarily detectable by sight on ground level, and be made of materials which can withstand the forces of nature and man.

3 ARCHAEOLOGICAL MARKERS

This section will investigate several ancient, man-made monuments. Section 3.1 is primarily a marker-by-marker description, providing the information and background which is drawn upon in the repository marking system design presented in Chapter 4. The markers were chosen to represent a variety of cultures and climates; the former to indicate that the making of monuments and their survival is not keyed to a particular culture, and the latter to ascertain the effect of climate on survival. Since we are interested in survival, each of the markers had to be at least one thousand years old. Some, as we shall see, are five times this age, which implies that they have already lasted for half the time period in which we are interested. These markers are:

- Pyramids, Egypt (Section 3.1.1)
- Stonehenge, England (Section 3.1.2)
- Nazca Lines, Peru (Section 3.1.3)
- Serpent Mound, Ohio (Section 3.1.4)
- Acropolis, Greece (Section 3.1.5)
- Great Wall, China (Section 3.1.6).

The information will be summarized on an aspect-by-aspect basis in Section 3.2, including materials used in construction, size range, and the effect of contemporary texts on our understanding.

3.1 SELECTED EXAMPLES

This section presents a description of six selected ancient markers. Each marker is discussed separately and the discussion will answer the following questions:

- What - what is the marker and from what materials is it manufactured?
- Who/when - who built the marker (person or cultural group) and when?
- Why - do we know, or can we reconstruct the purpose of the markers?
- State of preservation - what is the monument's present condition?
- Other markers of the same genre - does the marker represent a unique feature which survived, or does it represent an exemplar from a number of surviving markers?

- History - how far can we trace the history of the monument?
- Relevance - what can we learn from the monument which would be useful in designing a repository marking system?

3.1.1 Pyramids, Egypt

A mention of "Egypt" conjures up images of the Sphinx and three enormous pyramids at Giza near Cairo (Figure 3.1-1). The Great Pyramid was built by Khufu or Cheops, as the name is preserved in Greek historical texts. It originally measured 756 ft on a side and stood to a height of 480 ft. It now stands 450 ft tall and 750 ft on a side due to the loss of the casing stones. The core consists of large blocks (generally 2 1/2 tons apiece, but they can range up to 15 tons) of local limestone taken from a nearby quarry. The casing was of a finer, whiter limestone quarried from the other side of the Nile. The stones were so closely fit together that it is difficult to insert even a knife blade between them. The pyramid underwent three changes in plan while it was under construction, each marked by a burial chamber. The final chamber is lined, roofed, and paved with monolithic granite slabs; the roof slabs are estimated to weigh 50 tons each. Above this room is a series of

Figure 3.1-1 Pyramids, Egypt

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five chambers to relieve the weight of the upper portions of the pyramid from the burial chamber. The name of Khufu appears in the quarry marks on some of these stones. (11,12)

The second pyramid was built by Khafre, a son of Khufu, and it originally measured 708 ft on a side and was 475 ft high. Like the earlier pyramid it was made of a local limestone core and finished with a white limestone layer. Part of the original casing still remains on the summit. The internal plan is simple, with two passageways leading to a single chamber. (11)

The Sphinx is part of the pyramid complex of Khafre, but is a unique feature. It appears to be a gifted architect's way of changing an eyesore into a thing of beauty. The Sphinx lies within the quarry for the limestone blocks used in the construction of the various pyramids and their concomitant buildings. The best and hardest stone was chosen for the pyramids, leaving a mass of softer rock jutting out from the quarry bed. This eyesore was transformed by Khafre's architect into the nearly 70 ft tall Sphinx.

The third pyramid, built by Menkure, is the smallest of the three (356 ft square and 218 ft high), but its size was offset by the use of granite casing on at least the lowest sixteen courses. It was originally planned on a smaller scale since there is a second passageway which now ends in a cul-de-sac within the pyramid structure. (11)

Who/When - These pyramids were built by three rulers of the Fourth Dynasty of Egypt -- Khufu, Khafre, and Menkure. These names are preserved as Cheops, Chephren, and Mycerinus by the 3rd century B.C. Greek historian Herodotus. The Fourth Dynasty ruled from c. 2600-2500 B.C. (13,14)

Why - The pyramids are tombs for the rulers who built them, though they may have been finished by each one's successor. Their sarcophagi remained in the burial chambers until the 1840s when the carved basalt sarcophagus of Menkure was lost at sea as it was being shipped to England. The other sarcophagi (both plain) were never moved. These pyramids were part of funerary complexes which include mortuary temples and, sometimes, subsidiary pyramids. The complexes have been excavated by numerous people and the results are best summarized in Fahry's work. (11)

State of Preservation - The contents of the tombs were looted in antiquity, probably during the First Intermediate Period (c. 2180-2130 B.C.). (13) The exterior structures are so impressive that they were one of the seven wonders of the world in Roman times and still are today. They have

lost nearly all of the casing of finer stones, and part of the cores have been quarried, but these actions have only made a small dent in their immense bulk. Much more of the mortuary temples has been quarried away, leaving only the lower courses of stone. The Sphinx, made of softer stone, is more heavily eroded and was repaired in antiquity.

Other Markers of the Same Genre - The three pyramids at Giza represent the apex of a long tradition in Egypt. The earliest pyramid is the Step Pyramid of Sakkarah built for Zoser (c. 2700 B.C.).⁽¹³⁾ This six-layered monument was a sharp departure from the prior tradition of low bench-like structures called mastabas, and by the sixth century B.C. its architect, Imhotep, was deified for his wisdom.

Other pyramids followed (there are over 70 in Egypt). By the time of Snefru, first king of the Fourth Dynasty, the sides were sloped. The engineers of his pyramid at Dashur had to change the angle of the slope when they realized that the original design would have collapsed the ceiling of the interior rooms and corridors. It is now known as the "Bent Pyramid."

After Menkure, the pharaohs built much more modest pyramids but the tradition continued. If the funerary nature of these structures was ever in doubt, the alternative hypotheses would be disproved by the Pyramid Texts. These are inscribed on the walls of the burial chamber in the pyramid of Unis, last king of the Fifth Dynasty (c. 2350 B.C.)⁽¹³⁾, and occur in all the other remaining pyramids of the Old Kingdom. The texts contain chants and incantations to insure the future happiness of the deceased king. The contents of the Old Kingdom tombs were probably looted during the chaos of the First Intermediate Period (c. 2180-2130 B.C.)⁽¹³⁾ when centralized government fell apart. Order was regained and the Middle Kingdom pharaohs (c. 2130-1780 B.C.) resumed building pyramids as part of their funerary complexes. Excerpts from the pyramid texts also reappear in the funerary literature.

Another period of chaos followed (Second Intermediate Period c. 1780-1570 B.C.) which ended with the establishment of the New Kingdom (c. 1570-1100 B.C.). Within this period there was an important innovation. The Egyptians had learned that the towering pyramids of earlier times served as beacons to tomb-robbers. Thutmose I (c. 1525 B.C.) therefore ordered that his tomb be hidden and the funerary temple be located apart from it. Successive pharaohs followed suit; the place first chosen by Thutmose I is now known as the Valley of the Kings. Private individuals, however, continued to surmount their

simple tombs with small brick pyramids or to include a stele with a pyramidal top in their tombs. (11,15-18)

The use of royal pyramids was revived by Pianki (c. 720 B.C.) of the Twenty-fifth Dynasty whose capital was in Sudan. Pianki was impressed by the pyramids he saw in a military campaign in the north and modeled his tomb on them. Aside from minor changes in form (they were small, steep-sided, and solid), these later pyramids differed in that they were built for all members of the royal family, not just the pharaoh. Over sixty pyramids occur at the site of Nuri alone, more occur at el Kurru, Napata, and Meroe (all are located between the Third and Sixth Cataracts of the Nile). Pyramid building in the Sudan ceased in c. 350 A.D. with the fall of the Meroitic Kingdom when a new religion entered the Nile Valley. (11)

History - After it was constructed, the history of the Sphinx is that Thutmose IV (c. 1425 B.C.) cleared the sand away from the Sphinx and built brick walls around it to prevent sand from re-encroaching. (By this time it was considered a representation of the sun god). He also erected a stele between its paws to commemorate this action. Other New Kingdom pharaohs built a temple or left steles or statues to the Sphinx, as did the kings of the Saite Period (663-325 B.C.). (19) The figure must have been eroded by the time of the Ptolemaic Period, since the figure was restored at that time to its original contours by placement of small limestone blocks on its paws, flanks, and tail. As with the surrounding monuments, Greek and Roman travelers left their graffiti scratched in its stone. According to the Arab historian el Makrizi (died 1434) the Sphinx was first disfigured by a religious Arab, this presages the oft-told story of Napoleon's men using it for target practice. It is interesting to note that el Makrizi reports a popular belief that the sand encroaching on the cultivated land was caused by its disfigurement. (11,19)

The pyramids and the knowledge of why they were built survived long after their owner's deaths, even if the contents did not. Herodotus (5th Century B.C.) talks about them in some detail. Aside from simply describing the pyramids, he accurately records who built them and why. The casing stones were all intact at this time. Errors, however, occur when he estimates the height of the monument, and he was told that the Great Pyramid complex took thirty years to build while Khufu reigned only twenty-three years. This period also saw the restoration of the Sphinx which had begun to lose its shape through erosion. (11,19)

Diodorus Siculus (a Roman historian) was in Egypt from 60 to 57 B.C. Much of what he reports echoes Herodotus. He adds, however, that ramps were used in their construction. The remains of such a ramp occur at the Unfinished Pyramid of Sekhmet (c. 2650 B.C.).⁽¹¹⁾ Strabo, a contemporary of Diodorus Siculus, also visited Egypt and recorded that he entered the Great Pyramid.⁽¹²⁾ Pliny the Elder (23-79 A.D.), saw the pyramids but he condemned them as an idle and foolish exhibition of royal wealth. Pausanius, a second century A.D. traveller, also mentioned that he saw the pyramids when he visited Egypt.⁽¹²⁾

By the ninth century A.D., blowing sand and debris had covered the entrance to the Great Pyramid. The son of Caliph Harun el Rashid, el Mamun, forced a passageway through the masonry and found late intrusive burials in the interior. An Arab historian, Abd el Latif (born 1179 A.D.), mentions the numerous inscriptions which covered the casing of the Great Pyramid. These inscriptions were lost when the casing stones were quarried away during and after the 13th century. There was an attempt around 1200 A.D. to totally dismantle the Third Pyramid, but the expense of this project overwhelmed it.⁽¹¹⁾

It must be remembered that to the Muslims these monuments represented hostile forces which Mohammed had denounced, and also the monuments were pagan anathemas to the Christians. Small wonder that they were used as quarries for the nearby city of Cairo. In spite of this the casing of the Great Pyramid was only partly missing, while that of the Second Pyramid was nearly intact in the middle of the 16th century.⁽¹²⁾ In 1638, an Englishman published accurate measurements and drawings of the exterior and interior of the Great Pyramid. He concluded that its functions were those of a royal tomb and as a symbol of immortality.⁽¹²⁾ All the work done since that time has enlarged our knowledge but has not modified this basic conclusion.

Relevance - The pyramids exemplify the possibility for the continuity and survival of information for long periods of time (5,000 years). The section on history indicates how pyramids and the texts associated with them continued to be used after periods when the centralized government of Egypt collapsed. Even when Egypt was no longer an independent nation, knowledge about the pyramids continued to be transmitted through Greek and Roman writers, i.e., through different cultures. This thread continued into the medieval period with the Arab historian, and continues with the work in Egyptology which is being done today.

A second point to make is the importance of contemporary written records. It is only by such records that we know who built these structures and why they were built. It is the literary tradition which makes it possible for this information to be translated into more contemporary language.

The contents of the pyramids have not survived because they were looted for their intrinsic value. Most of the building stones, however, have remained. Some of these were removed, partially because the pyramids are located close to a large population center and it was easier to remove the stones than to quarry new ones, but the majority of the stones were not removed. So a third point to make is that stone may be a suitable medium for repository markers since it is generally not valuable in and of itself. If stone is used in the markers, the pieces should be of suitable size and shape to minimize the likelihood of being reused in later buildings.

A final point to make is the need for redundancy in the marker system design. The number of stones used in the pyramids is so immense that an intentional attempt to dismantle the smallest one (i.e., Menkure's) was overwhelmed by the expense of the project.(11)

3.1.2 Stonehenge, England

The impressive monument standing on the Salisbury Plain is actually the culmination of nearly a millenium of use and remodeling. A photograph of the inner circles is given in Figure 3.1-2, while the full plan of Stonehenge is given in Figure 3.1-3. A summary of the various features is given in Table 3.1-1. The ancient approach to the monument takes you past the outlying Heel Stone (when viewed from the center of the monument, it is in rough alignment with the position of the rising midsummer sun) to a gap in the banks and ditches which surround the circles of standing stones. This gap is flanked on one side by the fallen "Slaughter Stone," probably one of a pair which formed a gateway. Ringing the inner side of the bank are the 56 Aubrey holes, named after John Aubrey who noticed them in the latter part of the 1600s. Thirty-four of these holes have been excavated and 25 were found to contain cremated human remains. The chalk backfill of these excavated holes is clearly discernible in the grass which grows over the site.

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Figure 3.1-2 Inner Circles of Stonehenge, England

Figure 3.1-3 Plan of Stonehenge, England

8 0 0 4 0

1 0 4 6

Table 3.1-1. Architectural Features of Stonehenge, England

Feature	Approximate Diameter (ft)	Materials	Components	Dimensions	Building Phase	Visible Today
Outer Bank	350	Chalk		8 ft wide 2-3 ft high	I	Yes
Ditch	350			10-20 ft wide 4-7 ft deep	I	Yes
Inner Bank	320	Chalk		20 ft wide 6 ft high	I	Yes
Ring	260	Chalk Filled	56 Aubrey Holes	26 ft wide 4-7 ft deep	I	Yes
Station Stones		Sarsen	4	4-9 ft high	I	2 Survive
Heel Stone		Sarsen	1	56 ft x 20 ft (45 tons)	I	Yes
Ring	100	Sarsen	30 Monoliths with Lintels	7 1/2 x 1 1/2 ft (4 ft underground) (25 tons apiece)	III	18 Uprights 5 Lintels Survive
Ring	70	Bluestone	54-61 Monoliths	6-8 ft high 26-28 ft across (4 tons apiece)	III	6 Uprights 4 Lintels 5 Fallen 10 Scamps
Horseshoe		Sarsen	5 Trilithons	20-24 ft high (each lintel) (4-5 ft underground) (25-50 tons apiece)	III	3 Trilithons Intact 2 Each Lintel and 1 Upright
Horseshoe		Bluestone	15 Monoliths	6-12 ft high 26-28 ft across (4 tons apiece)	III	5 Survive
Slaughter Stone		Sarsen	1	7 1/2 x 2 1/2 ft	III	1 Fallen
Altar Stone		Pale Green Sandstone	1	11 1/2 x 1 1/2 x 16 ft	III	Original Position Unknown

The visitor now faces the most obvious part of the monument, the immense standing stones arranged in a ring of upright stones with lintels, an inner ring without lintels, a horseshoe formed by five trilithons (two uprights with a lintel) and a horseshoe of upright stones (Figure 3.1-2 and Table 3.1-1). The term "sarsen" refers to a local type of sandstone which occurs on the surface at Marlborough Downs about 20 miles to the north. The "bluestones" are a number of bluish stones which are mostly dolomite, but some examples of rhyolite, sandstone, volcanic and calcareous ash are included. The bluestones only occur together in a small area (about one mile square) in the Prescelly Mountains of Wales, some 200 miles from Stonehenge. (20-22)

Who/When - Stonehenge has been variously ascribed to the time of King Arthur by a 12th century chronicler, to the Romans by Inigo Jones in 1655, and

to the Druids in 1740.(22) Around 1900, the suggestion that Bronze Age Britains built Stonehenge was put forth, and that is the theory now accepted by most historians.

The question of who built Stonehenge was settled long before the question of when it was built. The re-calibration of carbon-14 dates has created a revolution in European prehistory,(23) and places Stonehenge as a contemporary of the pyramids of Egypt. Building at Stonehenge began c. 2700-2500 B.C., and the first building phase included the ditch and banks, the Aubrey holes, and the Heel Stone. It also may have included the Station Stones.

The main change in building Phase II was the transport and erection of the imported bluestones in two concentric circles. This took place c. 2100 B.C. but was never finished. Instead, the bluestones were removed and the circle and horseshoe of sarsen stones were raised (Phase IIIa). Finally, the bluestones also were arranged in a horseshoe and circle (Phase IIIb). The latter work was done c. 2100-1900 B.C.(20,23)

Why - The alignment of the Heel Stone with the midsummer sunrise was first noted by Stuckeley in 1740. However, it was not until the 1960s that further astronomical uses of the monument were hypothesized and tested; this was the work of Hawkins.(22,24,25) This work drew great protest, particularly from Atkinson, the excavator of the site,(20,26,27) but it is now generally accepted that the trilithons were used in following the motions of the sun and moon. How many other alignments are significant and whether or not the Aubrey holes constitute a "computer" for calculating eclipses is still a matter of debate.(23,28-31)

There are some 900 stone circles in the British Isles, of which Stonehenge is only one. It has, however, several unique features: the lintels and the ring of sarsen stones, the trilithons, the Altar Stone (whose original position and purpose is unknown) and the use of imported stones. Buri has made a comprehensive study of all of the known circles. He argues convincingly against astronomy being a prime factor in their construction by pointing out that, given the number of possible alignments, the odds of finding a significant alignment by chance are about even. He argues that the astronomical function of the ring was only part of its purpose as a ritual enclosure for periodic gatherings and comments, "another difficulty is the entire absence of written records that could confirm the astronomical theories,"(21) Because of the absence of written records, the purposes of these stone rings still are being debated.

State of Preservation - Stonehenge is visited by over three-quarters of a million people per year, and ropes now protect the bank and ditch from obliteration.(21) The monument, however, has survived while Britain has undergone invasions (in 55 B.C., 48 A.D., and 1066 A.D.), the Interregnum Wars of the Roses (1455-1485 A.D.), and the two World Wars. By the 1800s, with the rise of Romanticism, the monument was much visited, and hammers were rented to tourists for the purpose of chipping off mementoes.(22) Monoliths, however, are not easily demolished. As may be seen from Table 3.1-1 and Figures 3.1-2 and 3.1-3, about one-half to two-third of the upright stones survive and remain in position. Several of the stones had figures carved upon them in the Bronze Age, and these may be seen today.

Other Markers of the Same Genre - As mentioned above, Stonehenge is but one of many stone circles. Burl has compiled data on some 963 stone circles which occur in the British Isles, Ireland, and Brittany and this discussion leans heavily on his work.(21) Two-thirds of these circles are preserved well enough to estimate their diameter; these range from under 9 ft to over 200 ft with over half of the examples falling between 10 and 60 ft. The site of Avebury contains a ditch nearly one-quarter of a mile in diameter (1100 ft) and ranging from 23 to 33 ft in depth. Half the town of Avebury lies within it. The large megalithic ring inside the ditch is the largest in the British Isles with a diameter of 345 ft.

Much effort has been expended in measuring and reporting the position of the stones in the various rings; much less has been noted about their heights and materials. Stonehenge has the largest stones of any ring, with heights up to 24 ft above the present ground level. Stones as small as a meter in height are found in several rings and examples 12 to 15 ft tall appear to be somewhat taller than average (e.g., Long Meg is 12 ft tall and is 4 ft taller than any other stone in her ring). Stonehenge is also unique in that it contains imported stones. All other rings are made from stones which were transported no more than a few miles at most. Materials include limestones, sandstones, granite and volcanic breccia, porphyry, syenite, and diorite which were either locally quarried or occurred as glacially deposited boulders. The condition of the stones generally is not mentioned, and from this we can imply that they are still fairly sound. The Rollright Stones are an exception, and are usually pointed out as such. They are made of limestone and are in fragmentary condition.(21)

History - Stonehenge, per se, has been written about since the 12th century A.D., and has become well-enough ensconced in public knowledge to appear in many literary works including those by Wordsworth and Hardy.(22) An earlier reference (1st century B.C.) may occur in Diodorus Siculus (History, Book V), but no name is given and the attribution of this passage to Stonehenge is therefore debatable.(20) It is interesting to note that Geoffrey of Monmouth (c. 1136) tells of Merlin saying "send for the Giant's Ring in Ireland", when the stones actually originated in Wales. The quarry site may lie on the trade route from that part of England to Ireland, but the oral tradition, though remembering that the stones were imported, has the wrong place of origin. Geoffrey also relates that the monument was erected (by Merlin at King Arthur's request) for commemorating some slain nobles, but says nothing about its astronomical purpose.(20,22)

The monument continued to be known as a "special place", though the exact nature of the place is still debated. This debate extends to the other stone rings as well. The special nature of these rings and the influence they had upon the local population was a matter of great concern to the early Christian church. The edicts of Arles (452 A.D.), Tours (567 A.D.), Nantes (658 A.D.) and Toledo (681 A.D.) exhort the local bishops and clergy to destroy "those stones which in remote and woody places are still worshipped and where vows are still made".(23) The destruction or toppling of stones seen in the rings may be the result of these edicts and later attempts to wipe out the influence of these pagan monuments.

Many of the rings survived these attacks. They may have done so because of the oral tradition which says the stones do not like to be moved(24) and because of the dangers inherent in moving a monolith (Aubrey reports that a medieval surgeon was crushed to death at Avebury trying to remove a stone.(21) Also, they may have survived because they were still considered "special" places. Daniel documents what has happened to stone rings and other megalithic monuments in history and closes with the following comment:

This may be too blunt a way of putting it, but I find it difficult to envisage why there should be a Christian occupation of some megalithic sites, unless a real tradition of their importance as special and sacred places was carried through the period of the Bronze Age and Early Iron of barbarian Europe and into historic times.(25)

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Relevance - Stonehenge is a prime example of the difficulties encountered in marking a site with only level I information. It must be emphasized that the purpose of Stonehenge and the other stone rings is still being debated because of the "entire absence of written records that could confirm the astronomical theories".(21) It is this absence of written records which not only obscured the purpose of Stonehenge, but even the times when the various parts of it were constructed. That Stonehenge is a contemporary of the Egyptian pyramids was known only after the introduction of carbon-14 dating.

The history of Stonehenge points out the possible corruption in information conveyed by oral tradition. Though the medieval chronicle records the tradition that the stones are imported, it has the wrong place of origin.

The plan of Stonehenge and of the stone rings in general may be very useful for a repository marking system design. The use of multiple components means that the plan of the area can be reconstructed even though some of the components have been lost. Stonehenge has lost approximately one-third of its stones, yet there is no debate about its plan. For the other rings, with much smaller components, some 600 still survive well enough to estimate their diameters. It appears that redundancy in the number of components used to delineate an area helps that information survive. An examination of the size of the markers used in the stone rings also is illuminating. The heights of the stones range from 3 to 24 ft. Since the smaller stones would be easily removed, it appears that they have been protected by remote locations and oral traditions against moving them. The repository markers will not have this "special nature" attributed to them, and so they ought to fall in the upper range of height where their very size will make them difficult to move.

3.1.3 Nazca Lines, Peru

The Nazca lines are a collection of lines, geometric forms, and semi-naturalistic figures found on the desert floor near the town of Nazca in southern Peru. They have been the cause of much speculation for two reasons:

- They are much more visible from the air than on the ground.
- They are drawn on an enormous scale. For example, one large cleared trapezoid measures 2600 x 330 ft; a large figure may measure 500 ft in length; and single lines may run more than 6.5 miles in length.(25)

The lines (actually paths about 2 ft wide) are made possible by a set of geological circumstances. Wind erosion across the desert floor carried off the dusty surface soil, leaving behind a "pavement" of pebbles and boulders. Over time these stones develop what is known as "desert varnish," a brownish-black coating of iron and manganese oxides formed by the in situ decomposition of rock and the deposition of oxides upon the surfaces by capillary action. The rate of formation of this varnish is very slow, and may have begun as far back as the Pleistocene period. The underlying soil, however, remained pale in color. Picking up a stone will expose the light-colored soil underneath it. Picking up a row of stones will create a light-colored line.(35)

Who/When - The answers to the questions of who drew the lines on this natural blackboard, as well as when and why they were drawn are not definitely known. The figures drawn on the desert floor (monkey, lizard, spider, trophy-bearing killer whale, etc.) find parallels in Nazca wares, a distinctive type of pottery which dates from about 200 B.C. to 600 A.D. The similarity led to the conclusion that the same population was responsible for both creations. In addition, 85 percent of the potsherds collected on the desert floor by Hawkins in the late 1960s were Nazca wares.(36) A collection of sherds from the periphery of the desert proved to contain only Nazca wares.(36) Another type of evidence is the carbon-14 date obtained from a post which was set at the intersection of two lines, and gave a date* of 370 A.D. ±90 years.(37,38) Although we cannot be certain whether this is the original stake (or a later replacement), the date falls within the Nazca period. No finer chronology of the lines has been developed and, given the absence of associated archaeological material, it is unlikely that one can be.

Why - The question "why" still remains unanswered. Suggestions include:

- Astronomical sighting lines(39,40)
- Pictures to be viewed by the gods of the sky(41)
- Religious or ceremonial pathways(35,41)
- Mechanism to balance the resources and population.(36)

*The date was adjusted from the published data using the revised carbon-14 half-life of 5730 years and the MASCA recalibration curve.

One of these suggestions can be eliminated. Hawkins tested the hypothesis of astronomical sighting lines by accurately surveying them and using a computer to check the alignments as he did with Stonehenge. The lines cannot be used physically to sight stars, and 80 percent of the lines lack any semblance of solar or lunar alignment.⁽³⁵⁾ As for the remaining suggestions, there is insufficient evidence to either confirm or deny any of them and so the lines remain a mystery.^(42,43)

State of Preservation - The lines were made possible by a particular set of circumstances. They were preserved, in part, because of a very low local erosion rate. They have also been preserved because of their remote location (the area is too arid to support a permanent population), and the fact that the area was depopulated shortly after the Spanish conquest. The lines are a fragile phenomenon and undergo rapid degradation when people drive or walk over them in order to see them. A photographic essay by McIntyre⁽⁴⁴⁾ includes a photograph which shows the destruction undergone by one figure in only twelve years.

Other Markers of the Same Genre - Ancient markings of this sort occur in numerous places other than Nazca, Peru. Hawkins⁽³⁵⁾ estimates that there may have been 50-100 such sites in Peru alone. Morrison mentions sites in Chile and Bolivia.⁽⁴¹⁾ Over fifty drawings formed by the same technique occur in California and Arizona,⁽⁴⁵⁾ though the ages of these figures are not known. As with the Nazca material, most of these remains appear to have survived because of their remote location and suitable climatic conditions.

History - The figures were brought to the attention of the general world in the late 1940s by Kosok, though they were known before on a local level.⁽¹⁸⁾

Relevance - The Nazca lines are an example of the potential survivability of even a frail phenomenon given a suitably remote location. Although this effect cannot be quantified, the repository will also be located in an area removed from large population centers and the marking system should, therefore, have a similar increase in survivability.

Again we see the importance of written records to the understanding of ancient markers. The purpose of the Nazca lines is uncertain and there is a possible 800 year time span for their construction. Due to their very nature, it is unlikely that even a relative chronology can be built for the construction of the lines (if two lines cross, it is not possible to tell which is the

earlier). This lack of knowledge is due, in a large part, to the absence of contemporary written information about the culture which made the lines.

Finally, although these lines are clearly visible from the air, they are difficult to track on the ground. In contrast, a repository marking system should primarily stress ground visibility.

3.1.4 Serpent Mound, Ohio

The Serpent Mound is an embankment of earth in the form of a serpent in the act of uncoiling (Figure 3.1-4). In its present state of restoration, the Serpent consists of two parts, the serpent proper and the oval shape. The latter has diameters of 125 and 60 ft and is 4 ft high. A small mound of burned stones lies in the center of the oval. The length of the serpent proper is 1254 ft. The coils and convolutions, however, fit within an arc that is 737 ft long. The average width of the body is 20 ft. The height is generally 4 to 5 ft, but it tapers until the tail terminates in a bank about 1 ft high and 2 ft wide.

Figure 3.1-4 Serpent Mound

The serpent was formed by blocking out the pattern with stones and clay. On top of the stone core a foot thick layer of clay was added. Above this lies a 2 ft layer of dark soil. (46)

Who/When - No artifacts were found in the excavation of this monument. There is, however, a burial mound within 400 ft of the serpent. The artifacts found in this mound belong to the Adena Indians who lived in Ohio between 1000 B.C. and 700 A.D. It is generally accepted that the burial mound and the Serpent Mound were built by the same people. (46,47)

Why - The purpose of the mound is still not known. Since it is obviously in the form of a serpent, most interpretations use the role that creature played in Indian mythologies and religions as a basis for their hypotheses.

It should be noted that there are several interpretations of the figure. These differences are due to differences in interpreting irregular features on the ground. The form of the serpent and the oval shape have been quite clear, and these are identically shown in all the drawings. It is the features beyond the oval and to the sides of the neck which are in dispute. The earliest drawing was published in 1848 by Squier and Davis (48) who suggested that the mound shows a serpent in the act of swallowing an egg. Another drawing was published 37 years later by Marcellus who added a small oval to either side of the neck and interpreted a small mound beyond the oval as a frog. McKean interpreted his drawing as a serpent striking at a frog, which leaped away while at the same time ejecting an egg. (49) Willoughby, in 1919, interpreted the elevations at the side of the neck as horns, thus tying the Serpent Mound to the horned serpent found in the myths of the northern Indians of the United States. (50) In other words, although the existence of the snake figure is not in doubt, the interpretation of Serpent Mound is still uncertain and somewhat nebulous.

State of Preservation - The mound was restored to its present contour by Putnam in 1886 after his excavations. No further restoration or conservation work has been done since that time. The Ohio Historical Society has added a foot path around the monument to reduce the number of people walking on it.

Other Markers of the Same Genre - There are literally hundreds of prehistoric mounds in Ohio and neighboring areas, but none other in the shape of a serpent. Greenman identifies two other serpent effigies, one in Canada and one in Scotland. Although it is intriguing to postulate a connection between them, serpents are sufficiently common to make this unnecessary. (46,49)

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discussed by Travlos⁽⁵¹⁾ and the other references cited therein. A general photograph of the Acropolis is given in Figure 3.1-5, while a plan of the monuments discussed here is shown in Figure 3.1-6.

Beule Gate - As you approach the Acropolis, the first ceremonial entrance you reach is the Beule Gate. An inscription on the monument tells us that it was paid for by F. Septimus Marcellinus and built c. 280 A.D. The two pylons are pierced by a gate which is aligned with the central opening of the Propylaea. It is built of limestone and the blocks were taken from an earlier monument which dates to c. 310 B.C.⁽⁵²⁾

Agrippa Monument - The Agrippa Monument stands on a natural terrace between the Beule Gate and the Propylaea. The slab for the statue stands 29 ft high, was made of marble, and originally bore a four-horse chariot. Inscriptions on the slab tell us that the latest statue was raised to Marcus Agrippa in 27 B.C., while the original group was dedicated to celebrate a chariot victory by the city of Pergamon in the Panathenaic Games in c. 178 B.C. We know from the writings of Plutarch and Dio Cassius, that the slab once bore statues of Anthony and Cleopatra, but these blew down in 31 B.C.⁽⁵²⁾

Propylaea - The Propylaea is the classical gateway to the Acropolis, and is part of the overall monumental rebuilding of the site undertaken by Pericles after the Persian Wars. The architect was Mnesicles and it was begun in 437 B.C. after the construction of the Parthenon. Work halted in 432 B.C. with the advent of the Peloponnesian War and was never resumed. The gate is constructed of Pentelic marble (quarried about ten miles away), with some decorative features in black Eleusian stone (the source is about fourteen miles away). Part of the monumental ramp approaching the Acropolis continues through the center of the building. The ramp is flanked on both sides by a row of columns and two gates. The building wings on the north and south also frame the ramp. The north wing has a room called the Pinakothekē (picture gallery) because of the pictures Pausanias, a second century Roman traveler, says he saw there. It is quite well preserved; the walls stand up to the roof level and still bear architectural features.^(51,52)

The Temple of Athena Nike (Athena, bringer of Victory) is reached from the south end of the Propylaea. It is made of Pentelic marble and was built in 427-424 B.C. to celebrate the peace with Persia. The architect was Callicrates who built a similar temple at Ilion. A frieze, sculpted in high relief, ran around the exterior of the building; four of the fourteen

Figure 3.1-5 The Acropolis, Greece

Key

A: Boule Gate	D: Temple of Athena Nike
B: Agrippa Monument	E: Erechtheion
C: Propylaea	F: Parthenon

Figure 3.1-6 Plan of the Acropolis, Greece

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slabs are now in the British Museum. The temple is also known as the temple of "Wingless Victory", a tradition recorded by Pausanias.⁽⁵²⁾

The Erechtheion is an intriguing edifice, built on more than one level and meant to house several cults, including those of Athena, Poseidon and the founding rulers of Athens. It also housed an ancient and venerated statue of Athena. The building was part of Pericles' plan for the rebuilding of the Acropolis. It was begun in 421 B.C., interrupted by the Peloponnesian War, and completed in 409 B.C. With the exception of dark Eleusian stone used as the background for the frieze, the building was constructed of Pentelic marble. The exterior walls and porches are quite well preserved (up to the roof). Differences of opinion exist about the plan of the interior, which has undergone extensive remodeling in the course of time. The southern porch is known as the Porch of the Maidens (or the Porch of the Caryatids). Instead of six columns, there are six statues of young maidens in long tunics which support the roof. One of these was taken back to England (along with many other marble items) by Lord Elgin. The floor of this porch has disappeared, but the ceiling is nearly intact.

The Parthenon or temple of Athena Parthenos (Virgin Athena) occupies the highest part of the Acropolis. It was meant to be an artistic masterpiece and to serve as the state treasury but not to replace the Erechtheion in veneration. Forming the cardinal feature of Pericles' plan, it was built in 447-438 B.C., and the best and most celebrated sculptors in Athens were engaged in its construction. The result is considered the culmination of the Doric, if not the Classical, style of architecture.

The exterior of the temple is ringed by a series of 46 columns which stand 34 1/2 ft high. Above this was a band called the architrave, originally plain but later adorned with shields presented by Alexander the Great (334 B.C.) and an inscription relating to an honor bestowed on Nero (59-68 A.D.)⁽⁵³⁾. Above this was a band (frieze) of alternating sculptured (metopes) and vertically grooved panels (triglyphs). There were originally 92 metopes; Lord Elgin brought 15 to London, one is in the Louvre, and 41 remain in place. The remaining 35 were destroyed in the explosion of 1687 (see below). The roof was wooden. The triangular areas on the East and West (pediments) were filled with sculptures. Pausanias tells us that the Eastern Pediment showed the birth of Athena; it was largely destroyed by the building of a Byzantine apse. The British Museum contains several fragments of the

remaining sculptures. The Western pediment showed the contest of Athena and Poseidon; this group was destroyed when the sculpture fell during removal in 1687.

Around the outer walls of the building ran a continuous frieze of sculpture. Its original length was about 525 ft; 176 of which exist in Athens while 247 ft are in the British Museum. The remainder was destroyed in the explosion of 1687. The entire frieze was dedicated to showing the procession of celebrants in the Great Panathenaean Festival honoring Athena and is known for its masterful sculptures.(54)

It should be noted that none of these buildings have any mortar. The stones were closely fitted by careful dressing, and where extra strength was needed, the ancient Greeks used small bolts and clamps of iron. These were rendered nearly rustproof by coating them with lead. As we shall see, similar precautions were not taken at the turn of this century when restoration work was done on the Acropolis, and the methods used have actually accelerated its deterioration.(51,55)

Who/When - Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia. The Parthenon was built first (447-438 B.C.), then the Propylaea (437-432 B.C.). The temple of Athena Nike was next (427-424 B.C.), and finally, the Erechtheion was built. It should be noted that there exists a wealth of detail about the buildings, sculptures, and their construction in ancient texts. In several cases we know the architects and sculptors who worked on the project. We know that money was raised from the sale of old building material, from grants by the Treasuries of Athens and Nepheliston, and from private donations; yet we also know Pericles was accused of squandering funds of the Delian League in order to beautify the Acropolis. The level of detail available in the ancient texts is such that we even have annual building accounts for the Parthenon and Propylaea which were publicly displayed on the Acropolis.(56)

Why - There has never been any doubt that the major buildings of the Acropolis had a religious purpose. This is borne out by the transformation of the Parthenon into a Byzantine church and, later, into a mosque. There were secular parts, such as the Propylaea, but the purpose of each of the buildings is known.

State of Preservation - The last forty to fifty years have wreaked much havoc on the Acropolis. The country has become industrialized in this period,

and the concomitant atmospheric pollution and acid rain are dissolving away the marble sculptures and buildings. The problem is so pronounced that the city held the second International Symposium on the deterioration of building stones in 1976.⁽⁵⁷⁾ The Parthenon frieze and the caryatids are under temporary shelters. There are plans to replace the caryatids with casts and move the originals to a protected environment. It is ironic that the caryatid removed by Lord Elgin is the one to be the model for the casts. Since it has been indoors for over 150 years, it is in far better condition than the others.^(54,55,57)

The second problem is that steel bolts and girders were used in the extensive restoration done by Nicolas Balanos between 1896 and 1933. Iron was originally used in the construction, but it was lead coated to inhibit rust. No such precaution was taken with the steel replacements. Aside from weakening, steel expands as it corrodes. This extra stress has led to cracking of the marble in which the steel is imbedded; in some places this has led to an immediate danger of collapse.⁽⁵⁵⁾

The final factor contributing to the destruction of this monument is human. The Parthenon was intact, though modified for the architectural needs of different religions, until September 26, 1687. At that time, the Turks were using the building as a powder magazine and it received a direct hit by a Venetian mortar. The resultant explosion blew the temple into two parts, destroying most of what lay in the middle. The Temple of Athena Nike was taken down by the Turks in 1686 in order to use the area for a gun emplacement; the stones were used to construct another artillery position. (This was dismantled in 1936-40 and the temple was rebuilt using a temple at Ilioussos built by the same architect as a model.) The Propylaea remained intact until the 13th century when it was turned into a Byzantine episcopal palace. In 1640 or 1656 lightning struck a powder magazine within it, and more damage was done in the Venetian bombardment of 1687. The buildings on the Acropolis have suffered the greater part of their damage via the direct or indirect actions of man.

Other Markers of the Same Genre - The Acropolis of Athens has always had a military aspect to it because it is a natural bastion with a spring in it. This combination of military and religious usage can be seen at several other sites in Greece such as the cities of Mycenae and Tiryns, which were citadels in the Mycenaean period (when the Acropolis was first fortified c. 1300 B.C.), while Argos and Corinth had fortified elevated areas of the city contemporary

with that of classical Athens. The temples and secular architecture of the Acropolis find parallels in numerous other Greek cities. The body of literature about them is so extensive that it forms a sub-specialty in classical archaeology, and so many other markers exist that they cannot be discussed individually in this report.

History - The Acropolis is an example of an area with its monuments for which we can follow the history in some detail for over two millennia. This thread of information has continued through changes of religion, government, and occupying forces. Its spring and defensive position have attracted human habitation to the area since Neolithic times (c. 5000 B.C.). In the Mycenaean period (c. 1400-1200 B.C.), a massive fortification wall was built, part of which can still be seen today near the Propylaea. This wall and an altar seem to have survived until the Persian sack of 480 B.C. Though little is known about the Acropolis between 1200-700 B.C., the continuity of the cults suggests continued occupation.

The destruction of the Acropolis and its rebuilding under Pericles is described above. It was considered to be such an artistic masterpiece that little was done to it in the following centuries. Alexander the Great added votive shields to the Parthenon, Claudius added a monumental staircase (c. 52 A.D.), and a bronze inscription honoring Nero was added to the Parthenon in 61 A.D., but these were minor changes.

With the building of the Beule gate in the third century A.D., the Acropolis regained its fortified nature. Under Justinian (483-527 A.D.) the temples were converted to churches and a garrison was installed. The Franks occupied it during the thirteenth and fourteenth centuries, while the Turks took over in 1456. The damage done in the late 1680s during various skirmishes has been described above. The Greeks finally regained independence in 1833, and demolition of the Turkish and Frankish structures began soon thereafter. Investigations and restorations have gone on continuously ever since. (51, 52)

Relevance - The Acropolis can provide useful information on several points: the effect of accompanying textual evidence, materials used, and delineation of an area of interest. The above description does not do justice to the amount of information which is known -- we know names, dates, why the structures were built, to whom they were dedicated, how they were paid for, and even some of the politics involved. We even know, in rather detailed form, about things which no longer exist. For example, we know that the

Agrippa monument bore three different statues in its lifetime, although the monument itself only records two, and none survive today. A more modern example of the information still extant can be seen in the drawings of the sculptures on the Parthenon produced by Jacques Carrey in 1674. These have proved invaluable in telling us what was lost in the explosion of 1687 and the positions of the fragments which survived.^(52,54) The effect of written records on the survival of this information cannot be over stressed.

Another point to note is that what has survived is stone and not metal. The bronze shields and the inscription on the Parthenon were torn down in antiquity. The inscription was deciphered by a study of the mounting holes.⁽⁵³⁾ The base of the Agrippa monument remains in place with its inscriptions; the bronze sculpture groups have disappeared. Again and again, the holes for mounting metal objects are seen, while the objects are not. A glance through a reference text for Greek inscriptions shows that all but a small number of texts survive in non-metal media.⁽⁵⁶⁾ The few which we have indicate that metal could survive for that period of time, but that most metal seems to have been recycled.

The present condition of the Acropolis, due to the effects of acid rain, indicates that not all stone is an acceptable medium for repository markers. Limestones and marbles are not sufficiently durable for a 10,000 year marker, given the present levels of atmospheric pollutants.

The construction technique used in building the various structures is also of interest here. The stones were fitted together by careful dressing, not by the use of mortar. This obviated the need for certain types of maintenance such as pointing. The absence of a materials interface, with its potential for deterioration, most likely contributed to the survival of the monuments. The area of the Acropolis is delineated by the shape of the hill itself. It is unlikely that the repository will be so situated, and so another means of communicating the area of interest must be found. A useful analogy, however, may be found in the temple plans where series of columns are used to frame an area without covering it entirely as a wall or floor would. A series of components, such as columns, may therefore be an effective way of delineating an area with a minimum amount of material.

3.1.6 Great Wall, China

The Great Wall of China has been called one of the wonders of the world. It originally stretched from Shanhaikuan on the Yellow Sea to Kiayukuan in the West, a distance of some 1850 miles (Figure 3.1-7). Later additions, loops, and inner walls have nearly doubled its length.

The first wall was built by Ch'in Shih Huang Ti who unified China and who, in Chinese histories, is better known for his "Burning of the Books" than for the wall. The Wall was begun in 221 B.C., immediately after the final conquest of unification, and was completed in 210 B.C. The rapid time of completion was possible because the Wall incorporated some 1300 miles of walls built in earlier times. The actual building of the wall was entrusted to a general Meng T'ien.

The Wall was begun by setting up a series of watch towers along the frontier. These were generally 40 ft high and 40 ft square at the base, tapering to 30 ft square at the summit, and were located the length of two bow shots apart. This meant that the entire length of the Wall could be effectively defended. After the watch towers were constructed, they were joined by wall segments which ranged from 20 to 30 ft in height, about 25 ft wide at the base, and 15 to 16 ft wide at the top. Figure 3.1-8 shows a segment of the wall. (58-60)

The Wall was built by different methods in different areas according to the local building materials. In the east, where stone was plentiful, a foundation of rubble was laid without mortar. The wall was built of dry tamped earth (terre pleee). (61) The uppermost level was covered with brickwork. In the later Ming Period (1368-1644 A.D.), granite foundation stones as large as 14 ft by 4 ft were used. The rubble or earthen core of the walls was faced with either brick or stone; the latter contains pieces as large as 5 ft by 2 ft by 1-1/2 ft. Further west, the wall cuts across wide exposures of loess soil with little stone for building. This very fine silt was mixed into a slurry and poured between frames to create the wall, which was faced with stone or brick where possible. In several areas, two strips of loess were removed, leaving a rampart of earth. Stone again was used in the westernmost segment. The ends of the walls are each briefly marked by a tablet, though the texts may not be very informative to us today. The one in Kiayukuan reads, "The martial barrier of all under Heaven", while the tablet at Shanhaikuan reads, "Heaven made the sea and the mountains". (58-60)

Figure 3.1-7 The Great Wall of China

(Ref. 55)

Figure 3.1-8 A Segment of the Great Wall

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Who/When - The idea of the wall was conceived by Ch'in Shih Huang Ti, and was carried out by his general Meng T'ien. The construction was started in 221 B.C. and ended in 210 B.C.

Why - The most commonly stated reason for the wall, and one which is borne out by the inscription at Kiyukuan, was that it was to keep the barbarians out. But the lavish expenditure of manpower and capital on an endeavor which did not work has prompted other suggestions. The construction of the wall began very shortly after Emperor Ch'in finished conquering China. It has been suggested that the Wall was built to provide gainful employment for all the vast number of soldiers who were now unemployed. Another suggestion was that the wall not only served a military purpose but also marked the "outward limit of desirable expansion" drawing an arbitrary line between the nomadic and agricultural populations.(62) Finally, the Wall served to emphasize that there was now one China under one ruler with a single northern border, and so emphasized the bonds between the formerly warring states.(59,60)

State of Preservation - The section of the Wall near Peking was rebuilt during the Ming Period (1368-1644 A.D.) and is in excellent condition. This is the area most tourists presently see. Further west, in the loess section of the country, the Wall was more subject to deterioration given the manner of construction. Even so, at the turn of the century, an American traveler still found sections standing to 15 ft in height, and towers surviving to 30 ft.(58)

Other Markers of the Same Genre - As mentioned earlier, the Wall of Emperor Ch'in incorporated great stretches of walls built by warring states. There is a previous history of walled towns and even walled states in China.(60,63) The Great Wall, however, stands unique in its immense scale; later dynasties only rebuilt or added to the Wall as politics and security required.

History - The history of the Great Wall is inextricably bound up with the history of China itself, and it is not the purpose of this report to cover the latter. The Wall was maintained and strengthened when central authority was strong and left to deteriorate when it was not. During the Han dynasty (190-86 B.C.), Wu Ti extended the Wall some 300 miles west of Kiyukuan. The Wu Dynasty (385-535 A.D.) maintained the Wall and added more than 600 miles of wall in various loops. The wall was breached in 585, but repaired and extended in the same year. During 607 and 608, the Sui emperor heavily rebuilt the

wall from the Yellow Sea to the Yellow River. The ensuing T'ang dynasty (618-906 A.D.), however, refused to maintain and repair the Wall. With the fall of the T'ang dynasty the northerners crossed over, only to fall later under the Mongol invasion (thirteenth century). The wall was of little importance to the Mongols, although Genghis Khan had been defeated for years in his attempts to get over the wall. The Mongols were thrown out by a native Chinese dynasty, the Ming (1368-1644 A.D.) who probably carried out more construction on the Wall than any other ruling house since Emperor Ch'in. The many plaques and inscriptions in the wall commemorating the rebuilding of sections of the wall date to the Ming period. These can still be seen and read today. The Manchus (1644-1911 A.D.) were Northerners who replaced the Mings, but had been invited across the wall by a Ming emperor fighting for his throne.

This takes the history of the wall down to this century. The wall has been breached and repaired but never forgotten. Nor does this history do justice to the amount of literature which has grown up around the wall, ranging from poems about its beauty to tales of the horrors endured by the conscripted laborers who built it. Passing the gate at Kiyukuan was tantamount to leaving all that was civilized in the world and is often so portrayed in Chinese literature. In short, it was an integral part of Chinese military and cultural history, enduring several centuries and changes in government. (59,60,61)

Relevance - the Great Wall is an example of a marker which has been maintained and rebuilt for two millennia because it served a purpose for the rulers of the country. As such it shows the potential survival of the repository markers, since they also serve a protective function.

The wall itself does not contain much information about the Pre-Ming constructions and repairs. It is the written record which carries this data, and China is an example of how this tradition can survive in spite of various invasions and changes of government. The construction of the wall appears to indicate that building a marker using small components (e.g., bricks) means that it will need some maintenance for long-term survival. The segments of tamped earth or loess, however, are still visible even after the facing of brickwork has fallen away.

3.2 DISCUSSION

This section summarizes how the information on the various monuments presented in Section 3.1 relates to the issues on repository marking discussed in Chapter 2. The discussion will follow the order presented in Chapter 2 -- message existence, detectability, and comprehensibility.

3.2.1 Message Existence

A point which is mentioned repeatedly in Section 3.1 is the importance of written records to our understanding of the ancient monuments. The purposes of the Pyramids, the Acropolis, and the Great Wall are known because they were built by literate cultures who made contemporary records. This information has either survived to the present time, or has been recovered and spread to a wider audience through scholarly work. The level of detail is such that we not only know why they were built, but by whom and, sometimes, even how they were paid for. Much less is known about the Nazca lines, Stonehenge, and the Serpent Mound. Their builders are known only by general cultural names, not by the names of the individuals who conceived of or constructed them. In other words, it appears that:

- Level III and IV information may only be carried by the written word, and the repository marking system should therefore incorporate this.
- The keeping of records contemporary with the event is necessary in order to allow the survival of the information.

The work of the NITP and the marking of the repository site will ensure that the initial record is made. However and whenever the record of the repository's structure and contents is made, it should include the use of written records.

An inspection of the well-understood markers (the Pyramids, the Acropolis, and the Great Wall) indicates that information survives both in the monuments themselves and through "off-site" archival material. In one case, the Great Wall, the original inscriptions on the monuments tell us very little; it is the abundance of "off-site" literary evidence which provides the information. Ensuring that detailed information is located both on-site and elsewhere will improve its likelihood of survival.

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The monuments discussed in Section 3.1 may also be used to comment on message survivability. Several of the monuments, the Acropolis and the Nazca lines in particular, have suffered their worst degradations at the hands of man, not of nature. The monuments which survived in better condition were those which minimized the need for active maintenance. The Acropolis has no mortar used in the construction of its various buildings, while the Nazca Lines, Serpent Mound, and Stonehenge needed no mortar due to their means of construction. In contrast, the Great Wall used brick and mortar construction over much of its length and it needed active maintenance over the centuries to survive. (The Great Wall, however, is an example that such extended maintenance is possible for at least two thousand years.) Another point is that all the monuments are manufactured from what might be called "natural materials", i.e., stone or earth. These materials need only to be shaped to be used in the monuments; they require no additional processing (e.g., smelting or casting). The choice of these materials may reflect the technological limit of the cultures which used them. However, this does not negate the fact that these ancient monuments have survived in a variety of climates for up to 5,000 years. It should also be noted that metals are not suitable for markers because of their ability to be recycled, and that stones should be of suitable size and/or shape to minimize their potential reuse. A repository system must be designed with these points in mind.

3.2.2 Message Detectability

The large majority of monuments were meant to be detected by sight at ground level, and so provide a possible basis for designing the repository marker system. The Nazca Lines are an exception, but since they probably were not meant to be viewed by human eyes, they need not change this general observation.

The size range of the markers may be described on two levels: the size of the individual components and the size of the entire monument. The range seen in the individual components is immense: the Nazca Lines were formed by moving pebbles, while Stonehenge has monoliths weighing up to 50 tons. A closer inspection, however, reveals a relationship involving the size of the component, the accessibility of the public to the marker, and the state of preservation of the marker. Where the component parts are small, the marker

seems to have survived because it was located in an isolated region. This is the case with the Nazca Lines and with some of the smaller stone rings in the British Isles.

Three of the monuments discussed in the previous section are located near large population centers and have survived. The large sizes of the stones at Stonehenge have made them rather difficult to topple and vandalize. On the other hand, the Pyramids were made of smaller stones and have been used as quarries. They have survived only because of the immense number of stones used in their construction. The Great Wall has been maintained because it served a protective function and is of cultural importance.

A far more subtle relationship exists between the size of the individual components and the size of the entire monument. Stonehenge, the Acropolis, the Pyramids, and the Serpent Mound can all be taken in at a single glance. The patterns and forms of the monuments are immediately perceptible. The perception of form and content holds true for the Great Wall as well, even though the monument cannot be viewed in its entirety except, perhaps, by satellite. An inability to perceive a monument leads to a lack of understanding about it. The Nazca Lines are an example of this, and the phenomenon may explain why the stone circle of Avebury, which is far larger than Stonehenge, is less widely known. The component parts of Avebury are small compared to the scale on which they are set, and it is apparently easy to stand in one part and not realize that the remaining section of the monument exists. Thus it can be seen that the components of the repository system must be scaled to a size, and placed in such a manner, that an individual standing on the site recognizes the pattern of the marking system.

3.2.3 Message Comprehensibility

Written records have the ability to carry Level III and IV types of information, even though languages and cultures may change dramatically. In fact, written records may be the only means of carrying these higher levels of information; the history of Stonehenge points out the possible corruption which can creep into information which is orally transmitted. The use of written language, as well as pictures and symbols, applies to each of the marker components. Symbols, removed from a literary and cultural context, generally cannot carry higher levels of information. The Serpent Mound is an

example of this phenomenon. The pattern of an entire marking system, like those of the ancient monuments, must be recognizable in order for the monument to be properly comprehended. This may be done by using component parts with suitable sizes and locations.

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4 PRELIMINARY REPOSITORY MARKER SYSTEM DESIGN

This chapter presents a preliminary marker system design which incorporates many of the positive features found in the ancient monuments. Since the monuments discussed in Chapter 3 are only a small selection of the material surviving in antiquity, this chapter will begin by presenting a deduction of useful options which can be drawn from this larger body of information (Section 4.1). The marker system design is presented in Section 4.2, with various options which address the different issues that are presented in Chapter 2. It may not be necessary to incorporate all of these features in the final design, but that decision rests with the HITF. Section 4.3 concerns the messages that the marker will convey.

4.1 DEDUCTION OF USEFUL DESIGN OPTIONS

The previous chapter described several monuments which have survived for extended periods of time. With this information as background, we now turn to the problem of designing a marker system for a nuclear waste repository. Useful options (materials, construction, and the means by which the information is conveyed) may be identified by a deductive process which is shown schematically in Figure 4.1-1.

Archaeological materials may be divided into two categories, organic and inorganic. The former category is not suitable because organic materials do not survive for extended periods of time except in favorable climates, e.g., deserts or anerobic bogs.(42,64,65) Information about such materials may be stored if they will be located in a protected environment (e.g., paper in a climate-controlled library), but they are not appropriate for on-site markers. All the markers discussed in the previous chapter are made of inorganic materials.

The inorganic materials group is composed of metals and non-metals. Metals are not acceptable from an archaeological point of view because they show a strong tendency to be recycled by humans. This holds not only for the precious metals such as gold and silver, where this would be expected, but it is also seen with less expensive materials such as copper and bronze. There are archaeological examples which indicate that metals were in use even in early times, such as the Nahal Mishmar hoard, which dates to 3200-2850 B.C.

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Figure 4.1-1 Logic Diagram for Useful Options

and contained over 400 copper objects, but these appear to be the exceptions which escaped being melted down and reused.⁽⁶⁶⁾ (Since we do find these items, the burial conditions were obviously conducive to survival.) Recycling, however, is seen again and again in the archaeological record.⁽⁶⁷⁾ Not all situations are as clear as the Cape Gelidonya shipwreck c. 1200 B.C. which held a cargo of broken bronze implements destined for remelting.⁽⁶⁸⁾ In most cases we are left with negative evidence. For example, there were a bronze inscription and bronze shields mounted on the Parthenon, but they were removed. (The text was reconstructed from a study of the holes left by the mounting pins.⁽⁵³⁾ We only know the shields existed from contemporary descriptions.)

The durability of the metal itself is of secondary consideration in this case. The non-precious metals available in the archaeological periods, e.g., copper, tin, bronze, and lead are typically found in a state that would indicate they are not sufficiently durable to be used for a 10,000 year marker.

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There are, however, modern metals, e.g., titanium, which are far more durable than these. But the archaeological evidence indicates that the intrinsic value of metal makes it highly probable that it will be recycled. In other words, although modern metals may be sufficiently durable, markers made of such materials are not likely to survive. It is this aspect, i.e., human action, which removes metal from further consideration.

A non-metal marker may be constructed out of earth or stone. The bank and ditch enclosing the stone ring of Stonehenge, Serpent Mound, and the Great Wall are examples of surviving earthworks. This, therefore, is a useful option but one which is restricted to conveying information in its form or outline, thereby limiting the complexity of information it can carry. It would be suitable for delineating the repository area. Another possibility would be to make the earthwork in the form of an international hazardous waste symbol.

The marker system may also be constructed out of stone. Within this category, however, there are some unacceptable materials. Softer stones, e.g., steatite, are too easily damaged by erosion, abrasion, or intentional disfigurement to make desirable markers.

Marbles and limestones were commonly used in buildings and monuments. They have, however undergone severe deterioration within the last hundred years or so due to the increase in industrial pollution. The Acropolis in Greece has several buildings which are built of marble and are suffering noticeably from severe deterioration. The marked changes which have occurred within the last century may be seen by comparing a cast of one of the Parthenon reliefs with how it looks today.⁽⁶⁹⁾ The replacements for the Porch of the Maidens are made from a cast taken from the maiden Lord Elgin brought to England. Since it has been indoors, it is in far better condition.⁽⁵⁵⁾

Industrial pollution has created a conservation problem which is reflected in the numerous articles on this topic listed annually in Art and Archaeology Technical Abstracts.⁽⁷⁰⁾ (In this report, the term "conservation" refers to the repair, consolidation, and protection of antiquities and works of art.) The majority of these articles are concerned with marbles and limestones; for every four articles on these stones there may be one on sandstone. Granite and basalt are rarely mentioned. The materials which are more common in the conservation literature are those which require the most repair, reconstruction, and treatment to preserve. The more durable materials, such as granite and basalt, are notable for their absence from these lists.

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A final point in the argument against the use of marbles or limestone is the fact that they are often burned for lime. Many pieces of antiquity have disappeared in kilns.⁽⁷¹⁾

Recent work by Lewin and Charola indicate that limestone and marbles show significant direct solubility in environmental water. (The lack of rainfall in Egypt helps to explain the better condition of the monuments there.) Quartzite and arkosic sandstone appear to deteriorate more from stress incurred by freeze/thaw and wet/dry cycling.⁽⁷²⁾ Sandstones also tend to suffer from surface friability⁽⁶⁹⁾, a factor detrimental to preserving an inscription.

Tuff is a material which has been used for buildings.⁽⁷³⁾ Although it is strong, the ease with which it can be carved makes it unsuitable for a repository marker. It may be destroyed too easily by vandalism.

The remaining rocks which may be suitable for the markers would have the following characteristics: hard, compact, non-brittle, and relatively homogeneous. The harder a stone is, the more difficult it is to work, and therefore the more difficult it is to deface or abrade. The term "compact" here is used in the sense of being fine-grained and lacking cavities. If a stone lacks this characteristic, two difficulties result: the inability to have sharply cut inscriptions, and the ability of water to collect in the cavities, resulting in accelerated corrosion. (This would eliminate vesicular, but not compact, basalt.) Large scale inhomogeneities in the rock may lead to accelerated corrosion along grain boundaries. One homogeneous rock is quartz, but this was rarely used in antiquity for large scale objects because of the difficulties in finding it in sufficiently large pieces and in working it. The only discussion of this characteristic which appears in the literature is the comment in a reference work on conservation that basalt tends to be more homogeneous than granite is and therefore less prone to deterioration.⁽⁶⁹⁾

Brittleness in a rock (e.g., obsidian) makes it too easy to damage by vandals.

These characteristics -- hard, compact, non-brittle, and relatively homogeneous -- also imply that the rock has low permeability and porosity which inhibit water from collecting within it either from the atmosphere or by wicking it up from the soil. It is the uptake of water which can lead to corrosion or to the buildup of salts from the groundwater. The latter crystallize out on the surface of the object exposed to the atmosphere. This phenomenon has been noted on both stone and fired clay objects, and may result

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in exfoliation of the surface of the object. (69,74) This problem will be minimized by site selection factors which make it unlikely for a repository to be sited under or very near surface bodies of water. There are several rocks which fit the characteristics mentioned here. Granite, basalt, porphyry, and quartz are some examples. Modern materials science also allows the possibility of creating a man-made stone for this purpose, but these have no archaeological precedents and therefore fall outside the range of this discussion.

Having suggested a class of acceptable materials, we now turn to the plan of the marker system. The first question to address is whether there should be a single marker or a series of markers. A single marker, be it a pyramid, temple, or figure, tends to mark a spot. It is, then, a point estimate. A series of markers, such as those at Stonehenge or the columns around the Parthenon, tends to define an area and so is more appropriate for the project at hand.

A single marker has the added disadvantage of being too easily destroyed, thereby leaving the repository without any marking whatsoever. In order to build a single marker which is sufficient to withstand the ravages of vandalism and time, it must be built on an enormous scale like the pyramids of Egypt. A series of markers, on the other hand, would be less costly to erect and would provide the design with some redundancy. For example, the plan of Stonehenge can be drawn, even though a third of the stones are missing.

The next question is whether each marker itself should be a single piece construction (monolith) or built of component parts. A constructed marker has two disadvantages compared to a monolith. First, the use of a mortar or a binding agent between the components sets up a materials interface which is more susceptible to deterioration. As an owner of a brick house knows, it must be repointed every few years. Second, if it is easier to build, it is easier to tear down and reuse. The blocks of the pyramids and other ancient buildings were incorporated into other, more modern structures. (11,57,71)

The marker should also be megalthic. Museums are filled with statues, inscriptions, and other artifacts which are a reasonably portable size. A rough estimate or rule-of-thumb would be that objects twice the size of the average person and smaller are liable to be removed. Larger objects are rarely removed, although there are a few exceptions. For example, the Oriental Institute of Chicago brought back a winged bull from a gateway of Sargon II's palace at Khorsabad, Iraq which weighs about 40 tons. But even if

a few of the markers are taken, the remainder would continue to convey the desired information.

The series of monoliths can convey information by two means: spatial configuration and inscriptions on the object itself. As with the earthwork, the spatial configuration can convey only a particular type of information - delineating the repository area or forming the hazardous waste symbol.

The planar surfaces of each monolith are quite suitable for carrying a message in symbolic and/or textual form. The message should not be affixed to the marker, since this is removed too easily (cf. the inscription on the Acropolis). Nor should it be applied to the marker (e.g., paint) since this is too easily scraped off or painted over. The remaining option is that the marker itself should be engraved with the message.

Another point to consider is whether the lettering or symbols should be raised from or cut into the surface of the marker. Most ancient inscriptions are just that; they are cut into the stone or metal. Raised figures are generally reserved for artistic works, i.e., reliefs. Cutting the message into the stone creates crevices in which rain water could collect, leading to corrosion or, if it freezes, to stress. However, the choice of a desirable rock would minimize the potential damage. Raised letters, on the other hand, can be chiseled off more easily than an inscription can be hacked out, since less stone has to be removed, and may be damaged more easily by vandalism.

A final and small point to discuss is the depth to which the inscription should be cut. It should be noted that the depth could be set by the potential corrosion rate of the stone to ensure that the inscription would still be legible after 10,000 years. For perspective, it should be noted that ancient inscriptions were usually cut no more than a few millimeters deep, and even monumental inscriptions are usually cut under a centimeter in depth. Many of these inscriptions, however, have survived for a few thousand years.

In sum, three useful options for conveying information about the repository site have been identified:

- An earthwork would be useful to delineate the repository area or in the shape of the hazardous material symbol.
- A series of megalithic markers would be useful to delineate the repository area or in the shape of the hazardous material symbol.
- Inscriptions on each of the megaliths would be useful to convey information about the repository and its contents in symbols and language on the megalith itself.

4.2 MARKER SYSTEM DESIGN

The preliminary repository marker system design presented here contains three major components:

- A series of monoliths defining the perimeter of the repository site.
- An earthwork in the form of the hazardous material warning symbol.
- A marker at the center of the site.

Each component will be discussed in a separate section.

4.2.1 Perimeter Monoliths

The discussion of this perimeter monolith falls into two sections, the placement of the markers and a description of the marker itself. Several factors should be considered in placing the markers:

- The disposal area (and buffer zone if desired) should be defined with reasonable accuracy.
- The spacing of the markers should allow an investigator to stand at one marker and see the next marker on either side.
- A sufficient number of markers should be used so that the placement pattern can be identified even if some markers are lost.

The perimeter ring of monoliths defines the area to avoid when drilling in order to preclude intercepting a canister and bringing part of the waste directly to the surface. As mentioned in Section 2.1.1 the safety analysis may also be able to delineate a buffer zone around the repository area. If this is possible, then the perimeter of the buffer zone is the figure which should be outlined.

The next two factors interact and must be considered in light of the scale of the problem of marking the repository site. For example, the WIPP environmental impact statement^a states that all the waste will be buried within an 1800 acre area (designated as Zone II) which has a perimeter approximately 6.5 miles long.⁽⁷⁵⁾ The uniformed investigator must be able to see the next marker in either direction when standing at a marker in order to realize that these markers form a pattern. Although the actual placement of

^aThe WIPP site is chosen only for illustrative purposes; there are no plans at present to bury high-level waste at that site.

the markers will be determined by the topography of the site, a spacing of approximately 400 yards between them may be sufficient. Given the height of the markers (cf. below), they would be discernible at these distances in a flat, unwooded terrain.

This suggested placement pattern would result in 29 to 30 markers being used to delineate the WIPP site. A similar number of stones are used in the sarsen circle of Stonehenge, which implies that there will be sufficient markers to reconstruct the pattern if some of the stones are destroyed or carried off to museums. As mentioned above, the plan of Stonehenge can be reconstructed even though more than a third of the stones have disappeared over the last 5,000 years.

The option of simply using four stones to mark the cardinal points of the area is not acceptable for several reasons. First, the scale is so large that the uninformed investigator would not be able to see any of the other markers and so would not recognize the area to avoid when drilling. Second, the loss of any one marker would destroy the pattern. Finally, with such a small number of markers it is possible that all of them might be destroyed or moved during the time period of interest.

Thus far it can be seen that the markers should be of single piece construction, megalithic, and made from a hard, dense, nonporous rock like granite or basalt. It now remains to describe the shape of the marker. A preliminary design is given in Figure 4.2-1. The height of the markers (25 ft) is modeled after the sarsen stone rings and the horseshoe at Stonehenge (cf. Table 3.1-1). The stones would be set to a depth of 5 ft, resulting in a marker which stands 20 ft above the ground level. Unlike Stonehenge, however, the markers will be tapered to create a broad base for extra stability. This should reduce the likelihood of toppling, such as happened at that neolithic site.⁽²⁰⁾ The tapering form will reduce wind resistance, allow rain to run off the face, and also make it more difficult to bring the stones down intentionally, as was done with many members of ancient stone rings.⁽²¹⁾ If stability needs to be increased, shaped parking stones around the base of each monolith can be used.

The basal dimensions are 8 x 5 ft, i.e., slightly thicker than the Stonehenge monoliths. This is suggested for extra strength. The rectangular form should provide information about the direction from which it should be viewed. Leaving one of the broad faces of the monolith blank will enhance the notion

Figure 4.2-1 Perimeter Monolith

of which is the "front" of the monument. Ringing the site with the carved broad panels of the stones facing outward and the blank panels facing inward, should tell the uninformed investigator where he or she is standing, i.e., outside of the repository area.

The suggested design calls for the messages to be carved into the flat faces of the marker. The remaining surfaces should be polished to minimize

cracks and crevices in which rainwater can collect, i.e., to minimize corrosion and deterioration. If wind erosion is a potential problem at a repository site, the message can be protected by a raised band around the edge of the panel to bear the brunt of the wind damage. (The facade of the treasury at Petra, Jordan is in much better condition than most at that site. It has been suggested that this is due to the fact that this facade is recessed into the cliff walls.)(76) The messages carved on these panels will be fully discussed in Section 4.3, but it should be noted that the symbol in the upper left of Figure 4.2-1a is the hazardous material warning symbol developed by the HMTF.

4.2.2 Earthwork

If the decision is made that the repository markers should be visible from the air and should call attention to the site, an earthwork can be incorporated in the marker system design. The very nature of an earthwork limits the amount and type of information it can convey; making it in the form of a hazardous waste symbol would make the best use of its limitations. The earthworks of England are formed by using the material excavated from the ditch (usually chalk) to form the embankment as illustrated in Figure 4.2-2. The bank at Stonehenge is 6 ft high and 20 ft wide, while the one at Avebury was once 22 ft tall and 75 to 100 ft wide at the base.(21) The Serpent Mound is 5 ft high and 20 ft wide. The clay body of the Serpent covers a stone core. The height of this marker, therefore, should be at least 6 ft, but the height probably would be determined by the surface erosion rate at the specific repository site. The excess material remaining from the excavation and backfill of the repository could be used in the formation of the core of the earthwork.

Figure 4.2-2 Embankment and Ditch Construction (Section)

The visibility of the embankment can be enhanced by packing the top of it with a material which will inhibit vegetative growth, e.g., crushed stone. This change in vegetation, as well as the original color contrast between the stone and soil, would be quite visible from the air much as are the Nazca lines. Other possibilities include packing it with magnetic sand to create a magnetic anomaly.

Unlike the perimeter monoliths, the earthwork has no definite size requirements since it does not define a particular area. The size would be determined by a tradeoff between cost and the scale on which it will be viewed. The greater the scale, the greater the height from which it is visible until the width of the earthwork is no longer discernible. Using archaeological examples as models, the bank at Avebury is a quarter of a mile in diameter, while the large cleared trapezoid of the Nazca lines measures a half-mile on its longest side; an embankment within this size range would be appropriate.

It should be noted that this component of the marker system entails the largest environmental impact, particularly if steps are taken to inhibit vegetation on the top of the embankment. The perimeter monoliths would serve to delineate the site area, warn the potential intruders, and describe the repository in more detail than is possible to be done by an earthwork. The monoliths, however, would be a series of points when viewed from the air and the embankment might be more noticeable. A judgment must be made whether the increased detectability by remote sensing methods offsets the environmental impact.

4.2.3 Interior Marker

The marking system described in the previous sections delineates the site and carries information on Levels I through III. As such, it matches (or possibly exceeds) the information content of the three ancient monuments from literate societies discussed in Chapter 3. The Level IV information for these monuments comes from the off-site archival material. For an added level of redundancy in the marking system design, however, a record of the Level IV information could be kept at the site itself. This is the purpose of the interior marker.

In designing the interior marker, it is apparent that the need for access to the Level IV information will be necessary only if every other off-site

record has been destroyed. (It is not within the purview of this paper to comment upon the type of cataclysm which could lead to this situation or whether sufficient technology could be regained after such an event within the time frame of interest.) The Level IV information, therefore, need not be immediately accessible to the investigator. The preliminary design for the interior marker has the Level IV information stored in an underground vault, while the position and purpose of the vault is marked by a series of monoliths and a tumulus.

A tumulus is the name for an ancient burial mound. Here it refers to the mound of earth raised over a vault containing the Level IV information. The vault is located below ground to create a more stable environment for its contents (e.g., removing it from freeze-thaw, wet/dry cycles.⁽⁷⁷⁾) The mound above it serves as an additional buffer between the contents of the vault and the fluctuating environment, as well as being a marker.

In order to draw added attention to this marker, it should be placed in the center of the site and marked by four monoliths. A preliminary design for the tumulus and interior monoliths is given in Figure 4.2-3. The height of

Figure 4.2-3 Section and Top View of Tumulus and Interior Monoliths

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Figure 4.2-4 Interior Monolith

the mound is shown as 10 ft, making it within the range of other ancient tumuli, although the height may be determined by the erosion rate at the repository site.

Care should be taken to distinguish these monoliths from those marking the perimeter. For this reason they should be different in a number of respects. A preliminary design is suggested in Figure 4.2-4. The height and shape are different from those of the perimeter monoliths, and they should be made of a different material. The Altar Stone at Stonehenge (whose purpose is unknown) is a prime example of the attention given to components made of a

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different material than that which was used in the bulk of the construction.⁽²⁰⁾ Like the perimeter monoliths, they are tapered for stability. The difference in the messages on these monoliths and the perimeter monoliths are discussed in Section 4.3.2.

There is a possibility that the smaller size and fewer number of interior monoliths increase the likelihood of their being carried off or destroyed. The fact that these monoliths surround an obviously non-natural mound of earth is going to draw attention to that mound. Excavation of that mound probably would occur before the monoliths would be moved or damaged. Finally, the monoliths are still larger than the "twice human size" guideline for identifying materials likely to be removed to museums.

Vault - The vault contains the Level IV information. The ancient world, however, has not left an overly wide selection of durable materials used for texts -- papyrus, clay, and stone. There are two cultures in the Near East where writing has a 5,000 year history -- Egypt and Mesopotamia. The oldest Egyptian texts are on stone; only a few fragments of papyrus survive from the Old Kingdom.⁽¹³⁾ In Mesopotamia, papyrus did not exist and stone was very rare. Architecture and writing therefore utilized the common materials of mudbrick and clay. The earliest writing from this area is found on clay tablets of the Jemdet Nasr period c. 3100-2700 B.C.^(78,79)

Papyrus seems to have survived because of the nature of its burial environment. The dryness of that environment would be duplicated in the sealed vault, which suggests that the modern analogue of papyrus, an acid-free paper, has a potentially long survival period in an equally stable and dry environment. However, the longevity of this benign environment is difficult to estimate.

The Mesopotamian texts appear to have survived because they reached a rapid equilibrium with the burial environment. They are, after all, made from the same material as the environment. Everyday texts such as lists of commodities and private and business letters were on unfired, but sun-dried tablets; royal annals and literary works were often fired to enhance their survival. Fired tablets are much like potsherds; they may break but they are otherwise extremely durable. Problems in conservation arise only after the objects have been removed from the environment in which they are in a state of equilibrium. The durability of clay tablets is attested to by the 400,000 examples which survive⁽⁸⁰⁾; this estimate does not include the 16,500 newly

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discovered tablets and fragments from the site of Ebla in Syria.⁽⁸¹⁾ It should also be noted that these tablets are found in burial climates which would not be conducive to the survival of papyrus.

The archaeological evidence attesting the survivability of stone has already been given in several places in this report. Stone and fired clay, therefore, appear to be suitable materials for the Level IV information.

The vault and its contents are the only non-replicated components of the repository marker system. Once opened, the vault no longer functions as an on-site marker. Most of the contents would eventually be removed to the future equivalent of a library, university, or museum for safe keeping and study. This would occur even if the vault were initially looted. A parallel situation would be the Dead Sea Scrolls which were originally found by a Bedouin child.⁽⁸²⁾ The vault should, therefore, also contain a request that the information be translated into the languages in use at that time, placed on durable materials, and replaced in an on-site marker. If that society considers the information of sufficient interest, it is likely to be translated and made available to a wider audience, much like the works in Ancient Near East in Texts and The Literature of Ancient Egypt.^(7,8) Replacing the "updated" version on the site is less likely to be done. The society may not consider it necessary to replace the information, but the request must be made. It should be noted, however, that in this scenario, the marker serves its purpose by making the information available to the public, and initiating a new cycle of off-site information transfer.

4.3 MARKER MESSAGES

This section will deal with the types of messages that can be transmitted via each component of the marker system. The overall message to be conveyed has two parts -- warning and description; the latter aspect can be conveyed on several levels of complexity. The message elements for each component of the repository marking system are discussed in separate subsections.

4.3.1 Perimeter Monoliths

Each monolith would be inscribed on three sides, leaving one broad side blank. By placing each monolith so that the blank face is turned inward to

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the repository site, the observer is informed about where he or she should be standing, i.e., outside of the repository area facing the monolith. As mentioned earlier, the position of the monoliths defines the repository area.

The front face of the marker (Figure 4.3-1) bears the warning of the site and the simplest level of description. In the top left corner is the hazardous material warning symbol developed by the HMTF. The symbol to the right of it acts as a qualifier, i.e., radioactive material. This line can be "read" either from left to right or right to left. The symbol below it is patterned

Figure 4.3-1 Perimeter Monolith

8 0 7 4 0 1 0 8 7

after the international driving signs. It shows a human digging with a line drawn across it. (This may be interpreted as that no digging should be done at the site, but since we cannot convey the difference between surface and deep excavation in a single simple symbol, it is better to convey the more conservative message).

The next six panels repeat this information in the six languages of the United Nations. The use of six languages increases the possibility that at least one of them will be recognizable to a number of people and readable by some scholars. The wording is deliberately simple in order to facilitate its recognition. The English text reads "DANGER. RADIOACTIVE WASTE. DO NOT DIG DEEPLY HERE."

This aspect of the marker is obviously modeled on the Rosetta Stone. It may be argued that the amount of time it took before the Egyptian hieroglyphic text could be read (nearly 25 years after the stone's discovery) would not be in time to prevent interference in the repository. This ignores the important fact that one of the languages was recognizable and readable at the time of its discovery. To illustrate, a brief history of the Rosetta Stone is in order. The slab was found by French engineers in July 1799, and to quote the British Museum publication about the stone, "Since the last of these inscriptions was written in Greek and could therefore be read, they realized the possible importance of the Stone for the decipherment of the hieroglyphs..." (emphasis added).⁽⁸⁴⁾ The acquisition of the Rosetta Stone was part of the settlement between England and France in 1801. Needless to say, there had not been much opportunity for study during this period. The Stone arrived in England in February 1801 and was made available to scholars on March 11 by the Society of Antiquaries of London. About one month later, an English translation of the Greek text was formally presented at a meeting of that Society.⁽⁸⁴⁾

It is not possible to predict which language or language families will survive in the future. The information on the repository markers should therefore not be presented in only one language. The choice of languages -- English, French, Spanish, Arabic, Russian, and Chinese -- is based upon the fact that these languages are the ones used by the United Nations. If they are suitable for that international body, they should be suitable for this purpose. They also cover several language families, i.e., Indo-European, Semitic, and Uralic.

One side panel of the marker is devoted to a description of the repository in symbols, pictures, and figures. The derivation of a pictorial representation of what was done at the repository site is not within the scope of this report. Such a representation, however, should be included on this panel. In addition, diagrams can be used to show the areal extent and depth of the repository; an example, based on the WIPP site, is given in Figure 4.3-2. The areal extent and the positions of the perimeter and internal monoliths are drawn. The monoliths are not drawn in scale since they would not be visible. An arrow marks the position of the monolith which is being studied. This will help reconstruct the layout of the site even if several of the markers are gone. The earthwork, if included, should also be shown to indicate its contemporaneity with the rest of the system. (For example, we know that the temple at Luxor once had two obelisks in front of it, where only

Figure 4.3-2 Pictorial Representation of the Repository

one now stands, because the temple is drawn on one of the inside walls.(85,86) It is not possible to put a line of unit length on the marker and then show it on the figure -- the differences in scale are too great.

below the top view is a cross-sectional view of the repository. The sun and a plant (here, a tree) define the ground level. The present design calls for the monoliths to stand to a height of 20 ft above the ground; this is approximately 1 percent of the depth to the repository. The monoliths would not be immediately discernible if drawn to scale, and that would defeat part of the purpose of the plan. They are therefore shown out of scale in order to be visible. The ratio of the width of the site to its depth should, however, be accurately represented. The figures in the center should be circular or triangular depending upon the option chosen for the central marker.

On the bottom of this figure is a schematic representation of what is contained in the repository. It shows a neutron striking an atom which then fissions. As shown, the figure represents high-level waste; the disposal of spent fuel would be indicated by having the circle include the atom which fissions as well. This general representation was chosen for its simplicity and clarity. The large number of isotopes which are found in the waste precludes their representation, since they change in time (i.e., the representation would be inaccurate) and the representation would be too space-consuming while providing too little information. That level of information is appropriate for the more complex level, not here.

The other side panel is devoted to brief descriptions of the repository in text. The rationale for the use of multiple languages and the choice of those languages has been discussed above. The text should be kept simple, without jargon or abbreviations, and cover the following points: what, who, when, why, what to avoid, where to find more information, and marker replacement. The question of "how" requires too complex an answer to be included on this marker, but should be included in the vault.

A sample text may read: "This is a nuclear waste repository built by the United States government in _____. The area of the repository is _____ by _____ meters and is outlined by these monoliths. The radioactive waste is buried _____ meters down to put this dangerous material far away from mankind. Do not drill _____ meters deep. Do not drill and use a well without checking the water for radioactivity. Do not do anything which will change the rocks or water in this area. To do any of these things may cause

exposure of humans to radioactivity which may result in cancer. More information is located under the hill in the center of this site and in government libraries. Do not destroy this marker, but replace it by using long-lasting materials and languages common in your time."

4.3.2 Earthwork

As mentioned above, the earthwork can only convey a limited amount of information, i.e., something is here and it is hazardous. The first is conveyed

Figure 4.3-3 Interior Monolith

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by its very presence, while the second is told by its form. It is, however, the one component which is a suitable vehicle for conveying a message to remote sensing devices. Suggestions may be made for possible inclusions in the earthwork to enhance its detectability (e.g., magnetite), but these have no archaeological precursors.

4.3.3 Interior Marker

The message borne by the interior monoliths is simple -- more information is located under the mound. The interior monolith (Figure 4.3-3) does not bear the hazardous material warning symbol, since there is no danger from investigating the vault. The figure shown, however, specifies that the area to investigate is below the mound between the interior monoliths. The multi-lingual inscriptions explain what is buried; a sample text in English reads "More information is located below the mound".

4.3.4 Vault

The vault contains the Level IV information and will not need to be effective until all other off-site archival information is lost. If the site location is lost, the perimeter monoliths will serve to link the concept of "nuclear waste burial" and "burial at this site". If this has occurred, society will recover the technology to breach the vault before it recovers the technology to interfere with the repository system. In other words, there is likely to be a lag between the time the information is physically recovered and the time interference could occur; this lag would allow the potential for the information to be deciphered and thus prevent interference.

5 SUMMARY

The approach taken in this report is that the likelihood of human interference with the repository system can be reduced by the effective communication of warning messages. For this to occur, however, the message must exist, be detectable, and be understood. A message can exist only after it has been ascertained what should exist (message definition), where it should exist (message location) and how long it should exist (message survival). There are four possible levels of information for the message: (*)

- Level I: Attention-getter, i.e., something is here.
- Level II: Attention-getter and warning, i.e., something is here and it is dangerous.
- Level III: Basic information, i.e., what, who, when, why, what actions to avoid, and where to find more information.
- Level IV: Full record of information, i.e., plans, drawings, environmental impact statements, etc.

Archaeological data indicate that the utility of a Level I message without any association with a higher level message may be dubious, while Level IV data appear to be carried only by written documents which generally do not occur at a marker site. Incorporating all four levels of information in the repository marking system would be an improvement over most ancient man-made markers. The message should exist at the site itself to physically connect the concepts of "nuclear waste burial" and "burial at this site".

Archaeological information highlights the distinction between materials which are durable and materials which survive. Survivability includes the likelihood of withstanding human actions as well as being durable. A marker which is likely to survive for an extended period of time will be made of a material which is durable and of such low intrinsic value that it is unlikely to be recycled. The possibility of recycling can also be minimized by choosing a construction method, shape, and size for the marker which will make it difficult to reuse without a great deal of effort.

Ancient man-made markers are designed primarily to be detectable by sight at ground level. This provides a baseline for message detectability in the repository marking system. If added levels of detectability are desired, features which are visible by remote means (e.g., by aerial or satellite survey) may be included in the marking system, although knowledge of the repository

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and its contents at this distance will not affect the functioning of the repository system.

The third factor in the marking system design is message comprehensibility. The message can be conveyed by three different means -- symbols, pictures, and languages. Archaeological data indicate that the higher levels of information may only be able to be carried across great changes in time and culture via written languages. The repository marking system should incorporate all three means of conveying a message, and should utilize a number of languages to enhance the likelihood that at least one of them will be recognizable to a number of people and readable by some scholars. This report suggests using the six languages used by the United Nations.

The preliminary marking system design presented in this report has three possible components:

- A series of monoliths delineating the overall extent of the repository, or the repository plus buffer zone.
- An optional earthwork in the form of the hazardous material warning symbol (included in the marking system if visibility or detectability at great distances, e.g., satellite, is desirable).
- A central marker containing the most detailed level of information. The information is not immediately available to an investigator but is readily accessible.

Each of these components has an analogue in an ancient man-made marker which has already survived for at least one thousand years. The information about six ancient man-made markers is summarized to provide the background upon which the design is based.

Archaeological information indicates that the perimeter markers should have the following characteristics:

- They should be monolithic. One piece construction eliminates a materials interface between the bonding agent and component parts, a potential area of corrosion. This also means that the marker will require no active maintenance.
- They should be spaced so that the next monolith in each direction can be seen; i.e., the pattern delineating the site is recognizable at ground level.
- The monoliths should be made of a hard, compact, non-brittle, non-porous, and relatively homogeneous stone. Metal is too easily

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and too frequently recycled to use as a marker which should survive for extended periods of time.

- They should be megalithic. An unusually large size or shape for the marker will minimize the ease with which it could be removed and re-used in another structure.
- The monoliths should carry the first three levels of information (attention-getter, warning, and brief description).

The perimeter monoliths will be sufficient in number and carry enough information so that the areal extent of the repository can be ascertained even if some of the monoliths are removed. Inscribing the markers with symbols, pictures, and information in multiple languages will make this set of markers more informative than the large majority of ancient monuments. Sample drawings and texts are provided in Section 4.3.1. The perimeter markers, then, contain enough information to join together the concepts of "nuclear waste burial" and "burial at this site".

The earthwork can carry only Level I or Level II information (i.e., attention-getter, or attention-getter with warning). Its prime function will be to call attention to the site from great distances, such as those of aerial or satellite surveying. Whether or not this is a requisite part of the final repository marking system design is a decision which rests with the Human Interference Task Force.

Since access to the Level IV information (i.e., the most detailed, such as environmental impact statements) will not be necessary unless all of the off-site archival records have been destroyed, this information need not be immediately available to an investigator. For the interior marker, the information is placed on a desirable material (possible media are suggested on the basis of archaeological data) and contained in a shallowly buried vault. The location of the vault is marked (and protected by) a mound of earth which is, in turn, marked by four monoliths. The interior monoliths differ in size, shape, and material from those marking the perimeter and specify that only the area in between them should be investigated.

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WISCONSIN DIVISION OF STATE ENERGY
ROBERT HAINSTEAD
WISCONSIN GEOLOGICAL AND NATURAL
HISTORY SURVEY
MICHAEL G. MURPHY JR.
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BRUCE WINNER

NATURAL Resource Management Division
101 Long Avenue
Columbia, SC 29201

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Archaeological Data as a Basis for Repository Marker Design

Technical Report

October 1982

Maureen F. Kaplan

The Analytic Sciences Corporation
One Jacob Way
Reading, MA 01867

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The content of this report is effective as of August 1981. This report was prepared by The Analytic Sciences Corporation under Subcontract 1515-09000 with Battelle Project Management Division, Office of Nuclear Waste Isolation under Contract No. DE-AC06-76-RF01640 ONWI with the U.S. Department of Energy. This contract was administered by the Battelle Office of Nuclear Waste Isolation.

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ABSTRACT

This report concerns the development of a marking system for a nuclear waste repository which is very likely to survive for 10,000 years. In order to provide a background on the subject, and for the preliminary design presented in this report, a discussion is presented about the issues involved in human interference with the repository system and the communication of information. A separate chapter summarizes six ancient man-made monuments including: materials, effects of associated textual information on our understanding of the monument, and other features of the ancient monument relevant to marking a repository site. The information presented in the two chapters is used to provide the basis and rationale for a preliminary marker system design presented in a final chapter.

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1 INTRODUCTION

The Office of Nuclear Waste Isolation (ONWI) has established the Human Interference Task Force (HITF) to respond to the issues of human interference activities in nuclear waste isolation. The purpose of the HITF is to develop an approach to reducing the likelihood of future human interference with the nuclear waste repository system. The HITF has focused on the development of effective, long-term communication systems as being important for minimizing the likelihood of human interference. Thus, the HITF is concerned with communicating information about nuclear waste repository locations, contents, and associated risks, both at the repository site itself and at numerous places away from the site. The time frame of interest for the marking system is 10,000 years after repository closure; this is consistent with draft EPA waste management criteria.(1)

This report is written in support of, and is consistent with, the work of the HITF. It primarily addresses the problem of marking the repository site by designing a marker system based on a study of ancient man-made monuments, some of which have survived for up to 5,000 years. The marker system design entails both the physical marking of the site and the communication of information about the site by the markers. In order to delineate the general premises upon which the design is based, Chapter 2 presents a discussion of the issues involved in human interference and the communication of information. Chapter 3 contains information about six ancient man-made markers, including their relevance to marking repository sites. The section delineates, by case histories, the factors which result in a comprehensible long-lasting marker. The information presented in Chapters 2 and 3 is utilized in Chapter 4, where a preliminary marker system design is proposed.

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2 HUMAN INTERFERENCE

The safe disposal of high-level radioactive waste is a subject of much interest to the general public and the scientific community. One method of disposal calls for the waste to be buried in a deep mined repository with a series of barriers between the waste and the environment. These barriers include, but are not limited to, transformation of the waste into a long-lasting material, enclosure of this material in a durable container, filling the repository with a material which reduces the access of ground water and retards the transport of radionuclides, finding a suitable rock type for the repository, and locating the disposal site in a remote area. Much effort has been expended to develop these barriers between the waste and the environment. Human interference could perturb this system of barriers and reduce its effectiveness. For example, the system could be breached by intercepting the waste through mining or drilling. Or, inadvertent intrusion into the repository system could become a possibility in the future if records are lost, or memory of site locations and contents becomes hazy. Thus it appears important that nuclear waste repository sites be marked, and that these markers survive for an extended period of time. The period of interest used in this study (10,000 years) is based on draft EPA waste management criteria (10 CFR 191)(1). The logic and discussions which follow were derived from preliminary work of the Human Interference Task Force (HITF) modified by this author's perspective. However, those modifications are consistent with the overall logic used by the HITF.

There are three basic approaches to the issue of how to prevent human interference with a nuclear waste repository. The first is not to draw attention to the site and to leave it unmarked, relying upon the site requirements of remote location and minimum resources to make it unlikely that the site would be disturbed in the future.(2) Since we can neither predict what will be considered a resource or a remote location in the future, nor leave the site unmarked (with any sense of responsibility towards posterity), this approach is not suitable.

A second method is to dispose of the waste in such a manner that it could not be interfered with or recovered. This is not acceptable for two reasons. First, the disposal of nuclear waste in such a manner would preclude its possible future recovery, an approach which is inconsistent with the views held

by the EPA.(1,3) Second, it is unlikely that one disposal option, a repository system with disposal in a deep mine, could be designed which could not be breached by techniques developed by future technologists.(3)

The third and final approach is to mark the site and attempt to convey information about the repository location, contents, and associated risks to future generations. This section discusses the general logic followed in deducing what might be required by such a system, and it presents the underlying reasoning which was followed when designing the system presented in Chapter 4. An analytical framework for ascertaining the means by which this information can be conveyed is given in Figure 2-1. The first three points to consider are that the message must exist, be detected, and be understood in order to be effective. Each of these points is further discussed in separate sections.

It should be noted that the objective of this work is to have the message understood. The Department of Energy has taken the position that this generation bears no responsibility if a later generation decides to do something which would affect the repository behavior (e.g., retrieve the waste) if that generation is fully cognizant of the hazards and consequences of that action.(3)

Figure 2-1 Main Logic Diagram for Warning Messages

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2.1 MESSAGE EXISTENCE

The decision to mark the repository site means that it has been decided that a message to future generations should exist. The next level of decision (cf., Figure 2.1-1) involves what should exist (message definition), where it should exist (message location), and how long it should exist (message survivability). Each of these factors is discussed below in separate sections.

2.1.1 Message Definition

In order that a message may be conveyed to future generations, we must first define what that message is and the audience to whom it is addressed. Although this report speaks of "a message", i.e., in the singular, there may actually be several possible levels of information which can be conveyed. For example, the message can be classified into four levels:⁽⁴⁾

- Level I: Attention-getter, i.e., something is here.
- Level II: Attention-getter and warning, i.e., something is here and it is dangerous.
- Level III: Basic information, i.e., what, who, when, why, what actions to avoid, and where to find information.
- Level IV: Full record of information, i.e., plans, drawings, environmental impact statements, etc.

It is apparent that the utility of a Level I message without any association with a higher level message may be dubious. Indeed, such an approach is likely to spur interest in, and investigation of, the site, possibly resulting in actions the marking system was designed to avoid. The amount of effort which some people are willing to spend in investigating man-made phenomena may be seen in the work performed in the field of archaeology.

The medium of the message may determine the level of information the marker can convey. For example, if the site is to be marked in an obvious manner, an earthwork may be a suitable marker. An earthwork, however, is limited by its very nature in the amount and type of information it can convey. It can call attention to the site regardless of its form (Level I). If made in the form of a hazardous material warning symbol, it can convey Level II information. If it rings the site, it can convey one facet of Level III

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Figure 2.1-1 Logic Diagram for Message Existence

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information, but the Level II information is lost. The different levels of information, therefore, may require different media and methods of presentation in order to be effective.

Another aspect of message definition is the identification of the audience to whom it is addressed. For the purpose of repository marking, the technological level of the audience may affect how the message is structured. In particular, the technological level may affect what is mentioned as actions to avoid in the Level III and IV messages.

It therefore follows that an initial step in identifying the technological level of the audience is the identification of undesirable actions so that warnings against them may be made. These generally fall into two categories: direct intrusion into the site itself, and near-site activities. Direct intrusion is exemplified by drilling into the repository. Near-site activities, though not at the site itself, could diminish the effectiveness of the repository system. An example of near-site activities is injection of substances into the overlying aquifer which would reduce the ability of the aquifer to retard the transport of radiol isotopes.

The boundaries of the first category of undesirable actions (direct intrusion) are well defined, since they are set by the areal extent and depth of the repository. It is unlikely that these will change radically within the time frame of interest due to site selection factors. A repository marking system can then be designed to delineate the site and its potential hazards.

In contrast, the boundaries of the second category of undesirable actions (near-site activities) are not well-defined. It is not immediately evident how far away the action must take place for it not to have an effect on the repository system. In addition, it may be difficult to predict whether and where potentially undesirable activities may take place in the future, e.g., dam building or large scale irrigation projects. Both these factors make it very difficult to decide where to place the near-site markers. Finally, there is the difficulty in relating the presence of these scattered markers and actions to be avoided to a possibly remote repository site.

It should be noted that there are very different technological levels associated with on-site and near-site interference. The Romans were quite capable of building dams and water systems;⁽⁵⁾ however, it is only recently that the technological level has been reached which would allow deep drilling (the repository will be located at a depth of 2000-3000 ft), which would constitute on-site interference.

The site-specific safety analysis which would be undertaken at a repository site could be utilized here. First, the analysis would consider those actions and their consequences which would be detrimental to the repository system. This work may also facilitate the identification of a buffer zone around the repository to protect against actions such as drilling. If this can be done, then the repository site, plus buffer zone area, would be the area to mark. This still leaves action which may take place at some further distance from the site, e.g., dam building, to consider. The safety analysis could determine the severity of the consequences if actions such as dam building were taken. Given the potential difficulty in marking such a near-site area and determining the actions to be avoided, the results could be used as part of the site selection process, i.e., to judge whether a repository should be placed at that site. Finally, this information would be suitable to include in the Level IV message so that future generations could make an informed decision on whether to take a certain action.

2.1.2 Message Location

All four message levels should be located on the repository site, in order to physically connect the concepts of "nuclear waste burial" and "burial at this place". As mentioned in the introduction, this report is primarily concerned with the on-site marking of the repository and so shall only briefly discuss the off-site conveyance of information. The off-site information should be located in numerous places, preferably world-wide, to increase the likelihood of the survival of some copies even if local information blackouts occur. The off-site messages may be carried by both physical and non-physical means, e.g., oral tradition and archival material. Level III information can be conveyed by such means as having the site location denoted by the hazardous warning symbol on maps. The off-site archival material, with its ability to carry the more complex levels of information, should include information about the hazards of near-site activities, but as mentioned above, near-site marking for all undesirable actions may not be appropriate or feasible.

2.1.3 Message Survivability

The Human Interference Task Force has chosen a 10,000 year time frame as the period for which the markers need to survive, based on EPA draft

criteria.⁽¹⁾ There is a distinction drawn here between the durability of a message and the ability of that message to survive. Durability refers to the longevity of a material if it is left undisturbed after placement. Survivability takes into account not only the durability of a material, but its likelihood to withstand human actions as well. As such, survivability reflects a combination of factors, each of which is described below.

Archaeological evidence indicates that human actions are a prime factor to consider when assessing the potential survivability of the marker system. This factor can affect the choice of materials; metals may not be suitable because of their ability to be recycled (cf. Sections 3.2 and 4.1 for examples and further discussion). Removal, defacement, and vandalism are all possibilities to be considered. Chapter 3 contains examples of what has happened to some notable monuments at the hands of man. The reasons for removing or destroying monuments are varied, ranging from iconoclasm to museum acquisition, and the marker system must be designed to make removal and/or destruction undesirable or difficult to do.

Human actions can also indirectly affect the durability of markers. For example, industrialization has led to acid rain, which is having an adverse effect on many ancient monuments (Section 3.1.5 discusses its effect on the monuments of the Acropolis, Greece). The marker components must be chosen with this phenomenon in mind.

The marker system should also be able to withstand the natural events and processes which might occur at the repository site during the time period of interest. However, in some cases, this may not be feasible. For example, it is unlikely that any on-site marking system could withstand the onslaught of a glacier. It is also unlikely that the repository would be intruded upon while it was under glaciation. This restricts the situations which need consideration to those where a glacier could advance, retreat, and have time after the retreat for site exploration, all within the time frame of interest. Such a case can be eliminated because of its low likelihood of occurrence. In any case, for any such extreme scenarios, it is the off-site messages which will continue to convey the information.

In many cases, the site selection criteria for the repository would exclude many sites which could present a problem for long-term marking on the basis of other considerations.⁽²⁾ For example, it is unlikely that a repository would be located in an area in which lake formation, severe flooding, or river formation would occur within the time frame of interest. Other features

of the marking system, e.g., height of the markers, or whether they should be placed on platforms, could be chosen with consideration of site-specific factors such as soil erosion or deposition rates.

Finally, the marker system must require no active maintenance. Such maintenance cannot be guaranteed and to require it would be contradictory to the idea that the generation which receives the benefit of nuclear power should place no burdens on future generations for its disposal.

2.2 MESSAGE DETECTABILITY

The message must be noticed in order for it to be effective (Figure 2.2.1). This brings us to the questions of the distance at which the message should be detectable and the means by which it should be detectable. (As stated earlier, this discussion is concerned with the message at the repository site itself. It does not consider off-site information such as warning symbols on maps or reports stored in libraries.)

Figure 2.2-1 Logic Diagram for Message Detectability

The distance at which the message is detectable may be determined, in part, by whether it is desirable to actively call attention to the site or to warn people once they have decided to investigate the area. For example, if it is desirable to call attention to the site and have it be detectable by remote methods (e.g., aerial or satellite detection), it is possible to take such measures as creating a magnetic anomaly or changing the vegetation at the site. Such an approach could carry Level I or Level II information (if the unusual feature takes the form of the hazardous material warning symbol), but no higher levels. This approach, however, may trigger further investigations of the area where none had been previously planned. It may also be a superfluous level of redundancy in the marker system design, since whether the repository is known or noticed at this distance will not affect the behavior of the repository system. Interference can only begin through ground level activities by man or machine. (It is beyond the scope of this report to speculate on the possibility of the development of drilling or excavating techniques which would originate at a distance from the ground level.)

The second option, detectability on the ground level, is an obviously necessary part of repository system design. (Here, "ground level" includes up to human height above the ground as well.) Nearly all of mankind's previous markers have been designed on this basis. In addition, any action taken on or near the repository site which might disrupt the repository system would almost certainly take place with part or all of the personnel and equipment located on ground level. Such actions would not occur in a vacuum; that is, it is very unlikely that those performing or affected by the actions would be unaware of an unusual feature in the vicinity. The primary focus of the repository design, then, should be on ground-level detectability.

It may also be suggested that the repository marking system includes features located between the ground level and the repository, e.g., a buried mesh net to entrap a drill bit, or the inclusion of an odoriferous or unusually colored material to catch the attention of the drillers. These suggestions may not be practical for several reasons. First, these features come into use only after the intrusion has begun. The marking system should prevent the investigators from reaching this stage. Second, it may be difficult to design features which would survive for the period of time in which we are interested. Third, these features might intrigue the investigator and provide an incentive for more exploration, not less.

There are two general means of message detection: by humans or by machine. In either case, the means of communicating the message cannot be hazardous or require an energy supply in order to function. The human means of detection, the five senses, provide us with a baseline for the design, since these are not expected to change over the time period of interest. It is difficult to conceive of a message and/or warning which could be conveyed to the senses of hearing, tasting, smelling, or touching which would be practical, non-hazardous, and passive. Quite the opposite is true for the sense of sight; the ancient monuments and markers which have survived appeal to this sense. It is for this reason that the primary emphasis of the design presented in Chapter 4 is based upon detection by human sight.

Detection by machines can occur by the interception of various types of signals, e.g., electrical, magnetic, chemical, and so forth. This approach may not be practical for several reasons. It is not possible to predict what type of signal may be searched for by future technologies; it may be one which has not yet been developed. Some signals, e.g., gravimetric, may be extremely difficult to implement, while others, e.g., chemical, may be hazardous. The remaining possibilities, such as creating a magnetic or soil resistivity anomaly, can carry only the first two levels of information. For these reasons, the primary emphasis in the marker system design should be on detection by sight.

2.3 MESSAGE COMPREHENSIBILITY

As mentioned above, the objective of the repository marking system is to convey a warning and information about the site to future generations. This project differs from what was generally undertaken in the ancient world on two points.

First, when earlier cultures proclaimed messages to posterity, they appear to have pictured that culture as not differing substantially from their own. However, this project is being undertaken with the idea that societies, cultures, and languages may change drastically within the time period of interest. In spite of their failure to consider future culture change, the success of the earlier markers is evidence that messages can be conveyed to future generations with great disparities in technological levels and languages without overt efforts in this direction. It is suggested, therefore, that the repository marking system has a higher probability of survival

and understandability since it is being designed with culture change in mind. And, since we cannot predict the changes which will occur, we can use our present languages as part of the message and know we have done no worse than the ancients.

The message must not only be understandable, but believable. This is a second difference between previously made messages and the ones designed for the repository system. The ancients placed warnings and impediments in the way of intruders because there was something (or the intruder had reason to think there was something) of value stored in that place. The builders designed a curse or threat to frighten off persons who sought the wealth. That their curses failed to drive off tomb robbers can be seen in the wide extent of this type of intrusion. The excavation of the tomb of Tutankhamun created such a stir because it had been rifled only in a minor way. An example of a warning against intrusion is the text given below; needless to say, the inscription was found over an empty tomb.

I, Tabnit, priest of Astarte, king of Sidon, the son of Eshmun'azar, priest of Astarte, king of Sidon, am lying in this sarcophagus.

Whoever you are who might find this sarcophagus, don't, don't open it and don't disturb me, for no silver has been given me, no gold, and no jewelry whatever has been given me! Only I (myself) am lying in this sarcophagus.

Don't, don't open it, and don't disturb me, for such a thing would be an abomination to Astarte! But if you do open it and if you do disturb me, may (you) not have any need among the living under the sun or resting-place together with the shades!()

In contrast, the intent of the NITF is to prevent accidental or uninformed interference with a repository system which is designed to separate people from a hazardous material. Because of this difference in initial circumstances, i.e., desirable versus undesirable contents, the repository is in a very different category concerning human reactions to the message. The warning given in the above text was probably ignored because prior experience indicated that high-ranking people were often buried with valuable grave goods and the graves were therefore worth investigating. Such would not be the case with the repository and its contents. In other words, prior ancient warnings

were to protect the tomb, and its contents, i.e., its owner, while the repository system warnings are to protect the intruder. To this writer's knowledge, the intent to mark a hazardous waste site for such an extended period of time for the purpose of protecting the potential intruder is unprecedented. It cannot be guaranteed that the investigator will heed the warning even if it is understood. An analogous situation is the warning placed on cigarette packages. In either situation, the individual or investigator bears the responsibility of his or her actions because the decision to act was taken with knowledge of the potential consequences.⁽⁴⁾

The emphasis in this report, therefore, is to make the message as comprehensible as possible over the time frame of interest. The message may be conveyed by three different means -- symbols, pictures, and by languages (Figure 2.3-1).

Figure 2.3-1 Logic Chart for Message Comprehensibility

Symbols can be used to convey Level II information on the site itself and on such items as maps. Examples of two such symbols denoting atomic materials are given in Figure 2.3-2. The one on the left is standardly done in magenta against a yellow background. Given the wide-spread public interest in radioactive materials and their disposal, the symbol on the left is now recognized by a reasonably large segment of the population. Since symbols do not rely on language, they may be more adaptable for pancultural uses such as this, although they must be learned by the public.

Figure 2.3-2 Example Symbols Used With Atomic Materials

Pictures are an obvious means of communicating information without written language. For example, Figure 2.3-3 shows a statue being dragged by many people, something which is discernible even though most readers of this report cannot read Egyptian hieroglyphs.(8) (Since this scene comes from a 3,800 year old tomb, it is an excellent illustration of the potential for communication to future generations.) Although it is outside the scope of this report to develop a pictorial representation of the repository system, such a representation should be included in the marker system.

Figure 2.3-3 Scene From Tomb of Djehutyhotep
Transporting Statue to Shrine

Language is the third option for conveying information. Given the time frame involved for repository markers, it is extremely unlikely that English will not evolve significantly from its present form. For example, most native speakers of English can read Shakespeare (c. 1600 A.D.), a few can muddle through the original Chaucer (c. 1400 A.D.), but most could not read the original Beowulf (c. 700 A.D.). Yet it should not be overlooked that the latter two literary works exist in modern translations and are therefore available to a wider audience. A similar phenomenon may be seen in the translations of the Greek and Egyptian myths and histories, as well as the burial inscription quoted above. There are two points to be noted from this phenomenon. First, it appears that if the message is of sufficient interest, it will be translated or "re-encoded" into the languages used at that time. If the level of interest in the disposal of nuclear waste is indicative of future interest, the message is likely to be re-encoded. Second, the message need not be immediately readable by all members of the general public in order to have the information survive and be disseminated to that public. As long as some people can read ancient languages, the message can be translated for the general public.

In other words, we should neither overlook nor downplay the potential for language to carry information about the repository. Language also has the potential for conveying finer levels of information than is possible by the other two means. For example, we can say that Figure 2.3-3 shows a statue being moved, but to be able to say it is a statue of Djehutyhetep, governor of the Hare nome, and that it is being moved from the quarries to a shrine, requires the use of language. The effect of accompanying texts on our understanding of ancient markers is further discussed in Section 3.2.

The preceding paragraphs refer to the use of written languages. It is also possible that language may take the form of oral tradition. There are several factors which weigh against the reliance on oral tradition in the repository marking system. The most apparent is that such an approach requires a generation-by-generation update and renewal of the information (or, at most, an update every other generation). This contradicts the previously stated premise that no responsibility must be placed on later generations for the marking of the repository site.

The second factor is more subtle and requires familiarity with oral traditions. The examples discussed here are the well known compositions of

Homer, the Iliad and the Odyssey. There is little doubt that these were originally oral compositions. There were many versions of the Homeric epics when they were first written down, c. fifth century B.C. There were attempts to collate, reconcile, and edit the various versions by the third century B.C. Even after the outstanding work of a Homeric critic in the second century B.C., there were still "wild" texts (i.e., those which differ in length or in substantial wording of the text), though these now were more the exception than the rule.⁽⁹⁾ But once they were written out, it was the literary tradition, not the oral, which preserved Homer's epics to our time.

Research and studies of modern "singers of tales", primarily those in the Balkans, are the work of Parry and Lord, and it is useful to quote some of the latter's comments:

If the singer of oral epic tradition always sang a song in exactly the same words, it would be possible, of course, to ask him to repeat the performance a number of times but bards never repeat a song exactly

Those singers who accept the idea of a fixed text are lost to oral traditional processes.⁽¹⁰⁾

Oral tradition is an inherently vibrant and mutable phenomenon. Like language itself we cannot control the ways in which it will mutate, nor how it will change with each generation of transmission.

Moreover, Lord indicates that the oral and literary traditions are mutually exclusive for an individual; once there is a concept of a set text, the oral tradition is destroyed.⁽¹⁰⁾ In other words, the literary tradition supplants oral tradition; the latter is most often affiliated with an illiterate society and dies out when writing is introduced. To rely upon oral tradition as a primary facet of the repository marking system is to overlook the fact that those who build the repository are part of a millennia-old tradition -- a literary tradition. It is on this tradition that the primary emphasis of the repository marking system should be based.

There are several guidelines which it may prove useful to follow in designing a message, since we cannot predict the precise direction in which languages will evolve:

- o Use several languages. This enhances the probability that at least one of them will be recognizable and decipherable.

- Use languages currently in widespread use. There are more speakers of English or Spanish than there are of Esperanto, although the latter is an artificial language designed for international use.
- Try to avoid jargon since it has a limited audience and linguistic lifetime.

The use of language, in conjunction with symbols and pictorial representations, should provide the means for conveying different levels of information about the repository. This redundancy in the design will enhance the possibility that the information will be comprehensible to future investigators.

2.4 SUMMARY

In the discussion of the potential problems of human interference, there are several aspects of repository marker system design which rest upon factors determined outside of this report, e.g., technological level of the audience, and distance of detectability. Several guidelines, however, become apparent. Given the difficulty of correlating the repository with near-site features and detrimental actions, the main emphasis should be placed on marking the repository site itself (possibly incorporating a buffer zone). The on-site marking system should incorporate all four levels of information (i.e., from an attention-getter to the full record of information) utilizing symbolic, pictorial, and textual forms. It should delineate the areal extent of the repository, be primarily detectable by sight on ground level, and be made of materials which can withstand the forces of nature and man.

3 ARCHAEOLOGICAL MARKERS

This section will investigate several ancient, man-made monuments. Section 3.1 is primarily a marker-by-marker description, providing the information and background which is drawn upon in the repository marking system design presented in Chapter 4. The markers were chosen to represent a variety of cultures and climates; the former to indicate that the making of monuments and their survival is not keyed to a particular culture, and the latter to ascertain the effect of climate on survival. Since we are interested in survival, each of the markers had to be at least one thousand years old. Some, as we shall see, are five times this age, which implies that they have already lasted for half the time period in which we are interested. These markers are:

- Pyramids, Egypt (Section 3.1.1)
- Stonehenge, England (Section 3.1.2)
- Nazca Lines, Peru (Section 3.1.3)
- Serpent Mound, Ohio (Section 3.1.4)
- Acropolis, Greece (Section 3.1.5)
- Great Wall, China (Section 3.1.6).

The information will be summarized on an aspect-by-aspect basis in Section 3.2, including materials used in construction, size range, and the effect of contemporary texts on our understanding.

3.1 SELECTED EXAMPLES

This section presents a description of six selected ancient markers. Each marker is discussed separately and the discussion will answer the following questions:

- What - what is the marker and from what materials is it manufactured?
- Who/when - who built the marker (person or cultural group) and when?
- Why - do we know, or can we reconstruct the purpose of the markers?
- State of preservation - what is the monument's present condition?
- Other markers of the same genre - does the marker represent a unique feature which survived, or does it represent an exemplar from a number of surviving markers?

- History - how far can we trace the history of the monument?
- Relevance - what can we learn from the monument which would be useful in designing a repository marking system?

3.1.1 Pyramids, Egypt

A mention of "Egypt" conjures up images of the Sphinx and three enormous pyramids at Giza near Cairo (Figure 3.1-1). The Great Pyramid was built by Khufu or Cheops, as the name is preserved in Greek historical texts. It originally measured 756 ft on a side and stood to a height of 480 ft. It now stands 450 ft tall and 750 ft on a side due to the loss of the casing stones. The core consists of large blocks (generally 2 1/2 tons apiece, but they can range up to 15 tons) of local limestone taken from a nearby quarry. The casing was of a finer, whiter limestone quarried from the other side of the Nile. The stones were so closely fit together that it is difficult to insert even a knife blade between them. The pyramid underwent three changes in plan while it was under construction, each marked by a burial chamber. The final chamber is lined, roofed, and paved with monolithic granite slabs; the roof slabs are estimated to weigh 50 tons each. Above this room is a series of

Figure 3.1-1 Pyramids, Egypt

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five chambers to relieve the weight of the upper portions of the pyramid from the burial chamber. The name of Khufu appears in the quarry marks on some of these stones.(11,12)

The second pyramid was built by Khafre, a son of Khufu, and it originally measured 708 ft on a side and was 475 ft high. Like the earlier pyramid it was made of a local limestone core and finished with a white limestone layer. Part of the original casing still remains on the summit. The internal plan is simple, with two passageways leading to a single chamber.(11)

The Sphinx is part of the pyramid complex of Khafre, but is a unique feature. It appears to be a gifted architect's way of changing an eyesore into a thing of beauty. The Sphinx lies within the quarry for the limestone blocks used in the construction of the various pyramids and their concomitant buildings. The best and hardest stone was chosen for the pyramids, leaving a mass of softer rock jutting out from the quarry bed. This eyesore was transformed by Khafre's architect into the nearly 70 ft tall Sphinx.

The third pyramid, built by Menkure, is the smallest of the three (356 ft square and 218 ft high), but its size was offset by the use of granite casing on at least the lowest sixteen courses. It was originally planned on a smaller scale since there is a second passageway which now ends in a cul-de-sac within the pyramid structure.(11)

Who/When - These pyramids were built by three rulers of the Fourth Dynasty of Egypt -- Khufu, Khafre, and Menkure. These names are preserved as Cheops, Chephren, and Mycerinus by the 5th century B.C. Greek historian Herodotus. The Fourth Dynasty ruled from c. 2600-2500 B.C.(13,14)

Why - The pyramids are tombs for the rulers who built them, though they may have been finished by each one's successor. Their sarcophagi remained in the burial chambers until the 1840s when the carved basalt sarcophagus of Menkure was lost at sea as it was being shipped to England. The other sarcophagi (both plain) were never moved. These pyramids were part of funerary complexes which include mortuary temples and, sometimes, subsidiary pyramids. The complexes have been excavated by numerous people and the results are best summarized in Fakhry's work.(11)

State of Preservation - The contents of the tombs were looted in antiquity, probably during the First Intermediate Period (c. 2180-2130 B.C.),(13) The exterior structures are so impressive that they were one of the seven wonders of the world in Roman times and still are today. They have

lost nearly all of the casing of finer stones, and part of the cores have been quarried, but these actions have only made a small dent in their immense bulk. Much more of the mortuary temples has been quarried away, leaving only the lower courses of stone. The Sphinx, made of softer stone, is more heavily eroded and was repaired in antiquity.

Other Markers of the Same Genre - The three pyramids at Giza represent the apex of a long tradition in Egypt. The earliest pyramid is the Step Pyramid of Sakkarah built for Zoser (c. 2700 B.C.).⁽¹³⁾ This six-layered monument was a sharp departure from the prior tradition of low bench-like structures called mastabas, and by the sixth century B.C. its architect, Imhotep, was deified for his wisdom.

Other pyramids followed (there are over 70 in Egypt). By the time of Snefru, first king of the Fourth Dynasty, the sides were sloped. The engineers of his pyramid at Dashur had to change the angle of the slope when they realized that the original design would have collapsed the ceiling of the interior rooms and corridors. It is now known as the "Bent Pyramid."

After Menkure, the pharaohs built much more modest pyramids but the tradition continued. If the funerary nature of these structures was ever in doubt, the alternative hypotheses would be disproved by the Pyramid Texts. These are inscribed on the walls of the burial chamber in the pyramid of Unis, last king of the Fifth Dynasty (c. 2350 B.C.)⁽¹³⁾, and occur in all the other remaining pyramids of the Old Kingdom. The texts contain chants and incantations to insure the future happiness of the deceased king. The contents of the Old Kingdom tombs were probably looted during the chaos of the First Intermediate Period (c. 2180-2130 B.C.)⁽¹³⁾ when centralized government fell apart. Order was regained and the Middle Kingdom pharaohs (c. 2130-1780 B.C.) resumed building pyramids as part of their funerary complexes. Excerpts from the pyramid texts also reappear in the funerary literature.

Another period of chaos followed (Second Intermediate Period c. 1780-1570 B.C.) which ended with the establishment of the New Kingdom (c. 1570-1100 B.C.). Within this period there was an important innovation. The Egyptians had learned that the towering pyramids of earlier times served as beacons to tomb-robbers. Thutmose I (c. 1525 B.C.) therefore ordered that his tomb be hidden and the funerary temple be located apart from it. Successive pharaohs followed suit; the place first chosen by Thutmose I is now known as the Valley of the Kings. Private individuals, however, continued to surmount their

simple tombs with small brick pyramids or to include a stele with a pyramidal top in their tombs. (11,15-18)

The use of royal pyramids was revived by Pianki (c. 720 B.C.) of the Twenty-fifth Dynasty whose capital was in Sudan. Pianki was impressed by the pyramids he saw in a military campaign in the north and modeled his tomb on them. Aside from minor changes in form (they were small, steep-sided, and solid), these later pyramids differed in that they were built for all members of the royal family, not just the pharaoh. Over sixty pyramids occur at the site of Nuri alone, more occur at el Kurru, Napata, and Meroe (all are located between the Third and Sixth Cataracts of the Nile). Pyramid building in the Sudan ceased in c. 350 A.D. with the fall of the Meroitic Kingdom when a new religion entered the Nile Valley. (11)

History - After it was constructed, the history of the Sphinx is that Thutmose IV (c. 1425 B.C.) cleared the sand away from the Sphinx and built brick walls around it to prevent sand from re-encroaching. (By this time it was considered a representation of the sun god). He also erected a stele between its paws to commemorate this action. Other New Kingdom pharaohs built a temple or left steles or statues to the Sphinx, as did the kings of the Saite Period (663-525 B.C.). (19) The figure must have been eroded by the time of the Ptolemaic Period, since the figure was restored at that time to its original contours by placement of small limestone blocks on its paws, flanks, and tail. As with the surrounding monuments, Greek and Roman travelers left their graffiti scratched in its stone. According to the Arab historian el Makrizi (died 1436) the Sphinx was first disfigured by a religious Arab, this presages the oft-told story of Napoleon's men using it for target practice. It is interesting to note that el Makrizi reports a popular belief that the sand encroaching on the cultivated land was caused by its disfigurement. (11,19)

The pyramids and the knowledge of why they were built survived long after their owner's deaths, even if the contents did not. Herodotus (5th Century B.C.) talks about them in some detail. Aside from simply describing the pyramids, he accurately records who built them and why. The carvings were all intact at this time. Errors, however, occur when he estimates the height of the monument, and he was told that the Great Pyramid complex took thirty years to build while Khufu reigned only twenty-three years. This period also saw the restoration of the Sphinx which had begun to lose its shape through erosion. (11,19)

Diodorus Siculus (a Roman historian) was in Egypt from 60 to 57 B.C. Much of what he reports echoes Herodotus. He adds, however, that ramps were used in their construction. The remains of such a ramp occur at the Unfinished Pyramid of Sekhmet (c. 2650 B.C.).⁽¹¹⁾ Strabo, a contemporary of Diodorus Siculus, also visited Egypt and recorded that he entered the Great Pyramid.⁽¹²⁾ Pliny the Elder (23-79 A.D.), saw the pyramids but he condemned them as an idle and foolish exhibition of royal wealth. Pausanius, a second century A.D. traveller, also mentioned that he saw the pyramids when he visited Egypt.⁽¹²⁾

By the ninth century A.D., blowing sand and debris had covered the entrance to the Great Pyramid. The son of Caliph Harun el Rashid, el Mamun, forced a passageway through the masonry and found late intrusive burials in the interior. An Arab historian, Abd el Latif (born 1179 A.D.), mentions the numerous inscriptions which covered the casing of the Great Pyramid. These inscriptions were lost when the casing stones were quarried away during and after the 13th century. There was an attempt around 1200 A.D. to totally dismantle the Third Pyramid, but the expense of this project overwhelmed it.⁽¹¹⁾

It must be remembered that to the Muslims these monuments represented hostile forces which Mohammed had denounced, and also the monuments were pagan anathemas to the Christians. Small wonder that they were used as quarries for the nearby city of Cairo. In spite of this the casing of the Great Pyramid was only partly missing, while that of the Second Pyramid was nearly intact in the middle of the 16th century.⁽¹²⁾ In 1638, an Englishman published accurate measurements and drawings of the exterior and interior of the Great Pyramid. He concluded that its functions were those of a royal tomb and as a symbol of immortality.⁽¹²⁾ All the work done since that time has enlarged our knowledge but has not modified this basic conclusion.

Relevance - The pyramids exemplify the possibility for the continuity and survival of information for long periods of time (5,000 years). The section on history indicates how pyramids and the texts associated with them continued to be used after periods when the centralized government of Egypt collapsed. Even when Egypt was no longer an independent nation, knowledge about the pyramids continued to be transmitted through Greek and Roman writers, i.e., through different cultures. This thread continued into the medieval period with the Arab historian, and continues with the work in Egyptology which is being done today.

A second point to make is the importance of contemporary written records. It is only by such records that we know who built these structures and why they were built. It is the literary tradition which makes it possible for this information to be translated into more contemporary language.

The contents of the pyramids have not survived because they were looted for their intrinsic value. Most of the building stones, however, have remained. Some of these were removed, partially because the pyramids are located close to a large population center and it was easier to remove the stones than to quarry new ones, but the majority of the stones were not removed. So a third point to make is that stone may be a suitable medium for repository markers since it is generally not valuable in and of itself. If stone is used in the markers, the pieces should be of suitable size and shape to minimize the likelihood of being reused in later buildings.

A final point to make is the need for redundancy in the marker system design. The number of stones used in the pyramids is so immense that an intentional attempt to dismantle the smallest one (i.e., Menkure's) was overwhelmed by the expense of the project.(11)

3.1.2 Stonehenge, England

The impressive monument standing on the Salisbury Plain is actually the culmination of nearly a millenium of use and remodeling. A photograph of the inner circles is given in Figure 3.1-2, while the full plan of Stonehenge is given in Figure 3.1-3. A summary of the various features is given in Table 3.1-1. The ancient approach to the monument takes you past the outlying Heel Stone (when viewed from the center of the monument, it is in rough alignment with the position of the rising midsummer sun) to a gap in the banks and ditches which surround the circles of standing stones. This gap is flanked on one side by the fallen "Slaughter Stone," probably one of a pair which formed a gateway. Ringing the inner side of the bank are the 36 Aubrey holes, named after John Aubrey who noticed them in the latter part of the 1600s. Thirty-four of these holes have been excavated and 23 were found to contain cremated human remains. The chalk backfill of these excavated holes is clearly discernible in the grass which grows over the site.

Figure 3.1-2 Inner Circles of Stonehenge, England

Figure 3.1-3 Plan of Stonehenge, England

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Table 3.1-1. Architectural Features of Stonehenge, England

Feature	Approximate Diameter (ft)	Materials	Components	Dimensions	Building Phase	Visible Today
Outer Bank	380	Chalk		8 ft wide 2.5 ft high	I	Yes
Ditch	350			10-20 ft wide 4-7 ft deep	I	Yes
Inner Bank	320	Chalk		20 ft wide 6 ft high	I	Yes
Ring	280	Chalk Filled	56 Aubrey Holes	26 ft wide 4-7 ft deep	I	Yes
Station Stones		Sarsen	4	4-9 ft high	I	2 Survive
Heel Stone		Sarsen	1	54 x 20 ft (15 tons)	I	Yes
Ring	100	Sarsen	30 Menhirs with Lintels	7 x 3 x 1.5 ft (4 ft underground) (25 tons apiece)	III	18 Uprights 5 Lintels Survive
Ring	70	Bluestone	56-61 Menhirs	6-4 ft high 20-2 ft across (4 tons apiece)	III	6 Uprights 5 Lintels 5 Fallen 10 Scarps
Horseshoe		Sarsen	5 Trilithons	20-24 ft high (with lintel) (4-5 ft underground) (45-50 tons apiece)	III	3 Trilithons Intact 2 Each Lintel and 1 Upright
Horseshoe		Bluestone	19 Menhirs	6-12 ft high 20-2 ft across (4 tons apiece)	III	5 Survive
Slaughter Stone		Sarsen	1	7 x 6 x 2 ft	III	Fallen
Altar Stone		Pale Green Sandstone	1	31 x 13 x 16 ft	III	Original Position Unknown

The visitor now faces the most obvious part of the monument, the immense standing stones arranged in a ring of upright stones with lintels, an inner ring without lintels, a horseshoe formed by five trilithons (two uprights with a lintel) and a horseshoe of upright stones (Figure 3.1-2 and Table 3.1-1). The term "sarsen" refers to a local type of sandstone which occurs on the surface at Marlborough Downs about 20 miles to the north. The "bluestones" are a number of bluish stones which are mostly dolomite, but some examples of rhyolite, sandstone, volcanic and calcareous ash are included. The bluestones only occur together in a small area (about one mile square) in the Prescelly Mountains of Wales, some 200 miles from Stonehenge. (20-22)

Who/When - Stonehenge has been variously ascribed to the time of King Arthur by a 12th century chronicler, to the Romans by Inigo Jones in 1655, and

to the Druids in 1740.⁽²²⁾ Around 1900, the suggestion that Bronze Age Britains built Stonehenge was put forth, and that is the theory now accepted by most historians.

The question of who built Stonehenge was settled long before the question of when it was built. The re-calibration of carbon-14 dates has created a revolution in European prehistory,⁽²³⁾ and places Stonehenge as a contemporary of the pyramids of Egypt. Building at Stonehenge began c. 2700-2500 B.C., and the first building phase included the ditch and banks, the Aubrey holes, and the Heel Stone. It also may have included the Station Stones.

The main change in building Phase II was the transport and erection of the imported bluestones in two concentric circles. This took place c. 2100 B.C. but was never finished. Instead, the bluestones were removed and the circle and horseshoe of sarsen stones were raised (Phase IIIa). Finally, the bluestones also were arranged in a horseshoe and circle (Phase IIIb). The latter work was done c. 2100-1900 B.C.^(20,23)

Why - The alignment of the Heel Stone with the midsummer sunrise was first noted by Stuckeley in 1740. However, it was not until the 1960s that further astronomical uses of the monument were hypothesized and tested; this was the work of Hawkins.^(22,24,25) This work drew great protest, particularly from Atkinson, the excavator of the site,^(20,26,27) but it is now generally accepted that the trilithons were used in following the motions of the sun and moon. How many other alignments are significant and whether or not the Aubrey holes constitute a "computer" for calculating eclipses is still a matter of debate.^(23,28-31)

There are some 900 stone circles in the British Isles, of which Stonehenge is only one. It has, however, several unique features: the lintels and the ring of sarsen stones, the trilithons, the Altar Stone (whose original position and purpose is unknown) and the use of imported stones. Buri has made a comprehensive study of all of the known circles. He argues convincingly against astronomy being a prime factor in their construction by pointing out that, given the number of possible alignments, the odds of finding a significant alignment by chance are about even. He argues that the astronomical function of the ring was only part of its purpose as a ritual enclosure for periodic gatherings and ceremonies, "another difficulty is the entire absence of written records that could confirm the astronomical theories."⁽²¹⁾ Because of the absence of written records, the purposes of these stone rings still are being debated.

State of Preservation - Stonehenge is visited by over three-quarters of a million people per year, and ropes now protect the bank and ditch from obliteration.(21) The monument, however, has survived while Britain has undergone invasions (in 55 B.C., 48 A.D., and 1066 A.D.), the Interregnum Wars of the Roses (1455-1485 A.D.), and the two World Wars. By the 1800s, with the rise of Romanticism, the monument was much visited, and hammers were rented to tourists for the purpose of chipping off mementoes.(22) Monoliths, however, are not easily demolished. As may be seen from Table 3.1-1 and Figures 3.1-2 and 3.1-3, about one-half to two-third of the upright stones survive and remain in position. Several of the stones had figures carved upon them in the Bronze Age, and these may be seen today.

Other Markers of the Same Genre - As mentioned above, Stonehenge is but one of many stone circles. Burl has compiled data on some 963 stone circles which occur in the British Isles, Ireland, and Brittany and this discussion leans heavily on his work.(21) Two-thirds of these circles are preserved well enough to estimate their diameter; these range from under 9 ft to over 200 ft with over half of the examples falling between 10 and 60 ft. The site of Avebury contains a ditch nearly one-quarter of a mile in diameter (1100 ft) and ranging from 23 to 33 ft in depth. Half the town of Avebury lies within it. The large megalithic ring inside the ditch is the largest in the British Isles with a diameter of 345 ft.

Much effort has been expended in measuring and reporting the position of the stones in the various rings; much less has been noted about their heights and materials. Stonehenge has the largest stones of any ring, with heights up to 24 ft above the present ground level. Stones as small as a meter in height are found in several rings and examples 12 to 15 ft tall appear to be somewhat taller than average (e.g., Long Meg is 12 ft tall and is 4 ft taller than any other stone in her ring). Stonehenge is also unique in that it contains imported stones. All other rings are made from stones which were transported no more than a few miles at most. Materials include limestones, sandstones, granite and volcanic breccia, porphyry, syenite, and dolerite which were either locally quarried or occurred as glacially deposited boulders. The condition of the stones generally is not mentioned, and from this we can imply that they are still fairly sound. The Rollright Stones are an exception, and are usually pointed out as such. They are made of limestone and are in fragmentary condition.(21)

History - Stonehenge, per se, has been written about since the 12th century A.D., and has become well-enough ensconced in public knowledge to appear in many literary works including those by Wordsworth and Hardy.(22) An earlier reference (1st century B.C.) may occur in Diodorus Siculus (History, Book V), but no name is given and the attribution of this passage to Stonehenge is therefore debatable.(20) It is interesting to note that Geoffrey of Monmouth (c. 1136) tells of Merlin saying "send for the Giant's Ring in Ireland", when the stones actually originated in Wales. The quarry site may lie on the trade route from that part of England to Ireland, but the oral tradition, though remembering that the stones were imported, has the wrong place of origin. Geoffrey also relates that the monument was erected (by Merlin at King Arthur's request) for commemorating some slain nobles, but says nothing about its astronomical purpose.(20,32)

The monument continued to be known as a "special place", though the exact nature of the place is still debated. This debate extends to the other stone rings as well. The special nature of these rings and the influence they had upon the local population was a matter of great concern to the early Christian church. The edicts of Arles (452 A.D.), Tours (567 A.D.), Nantes (638 A.D.) and Toledo (681 A.D.) exhort the local bishops and clergy to destroy "those stones which in remote and woody places are still worshipped and where vows are still made".(33) The destruction or toppling of stones seen in the rings may be the result of these edicts and later attempts to wipe out the influence of these pagan monuments.

Many of the rings survived these attacks. They may have done so because of the oral tradition which says the stones do not like to be moved(34) and because of the dangers inherent in moving a monolith (Aubrey reports that a medieval surgeon was crushed to death at Avebury trying to remove a stone.(21) Also, they may have survived because they were still considered "special" places. Daniel documents what has happened to stone rings and other megalithic monuments in history and closes with the following comment:

This may be too blunt a way of putting it, but I find it difficult to envisage why there should be a Christian occupation of some megalithic sites, unless a real tradition of their importance as special and sacred places was carried through the period of the Bronze Age and Early Iron of barbarian Europe and into historic times.(35)

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Relevance - Stonehenge is a prime example of the difficulties encountered in marking a site with only level 1 information. It must be emphasized that the purpose of Stonehenge and the other stone rings is still being debated because of the "entire absence of written records that could confirm the astronomical theories".(21) It is this absence of written records which not only obscured the purpose of Stonehenge, but even the times when the various parts of it were constructed. That Stonehenge is a contemporary of the Egyptian pyramids was known only after the introduction of carbon-14 dating.

The history of Stonehenge points out the possible corruption in information conveyed by oral tradition. Though the medieval chronicle records the tradition that the stones are imported, it has the wrong place of origin.

The plan of Stonehenge and of the stone rings in general may be very useful for a repository marking system design. The use of multiple components means that the plan of the area can be reconstructed even though some of the components have been lost. Stonehenge has lost approximately one-third of its stones, yet there is no debate about its plan. For the other rings, with much smaller components, some 600 still survive well enough to estimate their diameters. It appears that redundancy in the number of components used to delineate an area helps that information survive. An examination of the size of the markers used in the stone rings also is illuminating. The heights of the stones range from 3 to 24 ft. Since the smaller stones would be easily removed, it appears that they have been protected by remote locations and oral traditions against moving them. The repository markers will not have this "special nature" attributed to them, and so they ought to fall in the upper range of height where their very size will make them difficult to move.

3.1.3 Nazca Lines, Peru

The Nazca lines are a collection of lines, geometric forms, and semi-naturalistic figures found on the desert floor near the town of Nazca in southern Peru. They have been the cause of much speculation for two reasons:

- They are much more visible from the air than on the ground.
- They are drawn on an enormous scale. For example, one large cleared trapezoid measures 2600 x 330 ft; a large figure may measure 500 ft in length; and single lines may run more than 6.5 miles in length.(35)

The lines (actually paths about 2 ft wide) are made possible by a set of geological circumstances. Wind erosion across the desert floor carried off the dusty surface soil, leaving behind a "pavement" of pebbles and boulders. Over time these stones develop what is known as "desert varnish," a brownish-black coating of iron and manganese oxides formed by the in situ decomposition of rock and the deposition of oxides upon the surfaces by capillary action. The rate of formation of this varnish is very slow, and may have begun as far back as the Pleistocene period. The underlying soil, however, remained pale in color. Picking up a stone will expose the light-colored soil underneath it. Picking up a row of stones will create a light-colored line.(35)

Who/When - The answers to the questions of who drew the lines on this natural blackboard, as well as when and why they were drawn are not definitely known. The figures drawn on the desert floor (monkey, lizard, spider, trophy-bearing killer whale, etc.) find parallels in Nazca wares, a distinctive type of pottery which dates from about 200 B.C. to 600 A.D. The similarity led to the conclusion that the same population was responsible for both creations. In addition, 85 percent of the potsherds collected on the desert floor by Hawkins in the late 1960s were Nazca wares.(36) A collection of sherds from the periphery of the desert proved to contain only Nazca wares.(36) Another type of evidence is the carbon-14 date obtained from a post which was set at the intersection of two lines, and gave a date* of 370 A.D. $\pm$ 90 years.(37,38) Although we cannot be certain whether this is the original stake (or a later replacement), the date falls within the Nazca period. No finer chronology of the lines has been developed and, given the absence of associated archaeological material, it is unlikely that one can be.

Why - The question "why" still remains unanswered. Suggestions include:

- Astronomical sighting lines(39,40)
- Pictures to be viewed by the gods of the sky(41)
- Religious or ceremonial pathways(35,41)
- Mechanism to balance the resources and population.(36)

*The date was adjusted from the published data using the revised carbon-14 half-life of 5730 years and the NASCA recalibration curve.

One of these suggestions can be eliminated. Hawkins tested the hypothesis of astronomical sighting lines by accurately surveying them and using a computer to check the alignments as he did with Stonehenge. The lines cannot be used physically to sight stars, and 80 percent of the lines lack any semblance of solar or lunar alignment.⁽³⁵⁾ As for the remaining suggestions, there is insufficient evidence to either confirm or deny any of them and so the lines remain a mystery.^(42,43)

State of Preservation - The lines were made possible by a particular set of circumstances. They were preserved, in part, because of a very low local erosion rate. They have also been preserved because of their remote location (the area is too arid to support a permanent population), and the fact that the area was depopulated shortly after the Spanish conquest. The lines are a fragile phenomenon and undergo rapid degradation when people drive or walk over them in order to see them. A photographic essay by McIntyre⁽⁴⁴⁾ includes a photograph which shows the destruction undergone by one figure in only twelve years.

Other Markers of the Same Genre - Ancient markings of this sort occur in numerous places other than Nazca, Peru. Hawkins⁽³⁵⁾ estimates that there may have been 50-100 such sites in Peru alone. Morrison mentions sites in Chile and Bolivia.⁽⁴¹⁾ Over fifty drawings formed by the same technique occur in California and Arizona,⁽⁴⁵⁾ though the ages of these figures are not known. As with the Nazca material, most of these remains appear to have survived because of their remote location and suitable climatic conditions.

History - The figures were brought to the attention of the general world in the late 1940s by Kosok, though they were known before on a local level.⁽¹⁸⁾

Relevance - The Nazca lines are an example of the potential survivability of even a frail phenomenon given a suitably remote location. Although this effect cannot be quantified, the repository will also be located in an area removed from large population centers and the marking system should, therefore, have a similar increase in survivability.

Again we see the importance of written records to the understanding of ancient markers. The purpose of the Nazca lines is uncertain and there is a possible 800 year time span for their construction. Due to their very nature, it is unlikely that even a relative chronology can be built for the construction of the lines (if two lines cross, it is not possible to tell which is the

earlier). This lack of knowledge is due, in a large part, to the absence of contemporary written information about the culture which made the lines.

Finally, although these lines are clearly visible from the air, they are difficult to track on the ground. In contrast, a repository marking system should primarily stress ground visibility.

3.1.4 Serpent Mound, Ohio

The Serpent Mound is an embankment of earth in the form of a serpent in the act of uncoiling (Figure 3.1-4). In its present state of restoration, the Serpent consists of two parts, the serpent proper and the oval shape. The latter has diameters of 125 and 60 ft and is 4 ft high. A small mound of burned stones lies in the center of the oval. The length of the serpent proper is 1254 ft. The coils and convolutions, however, fit within an arc that is 737 ft long. The average width of the body is 20 ft. The height is generally 4 to 5 ft, but it tapers until the tail terminates in a bank about 1 ft high and 2 ft wide.

Figure 3.1-4 Serpent Mound

The serpent was formed by blocking out the pattern with stones and clay. On top of the stone core a foot thick layer of clay was added. Above this lies a 2 ft layer of dark soil.(46)

Who/When - No artifacts were found in the excavation of this monument. There is, however, a burial mound within 400 ft of the serpent. The artifacts found in this mound belong to the Adena Indians who lived in Ohio between 1000 B.C. and 700 A.D. It is generally accepted that the burial mound and the Serpent Mound were built by the same people.(46,47)

Why - The purpose of the mound is still not known. Since it is obviously in the form of a serpent, most interpretations use the role that creature played in Indian mythologies and religions as a basis for their hypotheses.

It should be noted that there are several interpretations of the figure. These differences are due to differences in interpreting irregular features on the ground. The form of the serpent and the oval shape have been quite clear, and these are identically shown in all the drawings. It is the features beyond the oval and to the sides of the neck which are in dispute. The earliest drawing was published in 1848 by Squier and Davis(48) who suggested that the mound shows a serpent in the act of swallowing an egg. Another drawing was published 37 years later by McKean who added a small oval to either side of the neck and interpreted a small mound beyond the oval as a frog. McKean interpreted his drawing as a serpent striking at a frog, which leaped away while at the same time ejecting an egg.(49) Willoughby, in 1919, interpreted the elevations at the side of the neck as horns, thus tying the Serpent Mound to the horned serpent found in the myths of the northern Indians of the United States.(50) In other words, although the existence of the snake figure is not in doubt, the interpretation of Serpent Mound is still uncertain and somewhat nebulous.

State of Preservation - The mound was restored to its present contours by Putnam in 1884 after his excavations. No further restoration or conservation work has been done since that time. The Ohio Historical Society has added a foot path around the monument to reduce the number of people walking on it.

Other Markers of the Same Genre - There are literally hundreds of prehistoric mounds in Ohio and neighboring areas, but none other in the shape of a serpent. Greenman identifies two other serpent effigies, one in Canada and one in Scotland. Although it is intriguing to postulate a connection between them, serpents are sufficiently common to make this unnecessary.(46,49)

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discussed by Travlos⁽⁵¹⁾ and the other references cited therein. A general photograph of the Acropolis is given in Figure 3.1-5, while a plan of the monuments discussed here is shown in Figure 3.1-6.

Beule Gate - As you approach the Acropolis, the first ceremonial entrance you reach is the Beule Gate. An inscription on the monument tells us that it was paid for by F. Septimius Marcellinus and built c. 280 A.D. The two pylons are pierced by a gate which is aligned with the central opening of the Propylaea. It is built of limestone and the blocks were taken from an earlier monument which dates to c. 310 B.C.⁽⁵²⁾

Agrippa Monument - The Agrippa Monument stands on a natural terrace between the Beule Gate and the Propylaea. The slab for the statue stands 29 ft high, was made of marble, and originally bore a four-horse chariot. Inscriptions on the slab tell us that the latest statue was raised to Marcus Agrippa in 27 B.C., while the original group was dedicated to celebrate a chariot victory by the city of Pergamon in the Panathenaic Games in c. 178 B.C. We know from the writings of Plutarch and Dio Cassius, that the slab once bore statues of Anthony and Cleopatra, but these blew down in 31 B.C.⁽⁵²⁾

Propylaea - The Propylaea is the classical gateway to the Acropolis, and is part of the overall monumental rebuilding of the site undertaken by Pericles after the Persian Wars. The architect was Mnesicles and it was begun in 437 B.C. after the construction of the Parthenon. Work halted in 432 B.C. with the advent of the Peloponnesian War and was never resumed. The gate is constructed of Pentellic marble (quarried about ten miles away), with some decorative features in black Eleusian stone (the source is about fourteen miles away). Part of the monumental ramp approaching the Acropolis continues through the center of the building. The ramp is flanked on both sides by a row of columns and two gates. The building wings on the north and south also frame the ramp. The north wing has a room called the Pinakotheka (picture gallery) because of the pictures Pausanias, a second century Roman traveler, says he saw there. It is quite well preserved; the walls stand up to the roof level and still bear architectural features.^(51,52)

The Temple of Athena Nike (Athena, bringer of Victory) is reached from the south end of the Propylaea. It is made of Pentellic marble and was built in 427-424 B.C. to celebrate the peace with Persia. The architect was Callicrates who built a similar temple at Ilionosus. A frieze, sculpted in high relief, ran around the exterior of the building; four of the fourteen

Figure 3.1-5 The Acropolis, Greece

Key

A: Boule Gate	D: Temple of Athena Nike
B: Agrippa Monument	E: Erechtheion
C: Propylaea	F: Parthenon

Figure 3.1-6 Plan of the Acropolis, Greece

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slabs are now in the British Museum. The temple is also known as the temple of "Wingless Victory", a tradition recorded by Pausanias.⁽⁵²⁾

The Erechtheion is an intriguing edifice, built on more than one level and meant to house several cults, including those of Athena, Poseidon and the founding rulers of Athens. It also housed an ancient and venerated statue of Athena. The building was part of Pericles' plan for the rebuilding of the Acropolis. It was begun in 421 B.C., interrupted by the Peloponnesian War, and completed in 409 B.C. With the exception of dark Eleusian stone used as the background for the frieze, the building was constructed of Pentelic marble. The exterior walls and porches are quite well preserved (up to the roof). Differences of opinion exist about the plan of the interior, which has undergone extensive remodeling in the course of time. The southern porch is known as the Porch of the Maidens (or the Porch of the Caryatids). Instead of six columns, there are six statues of young maidens in long tunics which support the roof. One of these was taken back to England (along with many other marble items) by Lord Elgin. The floor of this porch has disappeared, but the ceiling is nearly intact.

The Parthenon or temple of Athena Parthenos (Virgin Athena) occupies the highest part of the Acropolis. It was meant to be an artistic masterpiece and to serve as the state treasury but not to replace the Erechtheion in venerability. Forming the cardinal feature of Pericles' plan, it was built in 447-438 B.C., and the best and most celebrated sculptors in Athens were engaged in its construction. The result is considered the culmination of the Doric, if not the Classical, style of architecture.

The exterior of the temple is ringed by a series of 46 columns which stand 34 1/2 ft high. Above this was a band called the architrave, originally plain but later adorned with shields presented by Alexander the Great (334 B.C.) and an inscription relating to an honor bestowed on Nero (59-68 A.D.)⁽⁵³⁾. Above this was a band (frieze) of alternating sculptured (metopes) and vertically grooved panels (triglyphs). There were originally 92 metopes; Lord Elgin brought 15 to London, one is in the Louvre, and 41 remain in place. The remaining 35 were destroyed in the explosion of 1687 (see below). The roof was wooden. The triangular areas on the East and West (pediments) were filled with sculptures. Pausanias tells us that the Eastern Pediment showed the birth of Athena; it was largely destroyed by the building of a Byzantine apse. The British Museum contains several fragments of the

remaining sculptures. The Western pediment showed the contest of Athena and Poseidon; this group was destroyed when the sculpture fell during removal in 1687.

Around the outer walls of the building ran a continuous frieze of sculpture. Its original length was about 525 ft; 176 of which exist in Athens while 247 ft are in the British Museum. The remainder was destroyed in the explosion of 1687. The entire frieze was dedicated to showing the procession of celebrants in the Great Panathenaean Festival honoring Athena and is known for its masterful sculptures.(54)

It should be noted that none of these buildings have any mortar. The stones were closely fitted by careful dressing, and where extra strength was needed, the ancient Greeks used small bolts and clamps of iron. These were rendered nearly rustproof by coating them with lead. As we shall see, similar precautions were not taken at the turn of this century when restoration work was done on the Acropolis, and the methods used have actually accelerated its deterioration.(51,55)

Who/When - Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia. The Parthenon was built first (447-438 B.C.), then the Propylaea (437-432 B.C.). The temple of Athena Nike was next (427-424 B.C.), and finally, the Erechtheion was built. It should be noted that there exists a wealth of detail about the buildings, sculptures, and their construction in ancient texts. In several cases we know the architects and sculptors who worked on the project. We know that money was raised from the sale of old building material, from grants by the Treasuries of Athena and Nepheliston, and from private donations; yet we also know Pericles was accused of squandering funds of the Delian League in order to beautify the Acropolis. The level of detail available in the ancient texts is such that we even have annual building accounts for the Parthenon and Propylaea which were publicly displayed on the Acropolis.(56)

Why - There has never been any doubt that the major buildings of the Acropolis had a religious purpose. This is borne out by the transformation of the Parthenon into a Byzantine church and, later, into a mosque. There were secular parts, such as the Propylaea, but the purpose of each of the buildings is known.

State of Preservation - The last forty to fifty years have wreaked much havoc on the Acropolis. The country has become industrialized in this period.

and the concomitant atmospheric pollution and acid rain are dissolving away the marble sculptures and buildings. The problem is so pronounced that the city held the second International Symposium on the deterioration of building stones in 1976.⁽⁵⁷⁾ The Parthenon frieze and the caryatids are under temporary shelters. There are plans to replace the caryatids with casts and move the originals to a protected environment. It is ironic that the caryatid removed by Lord Elgin is the one to be the model for the casts. Since it has been indoors for over 150 years, it is in far better condition than the others.^(54,55,57)

The second problem is that steel bolts and girders were used in the extensive restoration done by Nicolas Balanos between 1896 and 1933. Iron was originally used in the construction, but it was lead coated to inhibit rust. No such precaution was taken with the steel replacements. Aside from weakening, steel expands as it corrodes. This extra stress has led to cracking of the marble in which the steel is imbedded; in some places this has led to an immediate danger of collapse.⁽⁵⁵⁾

The final factor contributing to the destruction of this monument is human. The Parthenon was intact, though modified for the architectural needs of different religions, until September 26, 1687. At that time, the Turks were using the building as a powder magazine and it received a direct hit by a Venetian mortar. The resultant explosion blew the temple into two parts, destroying most of what lay in the middle. The Temple of Athena Nike was taken down by the Turks in 1686 in order to use the area for a gun emplacement; the stones were used to construct another artillery position. (This was dismantled in 1936-40 and the temple was rebuilt using a temple at Ilionos built by the same architect as a model.) The Propylaea remained intact until the 17th century when it was turned into a Byzantine episcopal palace. In 1640 or 1650 lightning struck a powder magazine within it, and more damage was done in the Venetian bombardment of 1687. The buildings on the Acropolis have suffered the greater part of their damage via the direct or indirect actions of man.

Other Markers of the Same Genre - The Acropolis of Athens has always had a military aspect to it because it is a natural bastion with a spring in it. This combination of military and religious usage can be seen at several other sites in Greece such as the cities of Mycenae and Tiryns, which were citadels in the Mycenaean period (when the Acropolis was first fortified c. 1300 B.C.), while Argos and Corinth had fortified elevated areas of the city contemporary

with that of classical Athens. The temples and secular architecture of the Acropolis find parallels in numerous other Greek cities. The body of literature about them is so extensive that it forms a sub-specialty in classical archaeology, and so many other markers exist that they cannot be discussed individually in this report.

History - The Acropolis is an example of an area with its monuments for which we can follow the history in some detail for over two millennia. This thread of information has continued through changes of religion, government, and occupying forces. Its spring and defensive position have attracted human habitation to the area since Neolithic times (c. 5000 B.C.). In the Mycenaean period (c. 1400-1200 B.C.), a massive fortification wall was built, part of which can still be seen today near the Propylaea. This wall and an altar seem to have survived until the Persian sack of 480 B.C. Though little is known about the Acropolis between 1200-700 B.C., the continuity of the cults suggests continued occupation.

The destruction of the Acropolis and its rebuilding under Pericles is described above. It was considered to be such an artistic masterpiece that little was done to it in the following centuries. Alexander the Great added votive shields to the Parthenon, Claudius added a monumental staircase (c. 52 A.D.), and a bronze inscription honoring Nero was added to the Parthenon in 61 A.D., but these were minor changes.

With the building of the Beule gate in the third century A.D., the Acropolis regained its fortified nature. Under Justinian (483-565 A.D.) the temples were converted to churches and a garrison was installed. The Franks occupied it during the thirteenth and fourteenth centuries, while the Turks took over in 1456. The damage done in the late 1680s during various skirmishes has been described above. The Greeks finally regained independence in 1833, and demolition of the Turkish and Frankish structures began soon thereafter. Investigations and restorations have gone on continuously ever since. (51,52)

Relevance - The Acropolis can provide useful information on several points: the effect of accompanying textual evidence, materials used, and delineation of an area of interest. The above description does not do justice to the amount of information which is known -- we know names, dates, why the structures were built, to whom they were dedicated, how they were paid for, and even some of the politics involved. We even know, in rather detailed form, about things which no longer exist. For example, we know that the

Agrippa monument bore three different statues in its lifetime, although the monument itself only records two, and none survive today. A more modern example of the information still extant can be seen in the drawings of the sculptures on the Parthenon produced by Jacques Carrey in 1674. These have proved invaluable in telling us what was lost in the explosion of 1687 and the positions of the fragments which survived.^(52,54) The effect of written records on the survival of this information cannot be overly stressed.

Another point to note is that what has survived is stone and not metal. The bronze shields and the inscription on the Parthenon were torn down in antiquity. The inscription was deciphered by a study of the mounting holes.⁽⁵³⁾ The base of the Agrippa monument remains in place with its inscriptions; the bronze sculpture groups have disappeared. Again and again, the holes for mounting metal objects are seen, while the objects are not. A glance through a reference text for Greek inscriptions shows that all but a small number of texts survive in non-metal media.⁽⁵⁶⁾ The few which we have indicate that metal could survive for that period of time, but that most metal seems to have been recycled.

The present condition of the Acropolis, due to the effects of acid rain, indicates that not all stone is an acceptable medium for repository markers. Limestones and marbles are not sufficiently durable for a 10,000 year marker, given the present levels of atmospheric pollutants.

The construction technique used in building the various structures is also of interest here. The stones were fitted together by careful dressing, not by the use of mortar. This obviated the need for certain types of maintenance such as pointing. The absence of a materials interface, with its potential for deterioration, most likely contributed to the survival of the monuments. The area of the Acropolis is delineated by the shape of the hill itself. It is unlikely that the repository will be so situated, and so another means of communicating the area of interest must be found. A useful analogy, however, may be found in the temple plans where series of columns are used to frame an area without covering it entirely as a wall or floor would. A series of components, such as columns, may therefore be an effective way of delineating an area with a minimum amount of material.

3.1.6 Great Wall, China

The Great Wall of China has been called one of the wonders of the world. It originally stretched from Shanhaikuan on the Yellow Sea to Kiayukuan in the West, a distance of some 1850 miles (Figure 3.1-7). Later additions, loops, and inner walls have nearly doubled its length.

The first wall was built by Ch'in Shih Huang Ti who unified China and who, in Chinese histories, is better known for his "Burning of the Books" than for the wall. The Wall was begun in 221 B.C., immediately after the final conquest of unification, and was completed in 210 B.C. The rapid time of completion was possible because the Wall incorporated some 1300 miles of walls built in earlier times. The actual building of the wall was entrusted to a general Meng T'ien.

The Wall was begun by setting up a series of watch towers along the frontier. These were generally 40 ft high and 40 ft square at the base, tapering to 30 ft square at the summit, and were located the length of two bow shots apart. This meant that the entire length of the Wall could be effectively defended. After the watch towers were constructed, they were joined by wall segments which ranged from 20 to 30 ft in height, about 25 ft wide at the base, and 15 to 16 ft wide at the top. Figure 3.1-8 shows a segment of the wall. (58-60)

The Wall was built by different methods in different areas according to the local building materials. In the east, where stone was plentiful, a foundation of rubble was laid without mortar. The wall was built of dry tamped earth (terre pise). (61) The uppermost level was covered with brickwork. In the later Ming Period (1368-1644 A.D.), granite foundation stones as large as 14 ft by 4 ft were used. The rubble or earthen core of the walls was faced with either brick or stone; the latter contains pieces as large as 5 ft by 2 ft by 1-1/2 ft. Further west, the wall cuts across wide exposures of loess soil with little stone for building. This very fine silt was mixed into a slurry and poured between frames to create the wall, which was faced with stone or brick where possible. In several areas, two strips of loess were removed, leaving a rampart of earth. Stone again was used in the westernmost segment. The ends of the walls are each briefly marked by a tablet, though the texts may not be very informative to us today. The one in Kiayukuan reads, "The martial barrier of all under Heaven", while the tablet at Shanhaikuan reads, "Heaven made the sea and the mountains". (58-60)

Figure 3.1-7 The Great Wall of China

(Ref. 55)

Figure 3.1-8 A Segment of the Great Wall

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Who/When - The idea of the wall was conceived by Ch'in Shih Huang Ti, and was carried out by his general Meng T'ien. The construction was started in 221 B.C. and ended in 210 B.C.

Why - The most commonly stated reason for the wall, and one which is borne out by the inscription at Kiyukuan, was that it was to keep the barbarians out. But the lavish expenditure of manpower and capital on an endeavor which did not work has prompted other suggestions. The construction of the wall began very shortly after Emperor Ch'in finished conquering China. It has been suggested that the Wall was built to provide gainful employment for all the vast number of soldiers who were now unemployed. Another suggestion was that the wall not only served a military purpose but also marked the "outward limit of desirable expansion" drawing an arbitrary line between the nomadic and agricultural populations.(62) Finally, the Wall served to emphasize that there was now one China under one ruler with a single northern border, and so emphasized the bonds between the formerly warring states.(59,60)

State of Preservation - The section of the Wall near Peking was rebuilt during the Ming Period (1368-1644 A.D.) and is in excellent condition. This is the area most tourists presently see. Further west, in the loess section of the country, the Wall was more subject to deterioration given the manner of construction. Even so, at the turn of the century, an American traveler still found sections standing to 15 ft in height, and towers surviving to 30 ft.(58)

Other Markers of the Same Genre - As mentioned earlier, the Wall of Emperor Ch'in incorporated great stretches of walls built by warring states. There is a previous history of walled towns and even walled states in China.(60,61) The Great Wall, however, stands unique in its immense scale; later dynasties only rebuilt or added to the Wall as politics and security required.

History - The history of the Great Wall is inextricably bound up with the history of China itself, and it is not the purpose of this report to cover the latter. The Wall was maintained and strengthened when central authority was strong and left to deteriorate when it was not. During the Han dynasty (190-86 B.C.), Wu Ti extended the Wall some 100 miles west of Kiyukuan. The Wu Dynasty (385-535 A.D.) maintained the Wall and added more than 600 miles of wall in various loops. The wall was breached in 585, but repaired and extended in the same year. During 607 and 608, the Sui emperor heavily rebuilt the

wall from the Yellow Sea to the Yellow River. The ensuing T'ang dynasty (618-906 A.D.), however, refused to maintain and repair the Wall. With the fall of the T'ang dynasty the northerners crossed over, only to fall later under the Mongol invasion (thirteenth century). The wall was of little importance to the Mongols, although Genghis Khan had been defeated for years in his attempts to get over the wall. The Mongols were thrown out by a native Chinese dynasty, the Ming (1368-1644 A.D.) who probably carried out more construction on the Wall than any other ruling house since Emperor Ch'in. The many plaques and inscriptions in the wall commemorating the rebuilding of sections of the wall date to the Ming period. These can still be seen and read today. The Manchus (1644-1911 A.D.) were Northerners who replaced the Mings, but had been invited across the wall by a Ming emperor fighting for his throne.

This takes the history of the wall down to this century. The wall has been breached and repaired but never forgotten. Nor does this history do justice to the amount of literature which has grown up around the wall, ranging from poems about its beauty to tales of the horrors endured by the conscripted laborers who built it. Passing the gate at Klayukuan was tantamount to leaving all that was civilized in the world and is often so portrayed in Chinese literature. In short, it was an integral part of Chinese military and cultural history, enduring several centuries and changes in government. (59,60,61)

Relevance - the Great Wall is an example of a marker which has been maintained and rebuilt for two millennia because it served a purpose for the rulers of the country. As such it shows the potential survival of the repository markers, since they also serve a protective function.

The wall itself does not contain much information about the Pre-Ming constructions and repairs. It is the written record which carries this data, and China is an example of how this tradition can survive in spite of various invasions and changes of government. The construction of the wall appears to indicate that building a marker using small components (e.g., bricks) means that it will need some maintenance for long-term survival. The segments of tamped earth or loess, however, are still visible even after the facing of brickwork has fallen away.

3.2 DISCUSSION

This section summarizes how the information on the various monuments presented in Section 3.1 relates to the issues on repository marking discussed in Chapter 2. The discussion will follow the order presented in Chapter 2 -- message existence, detectability, and comprehensibility.

3.2.1 Message Existence

A point which is mentioned repeatedly in Section 3.1 is the importance of written records to our understanding of the ancient monuments. The purposes of the Pyramids, the Acropolis, and the Great Wall are known because they were built by literate cultures who made contemporary records. This information has either survived to the present time, or has been recovered and spread to a wider audience through scholarly work. The level of detail is such that we not only know why they were built, but by whom and, sometimes, even how they were paid for. Much less is known about the Nazca lines, Stonehenge, and the Serpent Mound. Their builders are known only by general cultural names, not by the names of the individuals who conceived of or constructed them. In other words, it appears that:

- o Level III and IV information may only be carried by the written word, and the repository marking system should therefore incorporate this.
- o The keeping of records contemporary with the event is necessary in order to allow the survival of the information.

The work of the NITV and the marking of the repository site will ensure that the initial record is made. However and whenever the record of the repository's structure and contents is made, it should include the use of written records.

An inspection of the well-understood markers (the Pyramids, the Acropolis, and the Great Wall) indicates that information survives both in the monuments themselves and through "off-site" archival material. In one case, the Great Wall, the original inscriptions on the monuments tell us very little; it is the abundance of "off-site" literary evidence which provides the information. Ensuring that detailed information is located both on-site and elsewhere will improve its likelihood of survival.

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The monuments discussed in Section 3.1 may also be used to comment on message survivability. Several of the monuments, the Acropolis and the Nazca lines in particular, have suffered their worst degradations at the hands of man, not of nature. The monuments which survived in better condition were those which minimized the need for active maintenance. The Acropolis has no mortar used in the construction of its various buildings, while the Nazca Lines, Serpent Mound, and Stonehenge needed no mortar due to their means of construction. In contrast, the Great Wall used brick and mortar construction over much of its length and it needed active maintenance over the centuries to survive. (The Great Wall, however, is an example that such extended maintenance is possible for at least two thousand years.) Another point is that all the monuments are manufactured from what might be called "natural materials", i.e., stone or earth. These materials need only to be shaped to be used in the monuments; they require no additional processing (e.g., smelting or casting). The choice of these materials may reflect the technological limit of the cultures which used them. However, this does not negate the fact that these ancient monuments have survived in a variety of climates for up to 5,000 years. It should also be noted that metals are not suitable for markers because of their ability to be recycled, and that stones should be of suitable size and/or shape to minimize their potential reuse. A repository system must be designed with these points in mind.

3.2.2 Message Detectability

The large majority of monuments were meant to be detected by sight at ground level, and so provide a possible basis for designing the repository marker system. The Nazca Lines are an exception, but since they probably were not meant to be viewed by human eyes, they need not change this general observation.

The size range of the markers may be described on two levels: the size of the individual components and the size of the entire monument. The range seen in the individual components is immense: the Nazca Lines were formed by moving pebbles, while Stonehenge has monoliths weighing up to 50 tons. A closer inspection, however, reveals a relationship involving the size of the component, the accessibility of the public to the marker, and the state of preservation of the marker. Where the component parts are small, the marker

seems to have survived because it was located in an isolated region. This is the case with the Nazca Lines and with some of the smaller stone rings in the British Isles.

Three of the monuments discussed in the previous section are located near large population centers and have survived. The large sizes of the stones at Stonehenge have made them rather difficult to topple and vandalize. On the other hand, the Pyramids were made of smaller stones and have been used as quarries. They have survived only because of the immense number of stones used in their construction. The Great Wall has been maintained because it served a protective function and is of cultural importance.

A far more subtle relationship exists between the size of the individual components and the size of the entire monument. Stonehenge, the Acropolis, the Pyramids, and the Serpent Mound can all be taken in at a single glance. The patterns and forms of the monuments are immediately perceptible. The perception of form and content holds true for the Great Wall as well, even though the monument cannot be viewed in its entirety except, perhaps, by satellite. An inability to perceive a monument leads to a lack of understanding about it. The Nazca Lines are an example of this, and the phenomenon may explain why the stone circle of Avebury, which is far larger than Stonehenge, is less widely known. The component parts of Avebury are small compared to the scale on which they are set, and it is apparently easy to stand in one part and not realize that the remaining section of the monument exists. Thus it can be seen that the components of the repository system must be scaled to a size, and placed in such a manner, that an individual standing on the site recognizes the pattern of the marking system.

3.2.3 Message Comprehensibility

Written records have the ability to carry Level III and IV types of information, even though languages and cultures may change dramatically. In fact, written records may be the only means of carrying these higher levels of information; the history of Stonehenge points out the possible corruption which can creep into information which is orally transmitted. The use of written language, as well as pictures and symbols, applies to each of the marker components. Symbols, removed from a literary and cultural context, generally cannot carry higher levels of information. The Serpent Mound is an

example of this phenomenon. The pattern of an entire marking system, like those of the ancient monuments, must be recognizable in order for the monument to be properly comprehended. This may be done by using component parts with suitable sizes and locations.

This chapter presents a preliminary marker system design which incorporates many of the positive features found in the ancient monuments. Since the monuments discussed in Chapter 3 are only a small selection of the material surviving in antiquity, this chapter will begin by presenting a deduction of useful options which can be drawn from this larger body of information (Section 4.1). The marker system design is presented in Section 4.2, with various options which address the different issues that are presented in Chapter 2. It may not be necessary to incorporate all of these features in the final design, but that decision rests with the HITF. Section 4.3 concerns the messages that the marker will convey.

4.1 DEDUCTION OF USEFUL DESIGN OPTIONS

The previous chapter described several monuments which have survived for extended periods of time. With this information as background, we now turn to the problem of designing a marker system for a nuclear waste repository. Useful options (materials, construction, and the means by which the information is conveyed) may be identified by a deductive process which is shown schematically in Figure 4.1-1.

Archaeological materials may be divided into two categories, organic and inorganic. The former category is not suitable because organic materials do not survive for extended periods of time except in favorable climates, e.g., deserts or anerobic bogs.(42,64,65) Information about such materials may be stored if they will be located in a protected environment (e.g., paper in a climate-controlled library), but they are not appropriate for on-site markers. All the markers discussed in the previous chapter are made of inorganic materials.

The inorganic materials group is composed of metals and non-metals. Metals are not acceptable from an archaeological point of view because they show a strong tendency to be recycled by humans. This holds not only for the precious metals such as gold and silver, where this would be expected, but it is also seen with less expensive materials such as copper and bronze. There are archaeological examples which indicate that metals were in use even in early times, such as the Nahal Mishmar hoard, which dates to 3200-2850 B.C.

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Figure 4.1-1 Logic Diagram for Useful Options

and contained over 400 copper objects, but these appear to be the exceptions which escaped being melted down and reused.⁽⁶⁶⁾ (Since we do find these items, the burial conditions were obviously conducive to survival.) Recycling, however, is seen again and again in the Archaeological record.⁽⁶⁷⁾

Not all situations are as clear as the Cape Gelidonya shipwreck c. 1200 B.C. which held a cargo of broken bronze implements destined for remelting.⁽⁶⁸⁾ In most cases we are left with negative evidence. For example, there were a bronze inscription and bronze shields mounted on the Parthenon, but they were removed. (The text was reconstructed from a study of the holes left by the mounting pins.⁽⁵³⁾ We only know the shields existed from contemporary descriptions.)

The durability of the metal itself is of secondary consideration in this case. The non-precious metals available in the archaeological periods, e.g., copper, tin, bronze, and lead are typically found in a state that would indicate they are not sufficiently durable to be used for a 10,000 year marker.

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There are, however, modern metals, e.g., titanium, which are far more durable than these. But the archaeological evidence indicates that the intrinsic value of metal makes it highly probable that it will be recycled. In other words, although modern metals may be sufficiently durable, markers made of such materials are not likely to survive. It is this aspect, i.e., human action, which removes metal from further consideration.

A non-metal marker may be constructed out of earth or stone. The bank and ditch enclosing the stone ring of Stonehenge, Serpent Mound, and the Great Wall are examples of surviving earthworks. This, therefore, is a useful option but one which is restricted to conveying information in its form or outline, thereby limiting the complexity of information it can carry. It would be suitable for delineating the repository area. Another possibility would be to make the earthwork in the form of an international hazardous waste symbol.

The marker system may also be constructed out of stone. Within this category, however, there are some unacceptable materials. Softer stones, e.g., steatite, are too easily damaged by erosion, abrasion, or intentional disfigurement to make desirable markers.

Marbles and limestones were commonly used in buildings and monuments. They have, however undergone severe deterioration within the last hundred years or so due to the increase in industrial pollution. The Acropolis in Greece has several buildings which are built of marble and are suffering noticeably from severe deterioration. The marked changes which have occurred within the last century may be seen by comparing a cast of one of the Parthenon reliefs with how it looks today.⁽⁶⁹⁾ The replacements for the Porch of the Maidens are made from a cast taken from the maiden Lord Elgin brought to England. Since it has been indoors, it is in far better condition.⁽⁵⁵⁾

Industrial pollution has created a conservation problem which is reflected in the numerous articles on this topic listed annually in Art and Archaeology Technical Abstracts.⁽⁷⁰⁾ (In this report, the term "conservation" refers to the repair, consolidation, and protection of antiquities and works of art.) The majority of these articles are concerned with marbles and limestones; for every four articles on these stones there may be one on sandstone. Granite and basalt are rarely mentioned. The materials which are more common in the conservation literature are those which require the most repair, reconstruction, and treatment to preserve. The more durable materials, such as granite and basalt, are notable for their absence from these lists.

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A final point in the argument against the use of marbles or limestone is the fact that they are often burned for lime. Many pieces of antiquity have disappeared in kilns. (71)

Recent work by Lewin and Charola indicate that limestone and marbles show significant direct solubility in environmental water. (The lack of rainfall in Egypt helps to explain the better condition of the monuments there.) Quartzite and arkosic sandstone appear to deteriorate more from stress incurred by freeze/thaw and wet/dry cycling. (72) Sandstones also tend to suffer from surface friability (69), a factor detrimental to preserving an inscription.

Tuff is a material which has been used for buildings. (73) Although it is strong, the ease with which it can be carved makes it unsuitable for a repository marker. It may be destroyed too easily by vandalism.

The remaining rocks which may be suitable for the markers would have the following characteristics: hard, compact, non-brittle, and relatively homogeneous. The harder a stone is, the more difficult it is to work, and therefore the more difficult it is to deface or abrade. The term "compact" here is used in the sense of being fine-grained and lacking cavities. If a stone lacks this characteristic, two difficulties result: the inability to have sharply cut inscriptions, and the ability of water to collect in the cavities, resulting in accelerated corrosion. (This would eliminate vesicular, but not compact, basalt.) Large scale inhomogeneities in the rock may lead to accelerated corrosion along grain boundaries. One homogeneous rock is quartz, but this was rarely used in antiquity for large scale objects because of the difficulties in finding it in sufficiently large pieces and in working it. The only discussion of this characteristic which appears in the literature is the comment in a reference work on conservation that basalt tends to be more homogeneous than granite is and therefore less prone to deterioration. (69) Brittleness in a rock (e.g., obsidian) makes it too easy to damage by vandals.

These characteristics -- hard, compact, non-brittle, and relatively homogeneous -- also imply that the rock has low permeability and porosity which inhibit water from collecting within it either from the atmosphere or by wicking it up from the soil. It is the uptake of water which can lead to corrosion or to the buildup of salts from the groundwater. The latter crystallize out on the surface of the object exposed to the atmosphere. This phenomenon has been noted on both stone and fired clay objects, and may result

in exfoliation of the surface of the object. (69,74) This problem will be minimized by site selection factors which make it unlikely for a repository to be sited under or very near surface bodies of water. There are several rocks which fit the characteristics mentioned here. Granite, basalt, porphyry, and quartz are some examples. Modern materials science also allows the possibility of creating a man-made stone for this purpose, but these have no archaeological precedents and therefore fall outside the range of this discussion.

Having suggested a class of acceptable materials, we now turn to the plan of the marker system. The first question to address is whether there should be a single marker or a series of markers. A single marker, be it a pyramid, temple, or figure, tends to mark a spot. It is, then, a point estimate. A series of markers, such as those at Stonehenge or the columns around the Parthenon, tends to define an area and so is more appropriate for the project at hand.

A single marker has the added disadvantage of being too easily destroyed, thereby leaving the repository without any marking whatsoever. In order to build a single marker which is sufficient to withstand the ravages of vandalism and time, it must be built on an enormous scale like the pyramids of Egypt. A series of markers, on the other hand, would be less costly to erect and would provide the design with some redundancy. For example, the plan of Stonehenge can be drawn, even though a third of the stones are missing.

The next question is whether each marker itself should be a single piece construction (monolith) or built of component parts. A constructed marker has two disadvantages compared to a monolith. First, the use of a mortar or a binding agent between the components sets up a materials interface which is more susceptible to deterioration. As an owner of a brick house knows, it must be repointed every few years. Second, if it is easier to build, it is easier to tear down and reuse. The blocks of the pyramids and other ancient buildings were incorporated into other, more modern structures. (11,52,71)

The marker should also be megalthic. Museums are filled with statues, inscriptions, and other artifacts which are a reasonably portable size. A rough estimate or rule-of-thumb would be that objects twice the size of the average person and smaller are liable to be removed. Larger objects are rarely removed, although there are a few exceptions. For example, the Oriental Institute of Chicago brought back a winged bull from a gateway of Sargon II's palace at Khorsabad, Iraq which weighs about 40 tons. But even if

a few of the markers are taken, the remainder would continue to convey the desired information.

The series of monoliths can convey information by two means: spatial configuration and inscriptions on the object itself. As with the earthwork, the spatial configuration can convey only a particular type of information - delineating the repository area or forming the hazardous waste symbol.

The planar surfaces of each monolith are quite suitable for carrying a message in symbolic and/or textual form. The message should not be affixed to the marker, since this is removed too easily (cf. the inscription on the Acropolis). Nor should it be applied to the marker (e.g., paint) since this is too easily scraped off or painted over. The remaining option is that the marker itself should be engraved with the message.

Another point to consider is whether the lettering or symbols should be raised from or cut into the surface of the marker. Most ancient inscriptions are just that; they are cut into the stone or metal. Raised figures are generally reserved for artistic works, i.e., reliefs. Cutting the message into the stone creates crevices in which rain water could collect, leading to corrosion or, if it freezes, to stress. However, the choice of a desirable rock would minimize the potential damage. Raised letters, on the other hand, can be chiseled off more easily than an inscription can be hacked out, since less stone has to be removed, and may be damaged more easily by vandalism.

A final and small point to discuss is the depth to which the inscription should be cut. It should be noted that the depth could be set by the potential corrosion rate of the stone to ensure that the inscription would still be legible after 10,000 years. For perspective, it should be noted that ancient inscriptions were usually cut no more than a few millimeters deep, and even monumental inscriptions are usually cut under a centimeter in depth. Many of these inscriptions, however, have survived for a few thousand years.

In sum, three useful options for conveying information about the repository site have been identified:

- An earthwork would be useful to delineate the repository area or in the shape of the hazardous material symbol.
- A series of megalithic markers would be useful to delineate the repository area or in the shape of the hazardous material symbol.
- Inscriptions on each of the megaliths would be useful to convey information about the repository and its contents in symbols and language on the megalith itself.

4.2 MARKER SYSTEM DESIGN

The preliminary repository marker system design presented here contains three major components:

- A series of monoliths defining the perimeter of the repository site.
- An earthwork in the form of the hazardous material warning symbol.
- A marker at the center of the site.

Each component will be discussed in a separate section.

4.2.1 Perimeter Monoliths

The discussion of this perimeter monolith falls into two sections, the placement of the markers and a description of the marker itself. Several factors should be considered in placing the markers:

- The disposal area (and buffer zone if desired) should be defined with reasonable accuracy.
- The spacing of the markers should allow an investigator to stand at one marker and see the next marker on either side.
- A sufficient number of markers should be used so that the placement pattern can be identified even if some markers are lost.

The perimeter ring of monoliths defines the area to avoid when drilling in order to preclude intercepting a canister and bringing part of the waste directly to the surface. As mentioned in Section 2.1.1 the safety analysis may also be able to delineate a buffer zone around the repository area. If this is possible, then the perimeter of the buffer zone is the figure which should be outlined.

The next two factors interact and must be considered in light of the scale of the problem of marking the repository site. For example, the WIPP environmental impact statement* states that all the waste will be buried within an 1800 acre area (designated as Zone II) which has a perimeter approximately 6.5 miles long.⁽⁷⁵⁾ The uniformed investigator must be able to see the next marker in either direction when standing at a marker in order to realize that these markers form a pattern. Although the actual placement of

*The WIPP site is chosen only for illustrative purposes; there are no plans at present to bury high-level waste at that site.

the markers will be determined by the topography of the site, a spacing of approximately 400 yards between them may be sufficient. Given the height of the markers (cf. below), they would be discernible at these distances in a flat, unwooded terrain.

This suggested placement pattern would result in 29 to 30 markers being used to delineate the WIPP site. A similar number of stones are used in the sarsen circle of Stonehenge, which implies that there will be sufficient markers to reconstruct the pattern if some of the stones are destroyed or carried off to museums. As mentioned above, the plan of Stonehenge can be reconstructed even though more than a third of the stones have disappeared over the last 5,000 years.

The option of simply using four stones to mark the cardinal points of the area is not acceptable for several reasons. First, the scale is so large that the uninformed investigator would not be able to see any of the other markers and so would not recognize the area to avoid when drilling. Second, the loss of any one marker would destroy the pattern. Finally, with such a small number of markers it is possible that all of them might be destroyed or moved during the time period of interest.

Thus far it can be seen that the markers should be of single piece construction, megalithic, and made from a hard, dense, nonporous rock like granite or basalt. It now remains to describe the shape of the marker. A preliminary design is given in Figure 4.2-1. The height of the markers (25 ft) is modeled after the sarsen stone rings and the horseshoe at Stonehenge (cf. Table 3.1-1). The stones would be set to a depth of 5 ft, resulting in a marker which stands 20 ft above the ground level. Unlike Stonehenge, however, the markers will be tapered to create a broad base for extra stability. This should reduce the likelihood of toppling, such as happened at that neolithic site.⁽²⁰⁾ The tapering form will reduce wind resistance, allow rain to run off the face, and also make it more difficult to bring the stones down intentionally, as was done with many members of ancient stone rings.⁽²¹⁾ If stability needs to be increased, shaped packing stones around the base of each monolith can be used.

The basal dimensions are 8 x 5 ft, i.e., slightly thicker than the Stonehenge monoliths. This is suggested for extra strength. The rectangular form should provide information about the direction from which it should be viewed. Leaving one of the broad faces of the monolith blank will enhance the notion

Figure 4.2-1 Perimeter Monolith

of which is the "front" of the monument. Ringing the site with the carved broad panels of the stones facing outward and the blank panels facing inward, should tell the uninformed investigator where he or she is standing, i.e., outside of the repository area.

The suggested design calls for the messages to be carved into the flat faces of the marker. The remaining surfaces should be polished to minimize

cracks and crevices in which rainwater can collect, i.e., to minimize corrosion and deterioration. If wind erosion is a potential problem at a repository site, the message can be protected by a raised band around the edge of the panel to bear the brunt of the wind damage. (The facade of the treasury at Petra, Jordan is in much better condition than most at that site. It has been suggested that this is due to the fact that this facade is recessed into the cliff walls.)(76) The messages carved on these panels will be fully discussed in Section 4.3, but it should be noted that the symbol in the upper left of Figure 4.2-1a is the hazardous material warning symbol developed by the HMTF.

4.2.2 Earthwork

If the decision is made that the repository markers should be visible from the air and should call attention to the site, an earthwork can be incorporated in the marker system design. The very nature of an earthwork limits the amount and type of information it can convey; making it in the form of a hazardous waste symbol would make the best use of its limitations. The earthworks of England are formed by using the material excavated from the ditch (usually chalk) to form the embankment as illustrated in Figure 4.2-2. The bank at Stonehenge is 6 ft high and 20 ft wide, while the one at Avebury was once 22 ft tall and 75 to 100 ft wide at the base.(21) The Serpent Mound is 5 ft high and 20 ft wide. The clay body of the Serpent covers a stone core. The height of this marker, therefore, should be at least 6 ft, but the height probably would be determined by the surface erosion rate at the specific repository site. The excess material remaining from the excavation and backfill of the repository could be used in the formation of the core of the earthwork.

Figure 4.2-2 Embankment and Ditch Construction (Section)

The visibility of the embankment can be enhanced by packing the top of it with a material which will inhibit vegetative growth, e.g., crushed stone. This change in vegetation, as well as the original color contrast between the stone and soil, would be quite visible from the air much as are the Nazca lines. Other possibilities include packing it with magnetic sand to create a magnetic anomaly.

Unlike the perimeter monoliths, the earthwork has no definite size requirements since it does not define a particular area. The size would be determined by a tradeoff between cost and the scale on which it will be viewed. The greater the scale, the greater the height from which it is visible until the width of the earthwork is no longer discernible. Using archaeological examples as models, the bank at Avebury is a quarter of a mile in diameter, while the large cleared trapezoid of the Nazca lines measures a half-mile on its longest side; an embankment within this size range would be appropriate.

It should be noted that this component of the marker system entails the largest environmental impact, particularly if steps are taken to inhibit vegetation on the top of the embankment. The perimeter monoliths would serve to delineate the site area, warn the potential intruders, and describe the repository in more detail than is possible to be done by an earthwork. The monoliths, however, would be a series of points when viewed from the air and the embankment might be more noticeable. A judgment must be made whether the increased detectability by remote sensing methods offsets the environmental impact.

4.2.3 Interior Marker

The marking system described in the previous sections delineates the site and carries information on Levels I through III. As such, it matches (or possibly exceeds) the information content of the three ancient monuments from literate societies discussed in Chapter 3. The Level IV information for these monuments comes from the off-site archival material. For an added level of redundancy in the marking system design, however, a record of the Level IV information could be kept at the site itself. This is the purpose of the interior marker.

In designing the interior marker, it is apparent that the need for access to the Level IV information will be necessary only if every other off-site

record has been destroyed. (It is not within the purview of this paper to comment upon the type of cataclysm which could lead to this situation or whether sufficient technology could be regained after such an event within the time frame of interest.) The Level IV information, therefore, need not be immediately accessible to the investigator. The preliminary design for the interior marker has the Level IV information stored in an underground vault, while the position and purpose of the vault is marked by a series of monoliths and a tumulus.

A tumulus is the name for an ancient burial mound. Here it refers to the mound of earth raised over a vault containing the Level IV information. The vault is located below ground to create a more stable environment for its contents (e.g., removing it from freeze-thaw, wet/dry cycles.⁽⁷⁷⁾) The mound above it serves as an additional buffer between the contents of the vault and the fluctuating environment, as well as being a marker.

In order to draw added attention to this marker, it should be placed in the center of the site and marked by four monoliths. A preliminary design for the tumulus and interior monoliths is given in Figure 4.2-3. The height of

Figure 4.2-3 Section and Top View of Tumulus and Interior Monoliths

8 0 0 4 0

1 0 8 3

Figure 4.2-4 Interior Monolith

the mound is shown as 10 ft, making it within the range of other ancient mounds, although the height may be determined by the erosion rate at the repository site.

Care should be taken to distinguish these monoliths from those marking the perimeter. For this reason they should be different in a number of respects. A preliminary design is suggested in Figure 4.2-4. The height and shape are different from those of the perimeter monoliths, and they should be made of a different material. The Altar Stone at Stonehenge (whose purpose is unknown) is a prime example of the attention given to components made of a

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different material than that which was used in the bulk of the construction.⁽²⁰⁾ Like the perimeter monoliths, they are tapered for stability. The difference in the messages on these monoliths and the perimeter monoliths are discussed in Section 4.3.2.

There is a possibility that the smaller size and fewer number of interior monoliths increase the likelihood of their being carried off or destroyed. The fact that these monoliths surround an obviously non-natural mound of earth is going to draw attention to that mound. Excavation of that mound probably would occur before the monoliths would be moved or damaged. Finally, the monoliths are still larger than the "twice human size" guideline for identifying materials likely to be removed to museums.

Vault - The vault contains the Level IV information. The ancient world, however, has not left an overly wide selection of durable materials used for texts -- papyrus, clay, and stone. There are two cultures in the Near East where writing has a 5,000 year history -- Egypt and Mesopotamia. The oldest Egyptian texts are on stone; only a few fragments of papyrus survive from the Old Kingdom.⁽¹³⁾ In Mesopotamia, papyrus did not exist and stone was very rare. Architecture and writing therefore utilized the common materials of mudbrick and clay. The earliest writing from this area is found on clay tablets of the Jemdet Nasr period c. 3100-2700 B.C.^(78,79)

Papyrus seems to have survived because of the nature of its burial environment. The dryness of that environment would be duplicated in the sealed vault, which suggests that the modern analogue of papyrus, an acid-free paper, has a potentially long survival period in an equally stable and dry environment. However, the longevity of this benign environment is difficult to estimate.

The Mesopotamian texts appear to have survived because they reached a rapid equilibrium with the burial environment. They are, after all, made from the same material as the environment. Everyday texts such as lists of commodities and private and business letters were on unfired, but sun-dried tablets; royal annals and literary works were often fired to enhance their survival. Fired tablets are much like potsherds; they may break but they are otherwise extremely durable. Problems in conservation arise only after the objects have been removed from the environment in which they are in a state of equilibrium. The durability of clay tablets is attested to by the 400,000 examples which survive⁽⁸⁰⁾; this estimate does not include the 16,500 newly

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discovered tablets and fragments from the site of Ebla in Syria.⁽⁸¹⁾ It should also be noted that these tablets are found in burial climates which would not be conducive to the survival of papyrus.

The archaeological evidence attesting the survivability of stone has already been given in several places in this report. Stone and fired clay, therefore, appear to be suitable materials for the Level IV information.

The vault and its contents are the only non-replicated components of the repository marker system. Once opened, the vault no longer functions as an on-site marker. Most of the contents would eventually be removed to the future equivalent of a library, university, or museum for safe keeping and study. This would occur even if the vault were initially looted. A parallel situation would be the Dead Sea Scrolls which were originally found by a Bedouin child.⁽⁸²⁾ The vault should, therefore, also contain a request that the information be translated into the languages in use at that time, placed on durable materials, and replaced in an on-site marker. If that society considers the information of sufficient interest, it is likely to be translated and made available to a wider audience, much like the works in Ancient Near East in Texts and The Literature of Ancient Egypt.^(7,8) Replacing the "updated" version on the site is less likely to be done. The society may not consider it necessary to replace the information, but the request must be made. It should be noted, however, that in this scenario, the marker serves its purpose by making the information available to the public, and initiating a new cycle of off-site information transfer.

4.3 MARKER MESSAGE

This section will deal with the types of messages that can be transmitted via each component of the marker system. The overall message to be conveyed has two parts -- warning and description; the latter aspect can be conveyed on several levels of complexity. The message elements for each component of the repository marking system are discussed in separate subsections.

4.3.1 Perimeter Monoliths

Each monolith would be inscribed on three sides, leaving one broad side blank. By placing each monolith so that the blank face is turned inwards to

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the repository site, the observer is informed about where he or she should be standing, i.e., outside of the repository area facing the monolith. As mentioned earlier, the position of the monoliths defines the repository area.

The front face of the marker (Figure 4.3-1) bears the warning of the site and the simplest level of description. In the top left corner is the hazardous material warning symbol developed by the HITF. The symbol to the right of it acts as a qualifier, i.e., radioactive material. This line can be "read" either from left to right or right to left. The symbol below it is patterned

Figure 4.3-1 Perimeter Monolith

8 0 0 4 0

1 0 8 7

after the international driving signs. It shows a human digging with a line drawn across it. (This may be interpreted as that no digging should be done at the site, but since we cannot convey the difference between surface and deep excavation in a single simple symbol, it is better to convey the more conservative message).

The next six panels repeat this information in the six languages of the United Nations. The use of six languages increases the possibility that at least one of them will be recognizable to a number of people and readable by some scholars. The wording is deliberately simple in order to facilitate its recognition. The English text reads "DANGER. RADIOACTIVE WASTE. DO NOT DIG DEEPLY HERE."

This aspect of the marker is obviously modeled on the Rosetta Stone. It may be argued that the amount of time it took before the Egyptian hieroglyphic text could be read (nearly 25 years after the stone's discovery) would not be in time to prevent interference in the repository. This ignores the important fact that one of the languages was recognizable and readable at the time of its discovery. To illustrate, a brief history of the Rosetta Stone is in order. The slab was found by French engineers in July 1799, and to quote the British Museum publication about the stone, "Since the last of these inscriptions was written in Greek and could therefore be read, they realized the possible importance of the Stone for the decipherment of the hieroglyphs..." (emphasis added).⁽⁸⁴⁾ The acquisition of the Rosetta Stone was part of the settlement between England and France in 1801. Needless to say, there had not been much opportunity for study during this period. The Stone arrived in England in February 1801 and was made available to scholars on March 11 by the Society of Antiquaries of London. About one month later, an English translation of the Greek text was formally presented at a meeting of that Society.⁽⁸⁴⁾

It is not possible to predict which language or language families will survive in the future. The information on the repository markers should therefore not be presented in only one language. The choice of languages -- English, French, Spanish, Arabic, Russian, and Chinese -- is based upon the fact that these languages are the ones used by the United Nations. If they are suitable for that international body, they should be suitable for this purpose. They also cover several language families, i.e., Indo-European, Semitic, and Uralic.

One side panel of the marker is devoted to a description of the repository in symbols, pictures, and figures. The derivation of a pictorial representation of what was done at the repository site is not within the scope of this report. Such a representation, however, should be included on this panel. In addition, diagrams can be used to show the areal extent and depth of the repository; an example, based on the WIPP site, is given in Figure 4.3-2. The areal extent and the positions of the perimeter and internal monoliths are drawn. The monoliths are not drawn in scale since they would not be visible. An arrow marks the position of the monolith which is being studied. This will help reconstruct the layout of the site even if several of the markers are gone. The earthwork, if included, should also be shown to indicate its contemporaneity with the rest of the system. (For example, we know that the temple at Luxor once had two obelisks in front of it, where only

Figure 4.3-2 Pictorial Representation of the Repository

one now stands, because the temple is drawn on one of the inside walls.(85,86) It is not possible to put a line of unit length on the marker and then show it on the figure -- the differences in scale are too great.

below the top view is a cross-sectional view of the repository. The sun and a plant (here, a tree) define the ground level. The present design calls for the monoliths to stand to a height of 20 ft above the ground; this is approximately 1 percent of the depth to the repository. The monoliths would not be immediately discernible if drawn to scale, and that would defeat part of the purpose of the plan. They are therefore shown out of scale in order to be visible. The ratio of the width of the site to its depth should, however, be accurately represented. The figures in the center should be circular or triangular depending upon the option chosen for the central marker.

On the bottom of this figure is a schematic representation of what is contained in the repository. It shows a neutron striking an atom which then fissions. As shown, the figure represents high-level waste; the disposal of spent fuel would be indicated by having the circle include the atom which fissions as well. This general representation was chosen for its simplicity and clarity. The large number of isotopes which are found in the waste precludes their representation, since they change in time (i.e., the representation would be inaccurate) and the representation would be too space-consuming while providing too little information. That level of information is appropriate for the more complex level, not here.

The other side panel is devoted to brief descriptions of the repository in text. The rationale for the use of multiple languages and the choice of those languages has been discussed above. The text should be kept simple, without jargon or abbreviations, and cover the following points: what, who, when, why, what to avoid, where to find more information, and marker replacement. The question of "how" requires too complex an answer to be included on this marker, but should be included in the vault.

A sample text may read: "This is a nuclear waste repository built by the United States government in _____. The area of the repository is _____ by _____ meters and is outlined by these monoliths. The radioactive waste is buried _____ meters down to put this dangerous material far away from mankind. Do not drill _____ meters deep. Do not drill and use a well without checking the water for radioactivity. Do not do anything which will change the rocks or water in this area. To do any of these things may cause

exposure of humans to radioactivity which may result in cancer. More information is located under the hill in the center of this site and in government libraries. Do not destroy this marker, but replace it by using long-lasting materials and languages common in your time."

4.3.2 Earthwork

As mentioned above, the earthwork can only convey a limited amount of information, i.e., something is here and it is hazardous. The first is conveyed

Figure 4.3-3 Interior Monolith

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by its very presence, while the second is told by its form. It is, however, the one component which is a suitable vehicle for conveying a message to remote sensing devices. Suggestions may be made for possible inclusions in the earthwork to enhance its detectability (e.g., magnetite), but these have no archaeological precursors.

4.3.3 Interior Marker

The message borne by the interior monoliths is simple -- more information is located under the mound. The interior monolith (Figure 4.3-3) does not bear the hazardous material warning symbol, since there is no danger from investigating the vault. The figure shown, however, specifies that the area to investigate is below the mound between the interior monoliths. The multilingual inscriptions explain what is buried; a sample text in English reads "More information is located below the mound".

4.3.4 Vault

The vault contains the Level IV information and will not need to be effective until all other off-site archival information is lost. If the site location is lost, the perimeter monoliths will serve to link the concept of "nuclear waste burial" and "burial at this site". If this has occurred, society will recover the technology to breach the vault before it recovers the technology to interfere with the repository system. In other words, there is likely to be a lag between the time the information is physically recovered and the time interference could occur; this lag would allow the potential for the information to be deciphered and thus prevent interference.

5 SUMMARY

The approach taken in this report is that the likelihood of human interference with the repository system can be reduced by the effective communication of warning messages. For this to occur, however, the message must exist, be detectable, and be understood. A message can exist only after it has been ascertained what should exist (message definition), where it should exist (message location) and how long it should exist (message survival). There are four possible levels of information for the message:(4)

- Level I: Attention-getter, i.e., something is here.
- Level II: Attention-getter and warning, i.e., something is here and it is dangerous.
- Level III: Basic information, i.e., what, who, when, why, what actions to avoid, and where to find more information.
- Level IV: Full record of information, i.e., plans, drawings, environmental impact statements, etc.

Archaeological data indicate that the utility of a Level I message without any association with a higher level message may be dubious, while Level IV data appear to be carried only by written documents which generally do not occur at a marker site. Incorporating all four levels of information in the repository marking system would be an improvement over most ancient man-made markers. The message should exist at the site itself to physically connect the concepts of "nuclear waste burial" and "burial at this site".

Archaeological information highlights the distinction between materials which are durable and materials which survive. Survivability includes the likelihood of withstanding human actions as well as being durable. A marker which is likely to survive for an extended period of time will be made of a material which is durable and of such low intrinsic value that it is unlikely to be recycled. The possibility of recycling can also be minimized by choosing a construction method, shape, and size for the marker which will make it difficult to remove without a great deal of effort.

Ancient man-made markers are designed primarily to be detectable by sight at ground level. This provides a baseline for message detectability in the repository marking system. If added levels of detectability are desired, features which are visible by remote means (e.g., by aerial or satellite survey) may be included in the marking system, although knowledge of the repository

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and its contents at this distance will not affect the functioning of the repository system.

The third factor in the marking system design is message comprehensibility. The message can be conveyed by three different means -- symbols, pictures, and languages. Archaeological data indicate that the higher levels of information may only be able to be carried across great changes in time and culture via written languages. The repository marking system should incorporate all three means of conveying a message, and should utilize a number of languages to enhance the likelihood that at least one of them will be recognizable to a number of people and readable by some scholars. This report suggests using the six languages used by the United Nations.

The preliminary marking system design presented in this report has three possible components:

- A series of monoliths delineating the overall extent of the repository, or the repository plus buffer zone.
- An optional earthwork in the form of the hazardous material warning symbol (included in the marking system if visibility or detectability at great distances, e.g., satellite, is desirable).
- A central marker containing the most detailed level of information. The information is not immediately available to an investigator but is readily accessible.

Each of these components has an analogue in an ancient man-made marker which has already survived for at least one thousand years. The information about six ancient man-made markers is summarized to provide the background upon which the design is based.

Archaeological information indicates that the perimeter markers should have the following characteristics:

- They should be monolithic. One piece construction eliminates a materials interface between the bonding agent and component parts, a potential area of corrosion. This also means that the marker will require no active maintenance.
- They should be spaced so that the next monolith in each direction can be seen; i.e., the pattern delineating the site is recognizable at ground level.
- The monoliths should be made of a hard, compact, non-brittle, non-porous, and relatively homogeneous stone. Metal is too easily

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and too frequently recycled to use as a marker which should survive for extended periods of time.

- They should be megalithic. An unusually large size or shape for the marker will minimize the ease with which it could be removed and re-used in another structure.
- The monoliths should carry the first three levels of information (attention-getter, warning, and brief description).

The perimeter monoliths will be sufficient in number and carry enough information so that the areal extent of the repository can be ascertained even if some of the monoliths are removed. Inscribing the markers with symbols, pictures, and information in multiple languages will make this set of markers more informative than the large majority of ancient monuments. Sample drawings and texts are provided in Section 4.3.1. The perimeter markers, then, contain enough information to join together the concepts of "nuclear waste burial" and "burial at this site".

The earthwork can carry only Level I or Level II information (i.e., attention-getter, or attention-getter with warning). Its prime function will be to call attention to the site from great distances, such as those of aerial or satellite surveying. Whether or not this is a requisite part of the final repository marking system design is a decision which rests with the Human Interference Task Force.

Since access to the Level IV information (i.e., the most detailed, such as environmental impact statements) will not be necessary unless all of the off-site archival records have been destroyed, this information need not be immediately available to an investigator. For the interior marker, the information is placed on a desirable material (possible media are suggested on the basis of archaeological data) and contained in a shallowly buried vault. The location of the vault is marked (and protected by) a mound of earth which is, in turn, marked by four monoliths. The interior monoliths differ in size, shape, and material from those marking the perimeter and specify that only the area in between them should be investigated.

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105 King Avenue
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80040 1109