한국해양환경공학회지
Journal of the Korean Society
for Marine Environmental Engineering
Vol. 13, No. 2. pp. 121-125, May 2010

이산화탄소 해양 지중저장 시스템에서의 누출 위해성 평가방법에 관한 기술적 검토

황진환[1,†] · 강성길[2] · 박영규[3]
[1]동국대학교 사회환경시스템공학과
[2]한국해양연구원 해양시스템안전연구소
[3]한국해양연구원 기후 · 연안재해연구부

Technical Review on Risk Assessment Methodology for Carbon Marine Geological Storage Systems

Jin Hwan Hwang[1,†], Seong-gil Kang[2] and Young-gyu Park[3]
[1]*Dept. of Civil & Env. Eng., Dongguk University at Seoul. 26, 3 Pil-Dong, Jung-Gu, Seoul 100-715, Korea*
[2]*Maritime Safety & Pollution Response Res. Dept., MOERI/KORDI, Daejon 305-600, Korea*
[3]*Climate Change & Coastal Disaster Res. Dept, KORDI, An-San 425-600, Korea*

요 약

지중 저장기술은 대기로 방출되는 이산화탄소를 저감하는 기술로서 기후변화를 발생하는 온실효과를 저감 시킬 수 있다. 해양 저지대에 위치한 심층 대수층 혹은 폐유전 등은 이러한 이산화탄소 저장기술의 중요한 후보군이라고 할 수 있다. 관련된 이산화탄소 주입 및 저장기술은 전 세계적으로도 많은 관심을 받고 있으나, 이러한 시스템에서 이산화탄소 누출이 발생하였을 때의 부정적 영향에 대해서는 아직 심도 있는 연구는 진행되지 못하고 있다. 이산화탄소 저장기술의 안정성이 매우 높아서 누출의 가능성은 매우 낮다고 하더라도, 고농도의 이산화탄소가 만약의 사태에서 누출이 된다면 여전히 해양생태계 및 환경에 위험이 있을 수 있다. 그러나 이에 대한 연구가 충분히 이루어지지 않았기에, 본 연구에서는 하나의 신뢰성 및 위해성 평가방법을 소개하고자 한다. Feature, Event and Process(FEP)를 통해 다양한 요소를 고려하고, 결함수 분석을 통해 신뢰도를 평가하는 방법을 제안한다. 이러한 FEP 분석으로 시스템에서 시공 및 운영과정에서 발생할 수 있는 다양한 누출 가능성을 평가하는 방법을 소개하였다.

Abstract – Carbon Capture and Storage (CCS) technology mitigates the emission amount of carbon dioxide into the atmosphere and can reduce green house effect which causes the climate change. Deep saline aquifer or obsolete oil/gas storage etc. in the marine geological structure are considered as the candidates for the storage. The injection and storage relating technology have been interested in the global society, however the adverse effect caused by leakage from the system failure. Even the safety level of the CCS is very high and there is almost no possibility to leak but, still the risk to marine ecosystem of the high concentrated carbon dioxide exposure is not verified. The present study introduces the system and environmental risk assessment methods. The feature, event and process approach can be a good starting point and we found the some possibility from the fault tree analysis for evaluation. From the FEP analysis, we drove the possible scenario which we need to concentrate on the construction and operation stages.

Keywords: Carbon dioxide (이산화탄소), Capture and Storage (포집 및 저장), risk assessment (위해성 평가), mitigation technology (저감기술)

[†]Corresponding author: jinhwang@dgu.edu

1. INTRODUCTION

Carbon capture and storage (CCS) is one of the prominent technologies for reducing the emission of carbon dioxide into the atmosphere and so has been adopted by many countries as an option for mitigation strategies. Norway, Japan, Australia and U.S. are operating the CCS utilizing injection of CO_2 into the geological structure or have several plans for injection (Kevitiyagala, 2009). Each project includes the monitoring plans for detecting leakage, assessment of environmental and ecosystem risk and developing the mitigation technology of impact and remediation plan.

The main concerns of the storing carbon dioxide into geological structure is on leakage of gas (Deel *et al*., 2007). The leakage of carbon dioxide have two critical issue on; first, the loss or fail of project as a emission trading system and second is in that leakage can cause the serious damage on the environmental and ecosystem. The leakage path way could be forecasted in the various route and two distinctive pathway are that one is leakage to the atmosphere and another is the discharge from the ocean bottom as a non-point source or plume discharge. This failure can happen by crush down of transport pipes, breaking down of injection well, or unpredictable geological event etc. (IMO, 2006 and 2007).

No leakage will be desirable for the CCS, but based on the historical record of the under ground natural gas storage which employs the similar technology to CCS, such storage systems have failed by unexpected reason. Such historical record emphasizes on the importance why the risk assessment and environmental monitoring are critically prepared in the CCS. Around 320 of the underground geological storage systems are employed in US and 18 of those are located in Kansas (Tobin, 2006). Yaggy site has failed in near injection well and caused two death and damage on several building structures. Also, natural storage failure of carbon dioxide has been observed. For example, in California, the clear lake released 1ton/day due to thermal and chemical reaction in the sedimentary layer and caused 4 deaths. Not only two examples, since 1950, France has experienced 7 times of leakage accidents in industrial natural gas storage (Jennifer *et al.*, 2006). Those accidents make emphasize on the importance of the risk and environmental assessments in CCS project. The accident of CCS was reported recently in Norway. She employed Enhanced Oil Recovery system as a method for CCS and during injection, overly pressured geological system was broken and released 175 tons of toxic chemical material of oil and gas (Reuters, 2009). This accident made Green peach to warn the harm of CCS technology (Greenpeace, 2008).

To prevent the serious problem of CCS, IMO (International Maritime Organization) adopted the risk assessment protocol based on the agreement of conference of parties of the London Protocol 96, and ratified this standard (IMO2006). Therefore,

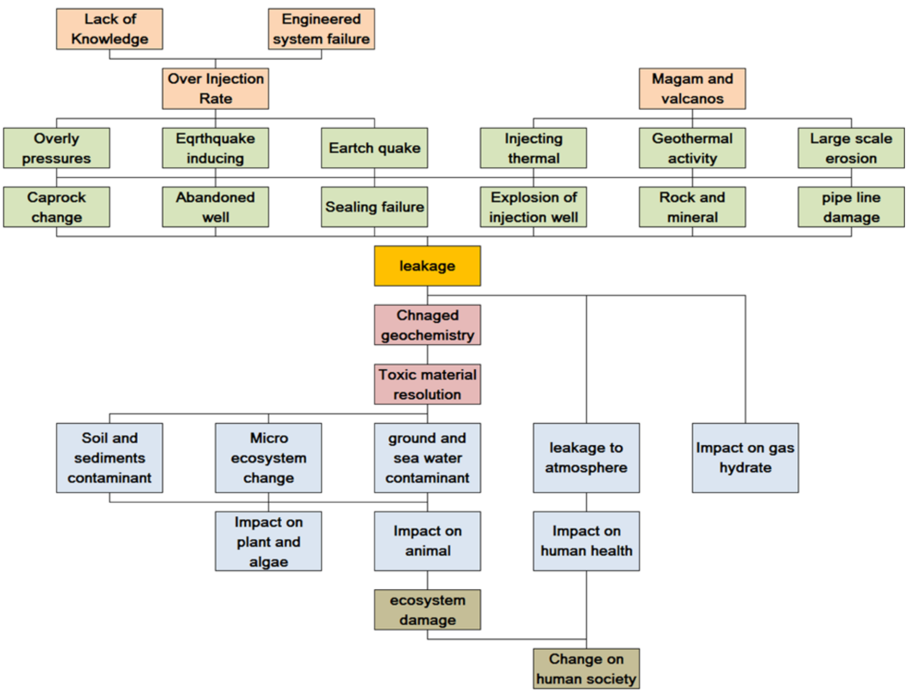

Fig. 1. Features Events and Process tree for designing the offshore geological carbon storage.

the parties are required to have their own risk assessment standard guideline which can evaluate and assess schematically. The present study is being performed to propose the risk assessment guideline and standard based on the Korean domestic maritime law and situation.

2. IMPACT and ANALYSIS

Carbon dioxide is not harmful in the low level of around 370 ppm, equivalent to the present atmospheric concentration. But, when carbon dioxide is released in the high concentration over 1% which could happen and be released in the near pipe or injection plant, carbon dioxide is harmful to the human and ecosystem. Fig. 1 presents the Feature, Event and Process (FEP) tree to determine the probability and scenario of when leakage can happen and what will results in. Two main system failures can be caused by human engineered system failure and natural unexpected processes. Since CCS is newly introduced technology, there are still many unknowns and the natural process as like as magma, earth quake and volcanic activity. Such causes can show up in the diverse physical and chemical sub processes as like as cap lock breaking down, inducing earthquake, inducing thermal increase and pipe failure caused by erosion processes. This leads to the leakage of carbon dioxide to the ground or underground and atmosphere. Also, when leaked carbon dioxide expose to the methane hydrate, we cannot guarantee what will happen. Leaked high concentrated carbon dioxide also can affect to the animal, plants and human society. When human body is exposed to the 1% of carbon dioxide, then one feels drowsy and exposed to over 7~10%, then fall in the dangerous situation and exposed over several minutes human lose their consciousness (Rice, 2003).

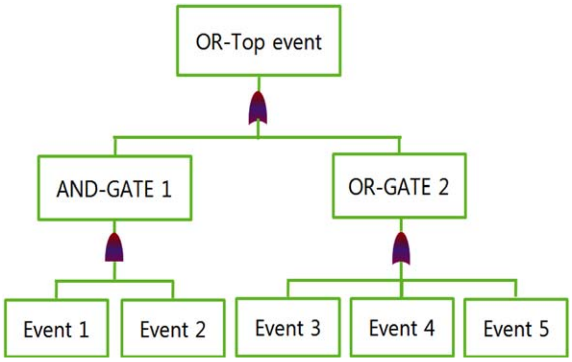

Fig. 2. An example of simple FTA (Lee, *et al.*, 2009).

Lee *et al.* (2009) construct fault tree to analysis risk in the CCS project mainly focused on the engineered management system. They employed Fault Tree Analysis (FTA) which is widely allied to analysis on the risk assessment to design the nuclear power plant of nuclear waste material storage. FTA is generally adopted to analyze the complex dynamic system.

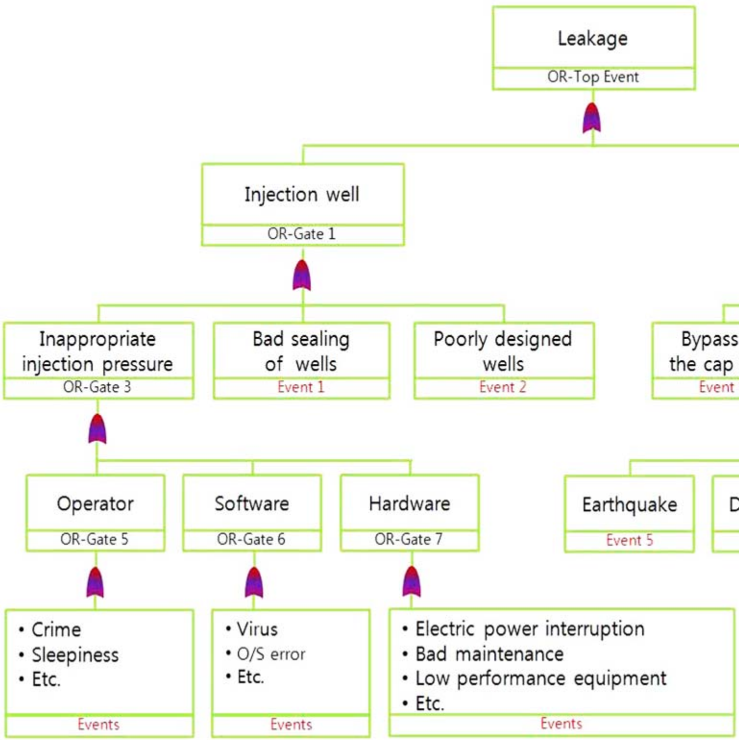

Fig. 3. The overall FT for CO_2 leakage (Lee, *et al.*, 2009).

FTA is purposed to assess and model the potential dangerous events and consists of Top event, Intermediate Event, and Basic event. Each even is connected by AND and OR gate and Fig. 2 is an example of FTA.

AND-gate is logic multiplication in the case which two upper and lower level events occur simultaneously and OR-Gate is logic summation when two events occur at least one of events. The given FEP, the detaield FTA is applied to the case of engineered system. Lee *et al.* (2009) construct over all fault tree as Fig. 3.

Finally, they concluded that the minimal cut which describes the most probable events of leakage, is the electricity power interruption in CCS based on the data base of many previous plants system failures. The present study tried to apply this approach to analysis on the natural geological system of CCS, but the CCS itself is newly introduced and there are not many report of CCS failure to apply statistical method.

3. PREDICTION FOR THE LEAKAGE DISPERSION IN THE CANDIDATE AREA

Once leaking from the storage, the carbon dioxide is dispersed and transported in the ocean water body. This can lead critical confliction between neighboring countries since the high concentration carbon dioxide can affect the ecosystem of other country. Therefore, the transported pattern and permanent monitoring of carbon dioxide should be performed during project period or over that period.

Ocean water transport modeling is performed as an initial test to prevent transboundary problem of carbon dioxide storage in the marine geological storage. Transboundary migration can be progressed through deep sea saline aquifer even though the international law does not regulate this issue in detail and also the leaked carbon dioxide can be migrated through water column. Figure 4 shows the current and bathymetry distribution in the east sea of Korea. In the future, based on this current distribution, dispersion experiment need to be done. There will be several ways to do this; firstly, one way coupling from hydrodynamic model toward dispersion of carbon dioxide and secondly, we can do wook with active tracer test of carbon dioxiide since large amount of carbon dioixde can generate density flows and this flows also are affected by circumstantial conditions. However, this effect will not be dispersed too much on the whole east sea area. Still, hydrologically important area, such as fishery filed and aqua aculturing zone, need to be considered. Carbon dioxide is easily dissolved into water, therefore, we can concluded that the carbon dioxide in the level of serious concentration will not be monitored even though leakage happens. But, still in the environmental perspectives, the change of pH and other chemical reaction should be monitored carefully since such a change can cause critical conflict between neighboring countries.

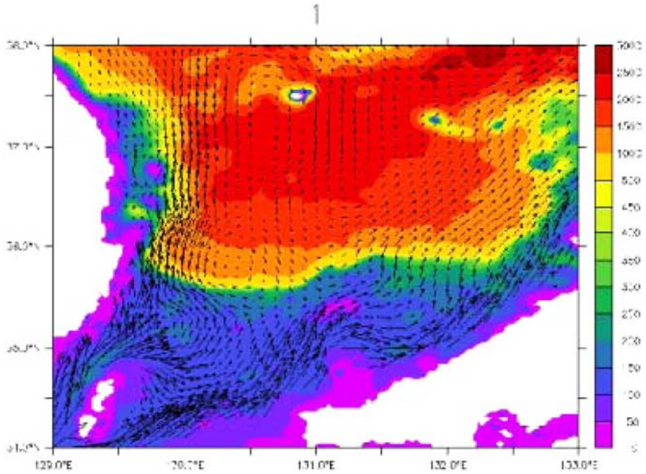

Fig. 4. Current and bathymetry distribution in the East sea of Korea.

4. CONCLUSION

The CCS technology is very safe as IPCC reported. But, we cannot exclude the possibility of accidents which can be produced by mal-operation of human. When leakage occurs, high concentrated carbon dioxide need to be predicted, detected and remedied since carbon dioxide can affect the environmental system, ecosystem, human society and also large scale transboundary problem. The present work is being performed to set a standard protocol to construct carbon capture and storage to prevent the accident and to resolve conflictions which are introduced by accident.

ACKNOWLEDGMENTS

This research is supported by the Ministry of Land, Transport and Maritime Affairs through the Korean Institute of Marine Science and Technology Promotion for the R&D for CO_2 Storage in Offshore Sediment in Korea.

REFERENCES

[1] Deel, D., Mahajan, K., Mahoney, C.R., McIlvried, H.G. and Srivastava, R.D. 2007, "Risk assessment and management for

long-term storage of CO_2 in geologic formations-United States Department of Energy R&D", Systemics, Cybernetics and Informatics, 5, 79-84.

[2] Greenpeace, 2008, "Leakages in the Utsira formation and their consequences for CCS policy", (Greenpeace Briefing).

[3] IMO, 2006, "Report of the meeting of the sg intersessional technical working group on CO_2 sequestration", Working Group on CO_2 Sequestration (3rd May), Meeting of the SG Intersessional Technical Working Group on CO_2 Sequestration. L/SG-CO_2 1/7.

[4] IMO, 2007, "CO_2 sequestration in sub-seabed geological formations: Report of the ad-hoc working group on the specific guidelines for carbon dioxide sequestration into sub-seabed geological formations".

[5] Jennifer, L., Lewicki, J. B., and Tsang, C.-F., 2006, Natural and industrial analogues for leakage of CO_2 from storage reservoirs: identification of features, events, and processes and lessons learned.

[6] Kevitiyagala, N., 2009, "Carbon sequestration", Science, 325, 1644-1645.

[7] Reuters News, 2009, "Norway bets on CO_2 capture, storage despite risks", (28th, May), http://www.reuters.com/article/latestCrisis/idUSLS313448.

[8] Lee, S.I., Lee, S.K., and Hwang, J.H., 2010, Fault Tree Analysis for risk analysis of CO_2 leakage from geologic storage, In progress.

[9] Riebesell, U., Zondervan, I., Rost, B., Tortell, P.D., Zeebe R.E., and Morel, F.M.M., 2000, "Reduced calcification of marine plankton in response to increased atmospheric CO_2", *Nature*, 407, 364-367.

[10] Rice, S.A., 2003, "Health effects of acute and prolonged CO_2 exposure in normal and sensitive populations", Second Annual Conference on Carbon Sequestration, May 5-8 2003, Virginia, USA.

[11] Tobin, J., 2005, U.S. Undergraduate Natural Gas Storage Development: 1998-2005. Energy Information Administration, Office of Oil and Gas.

2010년 2월 3일 원고접수
2010년 3월 2일 심사완료
2010년 3월 30일 수정본 채택