Markers and Beyond: Categorizing Human Intrusion Situations to be Addressed in Sub-surface Marking Concepts – 16378

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ABSTRACT

Concepts for the use of markers in the post-closure phase of deep geological repositories (DGRs), are often designed to prevent “inadvertent” human intrusion (HI), while it is common practice not to protect against deliberate intrusion (i.e. “advertent” HI). In the literature, inadvertent HI prevention studies usually combine future human activity scenarios with the assumption that all memory of the DGR has been lost, and analyze what can be done now to make the possible future intruder “aware” of the associated risks. In this paper, we show that the classical “advertent”/“inadvertent” duality classification of HI, as used in the performance assessment context, is not ideal to characterize potential HI situations in the RK&M preservation context. We suggest that the relevant HI categories are expanded and refined to “un/necessary HI”, “un/intentional HI” and “un/friendly HI”. Along with refining the taxonomy of HI that way, we refine the assumption relating to the loss of memory of the DGR. Different HI situations are likely to arise in different “loss-of-memory situations”. We analyze the resulting 5 classes of the proposed HI classification and find that 2 hold the classic “advertent” and “inadvertent” HI scenarios while 3 are “new”. We apply the proposed categories to sub-surface marking concepts from the literature and suggest that, in particular, sub-surface marking concepts would benefit from this new approach to HI and loss-of-memory categorization.

INTRODUCTION

Concepts for the use of markers in the post-closure phase of deep geological repositories for radioactive waste (DGRs), are often designed to prevent “inadvertent” human intrusion (HI). More than other measures for the preservation of records, knowledge and memory across generations (RK&M), markers are usually considered as dedicated means to (exclusively) raise awareness of the presence and possibly also of the danger of the DGR. The OECD/NEA RK&M initiative on the Preservation of Records, Knowledge and Memory across Generations (“RK&M initiative”) discussed the topic of markers repeatedly and its main observations as formulated during the first phase of the RK&M initiative (2011–2014) were presented at WM2014 [1]. In the second phase of the RK&M initiative (2014–2017), it is intended to analyze and conceptualize marking strategies in order to be able to place and integrate them within a systemic approach for RK&M preservation.

In this paper, we recall that marking strategies can be more refined than conveying a “don’t drill here, it’s dangerous” message to the unaware driller and we propose to

categorize marking concepts according to new HI categories proposed in this paper to facilitate conceptualization and assessment of such strategies. The only previous existing HI categorization of "inadvertent" vs. "deliberate" (sometimes named "advertent" or "intentional"), which comes from, and is useful for, performance assessment of DGRs, is not optimal for this purpose, as will be shown below.

The categorization proposed in this paper can be applied to above-ground markers and to sub-surface markers alike, but it may be indeed most useful for sub-surface marking concepts. The term "marker" is to be understood as defined in the RK&M initiative glossary [2]: "A long-lasting object that indicates an area of influence, power or danger. It is placed strategically at or near the site for immediate recognition or for discovery at a later time."[1]

"INADVERTENT" AND "DELIBERATE" HUMAN INTRUSION

It is commonly agreed, e.g. by the International Commission on Radiological Protection (ICRP) [3, 4] and the International Atomic Energy Agency (IAEA) [5, 6], that the issue of possible human intrusion (HI) in the post-closure phase of a deep geological repository (DGR) for radioactive waste needs to be considered in the safety case. In the current HIDRA project (Human Intrusion in the context of Disposal of Radioactive Waste) of the IAEA [7], this is further investigated and explicated to a high level of detail. Underlying principles in the current international requirements and recommendations with respect to future human actions are summarized in [7] (with reference to [3, 5 and 8]). One of those is that "some form of inadvertent intrusion (future human actions) needs to be considered to address consequences in the case of a loss of institutional control (notably, there is also agreement that advertent intrusion, knowingly disrupting a disposal facility, is not considered)."

A number of sources specify what is meant by "advertent" intrusion in this context, namely, "[actions from] a person who is aware of the nature of the facility" [4], "human actions with knowledge of the disposal site and the hazardous waste" [9], "[actions at a time when] society is still aware of the repository and its hazard potential" [10], or "[actions to] knowingly disrupting a disposal facility" [7]. So according to international guidance, this kind of human actions should not be considered in the safety case of a DGR.

The other side, "inadvertent" human intrusion, which needs to be considered in the safety case, is specified as "[HI where] the awareness of the repository and the knowledge of the hazard potential of the waste emplaced have been lost" [10], or "scenarios where any actions that disrupt the safety functions of the facility are undertaken without knowledge of the hazard presented by the disposal facility" [7].

[1] The RK&M initiative glossary complements the definition of "marker" by the following "Commentary: In the RK&M dual track strategy, a marker is an object meant to reach out to future generations in the medium to long term. Any marker is conceived to be immobile (i.e., in permanent association with a site), robust, in order to maximize survivability on its own, and to provide messages that are likely to be understandable across generations."

While the provided specifications of “inadvertent” and “deliberate” HI sound similar and clear at first, they differ in detail and remain unspecific with respect to certain kinds of HI situations. Unambiguously, a situation where an intruder is aware of the nature of the facility and is aware of intruding into and disrupting the facility and society is still aware of the repository and its hazard potential and keeps oversight over the facility—such a situation is regarded as “deliberate” HI. Also unambiguously, a situation where an intruder is unaware of the nature of the facility and is unaware of intruding into the facility and the awareness of the repository and the knowledge of the hazard potential of the waste emplaced have been lost (completely, i.e. by society at large and any group of individuals)—such a situation is regarded as “inadvertent” HI. But what about a situation where the awareness of the repository has not been lost completely, but the intruder, however, is unaware of intruding into the facility? Or a situation where society, represented by the intruder, is deliberately intruding into the facility but without knowledge of the hazard?

According to the specifications cited above, these situations bear aspects of both, “inadvertent” and “advertent” HI. For performance assessment of DGRs these situations are usually not considered as they do not clearly belong to the “inadvertent” HI group. And in the performance assessment context, it is not necessary to specify whether these situations are regarded as full members of the “deliberate” HI group or only as not belonging to the “inadvertent” HI group. For RK&M preservation strategies and particularly for marking concepts, however, it makes a difference what is the background to the potential intruder situation (independently from the technical tools to intrude), so acknowledging that no category really fits is not sufficient. And, as we will see below, a number of marking concepts do indeed cater for these situations sketched above. Therefore, as the taxonomy from the performance assessment context is not applicable for these situations a new classification scheme for HI situations in the context of RK&M preservation and marking is needed.

Some authors have mentioned before that the prevailing advertent/inadvertent classification is missing some allegedly important HI scenarios: Raimbault & Valentin-Ranc wrote as early as 1993: “Usually, only inadvertent intrusion is taken into account. It is however difficult to draw a line between inadvertent and intentional intrusion: how to classify archaeology, or an intrusion where people would know that a manmade structure is present underground but would not be aware of the content of the repository? To answer this question, we propose to distinguish three different types of intrusion: inadvertent intrusion, archaeology or curiosity, and pure intentional intrusion where actors are cognizant of the risks…”[11]. Ten years later, Chapman & McCombie observed (despite quoting [11] on a different matter): “Possible future intrusions have usually been categorised as: Intentional, in full knowledge of the presence of the repository and its probable contents; [and:] Inadvertent, accidental intrusion resulting from a loss of knowledge about the presence of the repository. […] There is a third possible category of intrusion, which has not been considered before: Intentional intrusion out of curiosity, when knowledge of the consequences has been lost. This is called ‘naive intrusion’ in this book, and is discussed further below.”[12]

Apparently, the advertent/inadvertent classification has been around in pretty much unchanged form for over a quarter of a century, and it has been labelled as “widely accepted in the waste management community”[12] repeatedly. At the same time, it has been discovered - also repeatedly - that this classification is somewhat fuzzy and is somehow missing out important HI scenarios in between the two end points. However, this discovery not only failed to become “widely accepted”, it even fell into oblivion so that it could be “discovered” again years later. We esteem [11] and [12] for providing important contributions to the HI classification analysis, but they fall short of providing suggestions for a better classification system. Adding one more scenario, like the “naive scenario”, does not deliver a complete system. It may close the discovered gap, but as soon as the next unorthodox scenario is “discovered”, the system would fail again. Instead of starting from an arbitrary list of scenarios, we suggest to start from a list of unambiguous criteria which guarantee to produce a number of disjunctive classes and a classification scheme that can be applied to any potential HI situation.

ASSUMPTIONS ABOUT TECHNOLOGY AND SOCIETAL STRUCTURE

Before introducing the new classification scheme in the next section, it is useful to state the first principles underlying the assumptions about those possible future human actions which we consider as relevant in this marking strategy context.

We adhere to the principle of assuming today’s technical capabilities when considering future human actions. This assumption is meant to avoid arbitrary, science fiction type speculations. In this sense, however, we do not limit our assumption to technical means of literally “today”, but, roughly speaking, to the technical means that have been available up to today including technical means currently under development (i.e. those which are about certainly available soon) and including technical means that have been used, but are not in practice today. By doing so, we are avoiding completely arbitrary speculations on the one hand, while on the other hand, we are taking the fact that societally favored technologies are not constant in time into consideration for our analysis. This is logical, as a strict assumption that today’s nuclear practices and technology remain in place at the DGR site forever would render all medium and long-term RK&M preservation efforts unnecessary.

We adhere to the same principle with respect to assumptions about the nature of future society. We avoid arbitrary, futuristic speculations by disregarding utopian societies, but we do not limit our assumption to the present-day social structure at the DGR site. Again, acknowledging that social structures will change in the long term is in line with current long-term radioactive waste management thinking.

In summary, we fix our assumptions with respect to the prospected future technology and societal structure to be (i) non-futuristic but (ii) flexible to the degree of the technical and societal revolutions that we see today.

HUMAN INTRUSION CATEGORIES AND THE LOSS-OF-MEMORY STATUS

We propose a classification of HI situations in the context of RK&M preservation made up of three criteria: necessity, intentionality and friendliness. The three pairs of attributes (also "categories") of the classification scheme are thus "un/necessary", "un/intentional", and "un/friendly". Any HI situation is classified by the triple of attributes (one of each pair) that is appropriate to describe it. Table 1 schematizes the classification scheme and the resulting 8 different classes (in column "Combination"). Explanations of the categories with examples follow below.

TABLE 1. Proposed Human Intrusion Taxonomy

Necessary	Intentional	Friendly	Combination
Yes	Yes	Yes	YYY
		No	YYN
	No	Yes	YNY
		No	YNN
No	Yes	Yes	NYY
		No	NYN
	No	Yes	NNY
		No	NNN

Each pair of attributes is meant to be disjunctive, i.e. any HI situation should be classified as either "necessary" or "unnecessary", either "intentional" or "unintentional", and either "friendly" or "unfriendly". To achieve this, the criteria need to be as well defined as possible, and we propose to understand them in the following way:

1. The first pair of attributes, "un/necessary", is to be understood "for safety". Here, "for safety" should be interpreted in the same way as, for example, we would consider now to retrieve the wastes if it was necessary "for (radiotoxic) safety".
    - Commentary: Defining it this way, "un/necessary" cannot be misunderstood as "un/necessary, because it was / was not decided so by society". For example, if society decided to retrieve some nuclear material from the repository for economic reasons, the associated HI situation would still be classified "unnecessary", no matter how large the need of the society was. Only if the HI situation is deemed necessary for safety or long-term safety reasons, it would be classified here as "necessary".
2. The second pair of attributes, "un/intentional", refers specifically to the breaking of the relevant barrier, i.e. to the main "disruption" event of the HI situation; whether this takes place intentionally or unintentionally.
    - Commentary: It does not imply an underlying reason for this, i.e. loss of memory may or may not be involved, and therefore, this category pair is similar but not identical to the "in/advertent" classification used so far.
3. The third pair of attributes is "un/friendly". We define a HI situation as "unfriendly" if negative consequences (usually radiotoxic ones) to society living

at the site and/or to third parties are intended by the intruder, or if negative consequences to society at the site are ignored by the intruder in combination with the intruder being aware that the intrusion is against the will of that society.

- Commentary: With this definition, clearly “unfriendly” is what may be called the “safeguards scenario”, where nuclear material is abstracted in order to cause negative consequences to society at the site or to some society elsewhere. Also clearly “unfriendly” is a situation where valuable materials from the DGR are stolen against the will of the society at the site. If the same recovery of valuables was wanted by society, it would be a “friendly” (though not “necessary”) act. However, it is unfortunately not always possible to apply this “un/friendly” category unambiguously. We find that some situations remain somewhat in between—they could be “friendly” or “unfriendly”—namely those, for which the decision depends on the motives of the intruder, and assessing them as “good” or “bad” is unavoidably fuzzy. Basically it comes down to the same fuzziness as the “friendly or unfriendly” fuzziness that one knows from everyday life, which, however, does not mean that this category is useless.

Besides the HI categories captured in our taxonomy table above, there is another characteristic elements of potential HI situations, namely the status of prevalent RK&M and—as brought forward by the ICRP—the presence or absence of oversight.[4]

By definition, there is no oversight category between “oversight” and “no oversight”. This does not change the fact, however, that the period of oversight may gradually slip into the period of no oversight and that in the far future all memory of the DGR may be lost. Having started from a full knowledge and detailed memory situation at the start of the DGR lifetime, the “loss-of-memory situation” or the “loss-of-memory status” thus changes from “full memory” to “no memory” over the medium and long term. This transition may not be one-dimension (which is why we prefer not to call it “loss-of-memory level”). Memory, “the awareness of events, people, places and levels of knowledge in the past” [2], takes place in individual people’s minds, but we are referring here to memory at large, which should be understood as memory of society, stakeholder (groups), and individuals. The exact path and timing of the loss-of-memory status from “full memory” to “no memory” may be unpredictable, but some characteristic loss-of-memory situations can nevertheless be identified.

The two end points “full memory” and “no memory” can be identified with the baseline conditions of the above mentioned HI situations usually invoked in the literature:

A. Deliberate HI with full knowledge (i.e. all necessary information available) and memory of all involved players on the one side, and
B. inadvertent HI with no memory left at all on the other side.

Between these two poles, we discretionarily depict more loss-of-memory situations as follows (these situations are distinguished not only by the level of actual memory, but also by the level of RK&M and by the degree of oversight).

- Society and/or some groups still have some memory and knowledge, but other groups (including the potential intruder) are unaware of the DGR.
- Society (including the potential intruder) is aware of something extraordinary existing deep underground, but they are not aware of the hazard.
- Memory is still quite detailed, records, however, have been lost so that, e.g. knowledge of the exact position of the DGR is unavailable.
- RK&M are available, but they are not trusted anymore.
- Society at large has lost awareness of the repository, but some individuals have sufficient awareness to take action (e. g., search for the facility).

This list is not meant to be exhaustive. Rather, it is meant to show that there are several loss-of-memory situations, all in between the two poles of “full memory” and “no memory” and all qualitatively different from each other. They may occur in the transition phase between strong indirect oversight and no oversight, or in the phase of no oversight.

The likelihood of any particular loss-of-memory situation sketched above to happen cannot reliably be quantified. However, this alone should be no reason to leave them unaccounted for. The likelihood of the “no memory” situation to happen within a certain timeframe cannot be quantified either, yet still it is common practice to take this situation into account, namely as baseline for the inadvertent HI considerations as described in international recommendations.

For potential HI situations, particularly when considering marking strategies to prevent them, the particular loss-of-memory situation is crucial. For example, it would make a difference whether memory of the exact position and geometry of a specific DGR, or of the entire concept of DGRs is lost.

Table 2 shows the classes of the proposed HI taxonomy (cf. Table 1) in connection with the “state of memory”. The “state of memory” “partial” refers to any RK&M situation in between the two poles “full” and “none” (cf. memory state “A.” and “B.” above) like any of the bullet point list above. The example scenarios are not necessarily exhaustive, i.e. they are typical for their class but they may not span their whole class.

TABLE 2. Human Intrusion Scenarios

Combi-nation	State of Memory[a]			Example Scenario
	Full	Partial	None	
YYY	✓✓[a]	✓	x	Recovery for safety reasons
YYN	Disallowed			Cannot combine “necessary” with “unfriendly”
YNY	✓	✓✓	x	Human error—actual intrusion by mistake
YNN	Disallowed			Cannot combine “necessary” or “unintentional” with “unfriendly”
NYY	✓	✓✓	✓	Recovery for economic reasons (classic advertent) or accredited archaeological exploration
NYN	✓✓	✓	x	Malicious purpose
NNY	x	✓✓	✓✓	Prospective drilling (classic inadvertent)
NNN	Disallowed			Cannot combine “unintentional” with “unfriendly”

a Key:
“✓✓” More likely with this state of memory
“✓” Possible with this state of memory
“x” Unlikely or impossible with this state of memory

In summary, we propose to apply the categories “un/necessary”, “un/intentional” and “un/friendly” to conceptualize HI scenarios and to illuminate the loss-of-memory status—i.e. the existence/availability of RK&M in/for society, groups and individuals—assumed.

SUB-SURFACE MARKING CONCEPTS

A number of sub-surface marking ideas were proposed in the early 1990’s, as reviewed recently in [13]. These include acoustic warning signals, large magnets, radiation markers, unnatural material in disposal tunnels, armoring against borehole penetration, and chemical marker in backfill to color drilling mud (see references in [13]). The latest marker planning for the WIPP [14] includes, besides large surface markers of stone monoliths and “the Berm” itself: Large strontium ferrite permanent magnets (~1 m cuboids) buried in the Berm “to alert future populations that something out of the ordinary is present at this site when aerial or other surveys are performed”, radar reflectors (~1 m trihedrals) buried in the Berm “to provide another mechanism for alerting individuals in the future that something out of the ordinary is present at this site”, and large numbers of small sub-surface markers (~20 cm message disks carrying a warning of danger message) buried within the Berm, within the shaft seals, and throughout the repository footprint at a depth of 1 to 3 m to provide “a reasonable likelihood that at least some of the markers will be discovered” by the potential drilling site preparation crew.

It should be mentioned that the maturity of these proposals differs considerably. However, the potential HI scenarios behind these proposals are similar and can be grouped into 2 main situations:

1. An unaware drilling crew (e.g. exploration drilling) shall be warned (or physically hampered in the case of the armoring) that it is about to perform

"unnecessary", "unintentional" intrusion. The loss-of-memory status of the potential intruder is on "complete loss". Whether or not society, or some institution, still knows about the existence and nature of the repository is unspecified and not important. However, "unfriendly" intrusion, i.e. intrusion knowingly against the will of this institution, is not addressed in this scenario (but see a.).

   a. One variant of this base scenario is—in case of the armoring—that the drilling crew is not only warned, but also physically hampered to drill into the DGR. As a combination of marker and barrier, armoring can principally be considered as a strong (hard to miss) marker and barrier to prevent "unnecessary", "unintentional", "friendly" HI, but it can also be considered for its function to hamper "intentional", "unfriendly" HI. However, in this latter case, it fulfills this function rather as a barrier than as a marker.
   b. Another variant of the base scenario is—if the markers, e.g. radiation markers, are distributed locally on the DGR horizon around the disposal cells—a scenario where not only the classical drilling crew is targeted, but more generally some unspecified exploration expedition looking attentively for something in the deep underground. Then the marking may serve the purpose to help locate the source on the detailed scale. In this case, the underlying loss-of-memory status is not on the "total loss" level, but rather some knowledge of the nature or of the presence of the DGR needs to be assumed still. And in this case, both the "unnecessary", "unintentional" HI (as in the base scenario) and also the "necessary", "intentional" HI may be targeted by the marking concept.

2. Independently from the drilling situation, society, rather than some interested stakeholder group, conducts "aerial or other surveys" and learns that "something out of the ordinary is present at this site". Such marking concepts—as in this case the permanent magnets and the radar reflectors planned for the WIPP—may fit particularly well to situations, where society is willing to learn more about the "extraordinary" nature and content of the site. It makes sense to provide this society with the necessary information so that it can learn more without disturbing the DGR, which the WIPP marking concept indeed foresees by locally connecting the signal of the markers with a "buried storage room" in the Berm, which is supposed to hold this information available for a long enough period. If the aerial survey mentioned is interpreted as a prospecting survey for a drilling campaign, then the potential HI situation is the same as in the first base scenario, i.e. an "unnecessary", "unintentional" HI situation. But if the aerial survey is interpreted as some other, not drilling-connected survey, then there is no concrete HI situation involved and the sub-surface markers serve the purpose of bare re-learning or restoring oversight.

Finally we apply the new categories to the classical "advertent" and "inadvertent" HI scenarios as depicted in the literature. The former one is an "unnecessary", "intentional", "friendly" situation at a time of "full memory". The latter one is an "unnecessary", "unintentional", "friendly" situation at a time of "no memory".

DISCUSSION

Out of the 8 classes of our classification scheme, 3 are impossible (see Table 2), since unfriendly implies by definition intentional and unnecessary. Of the remaining 5, two classes, NYY and NNY, hold (amongst others) the classic “advertent” and “inadvertent” HI scenarios. This leaves us with 3 “new” classes, where any scenario belonging to these is neither considered (like classic inadvertent) nor explicitly considered to remain unconsidered (like classic advertent) in the Safety Case HI considerations.

To the 3 new classes individually:

- YYY—Necessary/Intentional/Friendly: This class holds the classic scenario in retrievability thinking. It is interesting that this scenario is regarded as important enough to revoke full retrievability mechanisms (in some countries)—to remain in place in the first few centuries, but receives zero consideration so far for the period after the first few centuries.
- NYN—Unnecessary/Intentional/Unfriendly: This class holds the classic safeguards scenario. It is probably not an issue for marking programs in the positive sense, i.e. there may be no marking strategies available to prevent unfriendly HI, but from the safeguards point of view it must be considered. Also, this class may provide arguments against the use of markers; therefore it should be taken into account for sincerely balancing arguments against and in favor of marking, provided by this and the other classes, respectively.
- YNY—Necessary/Unintentional/Friendly: This class holds a sister scenario to the classic “retrievability scenario” (which actually is a retrieval scenario) above: In combination with incomplete memory and information, society may have noticed that it was “necessary” to act, but it was “unintentional” to actually intrude. To the knowledge of the authors, this scenario has never been explicitly addressed. The dissemination of “indicators” to indicate the existence of galleries has been considered before (see e.g. [15]), but not in the context of locating waste packages for “necessary” (i.e. safety related) purposes.

The probability of any of the HI scenarios to occur cannot be quantified. Therefore, they cannot be treated as the classical DGR evolution scenarios are treated in performance assessment. But they can still be considered in marking or other RK&M preservation concepts. Other, e.g. ethical, reasoning may provide arguments for some of our HI categories to be excluded from any sort of considerations for such concepts. At this stage however, we claim, cautiously, that it is at least not obvious that or why or which one of the depicted classes, scenarios and loss-of-memory situations should be excluded from any RK&M preservation considerations. And we believe that the new HI categories are useful in any case; for example to support ethical argumentation, should this be brought forward at some stage.

Applying the proposed categories to the classical “in/advertent” HI scenarios, we can say that the “unnecessary”, “unintentional”, “friendly” situation at a time of “no memory”—i.e. “inadvertent HI”—needs to be treated in the safety case (according to international guidance) while the “unnecessary”, “intentional”, “friendly” situation at a time of “full memory”—i.e. “advertent HI”—is not to be treated in the safety case.

The question about how to treat intermediate loss-of-memory situations and the other two branches of HI, the “necessary” HI and the “unfriendly” HI, is as yet undiscussed, let alone decided. Sub-surface marking concepts appear to be capable in principle to deal with such situations to some extent, but their very scope for RK&M preservation in this respect still needs to be explored.

CONCLUSIONS

We have shown that the classical “advertent”/“inadvertent” duality classification of HI, as used in the performance assessment context for HI scenario conceptualization, is not ideal to characterize potential HI situations in RK&M preservation scenarios. We suggest that the relevant HI categories are expanded and refined to “un/intentional HI”, “un/necessary HI” and “un/friendly HI”. This classification bears 5 classes of HI scenarios; 2 of which hold the classic “advertent” and “inadvertent” HI scenarios, the remaining 3 are “new” and contain important scenarios such as—what may appropriately be called—the “retrievability scenario” and the “safeguards scenario”. Along with refining the taxonomy of HI, we have refined the assumption relating to the loss-of-memory status to include situations in between “full memory” and “no memory”. The range of intermediate loss-of-memory status may be most likely to apply in the crucial timeframe (from an RK&M preservation point of view), when oversight is in danger of disappearing. Different HI situations are likely to arise in different loss-of-memory situations. We have applied the proposed HI categories to sub-surface marking concepts from the literature and suggest that, in particular, sub-surface marking strategies can benefit from this new approach to HI and loss-of-memory categorization.

REFERENCES

1. C. Pescatore, J. Schröder: “Markers and Deep Geological Repositories - Learning within the OECD/NEA Project on the Preservation of Records, Knowledge and Memory across Generations”, 14589, WM2014 Conference proceedings, Phoenix (AZ), 2014
2. Glossary of Key Terms of the OECD/NEA Initiative “Preservation of Records, Knowledge and Memory (RK&M) across Generations”, http://www.oecd-nea.org/rwm/rkm → Glossary
3. ICRP: “Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste”, ICRP Publication 81, Ann. ICRP 28(4), 1998
4. ICRP: “Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste”, ICRP Publication 122, Ann. ICRP 42(3), 2013
5. IAEA: “Disposal of Radioactive Waste”, SSR-5, International Atomic Energy Agency, Vienna, 2011
6. IAEA: “The Safety Case and Safety Assessment for the Disposal of Radioactive Waste”, SSG-23, International Atomic Energy Agency, Vienna, 2012
7. R. Seitz, Y. Kumano, L. Bailey, C. Markley, E. Andersson, T. Beuth: “Considerations Related to Human Intrusion in the Context of Disposal of Radioactive Waste: The IAEA HIDRA Project”, 14101, WM2014 Conference, Phoenix (AZ), 2014

8. OECD/NEA: “The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes: A Collective Opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency”, OECD Nuclear Energy Agency, Paris, 1995
9. D.A. Galson, P.J. Richardson: “PAMINA Project Summary Report”, Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA), Deliverable D5.1, EC, 2011
10. Working Group on “Scenario Development”: “Handling of Human Intrusion into a Repository for Radioactive Waste in Deep Geological Formations”, atw - International Journal for Nuclear Power, 53, p. 538, 2008 [http://www.kernenergie.de/kernenergie-en/service/fachzeitschrift-atw/hefte-themen/2008/aug-sep/09_vollstaendiger-atw-artikel-position-des-arbeitskreises-szenarienentwicklung-behandlung-des-menschlichen-eindringens-in-ein-endlager-fuer-radioaktive-abfaelle-in-tiefen-geologischen-formationen.php]
11. P. Raimbault, C. Valentin-Ranc: “How to Mark Repositories in Geological Formation ?”, SAFEWASTE 93: International Conference on Safe Management and Disposal of Nuclear Waste, Avignon, 13–18 June 1993, vol. 3, pp. 212–221, 1993
12. N. Chapman, C. McCombie: “Principles and Standards for the Disposal of Long-lived Radioactive Wastes”, Elsevier, Oxford, 2003
13. M. Buser: “Literaturstudie zum Stand der Markierung von geologischen Tiefenlagern”, Bundesamt für Energie, Bern , 2010. Available in English as: OECD/NEA: “A Literature Survey on Markers and Memory Preservation for Deep Geological Repositories”, NEA/RWM/R(2013)5, OECD Nuclear Energy Agency, Paris, 2013
14. WIPP: “Permanent Markers Implementation Plan”, DOE/WIPP 04-3302, US Department of Energy, Waste Isolation Pilot Plant, Carlsbad Field Office, Carlsbad (NM), 2004
15. T. Beuth, B. Baltes, W. Bollingerfehr, D. Buhmann, F. Charlier, W. Filbert, K. Fischer-Appelt, J. Mönig, A. Rübel, J. Wolf: “Studies Relating to Human Intrusion into a Repository”, GRS-348, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), 2014