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Communication Across 300 Generations: Deterring Human Interference With Waste Deposit Sites

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ABSTRACT

The conditions attendant on the deep land burial of nuclear waste products raise a number of possible scenarios to cover the necessary 10,000 years of burial. However, no matter what kind of futuristic scenario obtains, it is desirable to develop an information system indicating the locale and nature of the deposit site and the types of materials stored, along with forewarnings not to interfere with the sites. A variety of such informational sites are suggested. Attention then turns to the recipients of such messages, recognizing from the outset that the psychological/perceptual makeup of individuals across the next 300 or so generations is virtually impossible to predict, particularly since new technologies may well alter that makeup in the future. Nevertheless, current evidence suggests that certain human characteristics may be considered universal, and that these suggest the incorporation of selected signification into the message system. There are other such characteristics that, while probably not intrinsic, can probably be acquired with a minimum of formal training. That still leaves much of the message content to be deliberately created and, hence, learned. The common trefoil or other developed bio-hazardous signs emerge as the best candidates for a generic base symbol for the buried material.

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1 INTRODUCTION

A certain degree of risk is involved in most individual and collective human undertakings. Other things being equal, a given society develops its own risk trade-off calculus -- which risks to avoid at almost any cost, which to tolerate, what cost for others, etc. -- as it tries to reduce most risks to acceptable margins over the short or long haul. Since the evaluation of human morbidity and mortality varies among societies, along with other prevailing values, the selectivity and effort expended in risk reduction varies as well.

Risk reduction is not easy to accomplish in the here and now. It becomes increasingly difficult when we seek to extend it into the future, even to protect ourselves from the consequences of earlier actions in our own lifespans. Extending such protection to the next three generations is an uncertain proposition, and prolonging it to the next 30 generations makes it extremely problematical. Accepting the responsibility of preserving protection from potential peril for a virtual posterity may be totally unrealistic. Nevertheless, there are circumstances when something on that order is called for.

The problem of the secure storage of nuclear (and other biohazardous) waste products is an immediate and compelling case in point. The American society, through its duly vested political institutions, has accepted that responsibility. Furthermore, the critical component of such storage sites can apparently be accommodated. Such materials can be isolated (in specially designed canisters) below ground (at a depth of 500 to 1000 meters), in suitable geo-environments (with multiple natural barriers), and in selected locations (many already identified) so that their intrinsic hazard is negligible for all practical purposes. Such projects will be costly, time-consuming, and possibly regionally and politically fractious. But proper storage sites, to last as long as 10,000 years (a reasonable outside period for neutralization of the radioactivity to occur), are feasible.

External intrusions could jeopardize such repositories; natural interference, through ground-water movements and the like, can be reasonably controlled through proper initial siting. That leaves the human species itself (or how it survives over the 100 centuries) as the main potential intruder. It is possible for some individual or group, acting accidentally or deliberately, on its own or with social approval, to penetrate the protective

repositories at some point during that period. It is obviously desirable that the likelihood of inadvertent interference be minimized, and that any willfull interference be a fully informed one.

Barring the use of a system of protective site monitoring -- possibly feasible for several generations but not assurable beyond that -- the obvious need is for an information system to caution and inform future inhabitants. Such a system should be durable enough to last the full 10,000-year period, and to be reasonably decipherable and comprehensible to members of the three hundred generations (by present actuarial standards, although that may vary with time) expected to inhabit this area of the world. That task may be more elusive than designing and constructing the storage facilities, since it involves knowledge of human behavior and human communication which is harder to come by.

One mechanism to decrease the likelihood of human interference is a requirement by the U.S. Nuclear Regulatory Commission (NRC) in its regulation 10 CFR 60 (NRC, 1983), which requires permanent markers and records for waste repositories to warn potential intruders of what is there. The U.S. Department of Energy (DOE), anticipating the final closure of a completed repository and the requirement for a warning system set up the Human Interference Task Force in 1980 through the Office of Nuclear Waste Isolation. This paper is a part of the study. Its specific focus is the potential user -- whether the motivated, intentional individual or merely a passer-by -- who may be exposed to the information system. The paper's method is to examine what we know and do not know about human information processing that can be used to form the design of such a warning message system. The goal is to optimize the message system so that it will elicit the desired response -- essentially the avoidance of deep drilling activity -- throughout the period of concern.

2 SCENARIOS FOR THE FUTURE

Any projection into the future is filled with uncertainty. Ironically, the only sure elements are change and uncertainty about the nature and extent of that uncertainty. Yet, some assumptions are necessary for the task to proceed. The ones that concern us here relate to the kinds of social organizations that will exist over the next millenia and the kinds of human organisms that will inhabit them.

2.1 FUTURE SOCIETAL ALTERNATIVES

Given the kind and rate of technological development within the last century (let alone the last 1,000 or 10,000 years), the most likely projection is of a changing, advancing society in the future.* While many present social and political problems will probably persist, and new ones will be introduced, reasonably efficient social institutions will likely develop to accommodate them.

If a civilized society, considerably more advanced than ours, is the most probable forecast for the immediate future, then the longer-term communication problem is rendered less formidable. Such a highly technological civilization is apt to accommodate many of the pressing present problems. Assuming that survival of individual, social group, and species will still be dominant motivations, it is quite possible that dangerous substances like biohazardous waste deposits might either be neutralized or by-passed more efficiently than we can today.

Although opposite in effect, a similar consequence ensues from the improbable but still possible scenario at the other end of the futurist spectrum -- a catastrophe, either natural or created by humans, that will all

* For a not terribly fanciful projection to a century from now, involving developments which are extensions of already existing technologies, see O'Neil (1981).

but wipe out civilization to be replaced by a new but primitive society inhabited by people with primitive knowledge. Since such a society will lack the technology to drill deep enough to reach the waste deposits, there is little cause for concern. Clearly, there are many other legacies more valuable than hazardous waste information for such a society, and the message system being contemplated would be a generous but futile gesture.

This leaves us with the forecast of some version of the present society persisting into the future -- not necessarily static but a relatively slowly evolving one adapting to change. This is fortuitously the projection most appropriate for planning purposes as well, if for no other reason than that it is the situation with which we are most familiar. More to the point, concentrating on projecting into an uncertain future while neglecting a palpable present may in effect undermine the entire undertaking. Apart from the notion of a full-fledged relay system every several generations (Sebeok, 1984), some type of motivation to continue the system (to learn the signs and symbols to be used, if nothing else) seems indicated. Skipping a neglectful generation here and there can probably be tolerated, but if the system gets off to a wrong start -- if the current and immediately succeeding generations find the idea unworthy of their efforts -- it is possibly doomed to failure before it gets off the ground.

An important consideration in this context is that, in our current political environment, siting decisions will not be made secretly by fiat but are likely to become politically charged issues once plans for waste disposal locations are made public. While there is evidence of general support for nuclear plants and the need for proper disposal sites, a not unlikely reaction is that of "it's okay in your backyard but not in mine." This makes the initial communication of proper protection and safety all the more critical. Acceptability by the present and immediately upcoming generations appears to be a key ingredient in the project's short-term, and hence ultimately long-term, political feasibility.

2.2 CHANGES IN THE SPECIES

More critical to the task of designing a suitable message system structure is the assumed kind of human organism. From an evolutionary perspective,

100 centuries may not constitute a significant time span, and it may be safe to assume no major genetic changes within that period. But in this age of technology, genetic mutations and the like may be secondary considerations in assessing the capabilities of humans to receive, process, and act upon information. Applied knowledge can make for altered humans, as recent discoveries have made the human species increasingly free from the restrictions of their inherent sensory, intellectual, and motor facilities.

Some common examples are sufficient to make the point: optical devices extend and transform our visual apparatus, allowing us to view the smallest units of life through electron microscopes, or remote bodies through long-range telescopes and cameras that beam back detailed pictures of remote bodies from a billion miles in space. The marvels of film and television can transport us across space (and time, on occasion) to present a front-row view at historic events, and with the likes of zoom lenses, instant replays and slow motion can overcome intrinsic limitations of our eyes and short-term memory. Deficiencies in learning abilities and long-term memory are compensated for by accumulated knowledge already stored in computerized form readily available for retrieval, with further expansion possible through chemical coding, bubble memories, and the like. The supersonic jet and space vehicles allow people to flit around the earth and beyond virtually at will.

What is most impressive about these few examples is that they were all developed in one generation's span, not a century or a millenium. The mind boggles at the possibilities of new discoveries and developments in the next generation or two, especially since new communication technologies are already expanding our accessibility to and use of a vast range of information. On the immediate horizon are virtually limitless possibilities stemming from gene splicing and genetic engineering that cannot help but radically transform how we function. The species need not wait for nature to take its own sweet time, and nowhere is this more evident than in the means of humans to communicate.

With such a wide range of realistic possibilities, the selection of any particular human scenario is nevertheless too uncertain for planning purposes. That is probably best left to science fiction writers and other visionaries to generate while ordinary psychologists and other social scientists stick with

humans as we know them in the present. By default if nothing else, then, we use present-day models of humans and their social structures as the basis for generating the characteristics of a suitable message system.

3 MESSAGE LOCATIONS AND PURPOSES

While the message system at the repository site is the main concern in this undertaking, a multiple system of message centers in several locations appears necessary. One reason is to use sheer redundancy as a fall-back system in case any one location is destroyed. Another is some division of function between locations. Three basic locations suggest themselves.

3.1 DISTAL MESSAGE LOCATION

Although not absolutely essential, it would be helpful to have some advance notice, if not a full warning, for individuals in the general area of the repository site to realize that they are approaching some special place. The main purpose is to allow those persons who, for one reason or another, would prefer to avoid such sites to do so. It seems a decent gesture to convey such a message and is in keeping with the current trend for keeping consumers and travellers "fully informed".*

Limited-access routes (e.g., a single road in and out of the area), accompanied by appropriate notices, can serve such a forewarning purpose for a limited time. Although it obviously cannot be assumed these will remain in place for the full period, they nevertheless can be employed at the outset and let representative authorities of future generations decide whether or not to replace them when they erode or otherwise disappear.

If some sort of distinctive symbol or logotype is ultimately adopted for these repositories, it should be employed on such notices and be duplicated on other documents (e.g., land records, geological mappings) throughout the information system. The more widely such a common symbol is employed the more readily it will be learned by more people in any given generation, and the more it is apt to be passed on and picked up by subsequent generations. Its use (along with appropriate words) in the present case is merely to provide an early identification of the nature of the site.

*In several countries (e.g., Britain, West Germany) requests have been made for appropriate markers indicating nuclear plant and waste disposal sites to appear on road maps and highway signs.

Since such signs do not constitute a durable early alert system, it would be desirable to have a distinctive erection or monument at the site itself that could be seen from a distance. Obviously there is a limit to the distance of viewing (at least for individuals endowed with present-day visual perception) and this condition can be affected by other area features such as terrain and foliage, but something on the order of one to several kilometers should be possible. Since such a monument can serve other functions -- an obvious one being to house the onsite information -- its use for distal sighting is a virtually free bonus.

It would also help if the marker could be visible from different directions (or several could be used to meet the same purpose) and from the air space above the site. Again, recognition would be enhanced the more such a monument would incorporate the visual design features of the logotype. For example, if some variation of the biohazardous waste symbol or trefoil is adopted, it should be possible to design the layout so that the recognizable characteristics of the symbol are retained in all views. It would be useful to retain the triangular visual feature, as in a pyramid, which apparently has other desirable features for purposes of durability.

3.2 PROXIMAL MESSAGE LOCATION

The main information system is at the disposal site. Its purpose is to communicate an element of warning, the nature of the burial site, and what kind of activity should be avoided. These messages can be located at ground level, somewhat above, or below ground -- or any combination of the three. Clearly, ready access, visibility, even tactile contact are important considerations. A long-lasting message site that cannot be readily approached and accessed is useless for the purpose.

One attractive possibility suggested above is to have a monument of sorts which serves to contain onsite messages. Durable plaques can be mounted on the surface of the structure or can be included in cave-like niches, increasing the protective cover. These, however, cannot be too deep or below ground since the natural light necessary for visual perception is lost, and artificial light cannot be guaranteed.

4 MESSAGE CONTENT

At the core of any communication system are the messages themselves. What should they convey? What specific information should they provide? What kinds of factual, cognitive, or affective reactions should they evoke and instill? Which types of behavior should they encourage and, particularly in the present context, which should they discourage?

4.1 DENOTATIVE ELEMENTS

The main content to be communicated is essentially factual in nature. The required basic information is relatively straightforward and unambiguous: (a) the existence of the repository, (b) its location, (c) its contents, and (d) the risks of intrusion. Since technical information is involved and since the intended audience is potentially rather heterogeneous, some compromise solution is called for: too little information will not communicate enough, and too much may not get through to deflect those without the requisite prior knowledge.

A proposed solution is a series of messages at the site, varying in levels of complexity. Each level of message contains the minimum warning about the presence of wastes but they vary in degree of detail: the first is merely on the order of "Caution: Biohazardous Wastes Buried Here". The second is more of a warning -- that the waste is radioactive, where it is buried, and the boundaries of the repository. The third level goes into detail about the type and amount of waste, the characteristics of the site (such as type and structures of barriers), and the actions to be avoided to ensure safety. The fourth level message would give the detailed technical information, including tables, figures, maps, mathematical data, etc., and could run over 1,000 pages of text. This version would be available in a protected setting at the site and would be replicated in remote locations around the world.

Such a multi-level system, with appropriate redundancy, should be sufficient insofar as the basic information is concerned. Whether it works in evoking the desired behavioral level may be another matter. Part of the problem here is that the goal is not to elicit a particular response but

rather to inhibit one. However, considering that deep drilling is not (at present, anyway) a casual activity but one requiring advance knowledge, planning, special equipment, and substantial funding, the relevant information, properly coded for professional users, is all one can reasonably require. Even wild-catting drillers for oil or minerals would be foolish to undertake such deep excavation without consulting pertinent documents. But foolish individuals will probably exist then as now, which implies that the prohibition against digging should be introduced wherever possible.

4.2 CONNOTATIVE ELEMENTS

Since the human species does not live by factual information alone, its messages often contain connotative meanings, various emotional feeling-tones and nuances of impression that may be more significant in terms of intention and effect than the denotative content. The main such connotative element in the present case is the general feeling of approach or avoidance and its relationship to the degree of safety or risk at the site. In addition to the messages one seeks to convey, the nature of the site itself can play a significant role in this regard.

4.2.1 Physical Features

Because the surface of the post-closure site is deemed to be fit for human use and habitation, it can be employed in whatever manner seems appropriate -- merely as it is, as a travel route, camping ground, etc. One option is to make it as appealing as possible -- say, make it into a park, perhaps with a nuclear energy museum -- on the grounds that the more attractive the place is the less inclined people would be to despoil it by drilling activity. The opposite position makes sense as well: make the site so repulsive that people will tend to stay away; the fewer people around, the less likely any undesired obtrusive activity.

The middle-ground may again be the best solution: to leave the site as close as possible to its original state and let nature, chance, and future human actions determine its fate. If future generations knowingly want to develop it or make it more repellent it will be their choice. Again,

The onsite messages can, in principle, contain all the requisite information. But since some of it is apt to be of limited interest to the majority of users, it is best to keep the main message concise and limited to the desired particulars. The remaining detailed information can be located elsewhere in the repository area and duplicated in more remote locations. In that case, the onsite messages should contain directions for gaining access to this other information.

3.3 REMOTE MESSAGE LOCATION

The highly detailed information about the site can be maintained in appropriate places away from the site. Since this information is meant for professional drillers and the like, it should be kept in specialized locations and archives established specifically for hazardous waste information and related materials and/or in more common places. Multiple locations -- local, national, and international -- are indicated for this purpose.

Since currently available storage materials may not last the full term (although a suitable long-range storage system may become available), continuation of this remote information system will depend on periodic reproduction. This assumes some kind of responsible institutionalized authority at various junctures throughout the period. Since both these assumptions -- a long-lasting information storage medium, or a continuing and evolving society structure responsible for periodic renewal -- are not reliable at present, this system is of questionable duration. Redundancy in the form of identical deposits in a number of locations around the world would raise the probability of periodic reproduction.

contemporary local populations have an obvious stake in any such decision, and one should expect them to make their preferences felt, directly or through their elected federal, state, and local representatives.

4.2.2 The Safety Factor

Closely linked to the attraction-repulsion variable is the safety-danger dimension. Quite apart from the actual prevailing condition -- that the site is safe unless there is deep drilling (and even then the odds of penetrating one of the dispersed canisters are quite small) -- the public perception of a lurking dangerous presence can play a significant role in the initial and continuing acceptability of the entire program.

The inherent ambivalence -- that the site is both safe and dangerous -- creates a special communication problem, particularly if a rather parsimonious communication code is employed near and at the site. It is one thing to prepare a detailed message of the objective situation with all its nuances -- of relative safety and danger at different locations and depths, the consequences of radiation exposure, etc. -- but quite another to do so without risking under- or over-statement. Three approaches suggest themselves, each of which contains inherent near- and long-term trade-offs, especially at the first phase of the undertaking:

1. Should the message connote extreme danger, as if to say all those who venture here do so at their peril? The risk with such an over-statement is that it will serve to reinforce the ranks of those opposed to the entire nuclear energy enterprise in the first place. It probably would scare off residents within the area and might raise protests to a level where political feasibility would be seriously and perhaps irrevocably impaired.
2. Should the message connote a more moderate approach, one of caution, a forewarning to take heed? This strategy is probably closer to reality and seems more acceptable at face value. However, those who advocate a worst-case-possible approach may be dissatisfied with such a tepid tone and may agitate for a more conservative stance. This is probably not an insurmountable problem -- it will largely

depend on the "zeitgeist of risk" at the time it arises -- but still leaves potential political and organizational problems to be accommodated.

3. Should the issue be deliberately under-played with a low-key, soft-sell approach, connoting an improbable, remote likelihood of danger? The risk here is obviously that it will fail to satisfy many constituencies. The effort will suffer from a loss of credibility, possibly not that different than if no symbolic warnings at all were employed.

The moderate approach appears to be the most reasonable choice under these circumstances. If some of the political problems mentioned do materialize, the approach can possibly be adjusted to suit the circumstances at the time of adoption. From a long-term perspective it certainly seems the wisest choice, since later circumstances may change the risk equation significantly, in either direction.

5 MESSAGE RECIPIENTS

Perspectives change in psychology, as in other scientific disciplines, but the prevailing view of a human being as an information processing mechanism is likely to persist into the immediately foreseeable future. Information processing can be conveniently described as being a series of stages (although just where and when one ends and the next begins is not always clear). The stages are: the organism receives incoming stimuli (reception); there is a sifting and winnowing of which stimuli to select and which to reject (attention); the selected data are converted into information which is processed into meanings (perception and cognition); some if not all is stored for later retrieval as needed (memory). The organism may or may not behave in response to the information at the moment or at some later date, as circumstances dictate.

There is much research on each of these facets of the information-processing model, but firm knowledge -- that which can guide selection with a high degree of confidence -- is still lacking on most points. The following should not be taken as an exhaustive, detailed, substantive review of the psychological literature on these subjects but is selective in terms of the theoretical and empirical evidence as it applies to the problem at hand. The focus is on the recipient rather than on intrinsic properties of the sign system.

5.1 RECEPTION

Humans live by their senses and rely on them to receive data from their external and internal environments, both of which are under constant surveillance. Some senses (e.g., smell and taste) are less developed and reliable than others (sight, sound, and touch, possibly kinesthetic) but there are instances of one sense becoming more acute when other ones fail.

5.1.1 Sensory Preference

Twentieth century humans are largely audiovisual animals -- quite apart from the technology of film and television, although they do help coordination between the senses. The greater emphasis by far is on the visual modality --

a tendency which is further enhanced by a wide variety of devices (ranging from eye-glasses to microscopes and telescopes) that allow people to surpass intrinsic natural limitations. Sight requires light, but the sun can provide that readily and steadily.

Actually, auditory signals constitute a major channel for everyday communication, and can often be effectively used to augment visual ones. But since the production of sound by vibration requires an energy source and moving parts, neither of which can be guaranteed at the site,* it is of limited interest to us here. Smell and taste are similarly ruled out -- the sources for both deplete rapidly over time and are inadequate for the detail of information required. The kinesthetic sense, dealing with changes within the body, is ruled out by definition, unless one considers the use of noxious elements (e.g., rays, odorless gases).

In contrast, tactile communication does not require energy for production, can be maintained over time with the right materials, and accordingly may be effectively used along with visual stimuli. Though limited in semantic range and fidelity, the sense of touch is, of course, particularly effective in the dark when sight may be impossible. Moreover, given the current interest in catering to handicapped persons, some onsite signing in braille and/or embossed pictures to accommodate the blind may be required anyway.

This choice of sight and touch for technological reasons happily coincides with natural human sensory dominance. Research has shown that visual information tends to be detected more often and more accurately than auditory information (Colavita, 1974; Egeth and Sager, 1977; Posner, et al, 1976) and than kinesthetic information (Gibson, 1933; Pick, et al, 1969). Further, when nonconflicting redundant cues from different senses are used, the visual information adds significantly more to information from other sense organs (Jordan, 1972; Klein and Posner, 1974) than vice-versa (Garner, 1974a). Visual information is also better retained than other sensory information

*That is the situation at present. In time -- less than a century, by most informed guesses -- some form of solar energy might be tapped. The moving parts are another matter; eventual wearing-out and break-down are impossible to avoid.

(Posner, 1967). Tactile information is also more likely to be detected than auditory stimuli in limited contrast situations (Gescheider et al, 1975).

Thus, while there are occasional exceptions to the dominance of visual and tactile senses (e.g., Canon, 1970; Kelso et al, 1975), all indications are that these are the most suitable modalities to employ for both technological and recipient purposes. The site messages should be predominantly visual with tactile signs as a back-up to the degree possible, protected from abrasion and erosion over time, accessible to sunlight (for vision), and to human physical contact (for touch).

5.1.2 Types of Signs

Messages are composed of signs and, in general, each of the three major types of signs may have to be used in the messages under consideration. These include:

1. Iconic signs are so directly related to an image or attribute that their referential meaning is immediately apparent. They are virtually universal, do not have to be learned or can be rapidly acquired, and require a minimum of processing. For this reason, they should be used whenever possible in the present task. However, they are extremely restricted for communication purposes -- there are very few that are truly universal and they refer to relatively simple, readily apparent objects and events -- so only a restricted number of simple messages can be represented iconically.
2. Some classically conditioned signs are so pervasive and common in a given culture that they are acquired within the normal process of development and secularization, and do not require special learning. The trefoil or hazardous waste symbols are not quite in that class but they may become so as their use spreads. Classically conditioned signs are generally preferred because of this shared cultural basis.
3. Arbitrary signs comprise the great majority of signs and therefore require some degree of specialized learning. For such a sign to

gain meaning and usage in ordinary communication it must be commonly used and group sanctioned, so that an adequate base of shared meaning is present. Since only a comparatively few symbols are so urgently needed as to warrant the effort and expense of special training (e.g., traffic signs), the preference is to rely on those already in common use whenever possible. If necessary, the trefoil or hazardous waste symbols could be included for specialized training in the future; in fact, there may be many such particular signs to learn in the future.

4. A special subclass of arbitrary signs is composed of those signs that come precoded as part of normal language use. Since the range of information to be conveyed at the site cannot be covered without common language content, literacy in at least a single prevailing language will be a prerequisite for recipients. For a variety of purposes (not the least, prevailing political attitudes about a multi-linguistic culture), it is advantageous to include a number of languages, with those generally used by the United Nations providing an appropriate variety.

The indications are for a mixed-sign message, the messages to be composed of a mixture of the sign types, since none can do the total broad-based task adequately. These could include some identifying symbol, partly but not completely iconic, some diagrams and/or pictographs, some numerical specifications as required, and a substantial amount of verbal content seems unavoidable. These can be replicated in several languages, both to ensure wider comprehension and redundancy.

5.1.3 Legibility

Visual signs have to be seen to be perceived and processed; they must be legible. Legibility is a product of the interaction between the object or symbol and the perceiver. It can vary from one symbol to another (in print, from one type of style to another) and somewhat from one person to another. Color relationships, lighting, spacing, viewing angle, etc. may all affect legibility (American Institute of Graphic Arts, 1974; Brainard, et al, 1961; Cahill, 1975; Loo, 1978; Walker, et al, 1965).

The size of the sign and the relative distance between object and viewer are also important factors determining legibility. In general, an image that fills a substantial part of the field of vision is preferred, but when a stimulus is involved, the size of the constituent elements may have to be reduced so the whole can be viewed as a unit. Research has demonstrated a fairly constant (nonlinear) relationship between the observer's distance from the sign and the size of that sign, which holds for most normal-visioned persons (Ells and Dewer, 1979; Smith, 1979). By the same token, placing the sign within the observer's normal line of vision enhances recognition by reducing the effort required; a useful rule of thumb is not to exceed a ten degree angle from the natural horizontal plane (American Institute of Graphic Arts, 1974, pp. 120-129).

Other elements of the sign, such as color, shape, clarity, and contrast, can improve legibility (quite apart from attracting attention and from conferring meaning to a certain degree). Of particular interest here, the perception of depth can be enhanced by a variety of conventions -- e.g., linear perspective, relative size, contrasting clarity, an apparent blocked view -- all of which take advantage of the way the eyes normally use binocular disparity (slightly different images between the two eyes) and motion parallax (moving objects in three-dimensional space) to infer relative depth (Cornsweet, 1970; Hochberg, 1964; Julesz, 1971, 1975; Walk and Gibson, 1961).

5.2 ATTENTION

Humans have a limited capacity for processing input, and since far more stimuli are received at any one time than they can possibly attend to, some sort of selection must take place. Thus, the individual rapidly sorts through the myriad of incoming sensations, selecting the salient or "important" ones and rejecting the remainder. Current cognitive theory (see, e.g., Garner, 1974a; Groves and Thompson, 1970; Kahneman, 1973; Treisman and Davis, 1973) suggests two parallel processes taking place simultaneously to direct the attentional act: the first is that the person brings with him, as it were -- an active, deliberate, directed, voluntary, and conscious effort to locate cues that are relevant to his current concerns and anticipated goals. The second is that at the same time, he tries to monitor the environment in a less

active and indirect manner, yet be alert to certain unexpected but possibly significant input. The latter is part of a general alerting mechanism that seems to be common to all animals as an essential for survival.

In a sense these two processes define the main types of person to be expected at the site. The casual visitor, not particularly looking for the waste site, has to be able to identify something unexpected but important enough to attend to further by the "unconscious" monitoring process; his attention has to be drawn to the site. The second type of visitor (say someone set to explore for minerals below the surface) is "looking for the waste site", actively seeking information about it to guide his selective behavior. Rather than having to be attracted, his attention is already mobilized; without having the specific information, he "knows what he is looking for".

5.2.1 Monitoring Process

The basic function of the monitoring activity is to detect departure from the normal and expected. Individuals may not notice or identify or recall anything about many stimuli they are exposed to -- these are, in a sense, unattended input -- except for some relatively gross perceptual change (Cherry, 1953). These can take a variety of forms but are basically of two types: either a large shift in the perceptual magnitude of the input on a given sensory modality, or something that "stands out" as being especially significant or meaningful. Thus, for example, other things being equal (always a valid qualification in any attempts at generalization where individual differences are bound to prevail)*:

- Figures that stand out from their background are more readily attended to than those which blend in.
- It is difficult, if not impossible, to avoid attending to certain startling stimuli (e.g., a sudden flash of bright light).
- Contrast can play a significant role (e.g., a large object among small ones, or vice-versa).

*A useful general rule here as elsewhere is that few such generalizations apply to all individuals but that there is usually more commonality than individual differences.

- A departure from the anticipated (e.g., a new stoplight or sign along a familiar route) can be significant.
- One's anticipated usage can raise an otherwise neglected stimulus to the top of the attention hierarchy.
- To confuse matters, while the unfamiliar may stand out from the familiar in some cases, the reverse holds true in others.
- Certain spatial relationships -- not too crowded, yet not too far apart -- between the elements of a sign (e.g., lettering and arrows denoting direction) enhance the likelihood of attention.
- Aesthetic considerations can also play a role, in such a way that the more elegant and appealing stimuli are selected over the less balanced, less harmonious, and poorly composed ones.

Applied to the present situation, at least for purposes of attention, the accumulated evidence suggests the site should represent some marked change in the visual modality that is meaningful for most individuals. Thus, if a person has been walking on a gray earth with only a few small stones and suddenly comes upon red earth (color change) with large stones (shape and size changes) arranged in a pattern (meaningful), then he is likely to notice the change and shift from a monitoring stance to conscious attending processes.

By the same token, attention would be enhanced by the use of a bold, distinctive symbol, in a variety of situations, preferably with mild degrees of variation in form, and standing out from its surroundings. Certain shapes (e.g., angular ones) and colors (e.g., yellow) would claim more attention than others in most contexts, and setting off one unit against another (e.g., highly contrasting colors, such as yellow against black) also helps attract attention (as well as enhancing legibility). However, the constant repetition of the same sign in the same background might make the symbol more commonplace in time; individuals might cease being attracted and would just take it as "part of the scenery". That is when the negative side of familiarity becomes evident.

5.2.2 Selective Attending Process

Most people attend not to the entire range of modality, but to a relatively small number of stimuli within the complex. Each target is defined by

several distinctive features (e.g., size, color, shape, location, etc.), and a person can selectively attend to targets on the basis of one or more of these features. As long as stimuli are conceptually distinct and differ on some perceptual dimension, one particular stimulus target can be processed in the presence of the others. As the target features become more similar it is more difficult to selectively attend to only one, even if they remain conceptually distinct (Cherry, 1953). Thus, in order for a person to select a single target for attention, it must have features that are both perceptually and conceptually distinct from the others.

The individual who arrives at the site and notices that it is different from its surroundings will seek and attend to such distinctive features as color, shape, form, and position. Features that have particular meaning such as signposts, pictographs, patterned rocks, key words, etc. will attract attention for conceptual reasons. The biohazardous waste sign in a clearing will attract attention if there are few or no other perceptually similar shapes and colors in the surrounding area, and if the person perceives the sign to be meaningful (i.e., that someone has placed a marker to inform others concerning the adjacent area).

5.2.3 Divided Attention

People have more difficulty dividing their attention between two stimuli in the same sensory modality than between two stimuli from different modalities (Gescheider, et al, 1975; Moore and Massaro, 1973; Moray and Fitter, 1973; Treisman and Davis, 1973). The attentional processes seem to be specifically constructed to sample information from more than one modality, and stimuli that arouse different sensory modalities are generally attended to more often than stimuli arousing only one modality (Moray et al, 1976).

In the present case, these findings should not play a major role in attention mainly because the information load at the site is rather low for the deliberate, motivated information-seeker, at least up to the technically detailed fourth-level messages. The key information may be readily duplicated visually and tactilely, but the latter is meant to substitute for, rather than be used along with, the visual. As indicated earlier, messages in sound could more profitably be used to enhance attention to (and learning from) the visual messages, but these are ruled out here for technical reasons.

5.3 PERCEPTION AND COGNITION

The history of psychology as an experimental science is closely linked to the study of perceptual phenomena. There is vast and detailed literature about the organization of stimulus elements into coherent units, with both conventional and illusory stimuli, most but not all of it in vision. More recently, the dominant movement is to emphasize cognition (referring more to how those units are assigned signification), and tends to concentrate more on meaningful stimulus elements such as natural language. But the distinction between perception and cognition is often blurry and, for present purposes, it is best to treat them under the same rubric.

5.3.1 Gestalt Principles

The leading development in perception was the so-called Gestalt School, formed in Berlin before World War I (e.g., Ellis, 1938; Koffka, 1935; Wertheimer, 1923). It dealt mostly with form perception but its principles spilled over into other areas -- including the application by Lewin (1951) to social phenomena -- and influenced much of the work in psychology with the view of perception as an inborn attribute modified by the subjective phenomenological experience of the individual. Since elements of the theory are still in vogue (see, e.g., Garner, 1974b; Leeuwenberg, 1971; Palmer, 1977) an examination of some gestalt principles or "laws" merits some attention.

At the heart of the theory is the notion of perception as an organizing activity so that the incoming information and impressions may be coded, processed, and stored with less effort and with more efficiency. This is demonstrated in Figure 1 for a set of shapes using the familiar basic forms of triangle and circle. Thus, the pragnanz principle (Wertheimer, 1923) holds that certain figures -- essentially those with the properties of symmetry, regularity, and simplicity -- are more readily recognized, more stable, and will be remembered more readily than others. Because of such characteristics, these "good figures" are to be selected for general use -- a practice many designers and artists adopt without the benefit of exposure to gestalt psychology.

Figure 1. Variations on Triangles and Circles (Croy, 1972, p. 115)

(Reprinted by permission of Butterworth Publishers)

The key notion of the holistic law (Wertheimer, 1923) is of perceptual wholes having "emergent properties" which arise when a set of elements interact. The unity of the whole then predominates and is different from (greater or less than) the sum of its parts. This principle may show up in the phenomenon labeled transformation, where the whole maintains its perceptual unity even though it undergoes substantial change in form (e.g., transferring a melody to a new key and variation still leaves the basic melody clearly recognizable). In this way, for example, it is probable that the trefoil or biohazard symbol will maintain its identity across a variety of transformations and settings.

Another illustration of holism can be seen in the familiar figure/ground illusions, in which people do not perceive an object by itself as such but only in relation to other contextual elements. Thus, in the Rubin's illusion, a goblet figure may appear as white foreground against a black background, or it can be switched to be a representation of two faces, this time the black regions emerging as foreground and the white as background.

Grouping is another concept referring to the fact that the human perceptual system tends to organize the visual field into meaningful groups of objects or patterns (Wertheimer, 1923). Six characteristics are held to contribute to grouping -- proximity, similarity, symmetry, continuity, closure (tendency to complete incomplete wholes), and common fate (that different elements uniformly transformed over time are spontaneously reorganized together as a whole). The overall activity encourages individuals to perceive diverse elements as wholes or patterns.

These principles are illustrated in different ways in Figures 1, 2, and 3. Figure 1 demonstrates that different shapes composed of the two basic forms of triangle and circle "belong together" as a set. They are regarded as stable and "good" in that each member of the set has the properties of symmetry, transformability, regularity, etc. The added shape at the bottom is the symbol for fallout shelters, and clearly belongs in this collection.

Figure 2 shows a number of variations of the arrow sign, each with its own type of bilateral symmetry (number 12 may be considered an exception). Although many variations are introduced in the features of the sign, the basic arrow shape (and hence identification and meaning) is maintained.

Figure 3 starts with the basic circular and triangular shape components (A and B), and explores variations of the trefoil as a good form in gestalt

Figure 2. The Arrow and Its Many Faces (Croy, 1972, p. 133)

(Reprinted by permission of Butterworth Publishers)

Figure 3. Evolution of the Trefoil Symbol

terms. C is merely a variation of A, with a broader band and an added solid circle in the middle. In D, parts of the broad band are removed, leaving what might be termed a "triangular partial circle" -- the basic trefoil. That symbol is still easily recognizable when it is rotated (in E) and when field and ground are reversed (in F). When it is placed within a larger triangle, in G, the warning trefoil sign is formed. A suggested biohazard symbol (see Figure 4) shows many of these same characteristics. However, because its "flares", though representative of circles, create an asymmetrical clutter at the focal center, it may be less preferable, in gestalt terms at least, than the trefoil (as well as being more difficult to copy and reproduce faithfully).

As has been noted, many of the gestalt principles have been incorporated into practice by design artists and can be employed to inform the design of the onsite messages. As the above illustrations suggest, these principles can lead to a variety of coded messages from a few simple, familiar forms. In particular, since the evidence suggests that perceptions are first determined by symmetrical (Julesz, 1975) and entire patterns (Pomerantz, et al, 1977), it follows that the messages should feature these characteristics. In contrast, nonsymmetry can make recognition more difficult, and patterns whose "wholeness" is not apparent because of the clutter of too many diverse constituent features will be less readily perceived as such. On the other hand, when the intent is to distinguish between different sets of information, differences in overall pattern can be usefully employed for this purpose.

The gestalt theory, which mandates that like elements should be grouped together and that unlike elements should be separated by distinctively different features, may be merely stating the obvious. But it is surprising how often this principal is violated in designs and written messages.

5.3.2 "Top-Down" Versus "Bottom-Up" Processing

The direction followed to this point represents a "bottom-up" approach, one in which stimuli influence sense organs, which in turn, influence basic perceptions, which influence organization into functional units, and probably memory representations as well. This approach most applies when a person does not expect, or does not have experience with, a particular stimulus, as in the

Figure 4. A Suggested Biohazardous Waste Symbol
(Human Interference Task Force Design)

case of the uninformed and unseeking visitor who just happens upon the site. But for the experienced driller who is looking for the site, a "top down" approach to perception may be more relevant. Experience and expectations (cognitive representations) "set" or "prime" the perceptual process to search out and see what the person has experience seeing or an expectation to see.

This phenomenon is apparent in research on degraded pictures (those with missing parts or vague forms). In such instances, subjects were not able to combine the individual components into a single recognizable pattern; recognition is significantly improved, however, when the pictures were labeled and identified. When viewing conditions are poor (the object is distant, poorly lighted, partially degraded) then a "top down" approach is more likely (Franklin and Erickson, 1969; Schiffman, 1967; Slack, 1956), presumably because poor conditions force the individual to first impose some meaning and then seek cues. When viewing conditions are good (object is close, well lighted, completely intact), then "bottom up" perception is more likely. These general results do not always obtain, however, and some controversy persists over how much "bottom up" and "top down" processing actually takes place (Gibson, 1966; Hochberg, 1964, 1971; Ittelson and Kilpatrick, 1951).

Because the various visitors to the repository site will arrive with different preparations and expectations, both "top down" and "bottom up" processing should obtain across individuals. Accordingly, symbols that appeal to both kinds of processing strategies should be incorporated in the messages. Use of the perceptual principles mentioned above will aid especially in "bottom up" processing. Use of more cognitive strategies and representations will aid message construction using more "top down" processing.

5.3.3 Categorization

Closely related to the gestalt perceptual concepts of holism and grouping is the more contemporary cognitive idea of categorization (Rosch, 1978). This refers to the human tendency to treat two or more distinguishable objects, events, or concepts as members of an equivalent class, e.g., labeling distinct objects with the same name, or performing the same action in response to unique signs. The actual categories used are assumed to be products of both innate abilities (e.g., color or gestalt-type classifications) and learning

(Rosch, 1973) but the pervasive tendency to engage in such behavior is taken as a more fundamental need, e.g., to impose order on varying perceptions, or as a short-cutting device to cope with limitations of the human memory system. Having a large number of categories allows fine discriminations, but one of the purposes of categories is to reduce the infinite differences among stimuli to cognitively and behaviorally functional units.

Classical theories of concept formulation, which date back at least to John Locke, concentrated on the properties of the objects, and viewing the organism as passively and gradually acquiring common defining elements (Hull, 1920). More recent approaches (Bruner, 1973; Neisser, 1966) see individuals as actively "testing hypotheses" in learning the effective sets of relevant features and the rules combining them. Where earlier approaches saw the classification of objects as arbitrary, the new ones emphasize natural category structures.

Rosch (1978) identifies two dimensions along which categories vary -- one representing degree of specification (varying from abstract to concrete) and the other, degree of typicality (from least to most typical). The former is best seen as a taxonomic hierarchy with a particular level of abstraction at which the most basic categories are established. Such basic level categories (Rosch et al, 1976; Mervis and Rosch, 1981) are those perceptual and semantic classifications that are most cognitively efficient in terms of maximizing within-category similarity relative to between-category differences. These fundamental categories are assumed to be very widespread, if not universal, and are reflected in anthropological data from different cultures (cf. Berlin and Kay, 1969; Berlin et al, 1973; Brown et al, 1976) and specialized professional areas (Mervis and Rosch, 1981), as well as in common concrete objects (Rosch et al, 1976). They are seen as constituting a fundamental mental process in that they appear earlier in the normal development of the organism; undergo no substantial change or development other than that due to maturation with age; require less reaction time to accomplish; are reflected in natural language usage, and in specialized codes such as sign language; are recognized most rapidly; and the individual is generally not conscious of the actual working out of the process.

On the second dimension, categories are established in terms of prototypes that contain the attributes most representative of items inside, and

least representative of those outside, the category boundary. Thus, there is evidence that people show high agreement of prototypicality (Rips, et al, 1973; Rosch, 1973, 1975), do so with more rapid reaction time and frequency (Battig and Montague, 1969; Rosch, 1973), and allocate prototypes to categories more quickly than non-prototypes (Glass, et al, 1974). Attneave (1957) claimed that the main characteristics of a category that are learned are its central tendency or prototype, the dimensions along which its members differ, and the degree of variability among category members. People learn what the prototype is by examining particular instances of the category and by abstracting an idea of the central tendency from the examples.

To the degree to which basic categories and prototypes can be determined through experimental research for different sign characteristics such as shape, color, semantic attributes, etc., the categories and prototypes could help guide the selection of specific signs and symbols for use in the on-site, distal, and even remote information locations mentioned earlier. Systematic research (a set of response criteria have been developed for assessment purposes) might even uncover the kinds of denotative and connotative meanings that can most readily be projected at each location and site. For example, there is little doubt that the basic prototype for danger can be determined easily. Conveying caution may be more difficult, but appropriate research can help select a sign or combination of signs from the alternative basic level categories that more effectively evoke the desired interpretation or response.

5.3.4 Communication by Form

From gestalt theorists to more recent observers (e.g., Croy, 1972) there has been a tendency to take the simplest, symmetrical geometric figures to be the basic forms for developing a sign system for communication. Thus, for example, the International Organization for Standardization has recommended the circle to denote "interdiction", the isosceles triangle for "warning", and the square for "information". These assignments are apparently arbitrary, although there have been claims that these are "natural" forms for the designated meanings. For purposes of redundancy in recognition and improved transfer of meaning, color codes can be added -- e.g., "Don't" and "Danger" signs can use red and yellow background colors, and "Information" signs can use green or blue.

Assume that the triangle in yellow is selected as the basic danger warning signal. Now the task is to indicate what constitutes the source of danger, in this case a symbol to denote "nuclear wastes" or "nuclear radiation" for insertion inside the triangle. Since these are basically invisible or unknown to the message recipients, they do not have a distinctive visual perceptual sign; i.e., they lack a prototypical form. This suggests some arbitrary but meaningful symbol.

One likely candidate is the afore-mentioned trefoil, which was recommended as the standard radiation symbol by the International Commission on Radiation Protection (in 1956), and adopted by the American National Standards Institute (in 1969). It has been required by the U.S. Department of Transportation (1980) for labeling of all radioactive material since 1978, and is in use by many other western countries for the same purpose. Another possible candidate is the uranium pictograph, such as is used in Otto Neurath's Isotype (Neurath, 1972). A third is the biohazard symbol. There are several criteria for choosing between them and these can be evaluated empirically. It should be a simple enough matter to design an appropriate research study.

There follows the need to communicate that drilling activity beyond a certain depth should be avoided. Assume that the circle is selected for that purpose. In keeping with the practice on international traffic signs and other such notifications, the diagonal bar through the form could be used to indicate the "don't" component of the message. It is probably as good or better (mainly because it is already in use for this purpose) than any other, but further research could help settle that question as well. Symbolizing drilling is more difficult. There are a number of associated visual cues (e.g., a derrick above ground with a shaft below, a spiral drill bit, etc.) but none fills the bill ideally. Again, appropriate research can guide the selection between various suggested alternatives, although there is no guarantee the results will unequivocally favor any particular one. In a pinch one could always resort to the words "Don't Drill" (in several languages), which should be used as a redundant fall-back in any case.

Within the same "information" sign there should be some way to indicate the dimensions of the site, the dispersion of waste-filled canisters, etc. One example of such a depiction was recently contained in a magazine article to illustrate a potential salt dome waste burial site (Golden, 1981). Such art

work is often accompanied by substantial verbal content to enhance the meaning, and it is a proper topic for research to determine just how much that content adds in terms of communication efficiency. There are other possible versions of such a layout depiction, with forms alone or with words, but clearly the communication task at this level is more complex.

Before leaving this topic, it is worth noting a related area of theory and research attempting to link the physical attributes of a stimulus to various psychological judgments and reactions. For example, Attneave (1957) has demonstrated that a large proportion (90 percent or so, in various trials) of the variance in subjective judgments of stimulus complexity could be accounted for by certain structural characteristics. Arnoult (1960) expanded this line of research to show that other perceptual judgments such as size, familiarity, and meaningfulness, are similarly related to physical attributes, albeit to a lesser degree. In a more elaborate study, Elliott and Tannenbaum (1963) found striking correspondence between a set of eight structural characteristics of two-dimensional shapes and the connotative ratings usually obtained by the semantic differential technique (Osgood, et al, 1957). The judgment of activity was linked to such properties as total number of sides (and hence of angles) and to angular variability; potency was linked to size characteristics of area and perimeter, as well as symmetry; and evaluation (essentially pleasant versus unpleasant) to curvature and symmetry.

While the above findings do not relate directly to the waste site messages -- their judged symbolism does not address the specific intended meanings of the on-site messages -- the methodology employed is directly transferable. This again advocates the need for special research to examine the particular purposes and goals of the present undertaking, rather than an indiscriminate generalization and borrowing from previous research conducted for quite different, although related, purposes.

5.3.5 Communication by Color

Even more than shapes, color can play an enhancing role in the communication of visual messages. It can be a major factor used to attract attention. Moreover, color characteristics are often one of the distinctive features of a given object that can serve as a critically relevant cue in its

recognition, in recalling its appearance, in relating that object to others in its primary category, and in causing its particular selection from a set of otherwise similar objects. As the creators of commercial advertisements and product packages are well aware, color can also significantly enhance the intrinsic attractiveness of certain products by emphasizing certain desired attributes, e.g., a sizzling steak, a frosty glass of orange juice, etc.

Beyond such denotative correspondence, there is again evidence of a strong relation -- one is tempted to call it a sort of "visual onomatopoeia" -- between the main physical properties of color and the repeatedly dominant semantic dimensions (see Tannenbaum, 1966). The most apparent fit is between the physical characteristic of hue and the activity dimension -- the reds and yellows toward the active end, the blues and greens to the passive, a phenomenon reflected in general language usage, as when we speak of "warm" and "cool" colors. There is also a significant parallel between brightness and potency -- within a given hue, the systematic addition of black to the prime hue made for generally corresponding judgments of increasing potency, while adding white led to weaker ratings. Here again, there are appropriate language terms -- "strong, dark" colors versus "weak, pastel" shades.

It would be pleasing to aesthetic and theoretical predispositions to find a similar fit between the physical saturation dimension and the semantic evaluation factor. But here the data are not as consistent, not the least because color preferences appeared to be an individual affair. But the evidence is not completely random: for one set of subjects (about 65 percent in the original study), when hue preference is controlled for, there is a trend toward less favorable reactions with decreasing saturation. This difference may reflect differential usage of, and experience with, colors.

There is also evidence of substantial generalization of these connotations of color specimens per se to other objects with which those colors are associated. Thus, systematic variations in the judgment of meaningful products in advertisements, abstract sculpture, and even random two-dimensional shapes were found with variations in color treatment, paralleling those indicated above (Osgood, et al, 1957).

The very consistency and systematic nature of these relationships seem to argue for an innate interpretation, almost indicative of an isomorphism in our nervous systems between the physical and psychological domains. It can be

plausibly maintained, for example, that those hues representing higher wavelengths generate more energy potential, and thus are judged -- and cause other objects to be judged -- as more active. But this is obviously highly speculative, since it can also be argued that most humans have highly similar exposures to color in their environment, and it is such common learning experiences that make for such common response tendencies, possibly reinforced through verbal associations, as noted earlier. Even then, such language parallelisms represent a two-sided issue: do appropriate verbal labels reflect fundamental relationships, or do the observed relationships reflect common linguistic associations?

Innate or learned, the above results and the obvious denotative advantage of color strongly urge its use in the design of the various message systems, particularly the warning symbol. The one drawback here lies in the longevity question. While new color dyes, acrylic paints, etc. can last long periods of time by current standards, they are apparently still subject to fading over the very long haul. Unless new techniques are forthcoming, the issue of some kind of renewal procedure is again indicated. In fact, this issue arises with enough frequency to suggest closer attention to Sebeok's (1984) key recommendation of depending on a relay system across the board.

5.3.6 Rules and Generalizations

There is increasing evidence to characterize humans as rule-making and rule-abiding animals. Presented with an array of experience with a similar set of objects or events, they not only tend to categorize them but often seek a rule or generalization to "explain" the experience. The rule serves as an attribution of membership or causality and once formed, it serves to guide behavior.

Of course, when misattributions occur and the "wrong" rules are formed, the individual behaves inappropriately. In such cases, repetitive negative feedback may get the individual to amend or discard the rule. However, in cases where earlier functional rules later become dysfunctional, even counter-productive, the habit strength of the earlier generalization is often sufficient to keep the old patterns lingering on. Childhood behavioral patterns developing into adult neuroses are a rather extreme example of this

type of "misplaced epistemology", and there are other instances of poor decoding and cognitive habits as hangovers from previous experiences.

A special case of such rule making is drawing inferences of causality through the rules of logic. These are clearly important in allowing the organism to make sense of the environment and to determine the loci of possible peril or pleasure. Such rules of logic have their parallel in the deductive rules of "psycho-logic" (Abelson and Rosenberg, 1958). They, too, are part of the apparatus for decoding and deducing one's immediate or remote environment and are short-cuts to consistent behavioral approaches and avoidances. But because they are often based on partial evidence and over-generalization (e.g., "my enemy's enemy is my friend", or "if he favors something I dislike there must be something wrong with him"), such "cognitive scripts" (Abelson, 1981) can lead to faulty inferences, not equally applicable in all situations. It should nevertheless be recognized that many humans are more prone to such psychological reasoning than they are to the logical.

The application of such rule-making behavior to the information system design is rather limited. It is useful to recognize that humans seek rules for purposes of attribution and accounting, and in the absence of provided rules will make up their own. Since these can be premature and over-generalized, hence misleading, it would be helpful to apply and provide rules. For example, color usage, as a semantic device, should be consistent so the "correct" rule is acquired more readily and without ambiguity, and some sort of negation sign, such as a red diagonal line through some deposited object or event, used consistently would also help.

5.4 MEMORY

Logical and psychological rule making, categorizations, perceptual principles, and other such phenomena are all part of a similar pattern -- they provide means of structuring and combining diverse inputs into fewer and more manageable components. It makes sense for any organism to do this in the interest of efficiency (i.e., less expenditure of effort, energy, and other resources for similar results) and parsimony.

These are strong enough inducements for adaptation purposes, and become even more salient considering the inherent constraints of the human memory

system. Remarkable as that system is, it still has its limitations, and these, in turn, make it more economical for the organism to store a finite set of generalizations than the almost infinite number of specific, unique attributes, objects, and situations it is bound to encounter. The storage system is too precious a resource to have it cluttered with assorted trivia and bits of information that will be relatively rarely called upon for retrieval. The notion of classification and generalization in cognition has a correspondence in the concept of schema in the memory system (Shanks and Abelson, 1977; Anderson, 1976; Rumelhart and Ortony, 1977).

Despite considerable advances in techniques and equipment, theory and research in memory have yielded few breakthroughs in recent years. Just how sensory data, perceptions, and cognitions are encoded into memory, stored there, and then retrieved continues to elude us. Many of the problems of several decades ago are still not resolved, with contrasting theories and experimental data vying for preferential treatment.

5.4.1 Mental Imagery

One of those perplexing issues concerns the relationships between the nature of the sensory stimulus and that of its representation that is encoded for storage. The notion of modality-specific representation -- i.e., a direct correspondence between the sensory stimuli and its image -- still has its adherents (e.g., Nelson, 1978), but has generally given way to more complex models. The evidence suggests that the medium of presentation does play a role, albeit a limited one -- it may not be the message in the McLuhan sense, but it does modulate the message to some degree and remains part of its encoded representation.

The dual-code model (Paivio, 1971, 1976) contends that there is an analog pictorial code for visual materials, and a separate analytic verbal code, with connections between the two. Among other things, this would suggest that visual memory is enhanced by the fact that it may evoke a verbal representation along with the basic modality-specific one, and vice-versa (Loftus, et al, 1978; Pezdek, 1977). The above theories are discarded by the advocates of a single-code abstract model (Pylyshyn, 1973, 1976) in which all imagery is encoded in an abstract propositional format. In this formulation, the memory code is independent of the sensory input. The memory code provides a neutral

format into which -- and out of which -- sensory input, either pictorial or verbal in formation, or any other, is translated.

The advocacy of three separate possible memory processes naturally gives rise to a tri-code model (Anderson, 1978). This suggests that humans may process each and any of three kinds of information -- the visual-spatial, verbal-sequential, and abstract-proportional -- and that the optimal image representations of the three domains are different from one another. Presumably one kind of representation can be transferred into another at time of retrieval as a function of the anticipated behavior to be performed (e.g., the expectation of having to draw a figure would elicit the visual-spatial representation, but expecting to speak about the figure would give rise to the verbal-sequential use). Anderson (1978) has argued that the behavioral data can be accounted for by any of the models, so there is really no way to choose between them on that basis. He further suggests that treating all three models equivalently offers certain advantages (in a manner akin to how the wave and particle models of light are useful for different computations).

The above does not contribute substantially to the present concerns, but it does suggest that the current state of the art (such as it is) goes along with the idea of a visual stimulus supported by verbal messages. By and large, the evidence suggests that one can support the other for purposes of retention and recall, and there are other reasons mentioned earlier (e.g., redundancy) for having dual, coordinated message systems. Even if some suggested universal symbolic codes -- e.g., Eckardt's hieroglyphic symbols (see Croy, 1972) or Bliss' semantography (see Diethelm, 1974) -- are adopted, the suggestion is still to use multilingual verbal representation additionally.

5.4.2 Sequential Visual Information

If pictographs, cartoons and the like may be considered for use in the onsite messages to represent sequential events and episodes, there are few reliable, comprehensive research data to inform their construction for enhancing memory. Some scattered findings suggest that sequences are probably represented in abstract-propositional formats, rather than in the units as such (Kraft and Jenkins, 1977); that component objects of a picture composition are better recalled over time than the overall composition itself

(Mandler and Ritchey, 1977); and that those familiar with a complex task use memory schema but not so for the unfamiliar (e.g., chess players versus non-players; de Groot, 1965).

More generally, there is increasing support for Tulving's (1978) principle of encoding specificity, which contends that episodes are laid down in a total integrated memory trace -- a unique (to that episode) constellation of modes, associative links; and contextual elements. The effectiveness of any retrieval cues depends on the properties of the encoded event per se and not on one or more isolated items in that event. Remembering is thus viewed as being relative to the way the episode or the character of an episode was coded in the first place, and is heavily influenced by context.

An important contextual factor, for both sequential and other information, is apparently the kind of use the organism expects to make of the information at a later time. (Consider, for example, the different procedures for memorizing a poem one expected beforehand would be recited verbatim later, as opposed to memorizing parts of it in expectation of a discussion of the poem's "message" or style). Such differential anticipatory usage can influence how the information is encoded for storage (Postman and Krueski, 1977). Similarly, events of high emotional impact, with anticipated consequences for the person experiencing them, can lead to "flashbulb memories" in which peripheral details, as well as those of the event itself, are vividly recalled (Brown and Kulick, 1977).

Considered together, these diverse findings suggest that the meaning of the overall sequential message be made clear, and that the interconnection between its constituent parts follow logically and symbolically. The introduction of any obscure or ambiguous cues along the way may throw off the entire message. By the same token, the ultimate purpose of the message (presumably, in this case, don't dig deep, otherwise a series of unfortunate events await) and the cause-effect links of that information should be abundantly clear. One particular problem in this connection in the present case is that the anticipated consequences of interfering with the stored materials may not be immediately apparent but can take several decades to appear. Causal connections are difficult to grasp under such circumstances, and even more difficult to communicate to others through relatively primitive codes. To put it simply, to be properly accurate, fairly complex messages require fairly complex codes.

6 REVIEW AND CONCLUSIONS

The reader was forewarned at the outset that this review was not to be exhaustive of the psychological literature but would focus on materials relevant to the issue at hand. From this review, three types of findings emerge:

a. There are certain characteristics of humans that are so widespread across individuals and cultures as to be considered as being intrinsic in their perceptual makeup. Some of these universal characteristics will probably persist across future generations and hence can be incorporated as appropriate into the design of the various information systems under consideration.

b. There are other findings in the research data that are reasonably consistent within a given area of investigation but which have not been tested across a wide enough range of the phenomena and situations as to be directly generalizable to the immediate problem. For the most part, these are taken more as learned responses rather than truly intrinsic, and hence more dependent on the generality of learning opportunities both for the present and, even more so, for future generations. They are nevertheless reliable enough for the human organism to employ as shortcut, effort-reducing mechanisms, and hence can be highly functional.

The appropriate procedure in such instances is clear enough. Because they have not been tested with the types of signs and symbols that could be employed in the nuclear waste case, the various options -- both those already at hand and others that may be suggested for consideration -- should be tested under circumstances that replicate conditions that might obtain in the future. For example, the trefoil and various biohazardous signs currently used, augmented by other potential signs, could be tested for their present meaning and/or behavior-inducing potential but should also be tested with groups where specific learning of the necessary associations is induced. One or more choices may clearly show a wide range of shared meaning to suggest their adoption outright (as with the trefoil, for example); others may lack sufficient currency but nevertheless demonstrate a particularly high rate of functional acceptability with relatively modest rate of learning. Just such a phenomenon

emerged from some research the author recently conducted for designating various pharmaceutical characteristics (e.g., for only internal or external use, dosage size, etc.) and appears to apply to initially arbitrary but ultimately more functional signs to be used in various international exhibits.

The essential point is to test such potential signs systems under reasonably representative conditions and with appropriate rigor to compensate for the present lack of generalizable evidence. Appropriate methodologies are available and the costs involved are quite modest, even if large and variable samples will be employed for reliability estimates.

c. That still leaves a good deal of desired content to be communicated and for which our present knowledge base is totally inadequate to guide the selection process. Under such circumstances, practically the only alternative available is to have a number of experts (such as industrial designers, other artists, psychologists, linguists, etc.) submit their suggestions and then to expose all, or a pre-selected sub-sample, to appropriate testing. The critical factor here is not to treat the selection as a jury-type process but to use fairly rigorous scientific procedures to assess such relevant factors as communication effectiveness, fidelity of transfer, relative cost, possible political or cultural objections, etc. Again, suitable experimental methodologies are available and can be implemented without excessive effort and cost.

The above suggested research can apply only to present-day populations, of course, and more or less under the present-day circumstances. What we lack is knowledge of what future populations and circumstances will be. Even if we could estimate some of this missing information our ability to replicate it for testing purposes is severely restricted by the necessity of using present-day populations with their attendant degrees of ignorance and sophistication. Some anticipated environmental changes can be presented to a certain degree but, here again, current legal restrictions governing the use of human subjects in research and other such constraints mean limiting the testing to a proper range of conditions, especially the worst-case possibilities.

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