STRATEGIES FOR POST-CLOSURE LONG TERM INFORMATION MANAGEMENT

J.T. HOME
Horizon Nuclear Power,
Gloucester, United Kingdom
Email: Jacob.t.home@gmail.com

Abstract

The question of disposing of radioactive waste after it has been generated is an ongoing issue for the nuclear industry. Currently one of the preferred solutions is to encase the waste in containment structures and bury it deep underground until the radioactivity has decayed to safe levels. In order to prevent future human intrusion, the repositories containing the waste much be clearly marked in a way that understandable for future society.
The paper covers the previous research efforts to develop a suitable warning system for informing future generations of the hazard posed by radioactive waste interred in a deep geological repository (DGR) or geological disposal facility (GDF) and discusses the merits a variety of approaches as well as the ethical considerations of building such a system.

1. INTRODUCTION

In 1991 a group of scientist, anthropologists, architects and science-fiction writers gathered in the New Mexico desert at the request of the United States Department of Energy (DOE) to answer a single question: how best to protect buried radioactive waste from human interference for 10 000 years?

The paper provides context for this research, discusses the methods employed by the group and their eventual findings. The paper then presents a discussion on the ethical and regulatory considerations for warning marker systems. While much of prior research has focused on US facilities, the Yucca Mountain project and the WIPP in particular, the issues discussed here are relevant to all global deep geological radioactive waste repositories.

2. THE PROBLEM

One of the best known and problematic issues facing the nuclear industry (civil and defence) is how to dispose of the radioactive waste generated through various processes. It is estimated that the worldwide inventory of waste is currently 30 million m3 with approximately 81,000 m3 of waste produced in OECD countries each year [1] [2]. Many of the radioisotopes generated by nuclear processes have long half-lives, the most long lived being Iodine-129 with a half-life of over 15 million years as seen in Table 1[3]. In the shorter term radioisotopes including Ceasium-137 account for most of the radioactivity. Actinides such as Plutonium-239 and Plutonium-240 account for a large majority of the radioactivity after the shorter half-life isotopes have decayed. For timescales over 10,000 years isotopes such as Technetium-99 and Tin-126 continue to decay and produce the bulk of the radioactivity. These radioisotopes will continue to present a hazard to human health and the environment for many thousands of years after the projects and reactors that produced them have been decommissioned.

TABLE 1. HALF-LIVES OF ISOTOPES FOUND IN RADIOACTIVE WASTE

Element	T½ (Years)	Decay Mode
Caesium-137	30	γ, β-
Samarium-151	90	γ, β-
Americium-243	7370	α, γ
Plutonium-239	24 000	α, γ
Technetium-99	213 000	β-
Tin-126	230 000	γ, β-
Selenium-79	350 000	β-
Curium-247	1 560 000	α, γ
Caesium-135	2 300 000	β-
Iodine-129	15 700 000	γ, β-

3. THE SOLUTION

One of proposed solutions is to enclose the waste in vitrified form in large underground facilities known as geological deep repositories (DGR) or geological disposal facilities (GDF). These facilities will store the waste until the levels of radioactivity have decayed to acceptable levels. There are several GDF projects worldwide at various stages of development. In the US the Waste Isolation Pilot Plant in New Mexico has received HLW from the US nuclear weapons programme and the Morsleben and Schacht Asse II repositories in Germany store a mix of LLW and ILW. Further research work on deep geological disposal is being conducted in France, Australia, the UK, Belgium and Japan among others. In Finland the Onkalo facility is being constructed to receive used nuclear fuel in the form of HLW. The intention is to seal the repository in the 2120's after the final batch of waste is delivered [4].

These facilities will have to safely store their contents until the levels of radioactivity are considered acceptable. They are therefore built to last. In addition to vitrifying the waste the repositories are carefully selected based on local geology in order to lessen the probability that a future natural event such as an earthquake, erosion or ice age will damage the facility. The intention is, if left undisturbed, the GDF will withstand over 100 000 years of natural hazards to maintain its integrity. Most GDF designs share similarities of design: a series of tunnels or caverns containing the waste buried under hundreds of metres of rock [4–5]. See Fig. 1 for the layout of the Onkalo facility. After the final shipment of waste, the access tunnels would be filled in with non-porous clay. The physical site characteristics would be well understood, the site having been selected for its predictable geological characteristics. At the surface the entrance to the tunnels will be secured with physical barriers and active site controls such as alarms and security personnel.

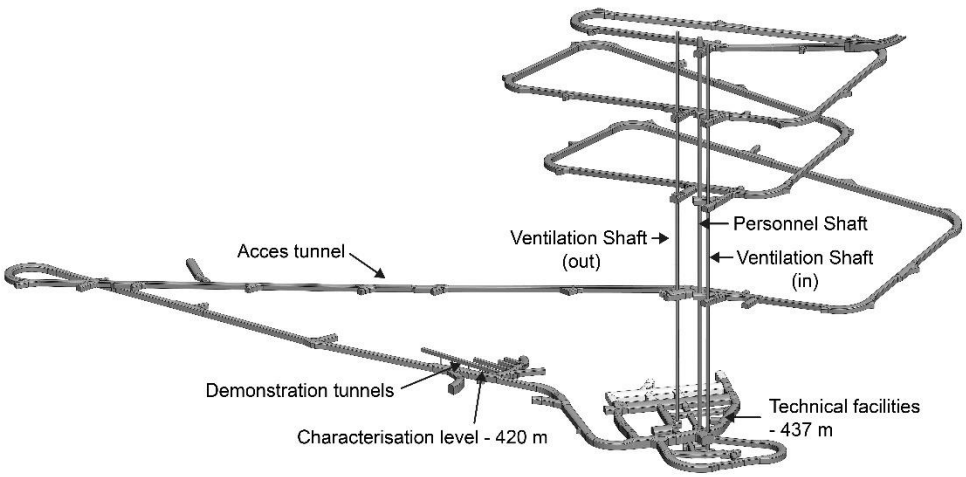

FIG. 1. Layout of the Onkalo deep geological repository [4].

4. THE PROBLEM WITH THE SOLUTION

However, less research has been done into the probability and effects of human interference with the buried waste. Either through accidental or malicious intent there is a significant probability of human interference with the GDF over its estimated 100 000-year lifetime. Due to the timescales involved it is very difficult to predict the state of the world at the end or even the mid-point of the GDF lifetime. The Future of Humanity [6] predicts that there is an up to 19% probability of human extinction by 2100 although predicting the future is notoriously difficult and the report itself cautions that "these results should be taken with a grain of salt". The report also shows probabilities for large scale deaths and disruption to human society. In the midst of these predicted societal upheavals it is very possible that institutional knowledge of the GDF and its contents will be lost. The loss does not necessarily have to happen overnight as civilisation collapses. There could also be a slow roll back of funding for expensive active protection measures as the central government looks to save

costs to deal with other important issues such as climate change. Information about the GDFs purpose, contents and even location could be misplaced on purpose or through decades of records mismanagement.

At this point the only barriers separating the waste from humanity will be passive physical barriers; the vitrified state of the waste, clay filled tunnels and border fences. While designed to isolate the waste from natural hazards these barriers will not withstand active human interference such as drilling. A concerted effort to mine for minerals around the GDF by a future society would have a significant probability (8.5% to 70% dependant on a number of envisioned types of future society) of impacting the integrity of the physical protection barriers [7]. It is even possible in this hypothetical future society that some information has been passed down regarding the caverns filled with mysterious treasure that the people who came before tried to hide. After all, if it isn't valuable why would past civilisations have tried to bury and hide it? There is historical precedent for this, the pharaohs of ancient Egypt initially designed their tombs to be grandiose pyramids with sealed passageways and buried secret rooms to deter curious thieves. Yet within 2000 years much of the tombs had been emptied by looters. 2000 years is only 2% of the period the GDF must keep the waste secure. The GDF must therefore be protected by a warning system which can endure and be understood by anyone who reads it in the future.

It was this problem that the US government tasked the eclectic group to solve in 1991. They were contacted as part of a study by Sandia National Laboratories, a US DOE contractor, to design a system of warning markers that could communicate the hazard of radioactive waste in a form that a future society could understand. In 1979 Congress had authorised the construction of a radioactive waste storage named the Waste Isolation Pilot Plant (WIPP) to be built near Carlsbad, New Mexico. The US Environmental Protection Agency requires that waste sites must include marker systems detailing hazards and information about the site [8] and therefore Sandia National Laboratories was tasked to develop the design for a marker system. Within the EPA Standard (191.14) the Assurance Requirements it states that:

"Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location."

5. REDUCING HUMAN INTRUSION

Sandia designated two panels of experts: the Markers Panel and the Futures Panel. The Futures Panel was to investigate and predict the possible paths that society might take in the next 10 000 years and the Markers Panel was to design a warning marker system that was capable of conveying information to any future society predicted by the Futures Panel. The paper concerns the efforts of the Marker Panel to develop the marker system. [9]. 10 000 years was chosen as the required time period as this was the regulatory requirement and it was considered that 100 000-year requirement was too onerous for an initial study into the markers effectiveness.

The Markers Panel was split into Team A and Team B to ensure a range of options would be generated and highlight areas where the two teams arrived at the same design or disagreed on the effectiveness of other designs. These comparisons would form the basis of further investigative work. The remit given to both teams was as follows [9]:

- The time frame for the Panel to consider must be 10 000 years because of the requirement that performance assessments cover a period of 10 000 years after closure of the disposal facility;
- The markers must be developed with a goal of being able to convey information to any future society (considering the broad spectrum of possible future societies developed by the Futures Panel [8]);
- To communicate the dangers associated with the waste buried at the WIPP.

The two teams presented their findings to Sandia National in the 1992 report "Expert judgement on inadvertent human intrusion into waste isolation pilot plant" [9]. Both teams assumed that there is potential for much change over the next 100 000 years and it is possible that knowledge of the GDF and what it contains may be lost. The languages spoken are also likely to change significantly so the messages cannot be written only in English, or any other language currently in use. In order to convey the content of the warning the message must be designed to communicate at a level beyond written alphabetical language.

If the message is to remain during the lifetime of the GDF it must be comprised of erosion resistant materials or located underground to preserve it. The material should not be considered a valuable or useful resource in case it is looted or repurposed for building material. The message must be capable of conveying 3 parts:

- That there is a message at all;
- That hazardous substances are located in this area;
- Information about the hazard.

Therefore, there is balance between the simplicity of the message which would allow it to be understood more easily and the complexity of the information contained in it which is required to describe the nuclear waste. A more complex message may have to rely on scientific prerequisites which may not exist when the message is read. Conversely, a simple message may rely too much on contextual cues or be unable to convey all the necessary information. While language is useful for transmitting specific information, it is heavily dependent on specific cultural context and knowledge so an ideal system would make use of both language and signs. The context for the reader of the message is unlikely to be the same as the designer.

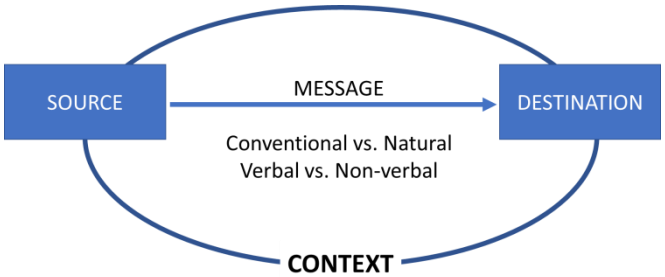

FIG. 2. Types of messages in relation to context [10].

As shown in Fig. 2 the context in which the message is received will affect its interpretation. As context changes rapidly, even daily the two teams examined methods of communication that were less reliant on context than language. Both teams recommended the use of symbols or signs as an effective method of communication. There a number of ways to classify signs dependant on their reliance on context and the complexity of information they can convey; symbolic, indexical or iconic. Fig. 3 shows examples of the three classes of signs and how the signifier message is related to the signified information. However, some signs are also heavily reliant on cultural context. Generally, a sign with significant cultural attachments (a symbol) is capable of conveying a lot more information than an iconic sign which does not rely on contextual cues. Iconic signs are therefore more likely to remain understandable for longer but are limited in the complexity of information they can convey.

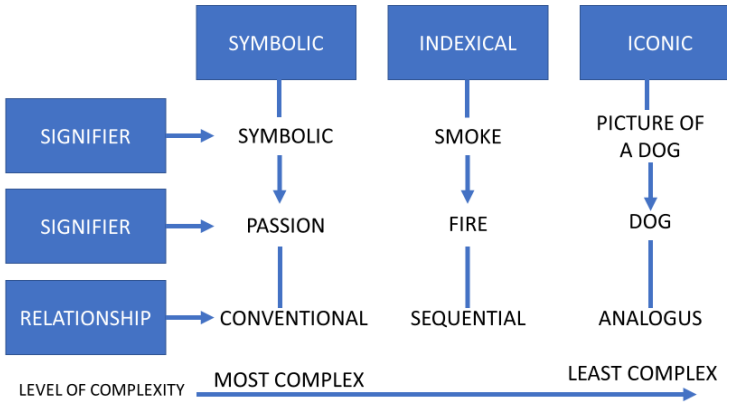

FIG. 3. Classes of signs and relationship between the signifier message and the signified information [10].

Iconic messages do not rely on contextual cues but can be limited in the information they can carry. They have a physical resemblance to the signified meaning of the message. The iconic message shown in Fig. 4 is a simple pictograph created from a previous study by MF Kaplan to design a warning message for the Hanford Site in Washington which stores transuranic waste. The diagram was meant to show the location of buried radioactive waste.

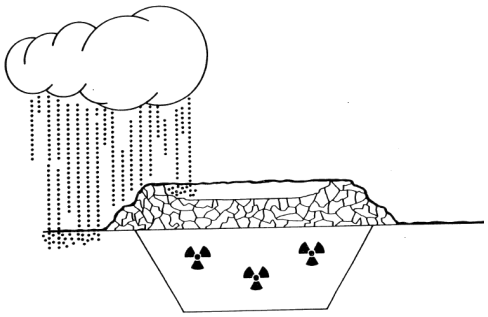

FIG. 4. Example of an iconic message showing the location of buried material [11].

An indexical message can show the connection between the physical form of the message and its meaning e.g. a picture of radioactive waste and its effect on the human body. Fig. 5 shows one of the Sandia teams proposed series that would be read vertically downwards showing the effect of radiation on the human body.

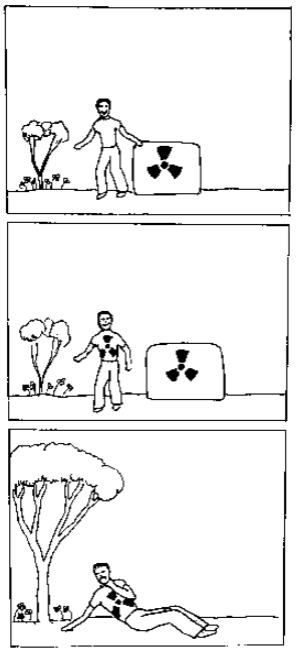

FIG. 5. Example of an indexical message showing the effect of radiation on the human body [9].

Symbolic messages are capable of carrying a lot of information but do not resemble the signifier that is being represented. They are learnt culturally and rely heavily on context. Symbols are widespread in our culture from the Golden Arches to the hammer and sickle to the skull and crossbones. Each of these symbols convey an array of meanings depending on the reader and where it is seen. However, these are relatively recent meanings in comparison to the expected lifetime of the GDF. The skull and crossbones in particular has had a variety of meanings from its origins in medieval paintings to piracy to denoting poisonous substances. It is very likely that well known symbols like these will continue to evolve over the centuries. Therefore, they cannot be relied upon to accurately convey information to future society.

FIG. 6. The skull and crossbones/Jolly Roger. An example of a symbol with changing meaning.

One of the other proposals by the teams was the use of human faces and expressions to convey information. While many symbols and signs will lose their effectiveness over time the human expressions of pain, fear and disgust are likely to remain effective ways to communicate danger and hazards. There was disagreement among some team members on the level of emotional weight the message should carry. They believed that even if future humans read and understood the information in message they may choose to ignore it unless there was an emotional component to the message as well. They recommended that any written message include a stark warning to the reader [9]:

Sending this message was important to us. We considered ourselves to be a powerful culture.
This place is not a place of honor…no highly esteemed deed is commemorated here… nothing valued is here. What is here is dangerous and repulsive to us. This message is a warning about danger.

The final recommendations from the two teams were to create large earthen berms to designate the area around the GDF which would contain monoliths inscribed with the above message in the 6 languages of the UN as well as the local Navajo language. The marker system would have several different components to ensure redundancy and 'defence-in-depth'. These included buried message discs or capsules made from durable but worthless materials such as clay, stone markers in the sealed tunnels, a world map of other disposal sites and multiple buried information chambers. These chambers would include information about the marker system and GDF in several levels of complexity. The two teams differed on the opinion of whether to direct visitors focus to the information with team A advocating no sense of centre ("nothing is here") and team B recommending that visitors be directed to the centre to provide information about the site [9].

6. HUMAN INTERFERENCE TASK FORCE

The Markers Panel was not the first attempt to design a warning marker system for a nuclear waste repository. In 1981 the US government recruited a variety of experts to form the Human Interference Task Force (HITF) for the purpose of investigating how to reduce the likelihood of humans intruding on the Yucca Mountain nuclear waste repository. The HITF generated several proposals for how a message might be communicated:

- Representative pictograms on stone markers or monuments around the repository;
- A series of clearly artificial earth berms surrounding a central vault which contains relevant information;
- Hostile architecture" around the site to deter intruders;
- A small, sheltered group of scientists who maintain knowledge of the repository regardless of events in the wider world; an "atomic priesthood";
- Genetically engineered animals and plants such as cats or cacti that alter colour in the presence of high radiation levels to alert local people to the threat of waste leaking;
- Security in obscurity: Make the surface of the site as plain as possible to avoid future generations investigating the site [12].

7. ETHICAL CONSIDERATIONS

While creating a permanent marker system at the WIPP was required by regulations those standards do not apply to other countries building GDFs. Some countries will not have the same requirements to warn future generations and it brings another factor into consideration. The costs involved with the design, construction and maintenance of any maker system robust enough to endure for 10 000 years are likely to be substantial. A recent paper by Van Luik et al [13] noted that the cost-benefit calculation for how many lives a marker system would save would be a very difficult enterprise. Even with the input of the Futures Panel the make up of any future society is problematic to estimate. For every prediction of societal collapse there is another where technological advance continues and radioactive waste is no longer a significant hazard or can be repurposed. In this instance the marker system would be an expensive and superfluous landmark. Hora et al [7] predicted that the worst-case intrusion scenario was from resource miners with 1800-level drilling technology and no knowledge of radioactive hazards. Even in this scenario the likelihood of drilling equipment damaging the waste drums and the estimated radiological release was low [7]. There is a reasonable argument to be made that the funding required to construct the marker system would be better used investing in local infrastructure around the GDF such as roads, hospitals and schools. This will not only improve the local stakeholders opinions on hosting a GDF in their area but may also contribute a stabilising effect to the local society to help it better resist any events that would cause knowledge of the GDF to be lost. Local communities would understandably be unhappy if it appears that future, unnamed people are being afforded more protection then them. Therefore, if there is no regulatory requirement for the warning marker system any GDF project must seriously consider the costs and benefits of having such as system.

8. CONCLUSION

Currently the WIPP site still has active control measures and a final decision has not been reached regarding the form of the marker system. Since 1991 assessment no further large-scale studies have been performed to design a system capable of communicating across 10 000 years. As nuclear reactors worldwide continue to operate and be decommissioned the quantity of nuclear waste will continue to grow. Assuming there is not technological solution found the GDF remains the best option for managing this waste. In the US there is a regulatory requirement for a marker system to warn future generations up to 10 000 years in the future of the hazard. However, it is important to consider the contemporary cost in relation to the potential future benefits when constructing the warning marker system. What is required now is further development of the design and analysis of the most cost-effective marker system taking into account future generations.

ACKNOWLEDGEMENTS

The author would like to thank Horizon Nuclear Power for providing the opportunity to present at this conference and Daniel Galson for providing expert information on reducing the likelihood of human interference to the repository.

REFERENCES

[1] International Atomic Energy Agency, Net-enabled radioactive waste management database, (2016)
[2] Nuclear Energy Agency, Radioactive waste in perspective, (2010).
[3] Baum E. Nuclides and Isotopes: Chart of the Nuclides, 17th Edition, KAPL, Schenectadry, NY (2009).
[4] POSIVA ONKALO Final Disposal Timeline, http://www.posiva.fi/en/final_disposal/general_time_schedule_for_final_disposal#.XHAj92xLFi4
[5] Sandia Laboratories, WIPP Conceptual Design Report, Springfield, Virginia, US, (1977).
[6] SANDBERG, A. & BOSTROM, N. (2008): "Global Catastrophic Risks Survey", Technical Report #2008-1, Future of Humanity Institute, Oxford University, (2008).
[7] HORA, S., Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant, Sandia National Laboratories, New Mexico, US, (1991).

[8] US Environmental Protection Agency, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR Part 191; EPA, 1985).
[9] TRAUTH, K., Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant, Sandia National Laboratories, New Mexico, US, (1991).
[10] SEBEOK, T., Pandora's Box: How and Why to Communicate 10,000 Years into the Future https://www.mat.ucsb.edu/g.legrady/academic/courses/01sp200a/students/enricaLovaglio/pandora/Pandora.html
[11] KAPLAN, M.F., Message development for surface markers at the Hanford Radwaste Disposal sites US DOE, Washington, DC (1984).
[12] HITF Reducing the likelihood of future human activities that could affect geologic high-level waste repositories HITF, Columbus, OH (1984).
[13] VAN LUIK, A., Ethical Considerations for Developing Repository Warning Messages to the Future, Carlsbad, New Mexico, US, (2016).