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Messaging the Future: The Marking of Deep Geological Repositories for Nuclear Waste

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Abstract

Nuclear technology has and continues to produce thousands of tons of high-level nuclear waste. Deep geological repositories appear to be the best method of disposal, yet these facilities can remain toxic for many thousands of years. Marking such sites with information and warning signs is very difficult, as the huge timeframes involved mean that enormous and unpredictable cultural and linguistic changes will occur. Writing will need to be presented in multiple languages. Symbols that are well-known today, such as the trefoil radiation symbol and the biohazard symbol, are also susceptible to loss and changes in perceived meaning. More iconic images, like the skull and crossbones, might be more effective in communicating danger yet this symbol is also open to misinterpretation. Images of faces can be effective as facial expressions share a commonality across cultures, which should continue be the case in the future. The growth of emoji used for interpersonal electronic communication has shown how people like to communicate with images of facial expressions and indicates the effectiveness of even simple facial designs. This essay investigates the approaches and plans of deep geological nuclear waste repositories currently under construction and offers some suggestions as to how future generations might be warned and informed of these toxic places.

Key words: nuclear waste repository markers, trefoil symbol, biohazard symbol, skull and crossbones, emoji.

1. Introduction

Nuclear technology is an integral part of scientific advancement and has benefited humanity in many ways, such as providing a highly efficient means of energy production and the development of life-

saving medical techniques. However, its application has also come at a huge cost. Nuclear warfare remains a very real threat, and the place names of Chernobyl and Fukushima are a constant reminder of what can go wrong. Another enormous cause for concern is that of nuclear waste, which continues to be produced and stockpiled by the ton every year. According to Jacoby (2020), "More than a quarter million metric tons of highly radioactive waste sits in storage near nuclear power plants and weapons production facilities worldwide". Most of this material is stored on a temporary basis aboveground (or near aboveground) often close to where it was produced. Even with advances in spent nuclear fuel reprocessing, it is inevitable that safer, permanent storage locations will be required. The practice of sea-dumping was halted due to its obvious dangers, and space disposal remains impractical. Deep geological repositories appear to be the only solution.

Finding permanent homes for highly radioactive material is extremely difficult. Democratic countries make for inherently difficult nuclear dumping grounds, as voters generally do not want their nation's (or any other nation's) toxic legacy dumped in their part of the world. A politician who supports the depositing of high-level radioactive material in or anywhere near their constituency is unlikely to win elections. The proposed Yucca Mountain Nuclear Waste Repository in Nevada, USA remains just that. In Japan, the town of Toyo (Kochi Prefecture) and the town of Suttsu and Kamoenai village in eastern Hokkaido are also unlikely to have any permanent nuclear repositories anytime soon. However, continuing to store radioactive waste above (or near above) ground is risky and untenable, with disadvantages including the high cost of security, site maintenance and monitoring, vulnerability from warfare and vandalism, and damage from natural disasters. Despite its general unpopularity, some nations have found a way to begin construction of deep geological repository sites, such as the Cigéo project (Centre Industriel de Stockage Géologique) at Bure, France, and the Onkalo spent nuclear fuel repository at Olkiluoto, Finland.

Simply burying our toxic legacy creates an important issue: Should we leave a warning for future generations, and if so, how can this be done? The builders of the Onkalo site have chosen not to leave any markers, so when completed the facility will be hidden – buried and the area landscaped to appear natural. This decision seems fitting as the site is on an island, and the waste will be buried in granite bedrock at an approximate depth of 450 meters in an area that has been (and is expected to be) geologically stable for millennia. Such a site might best be forgotten, as any message indicating that something of significance lies beneath may provoke unnecessary attention, curiosity and then investigation. Yet Onkalo is one site out of possibly many future sites in different areas throughout the world that could be found and opened, and some of these sites may not have Olkiluoto's geological and geographical advantages. A strong argument can be made that people of our time are obliged to at least attempt to warn and inform future generations of our toxic timebombs.

Some sites are planning such a message. The Cigéo site has a 'memory program' that investigates ways in which the facility might be able to leave or transmit messages to the future. According to

Gordon (2019), the head of the memory program, Jean-Noel Dumont, believes that the program is necessary as will serve as a warning for future generations and provide important information about the material stored there, and can also "provide a wealth of information for a future archeologist" (p. 4). The Waste Isolation Pilot Plant (WIPP) in New Mexico, USA is designed to store low-level, transuranic radioactive waste for 10,000 years, and as the name indicates serves as a pilot facility for future deep geological repositories. Extensive research and planning have been conducted concerning how future generations might be able to receive messages about the site, with experts in fields including linguistics, semiotics, engineering, and anthropology having produced the Sandia Report (Trauth, Hora, & Guzowski, 1993) and the Permanent Markers Implementation Plan (United States Department of Energy, 2004). According to the US Department of Energy (2003), the WIPP site will use "passive institutional controls" defined as "markers and methods designed to warn and inform future generations and civilizations about the location and purpose" of the site. These markers and methods will be extensive, involving earthworks, radar and magnetic detection, granite monuments, an information center and information storage rooms, buried markers and archives held in different locations throughout the world.

Despite our best efforts, creating successful messages of warning and information presents an enormous challenge given the huge timeframes involved. As pointed out by Benford (2000), leaving messages for the future, or even the not-so-distant future, is very difficult and often unsuccessful. Information essentially always exists in some physical form (e.g., encoded in neurons, sound waves in the air, ink on paper, carved into stone, put on a USB flash drive) so any signs humanity leaves behind will have to physically withstand (or be successfully passed along) the tens of thousands of years required for the radioactive material to stabilize, much longer than some Mesopotamian cuneiform tablets estimated to have been written 5200 years ago. Furthermore, the intended meaning of the message has to be understood after hundreds indeed thousands of years of linguistic and cultural change, which (as human history has indicated) will be enormous, continuous, and unpredictable. Furthermore, the main object of the message poses difficulty, as unlike the tangible and observable effects of radiation poisoning, radiation itself is invisible, silent, tasteless, and odorless to the human senses. Unlike a poisonous snake or a slippery road, radiation lacks concreteness, making it inherently difficult to 're-present' in a message.

Additionally, the receivers of the message are (of course) unknown. According to Peirce's triadic model of the 'sign', along with the *representamen* (the form that the sign will take) and the *object* (what is being stood for), a sign also consists of an *interpretant*, defined by Chandler (2017), as "...the effect produced by the sign or the sense made of it" (p. 29). How the message will be received and interpreted in the distant future will depend upon who (or even what) receives the message. They could be people who experienced a global catastrophe and consequently reverted to a pre-nuclear or pre-industrial level of technology. Such a population would be prime recipients for a warning due to their vulnerability, as they would not understand nuclear technology and therefore lack any means of

radiation detection. Or the message receivers may have a technological level vastly superior to our own: human/machine cyborgs or perhaps humans altered through generations of extensive genetic engineering. These beings may actually seek out our nuclear waste to use as a valuable resource. Or they could even be non-humans, with humans having been superseded by non-organic forms centuries ago. Regardless of who (or what) tries to make sense of the signs received – speculation easily becomes the stuff of fantasy and science fiction – signs left behind need to focus on two basic functions: warning and informing.

This message is a departure from others previously carved into stone, impressed onto clay, or written on bamboo, pottery fragments, or papyrus. It is not a religious message, nor is it philosophical, political, a record of accountancy, personal correspondence, an epic narrative, or some grandiose proclamation from a long dead ruler. Rather, it is an awkward statement, basically saying: *We left poison here. Be careful.* The message is unique in that it refers to an actual, existing threat – more than just a warning of a potential, future danger like the nearly forgotten (yet recently remembered) tsunami stones of Japan. The markers on a nuclear dump site need to connect their message to the real and present danger buried below. However, comprehension alone is not enough, as the message must also be believed; not taken for ancient mythology, a weird artistic endeavor, or a trick designed by the ancients to prevent the unearthing of secret treasure. And even if the warning is successfully understood and sufficiently believed, it must also be heeded.

2. Written in Stone

The invention of written language is a one of humankind's greatest achievements. According to Sagan (1980), writing possesses a magic that can transcend time; capable of "binding together people who never knew each other, citizens of distant epochs. Books break the shackles of time". However, this mystical quality becomes strained when dealing with the huge timeframes required for nuclear warnings. The WIPP site is designed for 10,000-year containment, but facilities storing high-level radioactive material will require even longer periods, as with the Onkalo site designed to last 100,000 years. A written message encountered even after a few hundred years is subject to natural attrition, as language change results in meanings becoming lost and misinterpreted. The English of Shakespeare, although still highly appreciated, has evolved – through a process of what could be referred to as linguistic natural selection – to become difficult for modern English speakers to understand, even after a (comparably) mere 400 years.

However, writing systems can survive remarkably well. According to Robinson (2007), cuneiform had become abstract signs (having originated from pictographic signs) by about 2500 B.C.E., and the last example of this writing is dated at A.D. 75, "Thus cuneiform was employed as a writing system for some 3000 years" (p. 71). Repeating, transcribing, copying, and translating language enables us

to keep an unbroken line with the distant past. Today, it is still possible to experience the ancient Mesopotamian poem *The Epic of Gilgamesh* first written in Cuneiform over 4000 years ago. Designers of the WIPP site encourage language continuity through the inclusion of inscriptions requesting that site information be translated into the languages of future times. Blank spaces in the stone panels are left for this purpose. However, despite the best efforts to preserve a message, the successful transference of information remains tenuous, as much of what has been written throughout history has been lost. Books have been burned, tablets destroyed, inscriptions defaced, and many languages have simply reached their end. Messages left at nuclear repositories can easily succumb to natural disasters, warfare, vandalism, pillaging, become buried, overgrown, forgotten, or be reduced to curious yet meaningless sets of markings from a people of long ago. Keeping information in written form across millennia is a fragile process relying upon an unbroken sequence of events; yet some writing has survived for thousands of years to perform its magic.

Any writing left for the distant future would require a system of redundancy through the use of multiple languages to convey the same message. Some languages presented may be lost, but others at least partly known. The fragments of a few scripts could suffice in order to gain a reasonable understanding of the whole communication. Languages invariably change – like a genome they carry remnants of information from their distant past. A study by Pagel, Atkinson, Calude and Meade (2013) analyzed 200 words common to Asian and European languages and identified 23 English words that may have been in usage 15,000 years ago. The five oldest words identified were *thou, I, not, that, we*. The authors believe that these results, despite multigenerational transmission, support findings indicating that "…human language can achieve a remarkable degree of replication fidelity among its highly used words, and especially so for some parts of speech" (p. 8476). Therefore, it may not necessarily be the case that all word meanings will inevitably be lost over thousands of years. Using a variety of languages and including high frequency words may better the chances of a written nuclear warning being read and understood. High frequency words such as *No Dig Here Danger Death* may still retain enough semantic punch for even future non-experts to get the gist of what the ancients were trying to say.

The WIPP project will have message translations in the official United Nations languages: English, Spanish, Russian, French, Chinese, and Arabic. These languages are a practical choice for any site as they are currently being used (either as a first, second, or foreign language) by the majority of the world's population, and involve the use of various scripts: Roman (or Latin), Cyrillic, Arabic and Chinese logographs. As the WIPP site is located in the southern US, English and Spanish are natural inclusions, yet sites in other areas should include the local language or languages in main usage (e.g., Japanese in Japan). Although there has to be a practical limit on how many languages can be used, other important languages should be included. The addition of Hindi would add, according to ethnologue.com, the third most spoken language. Additionally, the use of Hindi means the inclusion of Devanagari, which according to britanica.com is the fourth most common writing script. Latin

might also be of value, as despite being a ‘dead’ language, its classical status (i.e., its use in science, law, medicine, and literature including religious texts) may result in the language being well preserved and therefore understood far into the future. The WIPP site includes a Romanized version of Navajo, the language of the Native American Navajo people. Any local indigenous language or languages of the area should be included on sites throughout the world, as this would give acknowledgment and respect to native cultures and peoples past, present, and future, and leave a strong record of these (often endangered) languages.

Putting these chosen languages together provides a sample, a time capsule of how the majority of 21 century humans spoke and wrote. Even if the translations are never required for their intended purpose – the finders may have a far superior awareness and understanding of radiation that we currently do – warning markers may at the very least serve as Rosetta Stones. Much of the fragile paper, chemical and digital medium of our age will degrade, disintegrate, and disappear resulting in language loss. Future peoples might decipher and use the inscriptions as linguistic keystones. The Permanent Markers Implementation Plan for the WIPP states: “This spread of languages representing different cultures and geological regions will, it is hoped, potentially allow the markers to serve as “Rosetta Stones” for future populations, and thus increase the chance that they will be understood” (p. 41). Although our messages carved in granite (or other material) are not cheerful, at least they could – aside from their main purpose – potentially be of tremendous linguistic and cultural value to future civilizations.

Along with the redundancy an assortment of languages provides, the message will need to be written and presented in a way that increases its likelihood of being properly read. It is reasonable to assume that readers of the markers will be dealing with languages unfamiliar, and therefore a process of decipherment will be required, not unlike modern scholars piecing together ancient Chinese characters or Mayan scripts. This task might be made easier by presenting the text firstly in a very simple form, and then by raising the level of difficulty in terms of vocabulary, syntax, and content. Also, space on the inscription material will be at a premium, so the message will need to be as brief as possible. The Sandia Report (1993) recommended four levels of information that increase in complexity: (1) rudimentary; (2) cautionary; (3) basic; (4) complex. Similarly, written information could be presented in three levels as follows:

Level 1: A brief message. High frequency vocabulary, simplistic grammar, repetition, similar to a newspaper headline or a children’s book. Main focus on giving a warning and basic information of the danger. Example:

> ***Danger. Warning. Here bad. This place poison. Make people sick. Kill people. No dig here. No drill here. No get water here. No farm here. No live here.***

Level 2: Simple yet complete sentences. Inclusion of less frequent vocabulary, concrete concepts. Main focus on warning and basic information about the site. Example:

> ***It is dangerous here. Do not dig here. Do not drill here. Do not live here. Do not farm animals or plants here. Radioactive material was buried here 200 meters down in the year 2025 AD. It will be poisonous for 100,000 years. The radiation is toxic and will harm and kill human life. This is a warning from the people who made this place.***

Level 3: Naturalistic language forms involving abstract concepts. Detailed information including scientific terminology. Example:

> ***This site is dangerous due to high levels of radiation. This area of 350 meters squared contains 53 sealed chambers at a depth of 200 meters. The chambers contain a total of 25,000 tons of high-level radioactive waste, byproducts of nuclear energy production. The waste is mainly used nuclear fuel rods consisting primarily of cesium-137 and strontium-90, producing ionizing radiation in the form of alpha and beta particles and gamma rays. This site is called the Coronaland Geological Nuclear Repository (CGNR) and was completed in the year A.D. 2056 in the nation of Coronaland by the Coronaland Nuclear Authority. The radioactive material buried here is extremely toxic to all life and is dangerous for 100,000 years. Please maintain this site and write this message in the languages of your time to continue this important warning. We wish you well.***

The WIPP site serves as a pilot project in which considerable amounts of time, money and expert opinion have been utilized to develop an impressive, sophisticated array of messaging systems. According to the US Department of Energy (2003), writing will appear on perimeter monuments 25 feet high, on granite walls (both inner and outer) of an aboveground information center, on two buried storage rooms, and on small warning markers (made of granite, aluminum oxide and fired clay) randomly buried throughout the site. Furthermore, there are plans to keep achieves: “Extensive WIPP records will be stored, controlled and maintained in many locations around the world” (p. 2). It is unlikely that nuclear waste repositories built in other countries will have the resources and budget to produce messages to this extent. However, future storage facilities at the very least should be able to produce and install inscribed, standardized messages on a long-lasting material (e.g., stone, ceramics, glass) and then leave these units at differing depths in different locations, including sealed entrances and places close to the actual waste. The messages may then save lives, preserve languages, or perhaps simply be gathered and traded as antique curiosities.

3. Pictured in Stone

3.1 The use of symbols

Along with written languages, the use of symbols may provide an effective means of message transmission. However, similar to understanding a language with its (by enlarge) arbitrary relationship between form and meaning, symbols require their meaning to be properly understood. An exclamation mark enclosed in a triangle (a general warning symbol of 2022) is not self-explanatory so its meaning has to be known, just as the sound/symbol relationship of the letters of an ancient alphabet require a certain knowledge. Iconic symbols (that is, symbols bearing a physical resemblance to what they represent in the world) are promising in that they appear to transcend linguistic barriers, yet they also require correct understanding. The trefoil symbol for radiation (see Figure 1) does 'picture' an atom emitting ionizing radiation yet understanding this representation (albeit crude and extremely simplified) requires the necessary scientific knowledge. It is fair to say that most people, despite knowing what the sign represents, simply view it as the radiation symbol. And even if a sign does accurately depict its referent, it is still open to ambiguity, misunderstanding and meaning change. The widely known skull and crossbones symbol (see Figure 1) is effective at picturing a human skull and femur bones, so can effectively communicate its meaning of death and lethal danger, yet depends heavily upon context. The symbol communicates its intended message well on an old cobalt blue bottle found in a cupboard or posted on a field in a country littered with landmines. However, if found by people of the year 4022 engraved on a long-buried granite slab, the grinning skull and two crossed bones may mean a sacred place of burial – an ancient cemetery full of archeological riches requiring immediate excavation.

To most people of 2022, a symbol comprising of a shovel shape enclosed in a circle bisected diagonally by a line means: *Do not dig here*. The shovel represents digging and the diagonal line basically means: *No!* These diagonal lines (unlike shovels) do not exist in the real world, so any future observers will require knowledge of the diagonal line's meaning so as to successfully read the sign. The prohibitive slash should be avoided in nuclear site marking, as despite widespread and effective usage in today's world, it is susceptible to meaning loss and distortion that could result in disastrous misinterpretation. The depiction of a shovel to represent digging, especially if combined with a pictogram of a person using it, is likely to stand the test of time as it depicts a basic tool and a basic human action. A simple image of a drilling rig penetrating ground-level may also be successfully comprehended. However, when combined with our contemporary symbol of prohibition, these images may give the opposite intended meaning: *Dig here!* or *This is where you should drill*. The circle and slash may be interpreted as a means of emphasis, a grant of permission, invitation, or even a request to do the very thing depicted.

Regardless of their shortfalls, symbols, and iconic imagery (i.e., pictograms and ideograms) nonetheless should be an integral part of any messages left for the future. Along with a variety of written languages, images will complement textual information and thereby provide the main message with added redundancy. Even if all the written languages presented are lost in time, and with the message finders a society regressed to a pre-industrial revolution or pre-nuclear age level of

technology, these signs may at least give observers a chance to understand that all is not well in the area marked.

3.2 The radiation trefoil and biohazard designs

Despite the possibility of its meaning becoming lost, and the difficult task of a symbol representing something that cannot be seen or touched, it would be hard to imagine a radioactive burial site without the trefoil-design radiation symbol. The sign originated at the University of California Radiation Laboratory in Berkeley, and after several variations based on the original design, the symbol became standardized by the late 1950s. According to Lodding (2007), the International Atomic Energy Commission (IAEC) led a five-year, eleven-country study to determine the effectiveness of the symbol and found that "only 6% of those questioned in India, Brazil and Kenya could recognize the trefoil symbol for what it was." (p. 70). This finding led to the development of a symbol to supplement (not replace) the trefoil design. The new symbol (see Figure 1) makes the old one more understandable by adding tangible, concrete clues indicating what the trefoil sign means. Five wavy arrows emit from a trefoil onto a skull and crossbones symbol, and onto a pictogram of a person running away in the direction of an arrow pointing horizontally to the right. According to an IAEC press release by Dahlstrom (2007), "The symbol was tested with different population groups – mixed ages, varying educational backgrounds, male and female – to ensure that its message of "danger - stay away" was crystal clear and understood by all". Despite essentially being an arbitrary representation of radiation – three blocks fanning out from a circle is an extremely rudimentary representation of ionizing radioactive material – the trefoil was given more precise meaning through the iconic representation of the consequence and recommended response to radiation: death and running away. Dahlstrom (2007) quotes Carolyn MacKenzie, an IAEC radiation source specialist, who reported that when the IAEC tested the new symbol: "Initial interpretations of the symbols were that something bad could happen and caution was needed – but the source of that threat wasn't understood. Many thought it was a warning of AIDS, electricity, toxins or even a road hazard". The new radiation symbol may have a similar effect on people of the future who (for whatever reason) can only guess the meaning of the circular fan, yet are still able to surmise from the pictures that it represents something bad causing death, and therefore is best avoided.

Another symbol that should be included in any nuclear dump markings is the biohazard symbol (see Figure 1). In an interview with Cook (2001), Charles Baldwin, co-designer of the original symbol for Dow Chemical in 1966, explained how the symbol was to be "something that was memorable but meaningless, so we could educate people as to what it means". He explained how when testing the symbol, the symbol "got the fewest guesses" out of 24 symbols presented, yet one week later was best remembered. Similar to the trefoil radiation design, this testing bodes well for future recipients. The circular, curve-filled pattern is highly unique and recognizable, so it should attract attention and

be judged as significant. Its lack of meaning could also be an advantage in that it might be less likely to be easily confused with other (unintended) referents. The design team were aware that the difficult and complex concept of 'biological threat' could not be pictured and presented as an effective iconic symbol. They understood that the design would require an education – a process of learning to make the correct association. Similarly, people of the future seeing the symbol for the first time would need to gain that understanding. That is, the concept that what lies beneath is detrimental to life.

Figure 1. (Left to right). (1) The trefoil symbol for radiation; (2) A skull and crossbones hazard symbol; (3) The revised IAEC radiation warning symbol; (4) The biohazard symbol. All images open source.

Symbols can be powerful in that they can appear mysterious and significant – old alchemical and astrological symbols still have an air of importance despite science having moved on – yet any markings must be understood to have any practical value. The meaning of the radiation and biohazard symbols might be correctly realized in the distant future in four ways: (1) Proliferation – consistent and widespread use at different nuclear waste sites regardless of where and when constructed; (2) Association with text – understanding assisted through presentation with multiple written language forms; (3) Combination with pictographic signs – iconic information to explain associated and consequential dangers (e.g., the skull and crossbones); (4) Experience – (unfortunately), learning the meanings through actual exposure to radiation. Despite their symbolic nature, these signs can still serve an important function in nuclear site marking, especially for people who do not understand nuclear technology. The radiation and biohazard symbols may serve as tangible and unifying labels – points of reference onto which attention, awareness, knowledge and understanding of the concepts of radiation and biological threat can be focused and built upon. People who have no knowledge of radiation or a concept of biological hazard may coin terms for these symbols, and in doing so assimilate words for radiation and biohazard into their own language.

3.3 The skull and crossbones

Unlike the trefoil and biohazard signs, the skull and crossbones symbol does bear a striking and unambiguous resemblance to something in the real world. The exact origins of the symbol are

uncertain (possibly going back to ancient Rome and/or Egypt), yet the symbol of the skull and two crossed femur bones was used in Europe from the Middle Ages in cemetery and catacomb ornamentation to represent death. The sign is well known for having stood for sea piracy and has been used by various military forces from the times of mounted cavalry to modern warfare. In the interests of accident prevention, Theodore E Ladd MD wrote a letter to the editor of The Lancet in 1861 in which he proposed the use of the skull and crossbones sign to label poisons, offering the opinion that the label has "advantages over others, inasmuch as it serves to *warn those who cannot read*". The symbol (see Figure 2) is a classic skull and crossbones design (white on black background), with what he describes as "a grinning skull with two femurs crossed" and the inclusion of the word *POISON* underneath. The image has a history of being employed to signify poison (see Figure 2 for vintage cyanide warning labels), and now is used as an internationally recognized hazard symbol for poison and other lethal threats (also shown in Figure 2). The meaning of the skull and crossbones, or the Jolly Roger, has been softened and romanticized by modern popular culture, often being associated with theme park, cartoon, television, and movie versions of pirates. However, it can be argued that the image remains a very powerful warning sign. Perhaps even the most diehard fan of the *Pirates of the Caribbean* movie series (2003 to present) would be reluctant to drink, eat, touch or traverse anything with an official looking sign featuring the Jolly Roger. Even skulls by themselves, as described by Benford (2000), "have a powerful, universal horrific effect" (p. 78). Humans (overwhelmingly) prefer life over death, so the image of a human skull and leg bones appears to tap into the survival instinct. An individual is in no hurry to become the skeletal remains the striking symbol depicts.

Figure 2. (Left to right). (1) Dr Ladd's proposed poison warning label; (2) and (3) Vintage cyanide warning labels; (4) Modern skull and crossbones (GHS Hazard Pictograms). All images open source.

The skull and crossbones symbol features in various proposed applications for the WIPP site in the Sandia Report (from Team B) as shown in Figure 3. To make the symbol less ambiguous and more representative of poison, the artist and science journalist Jon Lomberg enclosed the symbol in a bottle shape. Despite the symbol's inclusion, however, the Sandia Report cautions against the use of symbols

in general. The report states how like languages the meanings of symbols can change over time (using the swastika as a good example) and furthermore predicts that people of the future will have created their own symbols. In the Permanent Markers Implementation Plan published eleven years later, there is no plan to use the skull and crossbones. Perhaps this exclusion is due to the ambiguity and wrong message (e.g., *here lies a cemetery*) the image of the human bones can present.

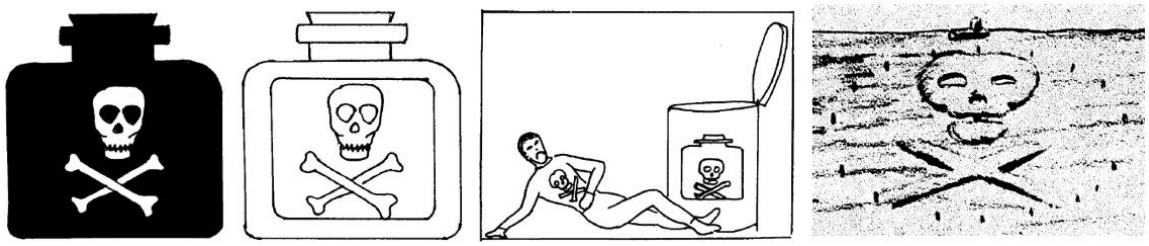

Figure 3. The skull and cross bones symbol featured in the Sandia Report. (From left to right). (1) and (2) Skull and crossbones symbol enclosed in a bottle to symbolize poison; (3) A pictogram indicating radiation poisoning; (4) Earthworks at ground level of the nuclear dump site in a skull and crossbones shape. Artwork by Jon Lomberg. Images used for educational purposes only.

However, a case can be made for the skull and crossbones. Included in the Sandia Report is a letter from scientist Carl Sagan (invited to participate in the Sandia Report yet unavailable) in which he expresses his strong support for making use of the symbol. In the letter, Sagan recognizes that the future for humanity is impossible to predict, yet a symbol is needed to transgress all possible changes; one that can be understood not only by the scientifically literate, but also by anyone who may stumble across the site. He wrote: “There is one such symbol. It is tried and true. It has been used transculturally for thousands of years, with unmistakable meaning”. Sagan believed that the skull and crossbones was “the key” for warning future generations, citing one commonality we should have with people of the distant future: “Human skeletal anatomy, we can be reasonably sure, will not recognizably change in the next few tens of thousands of years”. Certainly, the meaning of the skull and crossbones will alter across the ages, yet the same can be said of any symbol or the words of any language. The image’s capacity to evoke a strong emotional and visceral response in the observer cannot be ignored, as it can (and as it has done throughout history) give pause to even the most curious. And assuming that the intended audience has at least our basic anatomy, the symbol may well resound with humans well into the distant future.

3.4 Faces

Another common attribute humans will most likely share with their future selves is facial expression. Faces matter. When, for example, observing assorted artifacts from the Jōmon period of Japan (14,000 to 300 BCE), clay faces stand out. These facial forms, as shown in Figure 4, seem to facilitate a kind of human-to-human connection, despite the huge timeframes of separation involved. The observer tends to recognize and 'read' the expressions, something humans are hardwired to do. The way people use facial expressions, and the perception of their corresponding meanings, does appear to be universal. Ekman and Friesen (1971) demonstrated how different cultural groups associate the same emotions with the same facial expressions. Their research demonstrated that geographically isolated peoples with extremely limited contact with outsiders – they studied the Fore tribesmen of the New Guinea highlands – share the same basic understanding of what different facial expressions mean as do other (more connected) cultures. In line with Charles Darwin's belief that facial expressions are a product of evolutionary processes, as explained in *The Expression of the Emotions in Man and Animals* (1872), it is apparent that facial expressions are intrinsically and inextricably linked to what makes us human, as opposed to simply being the product of learned and acquired behavior. As well as being cross-cultural and global, facial expressions may also cross temporal boundaries. It might be the case that representations of basic human expressions will be 'read' in the same way thousands of years into the future.

Figure 4. Jōmon clay figures of faces on public display at the Hakodate City Museum (Hokkaido). Photographs by the author.

An indication of the power of facial depictions can be seen in the rapid rise of emoji. According to the Unicode Consortium (unicode.org), the governing body that oversees the codifying and standardization of text and emoji characters, 92% of people who communicate online use emoji. This

statistic indicates that pictorial forms are a normal means of communication for a significant part of the human population. The rise of emoji is rooted in the need for emotional expression, as emoji characters developed as a replacement for emoticons (textual representations of expressions, e.g., *smiling face* (^_^)). According to Danesi (2017), emoji "originated to represent facial expressions in written text through iconic visual images" (p. 62). Unsurprisingly, facial depictions dominate current emoji usage. According to Unicode.org, the most frequently used emoji are: (1) *face with tears of joy* 😂; (2) *red heart* ❤️; (3) *smiling face with heart eyes* 😍; (4) *rolling on the floor laughing* 🤣; (5) *smiling face with smiling eyes* 😊; (6) *folded hands* 🙏; (7) *two hearts* 💕; (8) *loudly crying face* 😭; (9) *face blowing a kiss* 😘; (10) *thumbs up* 👍. Of these ten, six emoji (60%) depict faces, representing basic expressions of happiness, sadness, and love. This preponderance for facial expressions, including expressive animal faces (e.g., *cat face with tears of joy* 😹) and inanimate objects (e.g., *sun with face* 🌞), continues down the frequency list. Ten emoji with faces (50%) appear in the 20 most used emoji, 25 (50%) in the top 50, 52 (52%) in the top 100, and 89 (44.5%) in the top 200. Once given the ability to do so through the development of information technology, humans displayed a natural propensity to communicate using the images of faces.

In the Permanent Markers Implementation Plan from 2004, two faces are featured on the proposed warning signs, as shown in Figure 5. (These images are an adaptation from similar marker images appearing in the Sandia Report, Team A, also shown in Figure 5). One image strongly resembles a face of horror from Edvard Munch's classic painting and print series *The Cry* and *The Scream*. This image has become iconic; the tortured face held in two hands is often recognized throughout the world as expressing, amongst other malaise like horror and despair, the torment of the human condition. However, future generations might not perceive the image in the same way, as despite (possibly) still being human, they will not have the same historical, cultural, and psychological 'baggage' of 21st century people. To them, the image could mean joy, elation, a proclamation, or enlightenment. The other image featured in the Permanent Markers report is a face showing a nauseated expression, which is an adaptation of an image by Eibl-Eibesfeldt (1989) reproduced in the Sandia Report. The nauseated face (although looking unpleasant) does not seem to signify a clear facial expression, as it looks angry or about to sneeze. These two image types appear quite open to interpretation, as the Munch face of horror could be seen as a troubled ghost or a spirt, and the nauseated/disgusted face could be taken as depicting wrath or fury. This may lead people of the year 7022 to believe that the faces represent angry and disturbed spirits – a sure sign they have stumbled across an ancient temple, or a burial site protected by very powerful yet long forgotten deities.

Figure 5. (Left to right). (1) Sandia Report nauseated face from Eibl-Eibesfeldt (1989); (2) Sandia report Munch-style face; (3) Permanent Markers Implementation Plan (PMIP) nauseated face; (4) PMIP Munch-style face. Images used for educational purposes only.

Any image (or any message for that matter) is open to misinterpretation. Modern depictions of faces used in electronic communication may however provide some indication as to what signs could be effective for nuclear site marking. Expressing happiness does not need to be complicated, as a simple line and two dots will suffice. This is most evident in the *Smiley* design, which originated in the 1960s and persists as an often used and easily recognizable cultural ideogram representing happiness. The emoji most resembling the smiley design would be *slightly smiling face* 🙂. Simple inversion of the mouth will result in sadness: *slightly frowning face* 🙁 or *frowning face* ☹. These simple designs might be sufficient to represent facial expressions at nuclear sites, as the basic emotion of sadness is clearly conveyed. Other designs could include *nauseated face* 🤢 to express sickness, and even *face vomiting* 🤮 to really put the point across. These simple images can effectively represent the feelings of sadness, sickness, and the act of vomiting, all of which are impactful and common to all people. Combined with the skull and crossbones, these images may at the very least give future observers the idea that something is wrong, even if the strange, long-forgotten writings of their ancestors are incomprehensible. Simple images also have an advantage in that their form is not intricate or complicated. If carved or engraved into a hard material such as granite, they might last longer than detailed designs, as they would be less susceptible to deterioration from weathering or vandalism. And so, their expressions might be better preserved to act as a warning. See Figure 6 for a cartouche of symbols and emoji that could be used to mark a nuclear waste repository.

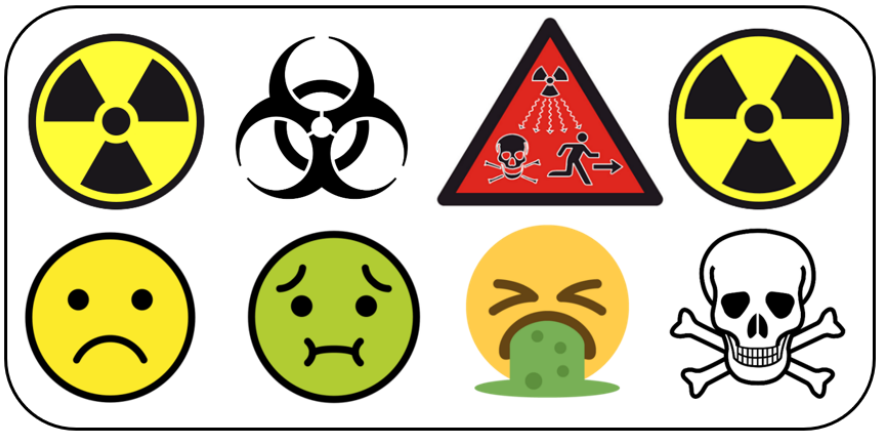

Figure 6. Combination of warning symbols and emoji for nuclear waste repository marking. All images open source.

4. Conclusion

Percy Bysshe Shelly's well-known sonnet *Ozymandias* ("*Look on my Works, ye Mighty, and despair!*") is frequently referred to when pondering the task of communicating a transgenerational nuclear warning. The Sandia Report (Team A) presents the work as an epigraph to their suggestions for the marking of the WIPP site. It could be said that this team of experts, knowing the enormity and perhaps even the futility of their task, chose to set a humble tone. Benford (2000) quotes Shelly after describing the Trinity Site in White Sands, New Mexico, where the first atomic weapon was tested in 1945. He tells of how the desert has reclaimed this area, as now there is very little (even radioactive) evidence that once there was a nuclear detonation at the site. This could be interpreted as Bedford saying that, just like the mighty 'King of Kings' Ozymandias, we do not command time; in fact, we are at time's disposal. The poetry also appears in Joyce (2020), with the point made that Ozymandias's statue was not a total failure, as we can still experience something of the artist who created the sculpture. Also, there is enough left of the statue for us to know and think of the great King, even though it might not be in the way His Majesty intended. Joyce, an archeologist, while recognizing the enormity of the nuclear message task, appears encouraged by the possibility that one day something left behind (something of ourselves) regardless of its intended purpose, may actually be found.

Effective communication with our far-distant future-selves may well be folly, yet the reality is high-level nuclear waste is extremely dangerous and deadly. Despite its serious drawbacks, nuclear energy is essentially carbon neutral. With the issue of global warming now at the forefront, and given the current inability of alternative energy sources to sufficiently replace fossil fuels, it seems

that nuclear waste (unfortunately) will continue to be produced well into the future. It would be tragic if people someday were to stumble across it, contract radiation poisoning, and then ask, “Why didn’t they at least try to tell us?”. Leaving behind our words and pictures to warn of our toxic garbage may not be the legacy we desire, yet like any other stored poison, it should be correctly labelled. Until a solution is reached, such as finding a means of reprocessing or somehow neutralizing the material, all we can do is bury the stuff with our heartfelt messages, and let time do the rest.

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