Status of natural analogue studies in Korea and how to use natural analogue information in the safety case

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Contents

Introduction

National Policy for RW Management in Korea

❑ 253rd AEC's Decision (Dec. 2004)

- **Final repository for LILW should be constructed by 2008.**

  → Delayed until June 2014 for some safety reasons

- **Spent Fuel Management**
  - All spent fuels will be stored at plant sites until 2016.

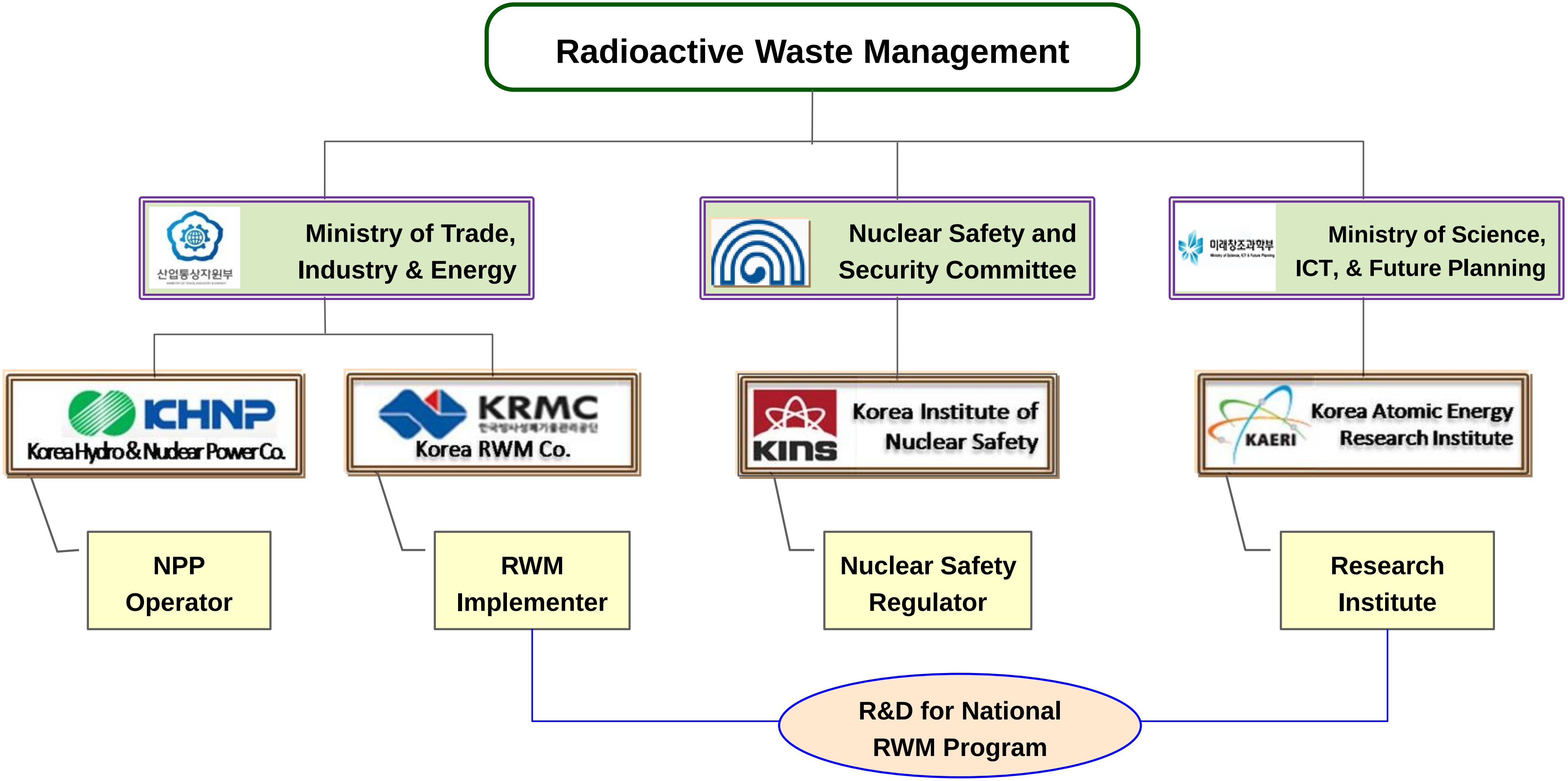
    → Now considering to delay to 2024
  - Future national policy for SF management will be decided through public debate taking into consideration of national and international trends on policy and technology development.

Act for RW Management in Korea

❑ Radioactive Waste Management Act

- This Act has been effective since January 1st, 2009
- Key contents are:
  - Establish. of a new Org., responsible body for radwaste management
    → Korea Radioactive Waste Management Corporation (KRMC)
  - Establish. of the Radioactive Waste Management Fund which will be paid by the radioactive waste generator(s).
    → KRMC is responsible for managing the Radioactive Waste Management Fund

Organizations Related to RWM in Korea



History of NA Studies in Korea

❑ Feasibility study (2000)

❍ KAERI and KIGAM jointly investigated the feasibility of NA studies focusing on uranium ore deposits in Korea

❍ The distribution and characteristics of Korean uranium ore deposits

→ A potential site for NA studies → Deokpyung-ri uranium ore deposit

→ No further study after this → only small lab-scale studies

❑ ASARR project from 1996 to 1999

❍ KAERI participated in ASARR project at Koongarra uranium ore body, Australia

❍ Research items

- Development of thermodynamic sorption model which can apply to the sorption of U onto soils from Koongarra site (Jung et al., J. Radioanl. Nucl. Chem. 242, 405-412, 1999)
- Development of a reactive transport model and its application and validation (Keum et al., Computers & Geosciences, 29, 431-445, 2003)

⇨ In terms of radioactive waste disposal, no large scale NA study in Korea

Needs of NA Studies in Korea

❑ Considerations for safety case in Korea

- ❍ Recently, safety concept has been changed from safety assessment into safety case
- ❍ Regulation body starts to require a safety case report for licensing a RW repository
- ❍ KAERI is carrying out safety case development for a Korean HLW disposal system

❑ Natural analogue in safety case and regulation

- ❍ NA is important supplementary considerations in safety case development
- ❍ Regulation body (KINS) is now considering to include NA in safety case as main supplementary consideration for HLW disposal
  - → Which NA information should be included ?
  - → Now feasibility study is being carried out by KAERI in support of KINS

NA Studies in Korea

NA Studies in Korea

❑ Studies at uranium ore deposits

- Studies on uranium ore deposits for mining investigation
- Occurrence, uranium minerals, uranium content, uranium anomaly

❑ Studies using rocks

- Distribution of uranium on rock surfaces
- Interactions of uranium with primary and secondary minerals from granitic rocks (KURT)

❑ Studies using groundwaters

- Contamination of groundwaters by uranium
- Geochemical behaviors of uranium at deep granitic groundwaters (KURT)
- Redox reaction of uranium in deep groundwaters

❑ Studies using ancient tombs

- Ancient toms for cover-layer performance for near-surface LILW disposal

Studies at Uranium Ore Deposits (1)

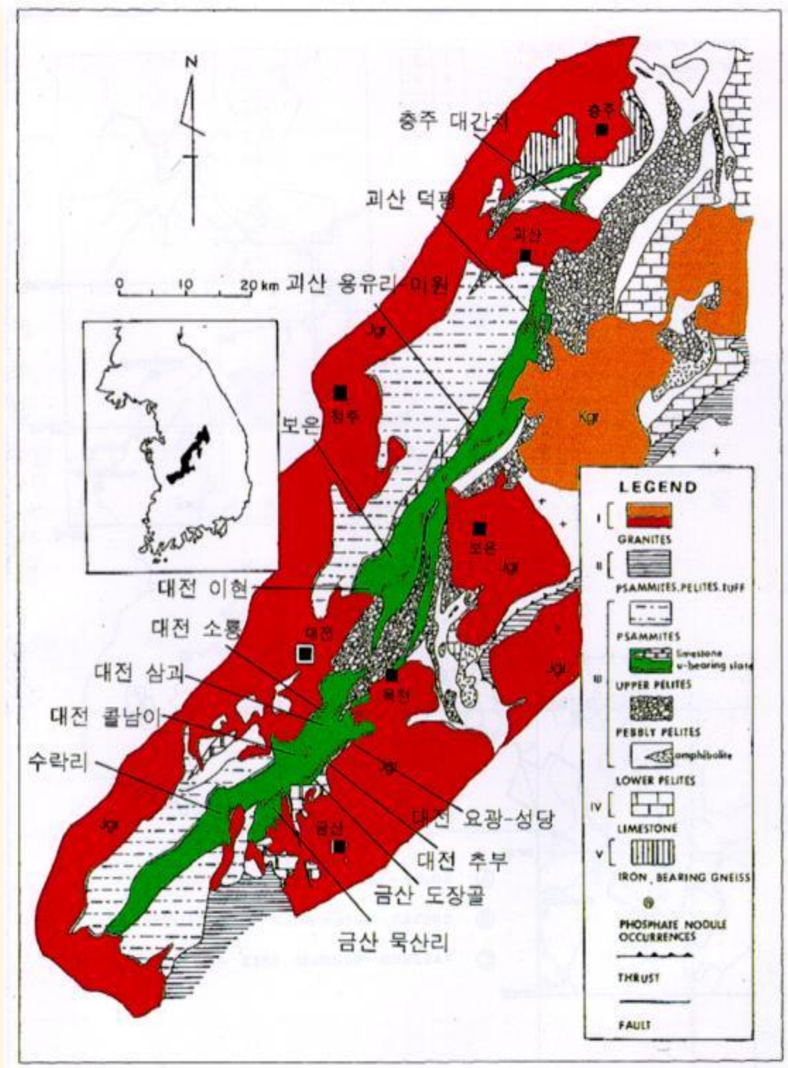
❑ Uranium ore deposits in Korea

❍ **Investigations for uranium mining development**

- 1955 ~ 1976: Preliminary investigation
- 1976 ~ 1985: Large scale investigation

❍ **Uranium deposits of Okchon group**

- Located in Okchon fold belt of middle Korea
- Formed between Silurian and Devonian periods
- Metasedimentary rock
  - Uraniferous black slate, perlite
  - Phyllite & chlorite schist
  - Dolomite, limestone
- U_3O_8 content: 0.02 ~ 0.5%
- Major U minerals: ferro-uranophane, chlopinite, uraninite, etc



[Uranium Deposits of Okchon Group]

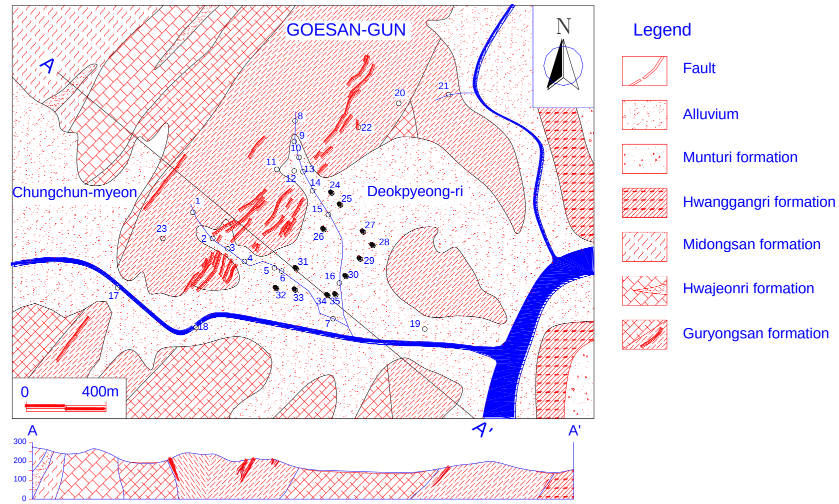
Studies at Uranium Ore Deposits (2)

❑ Deok-pyoung uranium ore deposits

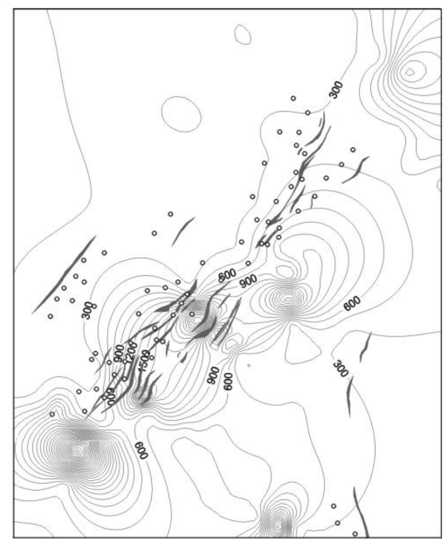
- **Feasibility study as a NA study site in 2000**
  - Goesan municapal, middle Korea
  - Black slate containing uranium
  - 0.041% U_3O_8 (Kim et al., KAERI TR-1527/2000, 2000)
  - Length: 200-300 m (1650 m max)
  - Width: 0.1 ~ 20.9 m (3.9 m).

(D. Shin and S. Kim, Econ. Environ. Geol. 5, 2011)

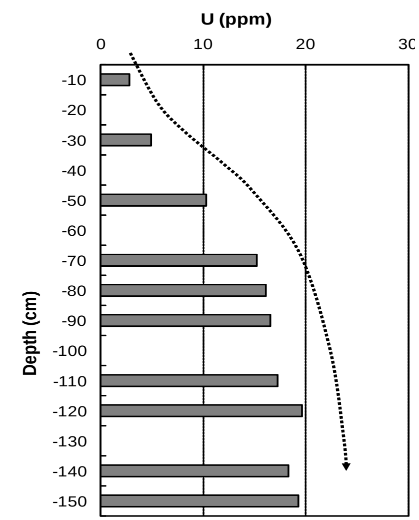
- **Geological environments**
  - Located within Okchon folded belt
  - Major U minerals: uranite, autunite, metatorbernite
  - Occurred by sedimentary deposit
- **Radioactivity survey using γ-counter**
  - Surface investigations on 3 lines: Lines A, B, C
  - Activity: 15 ~ 300 cps
  - Distribution is similar to the uranium contents
- **Distribution of uranium with depth**
- **Surface waters and groundwaters**



[Geological map and geological section of the Deokpyoung area]



[γ-radioactivity contour map]



[Distribution of U with depths]

Studies Using Rocks (1)

❑ Daebo granite

- **Samples**
  - Around Deok-pyoung uranium deposit, Goesan, Korea
  - Drilling cores from boreholes (~ 200 m length) at aquifer zone (40~90 m depth)
- **Mineralogy and groundwater**
  - Granite mainly quartz, microcline, muscovite, chlorite
  - Ca-Na-HCO_3 type groundwater
  - U concentrations in GW: 22.8 ~ 43.4 ppb
- **Observations**
  - No relationship of U contents in groundwaters and cores
  - U mainly involved in the zircon, monazite, xenotime, acanthite(Ag_2S) of 1~2 μm size
  - (Th, U)SiO_4: huttonite and thorite in monazite
  - Monazite(Ce, La, Th)PO_4 contains no U

❑ Two mica granite (Jeong et al., KSEG Conference . 2010)

→ Higher contents of U in two-mica granite (0.371 ~ 47.42 ppm of U)

	DYJ(Yeoju)	DHG(Pocheon)	DJW(Goesan)
	(mg/L)	(mg/L)	(mg/L)
Si	22.2	18.0	13.3
Al	0.0	0.0	0.0
Fe	0.0	0.0	0.0
Mg	1.1	1.1	0.5
Ca	21.2	13.2	2.9
Na	20.5	5.4	6.4
K	0.4	0.4	0.3
As	0.0	0.0	0.0
Cu	0.0	0.0	0.0
Pb	0.0	0.0	0.0
HCO_3^-	112.9	51.9	67.1
Cl	2.6	3.0	2.6
F	0.0	0.0	0.1
U*	*43.4	*24.1	*22.8
EC(uS/cm)	211.0	104.9	128.9
Eh(mV)	189.0	244.0	
pH	7.8	6.8	7.5
T(℃)	18.6	13.8	15.1
water type	Na-Ca-HCO_3	Ca-Na-HCO_3	Na-Ca-HCO_3
core sample depth(m)	55	43	90
maximum well depth(m)	200	200	200
uranium in rock(ppm)	9.1	8.4	15.3
rock type	Daebo granite	Daebo granite	Daebo granite

* μg/L for uranium

[Chemical compositions of GW and core samples]

(C. O. Choo, J. Miner. Soc. Korea 15, 2002)

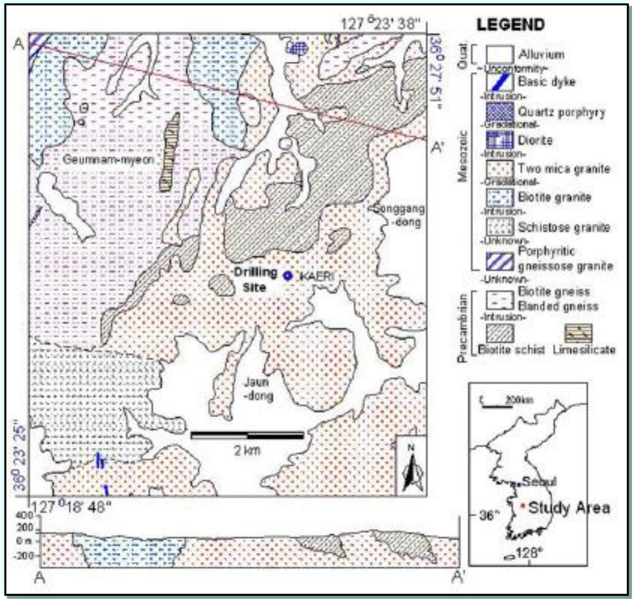
Sample	YJ-Th	YJ-U	YJ1-M
UO_2	2.375	46.393	
ThO_2	47.015	5.107	6.349
Ce_2O_3	11.609		25.688
SiO_2	16.543		3.513
Y_2O_3		28.168	
La_2O_3	6.701		15.707
CaO	1.079	0.536	0.636
Nd_2O_3			9.403
Bi_2O_3			4.888
Cs_2O			0.899
Xe			0.733
P_2O_5	14.678	19.785	31.137
total(wt.%)	82.947	100	67.816

[Chemical compositions of radiogenic element-bearing minerals]

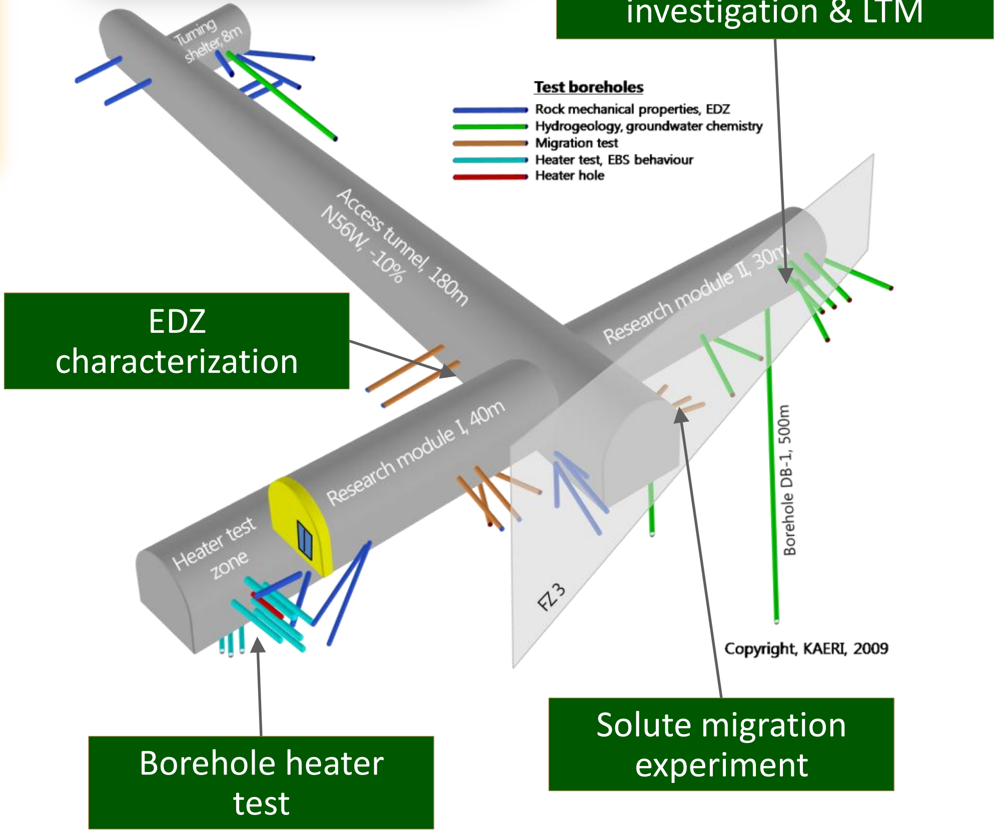
Studies Using Rocks (2) - KURT

❑ KURT Overviews

- Excavation completed in 2006
- Moderately fractured two mica granitic rock
- 100 m overburden
- 6 m x 6 m section
- 180 m access tunnel, 75 m research module
- Non-radioactive works
- A partner facility for IAEA URF Network



[Location and geological map of KURT]



Studies Using Rocks (3)

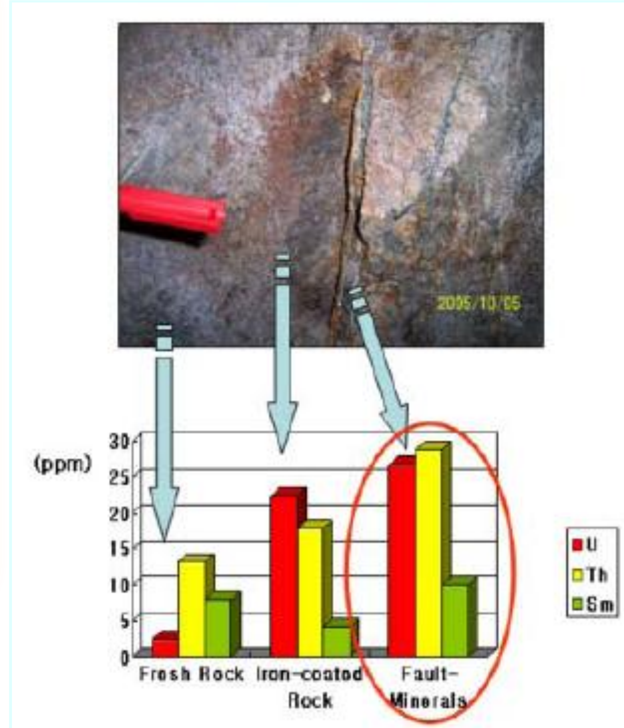
❑ KURT granite

❍ Mineralogy

- Two-mica granite
- Mainly quartz, microcline, biotite, muscovite, plagioclase
- Fracture fillings: smectite, illite, chlorite, calcite/dolomite, laumontite

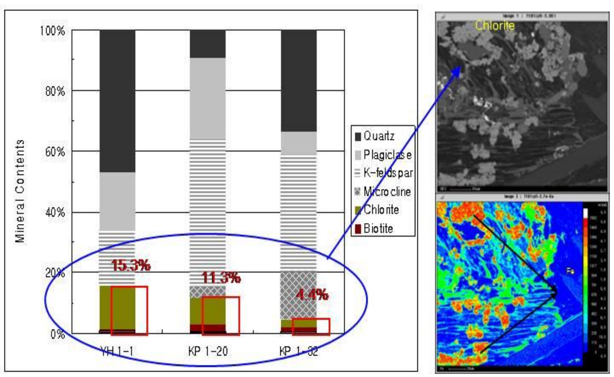
❍ U distribution

- U is mainly contained in fracture filling and coating materials
- U is mainly contained in Fe-bearing minerals such as mica

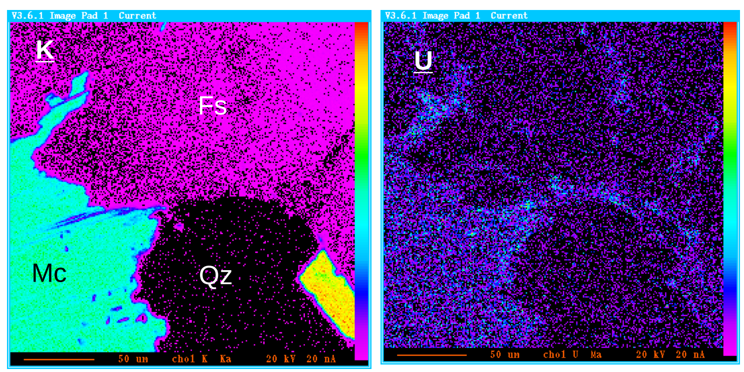


[U contents in KURT rocks and minerals]

(Lee et al., J. Miner. Soc. Korea,20, 2007)



[Major minerals in KURT granite]



[Uranium distribution in intact granite]

(Baik et al., Radiochm. Acta 92, 2004)

Studies Using Rocks (4)

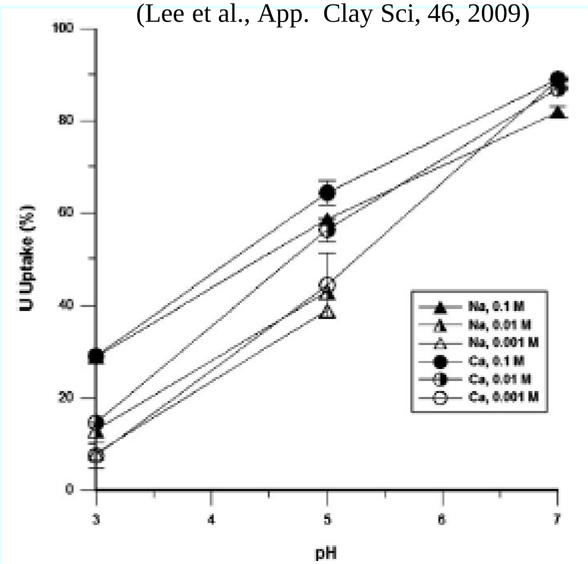
❑ Lab studies using KURT granite

- U sorption onto granite and fracture filling minerals
- U sorption onto biotite, iron oxides, clay minerals
- Weathering effects of U sorption onto granite
- Rock matrix diffusion of RNs

Nuclide	D_a (m^2/s) (Weathered granite) $\varepsilon = 0.023$	D_a (m^2/s) (Domestic fresh granite) $\varepsilon = 0.003$	D_a (m^2/s) (Foreign fresh granite)
THO	$> 1.0\times10^{-10}$	5.7×10^{-10}	2.87×10^{-10}
Np	8.66×10^{-11}		3.3×10^{-15}
Th	1.06×10^{-10}	1.1×10^{-14}	5.0×10^{-19}
Eu	3.96×10^{-12}	3.2×10^{-17}	-
U	3.35×10^{-11}	1.7×10^{-13}	4.7×10^{-13}
Co	1.67×10^{-10}	4.8×10^{-16}	4.8×10^{-16}
Sr	2.21×10^{-10}	6.4×10^{-14}	1.4×10^{-14}
Cs	5.46×10^{-12}	7.3×10^{-15}	7.2×10^{-15}

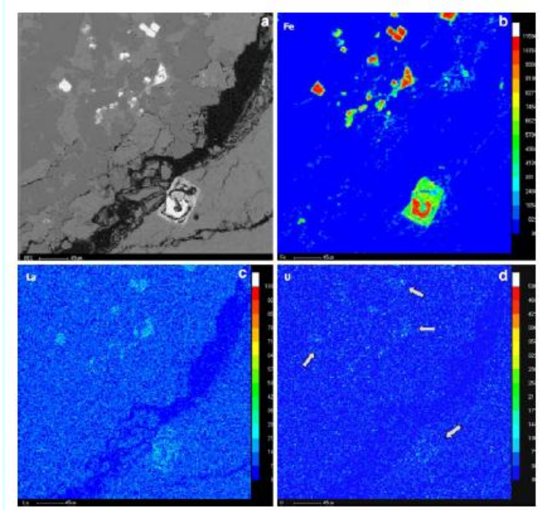
[Rock matrix diffusion of RNs using KURT granite]

(Lee et al., App. Clay Sci, 46, 2009)



[U sorption onto biotite]

(Lee et al., Environ. Geochem. Health 31, 2009)



[A backscattered-electron image and element maps for crystalline iron oxides found in the weathered granite]

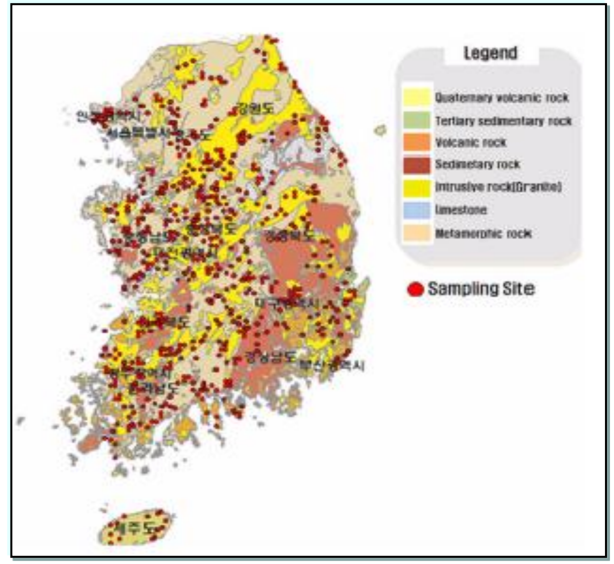
KAERI Korea Atomic Energy Research Institute

Studies Using Groundwaters (1)

❑ U concentration in groundwaters

- NIER (National Institute of Environmental Research)
  - 1st investigation: 1999 ~ 2002
  - 2nd investigation: 2006
  - 3rd investigation: 2007 ~ 2011
  - Investigation points: > 1000 (analysis 681 points)
- **Uranium MPC in Korea : 30 ppb**
  - → average concentration of U < 30 ppb in all areas
- Geology and U concentration are related

(Jeong et al., J. soil & Groundwater Env. 16, 2011)



[Sampling locations by NIER]

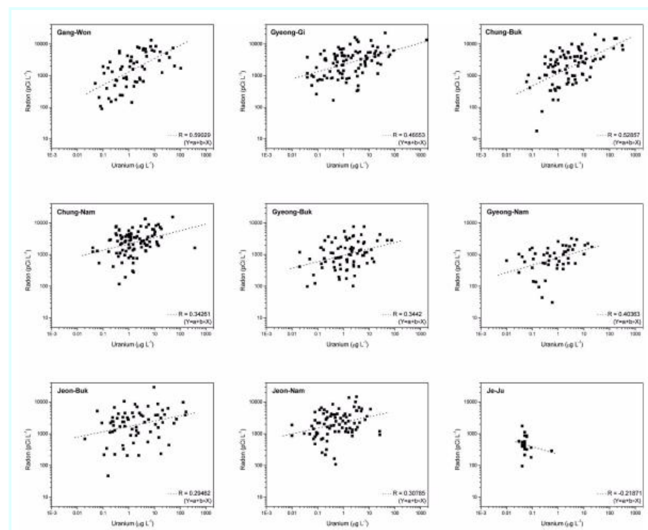
(A) Uranium

Province	No. of Sampling sites	Minimum	Maximum	Average	Median	Skewness
Gangwon	67	<0.01	106.22	6.86	1.29	4.20
Gyeonggi	96	<0.01	1,757.00	25.70	1.31	9.70
Chungbuk	91	0.06	335.50	18.64	2.45	4.51
Chungnam	99	<0.01	378.70	7.47	1.25	9.54
Gyeongbuk	84	<0.01	75.97	4.26	1.34	5.18
Gyeongnam	56	<0.01	21.04	1.99	0.46	3.38
Jeonbuk	70	<0.01	170.25	13.20	1.54	3.76
Jeonnam	97	<0.01	26.21	1.72	0.43	4.89
Jeju	21	0.03	0.56	0.08	0.05	4.47

(B) Radon

Province	No. of Sampling sites	Minimum	Maximum	Average	Median	Skewness
Gangwon	67	89	13,145	2,830	1,744	1.29
Gyeonggi	96	167	22,059	3,875	3,162	2.22
Chungbuk	91	3	19,773	3,373	2,284	2.11
Chungnam	99	117	15,467	3,397	2,662	1.84
Gyeongbuk	84	68	7,589	1,488	952	2.04
Gyeongnam	56	31	3,241	1,025	801	0.96
Jeonbuk	70	46	29,222	3,198	2,299	4.41
Jeonnam	97	108	14,516	2,948	2,147	2.06
Jeju	21	95	1,736	539	433	1.88

[Statistical analysis result for U (ppb) and Rn (pCi/L)]



[Correlation between U and Rn in groundwaters]

Studies Using Groundwaters (2)

❑ U/Rn concentrations in granitic area

❍ Sampling (Cho et al., J. Eng. Geol. 21, 2011)

- 74 points of groundwaters from Icheon granite area

❍ U/Rn concentrations

- U concentrations: 0.02 ~ 1540 ppb (median 2.03 ppb)
- Rn concentrations: 40 ~ 23400 pCi/L (median 4649 pCi/L)
- 8 points (10.8%) of U exceed 30 ppb (USA/Korea)
- 44 points (59.5%) of Rn exceed 4000 pCi/L (USA)
- 10 points (13.5%) of Rn exceed 8100 pCi/L (Finland)
- High correlations with U-HCO_3 (0.71), U-Ca (0.69)

❑ Uranium concentrations in Okchon group

❍ U concentrations (H. Jeong, J. Kor. Earth Soc. 31, 2010)

- U conc. in surface water: 0 ~ 371 ppb (avg. 9.4 ppb)
- U conc. in groundwater: 0 ~ 98 ppb (avg. 4.0 ppb)
- U conc. in mine water: 51.2 ~ 3334 (avg. 1250 ppb)

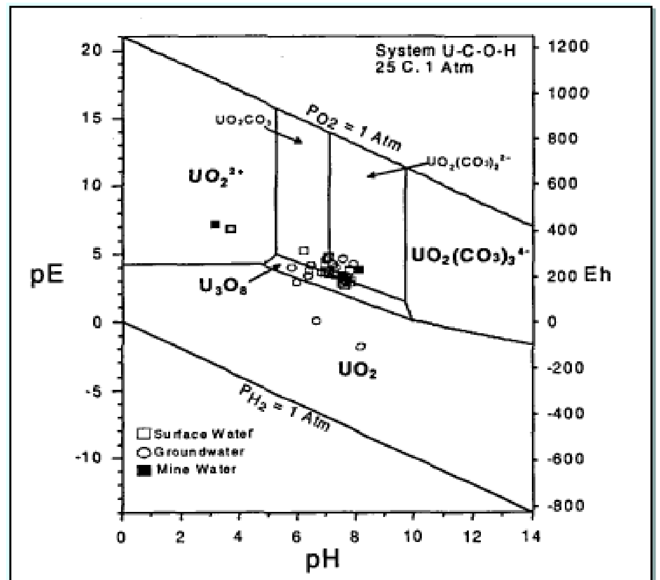
❍ Uranium species

- Ca-HCO_3 type groundwater
- Mainly uranyl carbonate
- Good correlations with Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-

Country	Sample	U (μg/L)		Rn (pCi/L)	
		Max.	Geology	Max.	Geology
Korea (Icheon)	74	1,640	Granite	23,400	Granite
Finland[1]	25,000 <	12,400	Granite	2,094,825	Granite
Norway	4,000 <	2,000[2]	Granite	862,257[3]	Granite
Sweden	35,000 <	-	-	1,540,710[4]	Granite
Canada[5] (Manitoba)	287	2,020	Granite	371,270[6]	Gneiss Granite
USA	200,000<	10,299[6]	Granite	1,600,176[7]	Granite

[1]Salonen and Hukkanen, 1997, [2]Frengstad et al., 2000 [3]Banks et al., 1998, [4]Morland et al., 1997, [5]Betcher et al., 1987, [6]Cothern and Rebers, 1990, [7]Lowry et al., 1987

[U and Rn concentrations in granitic areas]



[U species in Okchon area]

Studies Using Groundwaters (3)

❑ Uranium in KURT groundwater

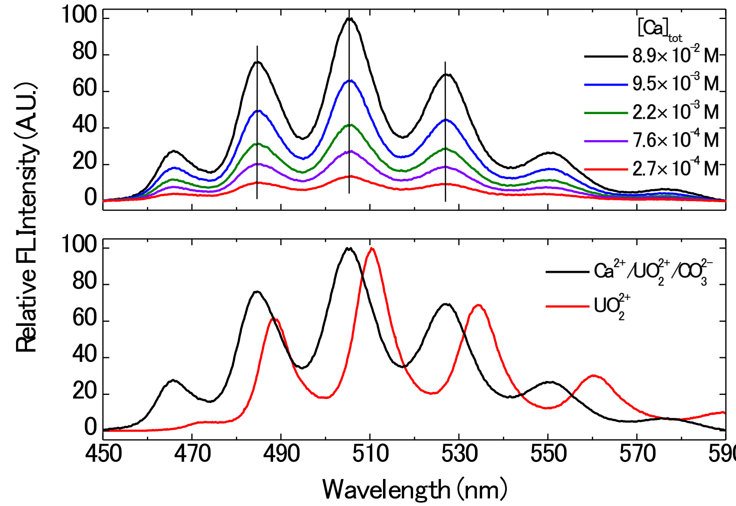
- **KURT groundwater**
  - Sampled from DB-1 of 500 m depth (multi-packer)
  - Ca-Na-HCO_3 type → Na-HCO_3 type with depth
  - U conc. :4.88 ~ 704 ppb
- **Activity ratios of uranium isotopes**
  - $^{234}U/^{238}U$: 0.993 ~ 1.39 by α-spectrometry
  - Naturally occurred and different origins
- **Uranium speciation by TRLFS**
  - Calcium uranyl carbonate ternary complex
  - log β^0 = 27.1 ± 0.14 for $CaUO_2(CO_3)_3^{2-}$ (τ=12.7 ns)
  - log β^0 = 29.84 ± 0.26 for $Ca_2UO_2(CO_3)_3(aq)$ (τ=29.2 ns)

Sample position	Depth(up) (m)	pH	Eh (mV)	EC (μS/cm)	U (ppb)
i2	43.6 ~ 59.5	8.6	177	159	11.9
i3	92.0 ~ 116.0	8.8	236	131	704.0
i4	156.0 ~159. 0	8.7	498	145	26.9
i5	183.0 ~ 194. 0	8.6	398	160	10.8
i6	201.5 ~ 226. 0	8.9	-107	159	4.88
i7	234.0 ~ 244.0	8.5	-191	174	5.03
i8	279.0 – 293.0	9.0	-56	172	2.77

[U concentrations from DB-1 borehole of KURT]

Sample position	Activity of U			Activity ratio	
	U-238	U-235	U-234	$^{234}U/^{238}U$	$^{235}U/^{238}U$
i2	407.1	16.5	472.2	1.16	0.0455
i3	103554.5	413.8	12019.6	1.16	0.0400
i4	1610.7	63.8	2244.5	1.39	0.0396
i5	5119.1	251.9	5051.6	0.987	0.0492
i6	6079.6	234.0	6000.8	0.987	0.0385
i7	5076.4	207.5	5040.2	0.993	0.0409

[Activity ratios of U isotopes from DB-1 borehole of KURT]



[TRLFS spectra of U species in KURT groundwater]

Studies Using Ancient Toms

❑ Archeological analogue study using ancient tombs

(Park et al., J. Kor. Radioac. Waste Soc. 3, 279-291, 2005)

❍ Purpose

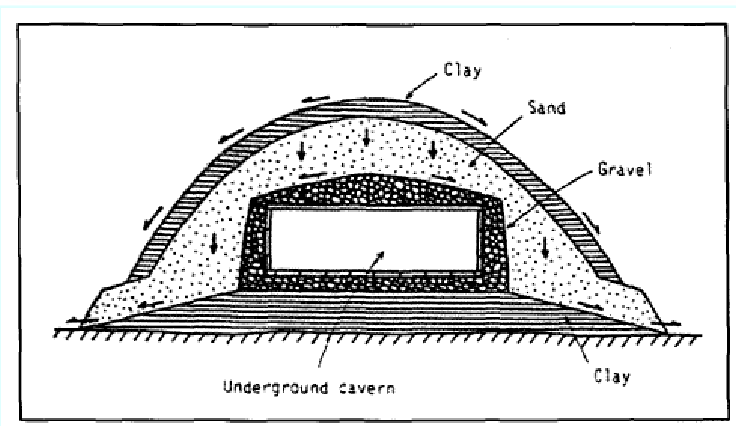
- To support the design concept and the performance assessment of the cover system for LILW disposal facility
- Using ancient toms from Chang-nyung Kyo-dong in the Three Kingdom Period (excavated in 1992)
- Diameter = 22.5 m, stone chamber and clay liner

❍ Investigations

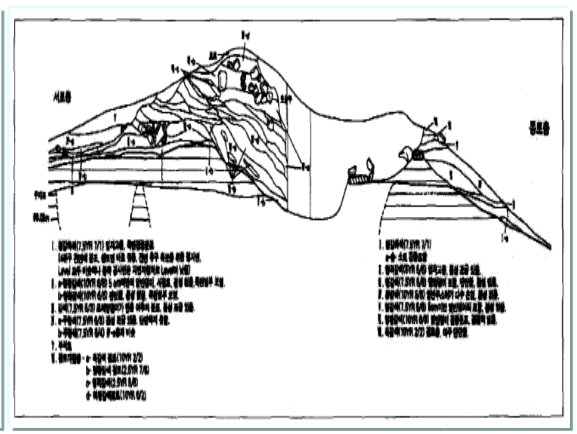
- Hydraulic conductivity of the unsaturated cover soil using HYDRUS 1-D program
- Hydraulic property of the cover soil between clay/sand (70:30) and silt/sand(70:30)

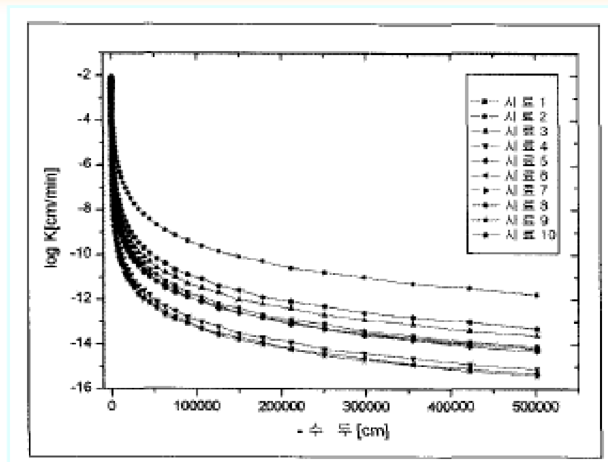
❍ Lessons learned

- Sample should be collected when tombs are excavated
- Communication and collaboration with archeological society is necessary



[Conceptual diagram for natural analog study]


[Soil layer of the ancient tombs]



[Hydraulic conductivity wrt hydraulic head]

NA Information Database

Application of NA Information

❑ Application of NA information

❍ Application methods

1) Direct methods

- Quantitative: Data acquisition, Model calibration
- Qualitative : Conceptual model development
- Illustrative

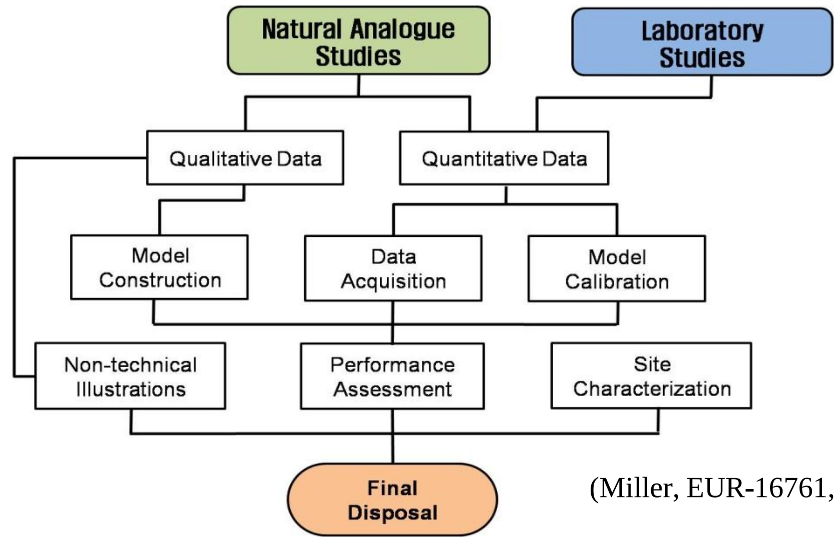
2) Indirect methods

- FEPs identification
- Scenario development

❍ How to use NA information

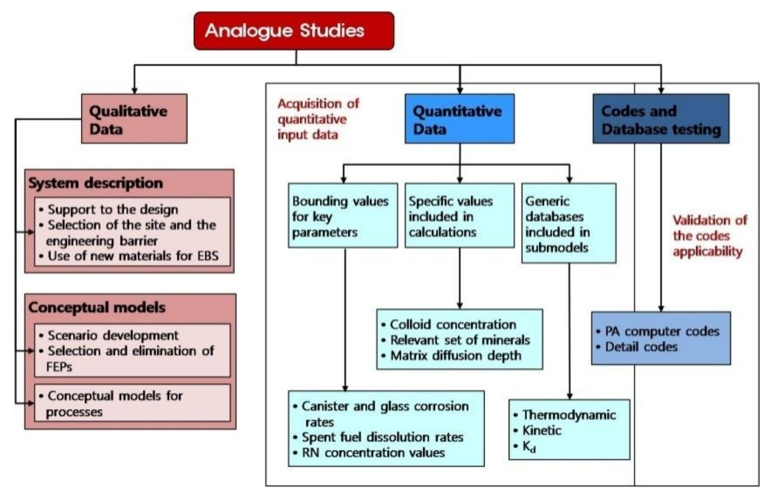
- Large amount of NA information
- Lack of methodology
  (e.g., NA information matrix)
- Easy use in safety case development

➡ **Natural Analogue Information Database**



(Miller, EUR-16761, 1996)

[Relationship between safety case components and NA information]



[Direct application of NA information in safety case]

NA Information Database (1)

❑ NA information database

❍ **Database**

- Collect ~ 170 NA information from papers, reports, and books
- Database by using MS-Excel program
- NA information data were categorized and evaluated

❍ **Categories**

- Site information for the NA site
  - Geological formation: Crystalline, Sediment, Sandstone…, • Site name/location, • Nationality
- Disposal system and components/processes corresponding to NA information
  - System: EBS, NBS
  - Component/Process: Main components of EBS and processes of NBS
  - Properties/Phenomena: Properties and phenomena related to the components and processes
- Basic Information: Information which can be obtained (e.g., hydraulic barrier, colloid filtration)
- NA Information: Brief description of NA information
- Reference: References where NA information was obtained
- Safety case: If any, the safety case applied to
- Application: Classification of NA information according to the application methods to safety case
- Suitability: Evaluation of NA information based upon the suitability to domestic safety case

NA Information Database (2)

❑ Categories of NA information in the database

System	Component Process	Properties/Phenomena
EBS	Silicate glass	Devitirification
		Radiation induced effects
		Dissolution and alteration
		Radionuclide retardation by secondary alteration products
	Spent nuclear fuel	Dissolution and radionuclide release
		Radionuclide retardation by secondary alteration products
		Etc.
	Metal	Durability and longevity of iron and steel
		Durability and longevity of copper
		Radionuclide retardation by secondary alteration products
	Bentonite	Longevity of bentonite and the rate of alteration
		Physico-chemical changes due to heating
		Canister sinking
		Interaction with other repository materials
		Hydraulic barrier and colloid filter functions
	Concretes and cements	Durability of cement
		Cement-rock-groundwater interactions
		Radionuclide sorption
		Colloid production and filtration
		Gas and water permeability
		Bonding properties of cement and concrete
	Bituman	Durability and longevity
		Groundwater leaching
		Microbial degradation
		Radiation induced degradation
		Interaction with saline water
	Organic materials	Cellulose degradation
		Cellulose degradation products
		Natural resins

System	Component Process	Properties/Phenomena
NBS	Elemental solubility and speciation	Elemental solubility
		Speciation
	Elemental retardation	Transport and retardation within fractured crystalline rocks
		Transport and retardation within argillaceous rock
		Transport and retardation within volcanic ash deposit
		Transport and retardation within evaporites
		Transport and retardation at the geosphre-biosphere interface
		Measurement of in situ distribution coefficient
	Matrix diffusion	Depth and volume of interconnected porosity
		Bulk rock chemical buffering capacity
		Extent of matrix diffusion in sedimentary formation
		Estimation of diffusion coefficient
	Radiolysis	Process involved in radiolysis of groundwater
		Radiolysis in nature (how common is radiolysis in nature)
		Potential buffering capacity of reduced iron corrosion phases from corroding engineered barriers
	Redox Front	Redox front formation and behavior in crystalline rocks
		Redox front formation and behaviour in argillaceous rocks
		Radionuclide migration at a redox front
	Colloids	Populations of colloids in natural systems
		Stability of colloids in natural systems
		Radionuclide uptake and transport by colloids in natural system
		Colloid in anthropogenic systems
		Biocolloids
	Microbial activity	Microbial populations at depth in natural systems
		Tolerance to hyper alkaline conditions
		Netrient and Energy availability
	Gas generation and migration	Gas production rates
		Gas migration and reaction with the geosphere
		Gas migration effects on solute transport

NA Information Database (3)

❑ Classification of NA information by application methods

	Categories	Description
Quantitative	**ISP** (Input for Safety and Performance Assessments)	• Direct application as input parameters for safety/performance assessments of a repository
	MV (Model Validation)	• Direct application in model development and validation for safety/performance assessments of a repository
Qualitative	**SD** (Scenario Development including FEPs)	• Indirect application as FEPs and scenario developments necessary for safety/performance assessment of a repository
	UI (Understanding Improvement)	• Direct application as information for understanding improvement on the behaviors of disposal system including EBS and NBS
	DE (Demonstration and Education)	• Direct application as demonstration and education materials to the public and stakeholders for the radioactive waste disposal

NA Information Database (4)

❑ Classification of NA information by suitability to domestic safety case

		Applicability to Domestic Safety Case	
		High	Low
Importance in Safety Case	High	1	2
	Low	3	4

Categories	Description
1	• NA information important in the safety case and high domestic applicability
2	• NA information important in the safety case but low domestic applicability
3	• NA information not important in the safety case but high domestic applicability
4	• NA information not important in the safety case and low domestic applicability

NA Information Database (5)

Geological formaiton	System	Component Process	Properties Phenomena	Basic Information	NA information	NA Site	Nationality	Reference	Safety case	Application [1]	Suitability [2]
Sandstone	EBS	Spent nuclear fuel	Dissolution and radionuclide release	Dissolution rate	• Dissolution rate, by measuring the amount of FP released (Tracer: TC-99&Ru-99 in rock, I-129 in ground water) - Tc-99: 1.1x10^-6 /yr (Cigar Lake) - I-129: 3x10^-9 ~ 9x10^-9 /yr (Cigar Lake)	Cigar Lake	Canada	Miller et al., 2000		MV	1
Sediment	EBS	Bentonite	Hydraulic barrier and colloid filter funcions	Hydraulic and microvial activity barrier	• 2 million year old preserved forest (enveloped in lacustrine clay, above which are sand deposits with freely circulating, oxidising water, clay envelope restrict ingress of the oxygenated water)	Dunarobba	Italy	Ambrosetti et al., 1992; Benvegnu et al., 1988)	SR-97 (Sweden, 1999)	DE	1
Sandstone	EBS	Bentonite	Hydraulic barrier and colloid filter funcions	Hydraulic barrier	• locally isolated orebody from overlying sandstone(hydraulic conductivity of 10^-6 m/s) host rock by surrounded 10-50m thick illite/kaolinite clay holo(hydraulic conductivity of 10^-9 m/s) for 1300 million years	Cigar Lake	Canada	Sinberg & Stevenson, 1994		MV	2
Granite	NBS	Elemental solubility and speciation	Solubility and speciation	U release - lacial aspect	• in a rock matrix around water-carrying fractures were studied using U-series disequilibrium modelling and mass balance calculations. • Release appears to have occurred in two or three violent episodes during the last 300 ky. A release after the last glaciation can be excluded on mass flow grounds. Continuous release for more than 300 ky can be excluded on radioactive disequilibrium grounds. Repeated inflows of oxic glacial meltwater seem to have triggered th release episodes.	Palmottu	Finalnd	Rasilainen et al., 2003		MV, SD	3
Schistose	NBS	Elemental retardation	Transport and retardation within fractured crystalline rocks	Fracture mineral and retardation	• Uranium-series of the bulk samples indicate that most of the fractures remained as closed systems in the last 1.6 Ma, while in other fractures water/rock interaction processes affecting the upper part of the U-series have been identified. These processes indicate that recent or rapid U accumulation or losses (<1E2 ka), old 234U acculation (> 1E2 ka) or 234U+230Th recoil gain. • closed for U migration, while U retention occurred in most of the open	Mina Fe site	Spain	Crespo et al., 2003		UI	1
Granite	NBS	Matrix diffusion	Depth and volume of interconnected porosity	Diffusion depth	• spatial variablity of matrix diffusion depth (significant alteration around 25 mm and less) results from natural heterogeneity in the rock matrix structure and groundwater flow due to channelling	Palmottu	Finland	Kumpulainen et al., 1992		ISP	1
Crystalline	NBS	Redox Front	Redox front formation and behaviour in crystalline rocks	Redox front migration	• 1-20 m in 1E6 yr, same as the rate of erosion at the site Osamu Utsumi uranium mine, predominantly phonolites: overlying oxidised - iron oxyhydroxides, underlying fesh and reduced - pyrite // model test	Pocos de Caldas	Brazil		SR-97 (Sweden, 1999)	MV, UI	1

1 2 3 4 5 6 7 8 9 10 11 12

1 Geological formation

2 System

3 Component or Processes

4 Properties or Phenomena

5 Basic information

6 NA Information

7 NA site

8 Nationality

9 References

10 Safety case

11 Application

12 Suitability

Use of NA Information Database

❑ NA information suitable for Korean safety case (Suitability Level 1)

System	Component Process	Application	Properties/Phenomena
EBS	Spent fuels	MV	Dissolution rate and processes of spent fuels
		MV	Radiolysis effect on dissolution of spent fuels
		DE	Criticality od spent fuels
		UI	Formation and alteration of uranium minerals
	Metals	ISP, MV, DE	Corrosion rate and corrosion products of copper
		UI, DE	Durability and longevity of copper
		ISP	Pitting factor of copper
		MV, DE	Durability and longevity of iron
		MV, UI, DE	Corrosion rate of iron
		UI	Radionuclide retardation by corrosion products of iron
	Bentonite	UI	Colloid filtration by bentonite
		DE	Hydraulic barrier of bentonite
		DE, UI	Interactions of bentonite with other materials
		DE	Durability and longevity of bentonite
		SD, UI	Alteration of bentonite
		UI	Thermal alteration of bentonite
	Concrete/ Cement	MV, UI	Interaction of cement with groundwater
		UI	Interaction of cement with rocks
		DE	Durability and longevity of cement and concrete

System	Component Process	Application	Properties/Phenomena
NBS	Solubility/ Speciation	MV	Calculation and measurement of solubility and speciation of RNs in groundwater
	Retardation	UI	Radionuclide mobility in rocks
		UI	Radionuclide migration and retardation through rock fracture
		UI	Fracture filling and coating materials
		UI	Interactions of RNs with minerals/oxides
		MV, SD	Migration model development and validation
		ISP, UI	Determination of distribution coefficient
	Matrix Diffusion	ISP, MV, UI	Rock matrix diffusion depths
		ISP, MV, UI	Rock matrix diffusion coefficients
	Radiolysis	UI	Effects of radiolysis in the groundwater
		MV, UI	Gas generation rate by radiolysis
	Redox front	UI	Migration and retardation in the redox front
		MV, UI	Migration of redox front
	Colloids	ISP, UI	Characteristics of aquatic colloids
		ISP, UI	Radionuclide uptake by colloids
		ISP, UI	RN migration by colloids
	Microbial Activity	UI	Characteristics of microbes
		UI	Migration and retardation of RNs by microbes
	Gas Generation/ Migration	UI	Gas migration and reactions with the geosphere

75 NA information was evaluated as suitability level 1 (SL-1) among 176 NA information data (SL-2: 63, SL-3: 15, SL-4: 23)

Remarks and Future Studies

Remarks

- ❑ In this study, the status of natural analogue studies in Korea was investigated and summarized. In Korea, only few NA studies have been carried out but recently the necessities for NA studies are increasing.
- ❑ NA information was collected and a NA information database was developed for effective application of NA information to the safety case. In the database, information was categorized by components of EBS, processes of NBS, and application methods.
- ❑ NA information was evaluated and classified by the suitability to the Korean safety case and 75 NA information were selected as important NA information
- ❑ The results from this study will be used to provide necessary information for the safety case development of radioactive waste disposal and a regulation guide for natural analogue..
- ❑ Natural analogue studies can effectively contribute to the improvement of the disposal safety confidence and can be used as a communication tool among nuclear expert, non-nuclear expert, and the public on the safety of geological disposal.

Future Studies

- We will continue to collect NA information and update the NA information database.
- Methodologies for effective application of NA information to the safety case need to be developed further in the future.
- Natural analogue studies which can be carried out in Korea

  1) NA studies in Okchon uranium deposit (Deokpyungri uranium ore deposit)

  2) NA studies in KURT (Uranium anomaly, redox front, colloids, microbes)

  3) NA studied in bentonite mines around Gyeongju city (near to LILW repository)

  4) Archeological analogue studies for copper and iron
- In Korea, natural analogue studies in terms of radioactive waste disposal are now being planned, so many helps from NAWG may be necessary.

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Thank you for your attention.