How will new knowledge be reflected to the management of geological disposal?
- Influence of an FEP not considered so far to some sub-scenarios -

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Abstract

After it became clear that geological disposal of high-level radioactive waste would not be realized without the understanding from the society when all siting approaches in western countries around 1980s tumbled, international communities and OECD/NEA made efforts to attain the understanding from the society and established important principles concerning social and ethical aspects. Some of the key words were responsibility of present generation, safety case, stepwise decision, stakeholder involvement, preservation of RKM (records, knowledge and memory), and so on. Safety case is stipulated to include the assessment of all features, events and processes (FEPs) that could significantly influence the performance of the disposal system. And as such, the safety case is a document to share the consensus on the safety of a disposal system among the present generation, to serve as the ground for stepwise decision, and to transmit the technical information about the disposal system and our sincere endeavor on it to the future generation. In the stepwise approach, decisions made in the previous steps may be changed based on new scientific knowledge and others.

Meanwhile, an FEP, pressure solution, which has not been dealt with in previous safety case documents, has been pointed out that it can affect the geological disposal system through some sub-scenarios. One is a process of permeability evolution around a disposal tunnel due to mass transfer through pressure solution, diffusion and precipitation. Another one is a process of sinking of a heavy container in the buffer due to pressure solution creep. This report reviews the pressure solution phenomena and above mentioned sub-scenarios, points out that the phenomena and sub-scenarios need to be duly addressed in a safety case, and gives a thought to fulfilling the responsibility of present generation.

1. Introduction

Countries that are using or have used nuclear energy are making efforts to realize the final disposal of high-level radioactive wastes. Since it requires a lot of time, it is a consensus among the international community to adopt an approach of stepwise decision making to cope with new knowledge and situation and to reverse the decisions in the former steps if necessary. R&D's are being undertaken to ensure safe and rational disposal. When and if new knowledge poses a concern which needs to be clarified, the disposal may be delayed, and the delay can be unduly. What will be a rational strategy for the realization of the disposal, which is the responsibility of the present generation?

The section 2 of this report shows examples of new knowledge which have not been considered in the previous safety case documents. The FEP of concern is pressure solution. There are papers pointing out that pressure solution can affect some sub-scenarios which can have significant effects on the safety assessment. The sub-scenarios are evolution of permeability of rock around disposal tunnel, canister sinking in the bentonite buffer, and other.

In the 3rd section, the international endeavor so far made and resultant principles established to gain the understanding from the society are reviewed.

The R&D is the pivot to ensure the safety of the disposal, but there will not be a conclusive end to the R&D for evaluating the safety for the far future. If new knowledge obtained by a research creates another research topic and the disposal is delayed, is it an adequate way to fulfill the responsibility of the present generation? This question is raised in the 4th section.

2. Examples of New Scientific Knowledge

2.1 Pressure Solution

Although it is a phenomenon (FEP) which can affect significantly the safety of disposable system, pressure solution has never been considered in relevant scenario analyses in previous safety cases.

Pressure solution is defined as enhanced dissolution of solids into aqueous solution by stresses in the solids, and it often broadly means the resultant deformation process through dissolution and diffusion. It was found in geological observations in as early as 1860s. Sorby pointed out in 1865 that stylolite and impressed pebble were formed by pressure solution. Gibbs formulated the thermo-dynamic chemical potential of solid as a function of temperature and stress on the surface concerning the phase equilibrium in 1877. However, pressure solution was considered as a relatively limited geological phenomenon for a long time. Referring to Japanese geological dictionaries, the one published from Shin-kokin-shoin in 1973 has no entry for pressure solution and suggests the cause of stylolite as partial melting. But another dictionary published from Heibonsha in 1996 includes pressure solution and explains the cause of stylolite as pressure solution as with the present understanding.

In recent years, pressure solution has come to be recognized as an omnipresent phenomenon observed in the crust deeper than about 90m [Tada & Siever, 1989], and one of the most important mechanisms of crustal deformation [Gratier et al, 2013] (**Fig 1**). In recent years, researches have been conducted not only in the field of geology but also in engineering [Yasuhara et al, 2016] and others.

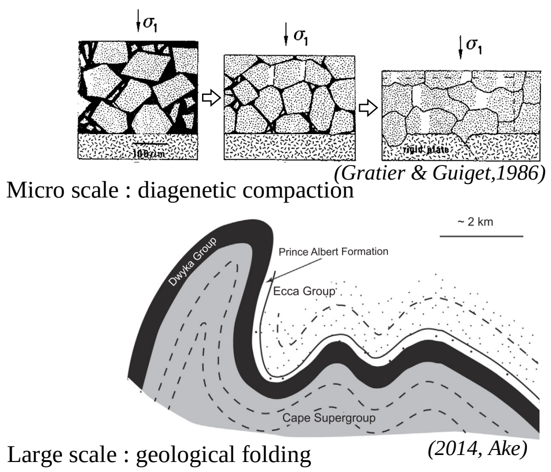

Fig.1 Omnipresent effects of pressure solution

Others include mica's penetration into quartz, impressed pebble, stylolite, salt flow under low T and P, etc.

2.2 Its effects on disposal system

In recent years it has been pointed out that pressure solution affects geological disposal systems in some way or other.

(1) Permeability of rock around disposal tunnel

Yasuhara et al (2016) (**Fig 2**) evaluated the fluctuation of permeability during 10,000 years around a radwaste disposal facility through T-H-M-C coupling simulations taking into account the pressure solution. Parameters were taken from quartzite data. The simulation suggested a favorable result for the safety of geological disposal because the permeability around a disposal tunnel decreased with time.

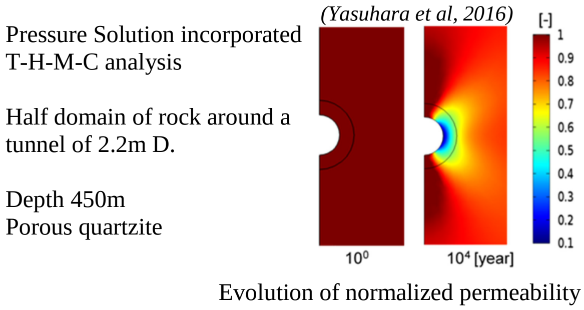

Fig.2 Permeability change due to pressure solution

(2) Rock sinking in salt dome

Dislocation creep and pressure solution creep have been pointed out as the mechanisms of salt deformation, and the pressure solution creep is predominant at low temperature and pressure in wet condition [Urai et al, 1986].

Burchardt et al (2012) have numerically simulated the sinking of entrained anhydrite (2.9 g/cm^3) in the Gorleben salt diapir (2.2 g/cm^3) and pointed out that the interaction between the sinking rocks and facility in salt dome should be considered in a safety assessment of waste disposal.

(3) Canister sinking

The sinking of canister in buffer can be detrimental to safety because too small thickness of the buffer deteriorates the buffer functions of water tightness and nuclide adsorption. Therefore the sinking has been quantitatively evaluated [SKB, 2011] [JNC, 2000], but only from the viewpoint of mechanical deformation of buffer. Shin(2017) has pointed out that canister can sink also through chemical deformation via pressure solution (**Fig 3**). A review of previous works on pressure solution concluded that the rate of sinking can be non-negligible considering the assessment time of 1Ma (**Table 1**).

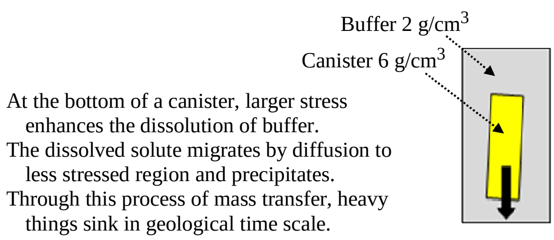

Fig.3 Canister sinking due to pressure solution

Table 1 Rate of deformation by pressure solution from various sources (Shin, 2017)

	Discription		rate	(unit)
1	Laboratory experiment	single contact, 0.5MPa, 8℃, (halite-fused silica)	>3.65	m/Ma
2		Single contact, 0.2MPa, 25℃, (quartz-mica)	5	m/Ma
3		Aggregate of calcite, 1MPa, room temp.	>350	m/Ma
4	Salt dome	Anhydrite sinking in saltdome (numerical calculation)	1,600	m/Ma
5		Salt dome development, East Texas Basin, US	150-530	m/Ma
6	Folding	Cape fold belt, SA	0.03-0.3	1/Ma

3. Principles for Acquiring Understanding from the Society

Countries with nuclear power plants are making efforts for geological disposal of high level radioactive waste as the responsibility of the present generation. Some countries in Europe and the US started selecting the disposal site in 1970's and 1980's but met with oppositions from the communities and the society. In this background, important principles and good practices have been established by OECD/NEA and others to acquire the understanding from the society. They are in the perspective of ethics, safety case and decision making including stepwise process, stakeholder involvement and others. Some of them are listed in **Appendix**.

3.1 Ethics

NEA(1995) pointed out that our responsibilities to future generations are better discharged by a strategy of final disposal, and that applying the same standards of risk in the far future as it does to the present is required from the viewpoint of intergenerational equity.

3.2 Safety Case

Safety case is the collection of arguments and evidences in support of the safety of a disposal facility. The most important part of the safety case is the safety assessment based on scenarios of evolution of a disposal system.

IAEA(2012) stipulated that the process of development and screening of scenarios should be fully documented, and that all features, events and processes (FEP) that could significantly influence the performance of the disposal system should be addressed. NEA(2017) also mentioned scenario development to the same effect as above.

NEA(1999) and NEA(2001) pointed out that scenarios should be developed through clear communication between implementer, regulator and other audiences.

3.3 Decision Making

(1) Stepwise process

NEA(2017) pointed out that stepwise process could secure flexibility in case of change in site conditions, technical and political situations and new scientific knowledge and others.

NEA(2004) pointed out that stepwise approach was necessary also to enable stakeholders not yet born to involve in the decision process meaningfully.

(2) Stakeholder involvement

NEA(2003) pointed out the importance of fair and participatory decision making process, and of national commitment to its creation and involvement.

NEA(2014) pointed out that stakeholders other than regulator and implementer should be involved in the national decision process, and that stepwise approach involving various stakeholders is a responsible way.

NEA(2015) stated that stakeholder involvement should start early in time and upstream in process.

(3) Balance

NEA(2014) stated that decisional framework should include the viewpoint not only of safety but also of society, economics, technology, ethics, and others.

(4) Records, knowledge and Memory (RK&M)

NEA(2011) pointed out the necessity of preservation of RK&M across generations in order to support the long and complex decision making processes for radioactive waste management.

4. Radioactive Waste Management (RWM)

4.1 Involvement of General Public

The previous chapter dealt with the principles and good practices established by OECD/NEA and IAEA, both are the international organs for the promotion of civilian use of nuclear technology.

Meanwhile, US National Academy of Science (1999) and Science Council of Japan (2015) made comments to the respective governments about RWM as the representatives of the general publics, so to speak.

NAS(1999) stated that the management had been focused mostly on technology and societal aspects had been insufficient. It suggested two principles from the viewpoint of social science for gaining public acceptance. First, participation in the decision process leading to a geological repository should be open and transparent. For this, extensive review of the repository program by independent scientific experts would be necessary. The second principle is staged decision making, and if necessary, the site selection process can be restarted.

NAS(2003) made a suggestion in response to a request from the US DOE about staged decision making. It pointed out that iterative review of the safety case in view of new information is the central to the staged decision making.

Science Council of Japan was requested by Atomic Energy Commission of Japan to make suggestions on how to explain and provide information to the public about the radioactive waste disposal in Japan. In reply to AEC of Japan, SCJ(2012) pointed out that the cause of the delay in site selection in Japan was not the way how to explain but the lack of social consensus in the nuclear energy policy in general. Another cause was pointed out as the uncertainty of safety. And SCJ(2015) made complementary suggestions on RWM, one of which is the creation of RWM Policy Commission to form policy based on consensus among broad range of stakeholders.

4.2 Will We See Progress in RWM ?

As reviewed so far in chapter 3 and 4.1, in order for us to take responsibility of the present generation as a whole, important principles and good practices have been established. But will we be able to see progress in RWM only with these?

(1) FEP not yet evaluated

Taking up pressure solution as an example of FEPs not yet evaluated in previous safety cases, what will be the right way to handle it? Pressure solution can affect two sub-scenarios, evolution of permeability of rock around disposal tunnel and canister sinking in buffer. These sub-scenarios can have significant influence on the safety of disposal system, and hence, these need to be evaluated in a safety case according to the principle mentioned in section 3.2. Conceptually, assessing the sub-scenario of canister sinking via pressure solution may have two options. Option A requires detailed study of pressure solution and option B does not. In the case of option A, dissolution rate will need to be clarified as a function of pressure between contacting minerals, temperature, pH, mineral species, and others. Diffusion rate of dissolved mineral in buffer material and precipitation process will also need to be studied. Then incorporating these mechanisms, a numerical model needs to be developed to evaluate quantitatively the process of canister sinking due to the pressure solution. Taking into consideration the canister's position in the buffer in the future, safety will be assessed for the reference design of engineered barrier and the site. Depending on the result, some adjustment to engineered barrier system (EBS) or change of disposal concept may be required. In the case of option B, the time needed for research on pressure solution is shortened by adopting a conservative approach of sufficiently robust EBS or disposal concept. Both options will require long time and thus pose the problem of balance between safety and time.

(2) Decision criteria for uncertain safety

Confirming the safety for the future generation is the core of safety assessment. But, as well acknowledged, evaluation of the future entails uncertainty. Decisions will be made at each stage of stepwise process via renewed safety case. All stakeholders including general public will be participating in making safety case and in decision. How can we, the present generation, evaluate the uncertain safety and come to agreeing? Presently we do not have the decision criteria for uncertain safety and hence it seems we cannot expect progress in RWM.

(3) Balance between safety and economics,,

Securing safety is the foremost importance on the one hand, economics and efficiency are also required in implementing geological disposal on the other. When various stakeholders are to reach an agreement, they need an agreed methodology how to take the balance. But it seems we do not have such consensus yet.

4.3 Conclusion

As discussed so far, it is not sure we can see progress in RWM only with the principles and good practices which have been so far established hopefully to promote RWM. The underlying problems are how and at which level we can agree on uncertain safety, and how to take a balance between safety, economics, time and so on.

The most needed action now in order to resolve the RW problem is to develop decision criteria and methodology how to take balance on which the present generation can agree, with the recognition of our supreme responsibility for the RW disposal.

Appendix

Some of Principles and Good Practices for RWM

E	NEA,1995	Our responsibilities to future generations are better discharged by a strategy of final disposal. /p5
E	NEA,1995	Intergenerational equity issues should be taken into accout, by applying the same standards of risk in the far future as it does to the present. /p5
Sc	IAEA,2012	The process used for development (including screening) of scenarios should be fully documented and justified. /c5.40
Sc	IAEA,2012	**All features, events and processes that could significantly influence the performance of the disposal system should be addressed in the assessment. /c5.42**
Sc	NEA,2017	A scenario not considered in either the normal evolution or alternative scenarios should be given the reasoning behind the screening out. /p16
Sc	NEA,2017	If a scenario seems credible but has not been previously considered, an action should be taken to consider it. /p16
Sc Sh	NEA,2001	**Clear communication between the applicant and the regulator, and with other audiences, is essential to the success of a scenario development effort. /p31**
Sc Sh	NEA,1999	The safety case compiled by an implementer will be presented periodically to the regulator for review. However, the regulator, and stakeholders, should have a broader role in the iterative development of the safety case. /p46
Sc	NEA,1999	A role of the regulator is to define criteria, for use as a "measuring stick", against which to judge the safety case presented by the implementer. Another role of the regulator is to form a judgement as to whether sufficient confidence has been achieved that the criteria have been met. /p18
Sc	IAEA,2012	Development of the safety case should commence at the inception of the project and should be continued through all steps in the development and operation of the facility through to its closure and licence termination. /c4.8
Sc	NEA,2001	Complete documentation must be provided of all scenarios (or features, events, and processes) that have been excluded from the quantitative assessment, as well as of those that have been included. /p31
Sw	NEA, 2017	The strategy for implementation of a repository should provide sufficient flexibility in a stepwise process to cope with unexpected site features or changes in technical or political boundary conditions, as well as to take advantage of advances in scientific understanding and engineering techniques. /p27
Sw Sh	NEA,2004A	**The key feature of the concepts of stepwise process is development by steps or stages that are reversible. /p3** **RWM involves stakeholders who have not yet been born. From this view point also, stepwise decision making is important. /p17**
Sh	NEA,2003A	One of the factors that can contribute highly to stakeholders' confidence is: an open, transparent, fair and participatory decision making process. This should be decided on a national level, and national actors must demonstrate commitment to the process. /p43
Sh	NEA,2014	**The dialogue between regulator – implementer is part of a national decision process for developing and implementing a geological disposal system, in which other technical and non-technical stakeholders are involved. /p6**
Sh Sw	NEA,2014	A step-wise process, involving various stakeholders, is considered as a responsible approach to planning for disposal development and implementation, including final closure. /p2
Sh	NEA,2015	**Stakeholders should be involved early and upstream while options are still wide open. /p12**
Sh	NEA,2003B	Regulators should establish good contact with the different stakeholders. Open channels of communication should be maintained with the general public, implementers, government departments, parliament, concerned action groups and others. /p11
Sh	NEA,2004B	On stakeholder involvement; The participants in a dialogue may have different views about its goals and so the planning and evaluation should involve these persons in order to come to a shared understanding of what the dialogue process is trying to achieve. /p9
Sh	NEA,2004B	**Public involvement in decision-making processes should be facilitated. /p10**
Sh	NEA,2004B	It is not too strong to say that a cultural change had taken place: stakeholder dialogue had become a lead principle in radioactive waste management. /p15
Sh	NEA,2004B	The OECD countries are moving away from a traditional "decide, announce and defend" model, for which the focus was almost exclusively on technical content, to one of "engage, interact and cooperate", for which both technical content and quality of process are of comparable import to a constructive outcome. /p41
Sw Sh	NEA,2013	The features of the stepwise approach to decision-making allow stakeholders to gain familiarity with technical options and institutions and therefore, to build confidence in the safety and trust in the institutions managing waste. \p13
B	NEA,2014	**A broader decisional framework integrating dimensions of safety, society, economics, technology, ethics… is needed. /p3**
B	NEA,2008	There is a need to balance the benefit and the cost of options and societal aspects should be considered. /p27
B	NEA,1995	In the case of nuclear energy production and the management of radioactive wastes, the balance between the benefits which are enjoyed by present and future generations through sustained technological development, and the liabilities which may be imposed on future generations over a long period, must be carefully scrutinised. /p7
Ot	NEA,2011	RK&M is needed in order to • Maintain confidence in the safety and security of the system ; • Address concerns and answer requests from the public, especially local communities; • Ensure that future generations can base their decisions on relevant and pertinent data; • Promote awareness of past activities. /p1
Ot	NEA,2004B	In RWM, a hierarchy of objectives should be considered. First a recognition is required by the national government that the status quo is no longer acceptable. And the link between current waste management policy and the future of nuclear energy should be openly addressed. Then identification of a licensable site and a safe waste management concept should follow. Next, siting efforts should allow for consideration of local and regional development schemes. Finally, radioactive waste management facilities should be designed and implemented in ways that reflect the values and interests of local communities. /p11

E: Ethics, Sc: Safety case, Sh: Stakeholder, Sw: Stepwise, B: Balance, Ot: Others

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