Tectonic Hazard Evaluations for Korean Nuclear Sites

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2 Tectonic Environment of Korea

3 Tectonic Hazard Evaluation for Korean NPPs

4 Deal with Uncertainties

5 Conclusions

1. INTRODUCTION

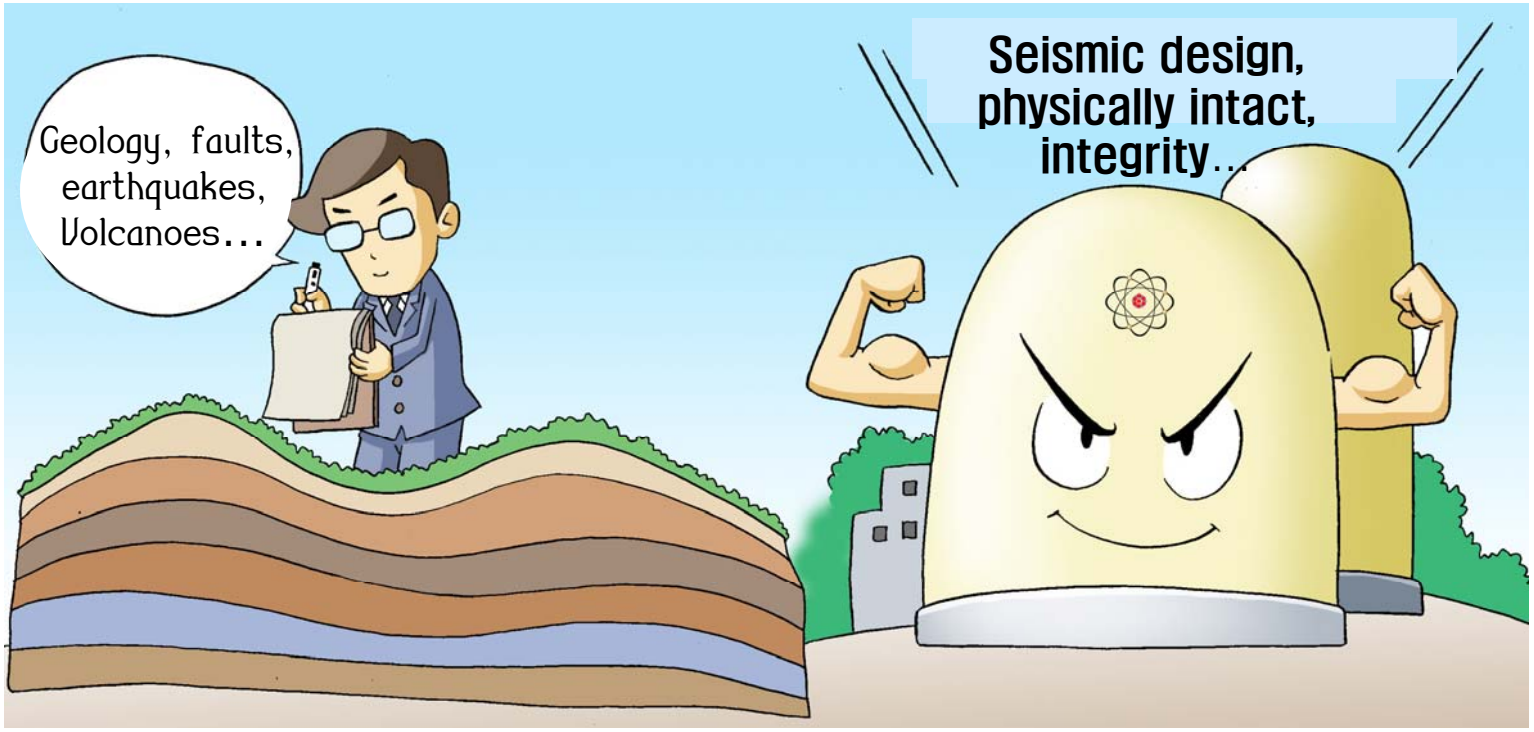
- **Tectonic Hazards**
  - Surface faulting, folding
  - Earthquakes
  - Earthquake-induced hazards
    - Tsunami, Liquefaction, Landslides, etc.
  - Volcanic activities

- **Some Other Geological Features**
  - Karsts, Subsidence, Creep, Landslides,
  - Precipitation, Fast erosion, etc.

1. INTRODUCTION

- **Purpose of Tectonic Hazard Evaluation**

Tectonic hazard evaluation for the safety of NPPs concerns
1. Geological data of the foundation used for the design
2. Siting and site suitability for planed NPPs

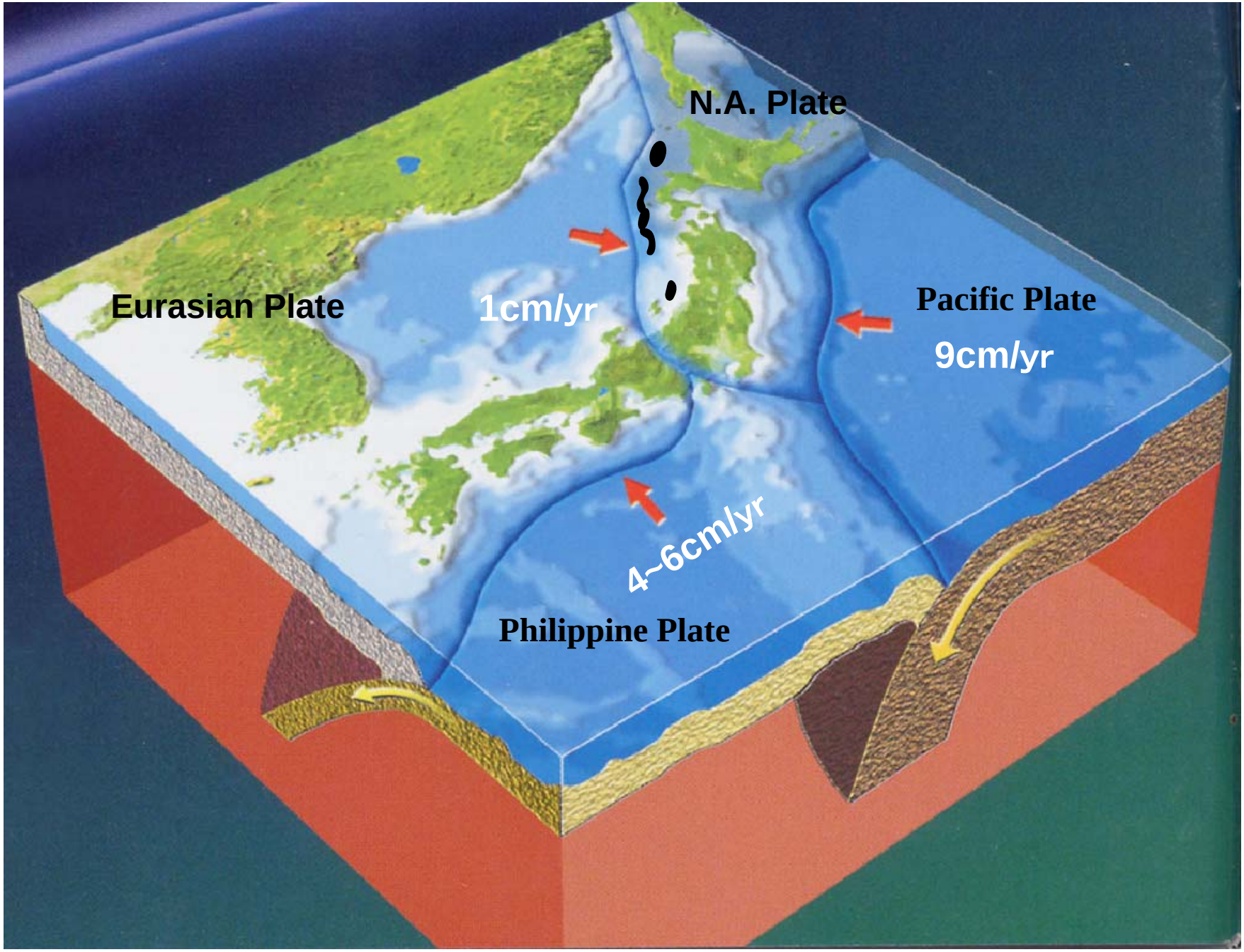


1. INTRODUCTION

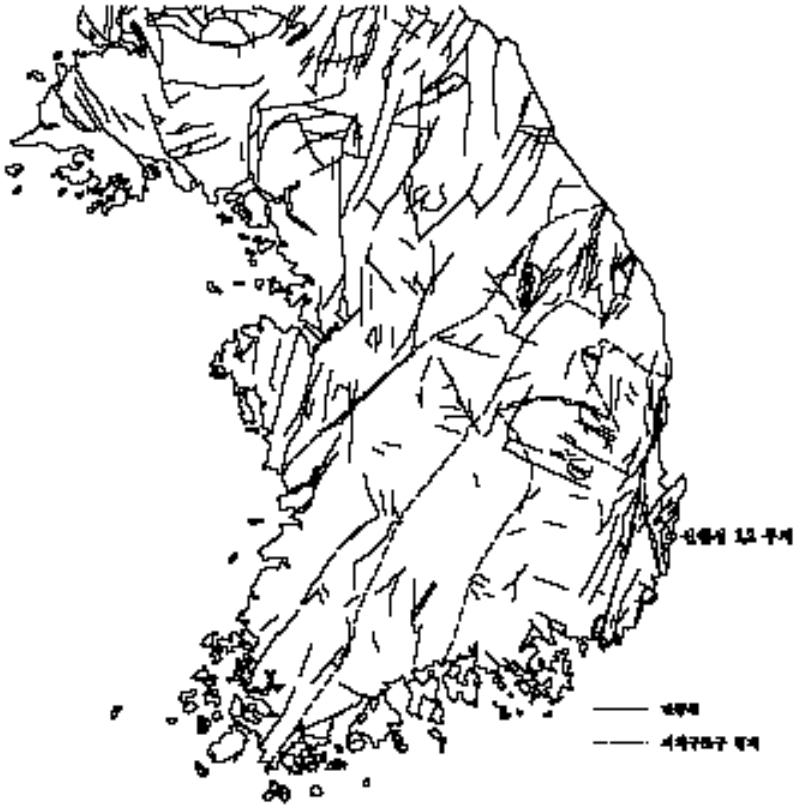
- **Scope of the Presentation**
  - Tectonic Environment of Korea
  - Tectonic Hazards concerned for Korean NPP Sites
  - Safety Evaluation on Tectonic Hazards for NPPs
  - Regulatory Criteria constraint to Tectonic Hazards
  - Uncertainty Issues and the Solution

2. TECTONIC ENVIRONMENT OF KOREA

- Tectonic Environment of Korea
- Regulatory Criteria for Korean NPP Sites
- Tectonic Hazards/Safety Evaluation for NPPs


N.A. Plate
Eurasian Plate
1cm/yr
Pacific Plate
9cm/yr
4~6cm/yr
Philippine Plate

Fracture Map

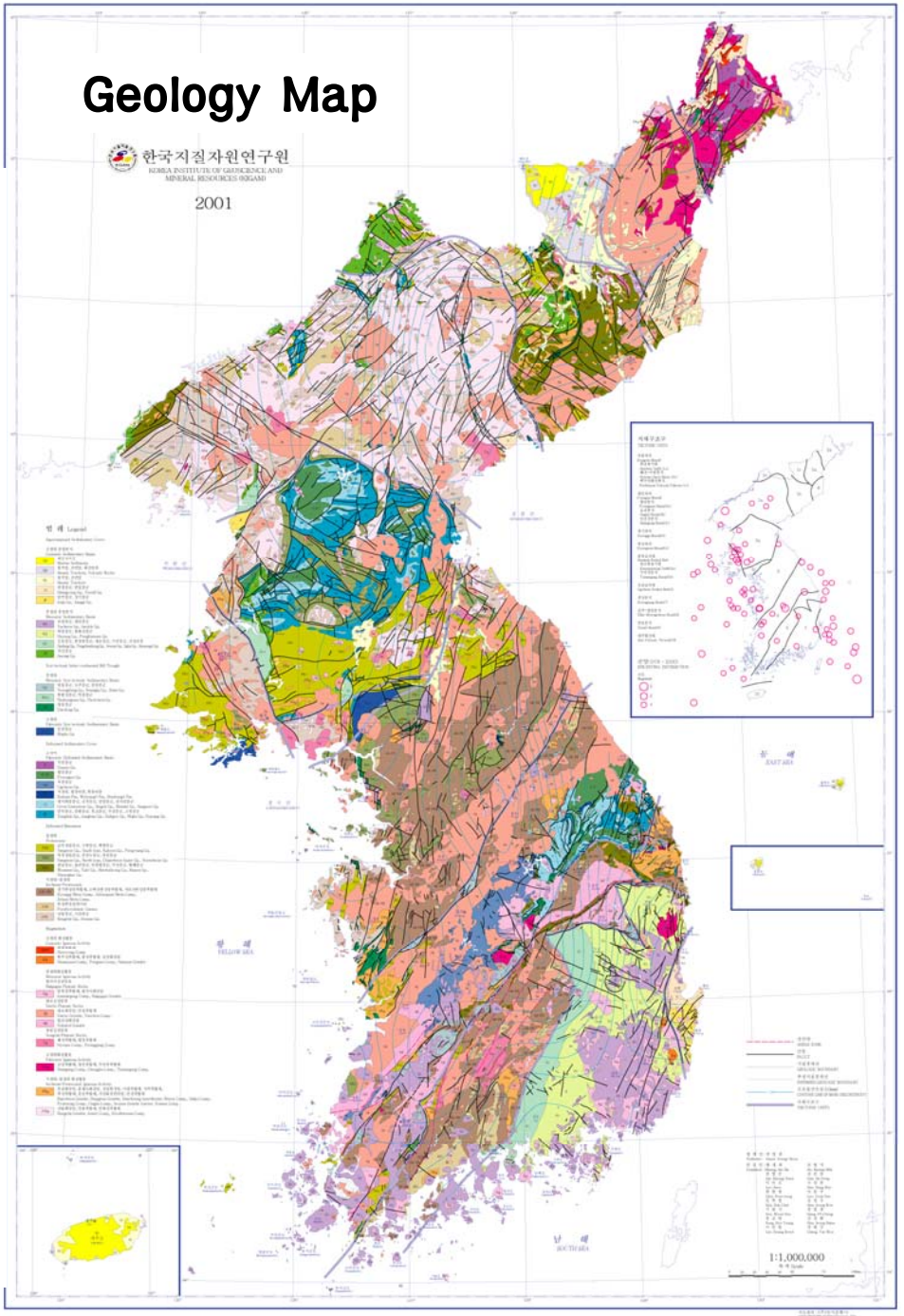


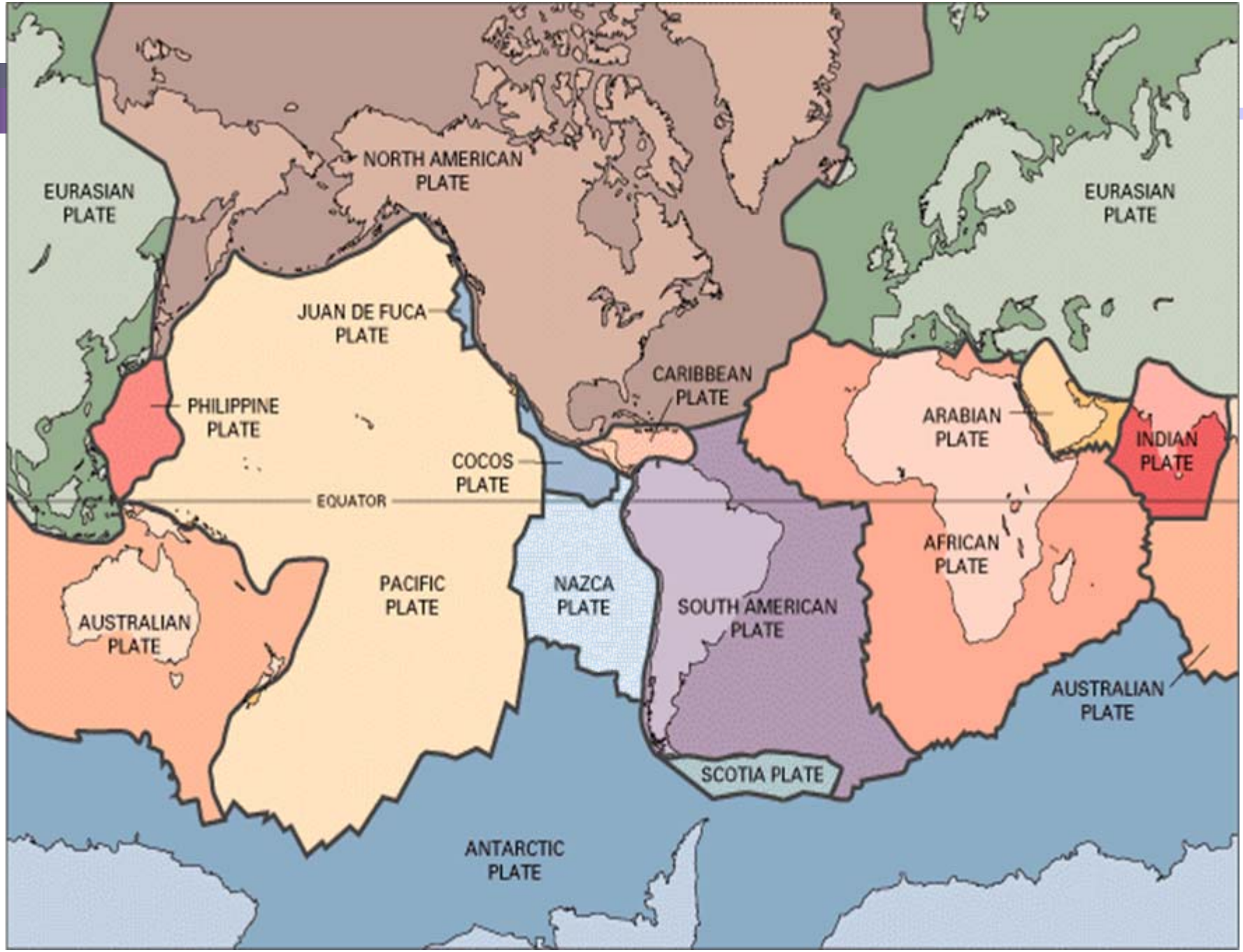
한국수력원자력주식회사
신월성 1,2호기
예비안전성분석보고서

반경 320 km 지역의 단층분포도

그림 2.5-6

Geology Map




EURASIAN PLATE
NORTH AMERICAN PLATE
EURASIAN PLATE
JUAN DE FUCA PLATE
CARIBBEAN PLATE
PHILIPPINE PLATE
ARABIAN PLATE
INDIAN PLATE
COCOS PLATE
EQUATOR
AFRICAN PLATE
PACIFIC PLATE
NAZCA PLATE
SOUTH AMERICAN PLATE
AUSTRALIAN PLATE
AUSTRALIAN PLATE
SCOTIA PLATE
ANTARCTIC PLATE

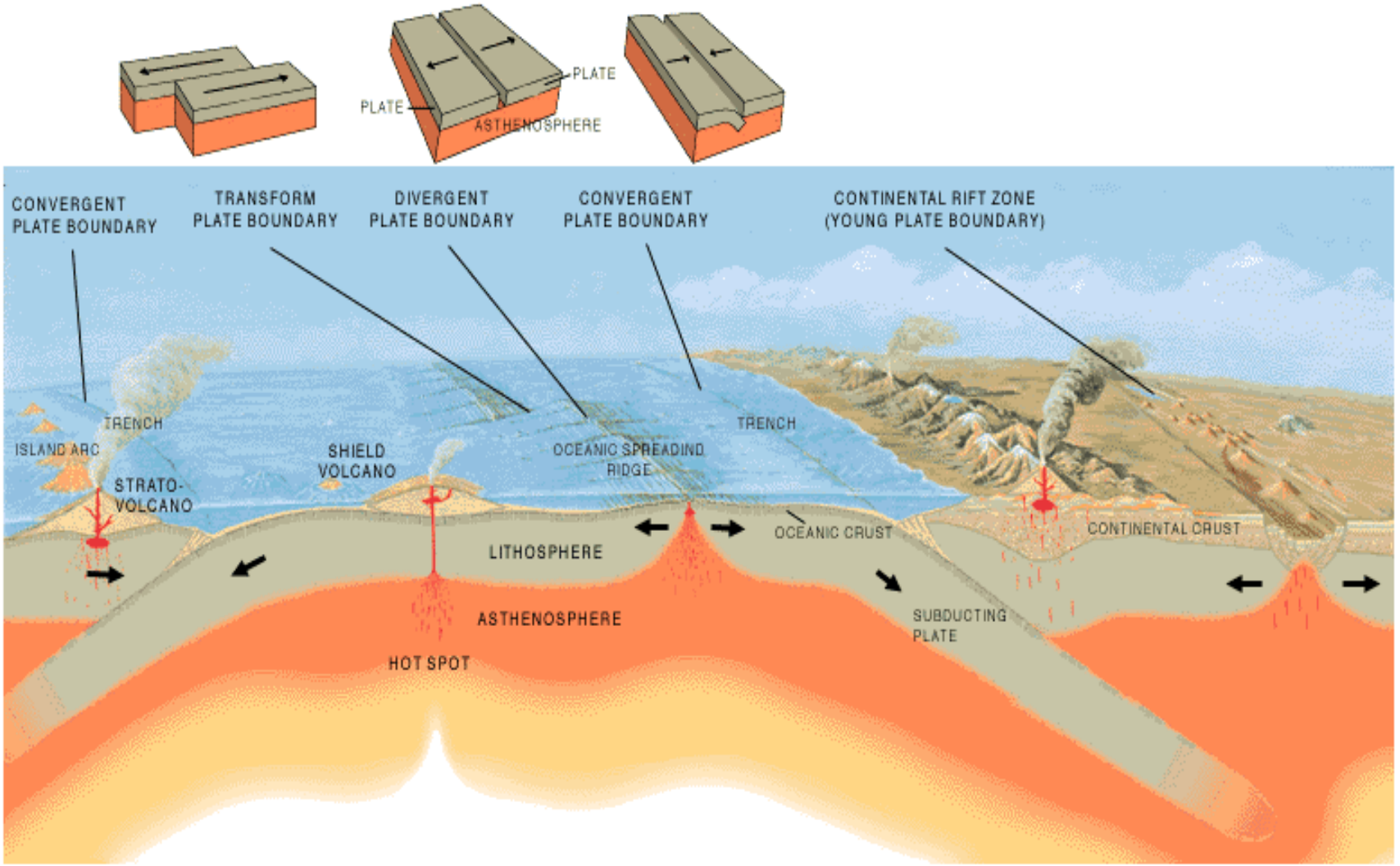
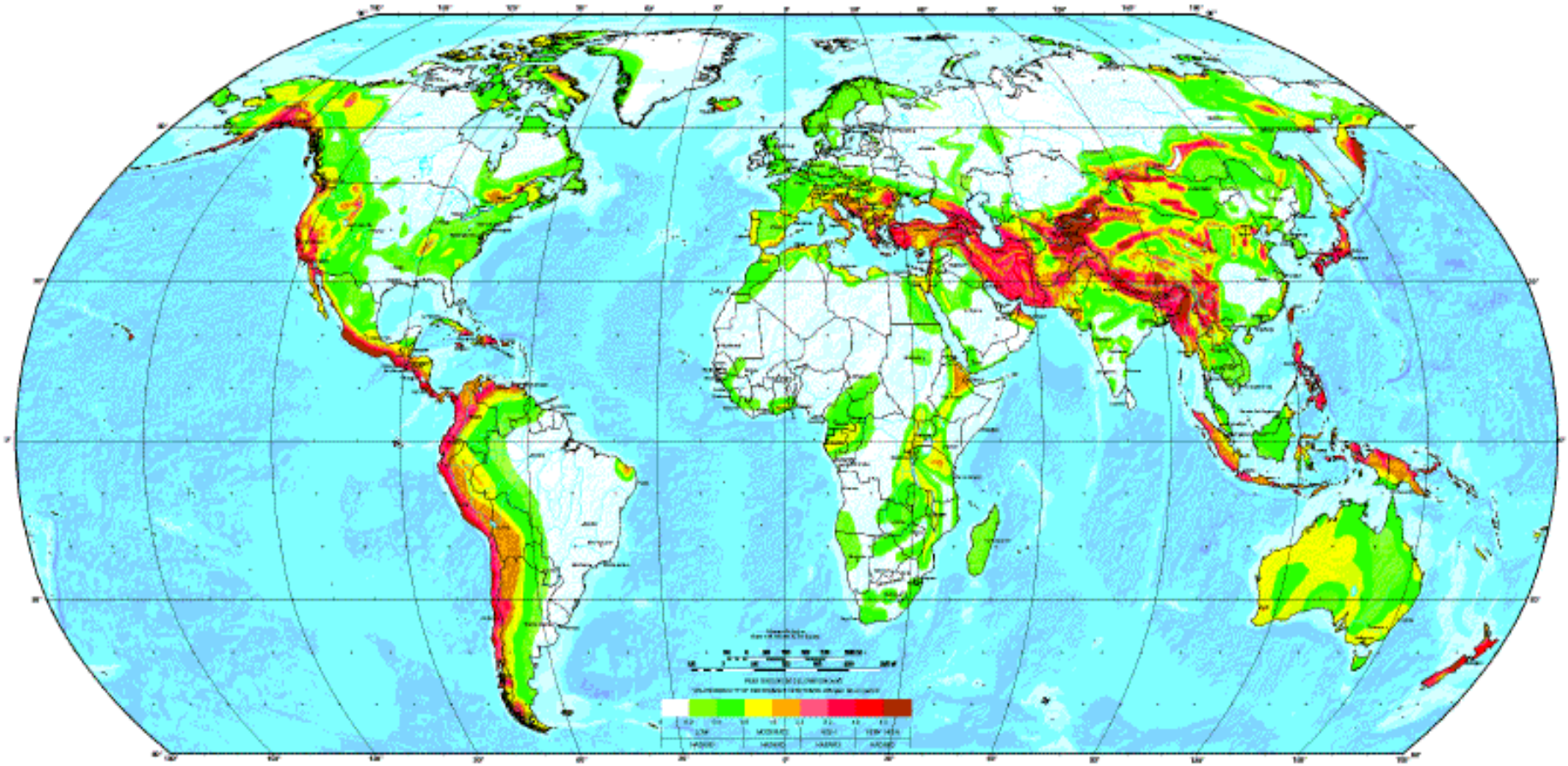
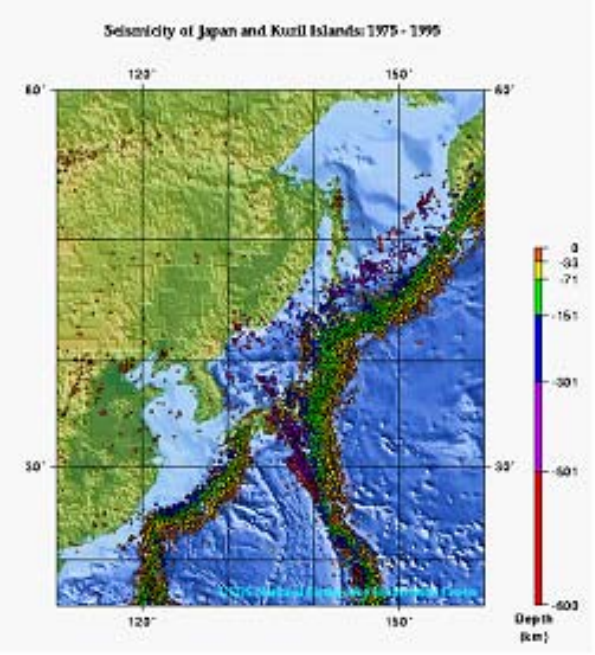
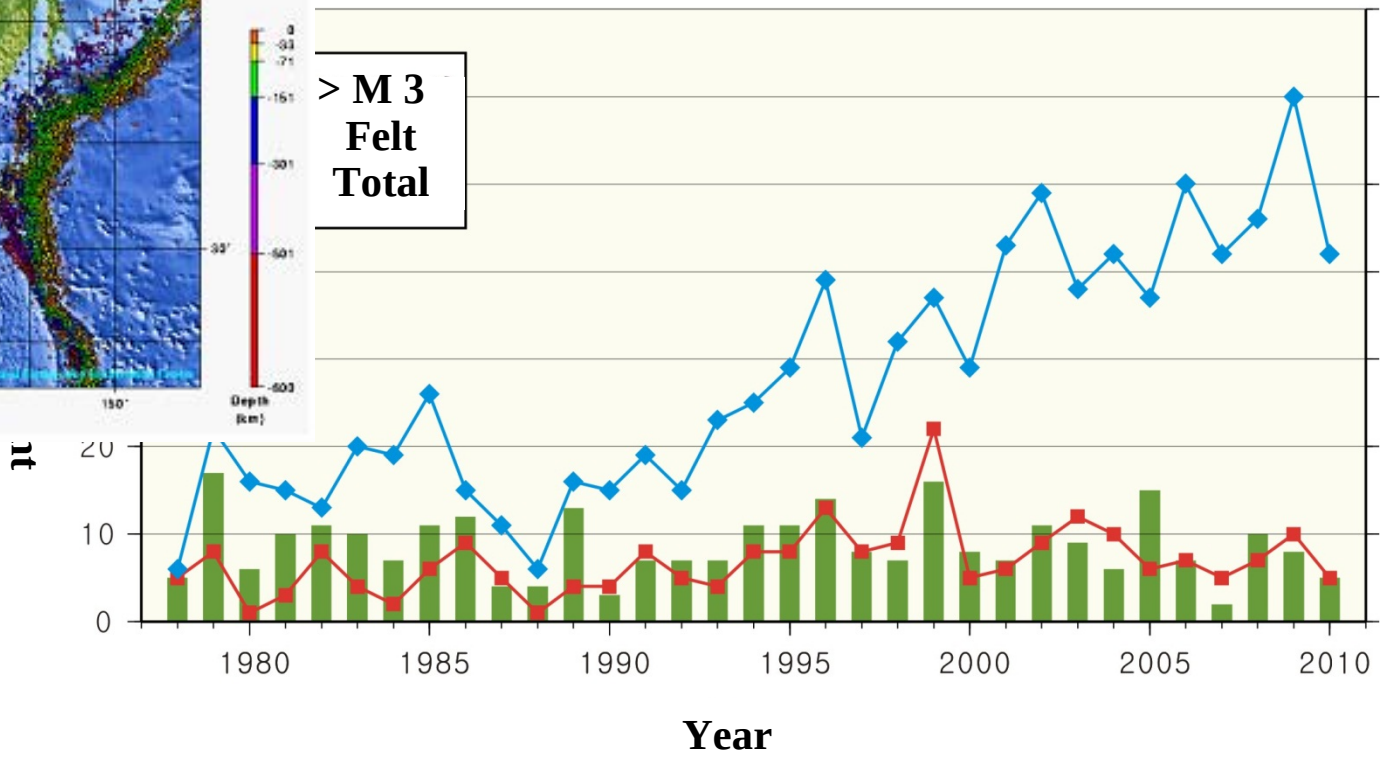


PLATE
PLATE
ASTHENOSPHERE
CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADING RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING PLATE

GLOBAL SEISMIC HAZARD MAP





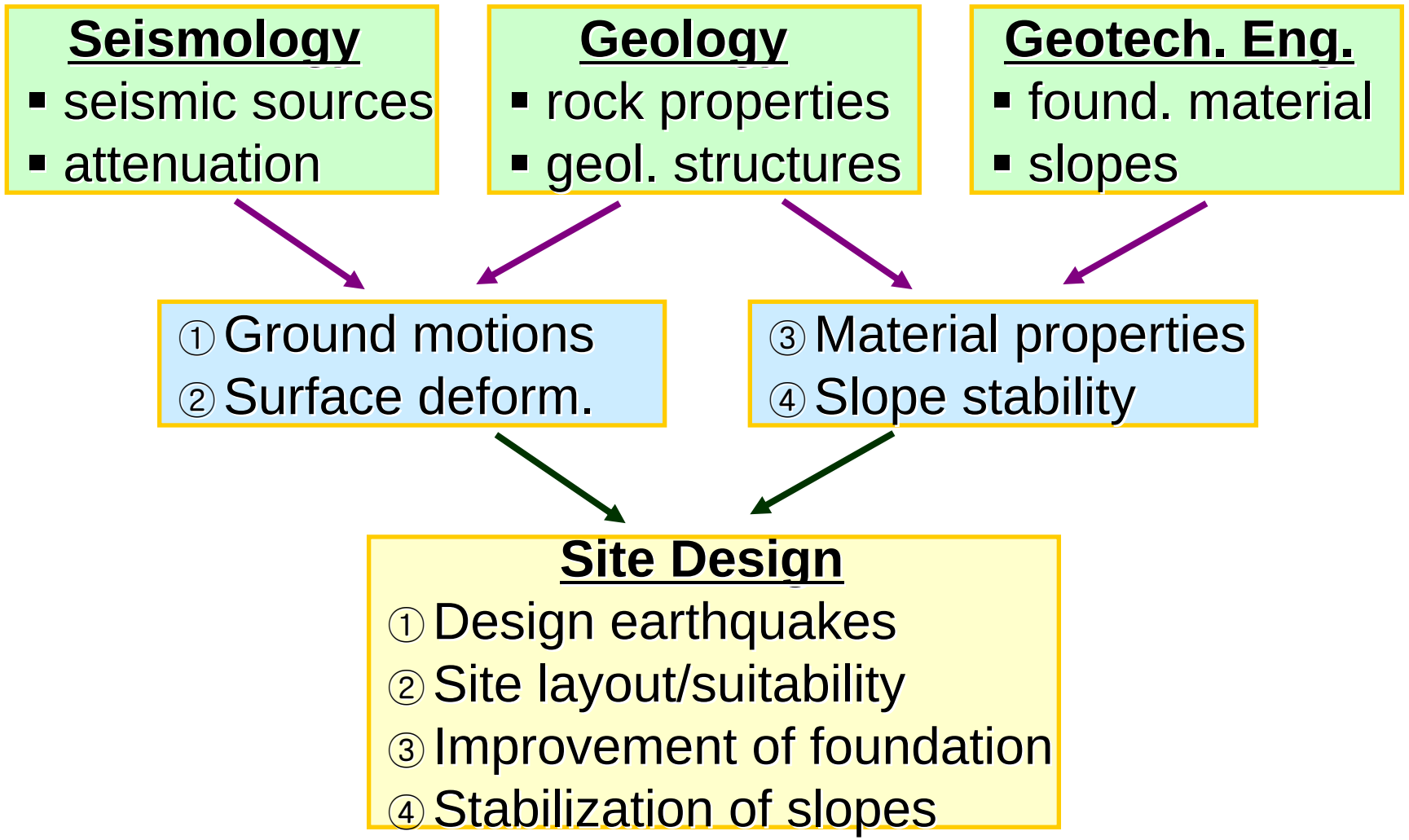


Total number of earthquake events increase, however,
earthquakes greater than M 3 occurs steadily about 10/year

Gradually improved Instruments and network system for seismic monitoring

3. Tectonic Hazard Evaluation for Korean NPP Sites

Overview of Tectonic Hazard Evaluation



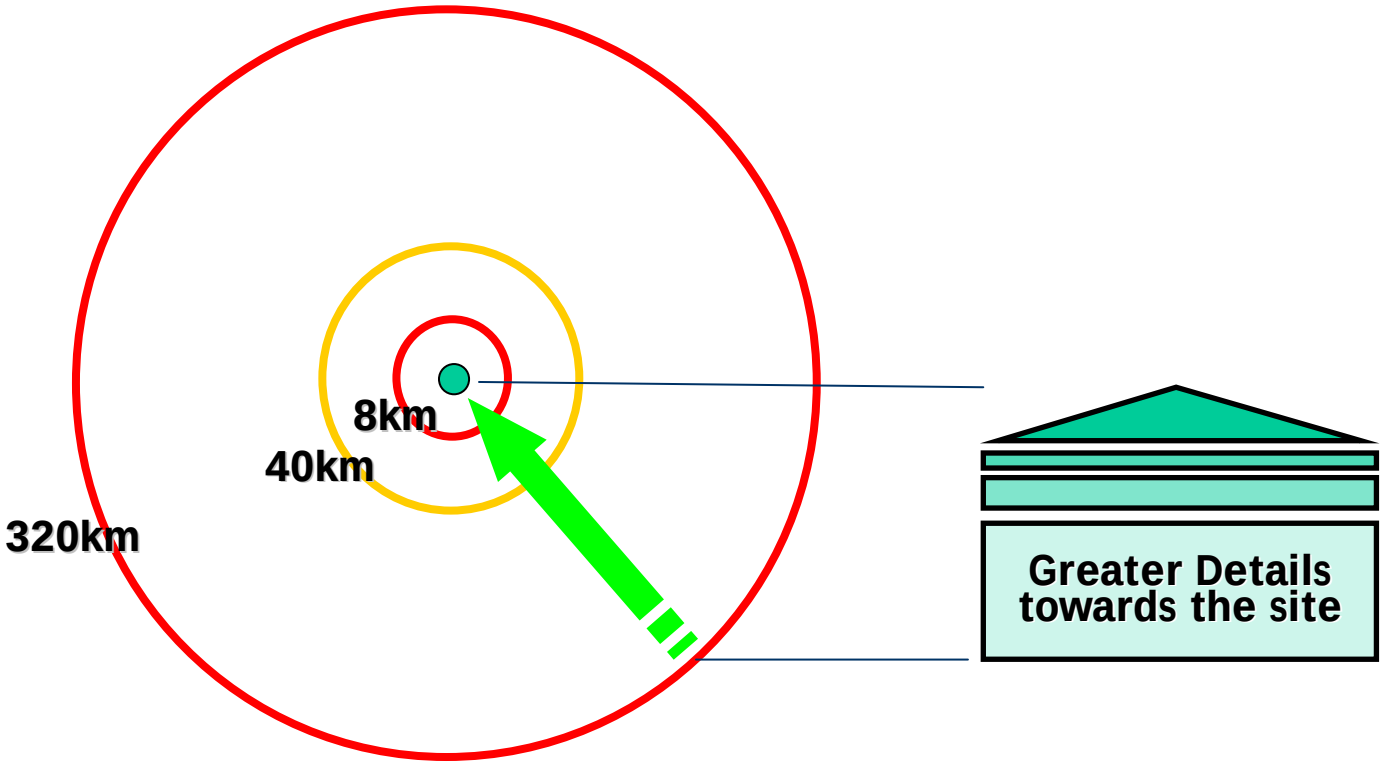
3. Tectonic Hazard Evaluation for Korean NPP Sites

Scope of Site Survey

Geology

Seismology

Engineering Geology



Data required

literature reviews, tectonic models, seismic records
aerial photos, geological maps, fault maps, outcrop/trench profiles,
geological history, ages, geological structures, Paleostress history
geophysical profiles, core-log profiles, laboratory tests, etc.

3. Tectonic Hazard Evaluation for Korean NPP Sites

Scope of Site Survey

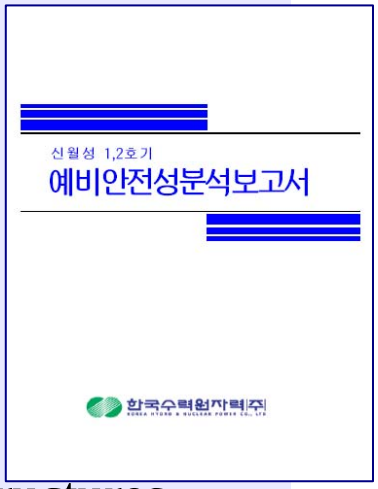
Step	Range	Investigation Method
Regional	320 km	• Comprehensive literature review supplemented by geological reconnaissances • Map scale - 1:500,000 or smaller
Intermediate Regional	40 km	• Reconnaissance-level investigation supplemented by explorations • Map scale – 1:50,000 or smaller
Near Site	8 km	• Detailed investigations to delineate the geology and the potential for tectonic deformation at or near surface • Map scale – 1:5,000 or smaller
On-Site	1 km	• Most detailed investigations including geotechnical engineering investigations • Mapping of excavations and logging of trenches for plant structures • Map scale – 1:500 or smaller

3. Tectonic Hazard Evaluation for Korean NPP Sites

Safety Analysis Report

Format of SAR accords to
- The Safety Review Guide (KINS/GE – 001)
- Regulatory Guide 1.70

- **SAR contains**
  - **2.5.1 General geology**
    - 2.5.1.1 Regional geology (320km radius)
    - 2.5.1.2 Site geology (40km, 8km & 1km radius)
  - **2.5.2 Seismology**
    - 2.5.2.1 Seismic activity
    - 2.5.2.2 Activities of Tectonic structures
    - 2.5.2.3 Correlation between Earthquakes & Tectonic structures
    - 2.5.2.4 Maximum Potential Earthquake
    - 2.5.2.5 Seismic attenuations to the site foundation
    - 2.5.2.6 Safe Shutdown Earthquake (SSE)
    - 2.5.2.7 Operation Based Earthquake (OBE)



3. Tectonic Hazard Evaluation for Korean NPP Sites

Safety Analysis Report

- **SAR contains (continued)**
  - 2.5.3 Surface faulting
    - 2.5.1.1 Geology, Seismology & Geophysical data
    - 2.5.1.2 Geological evidence of Surface deformation
    - 2.5.3.3 Correlation between Capable tectonic structures & Seismic activities
    - 2.5.3.4 Age of Recent tectonic deformation
    - 2.5.3.5 Correlation between Local & Regional Tectonic structures
    - 2.5.3.6 Characterization of Capable tectonic structures
    - 2.5.3.7 Evaluation of Possible Quaternary deformation
- 2.5.3.8 Evaluation of Possible tectonic deformation
  - 2.5.4 Foundation Stability
  - 2.5.5 Slope Stability

3. Tectonic Hazard Evaluation for Korean NPP Sites

Capable Fault Criteria

- **Definition**
  - Evidence of one fault movement within the past 35,000yrs or, recurrent behavior within the past 500,000yrs
  - Correlation with instrumentally determined macro-seismicity
  - Structural correlation to other active faults
- **Siting Criteria**
  - Define capable faults within 8km from the reactor center
  - Avoid a site with a potential for surface faulting unless engineering design or reinforcement is demonstrated to be feasible against the deformation
- **Seismic Design**
  - Maximum potential earthquake for capable faults of certain size within certain distance.
  - Design against potential surface faulting for capable faults within 8km from the reactor center.

3. Tectonic Hazard Evaluation for Korean NPP Sites

Capable Fault Criteria

☐ **Design Against**

- ❍ Surface deformation
- ❍ Vibratory ground motions

Capable Fault

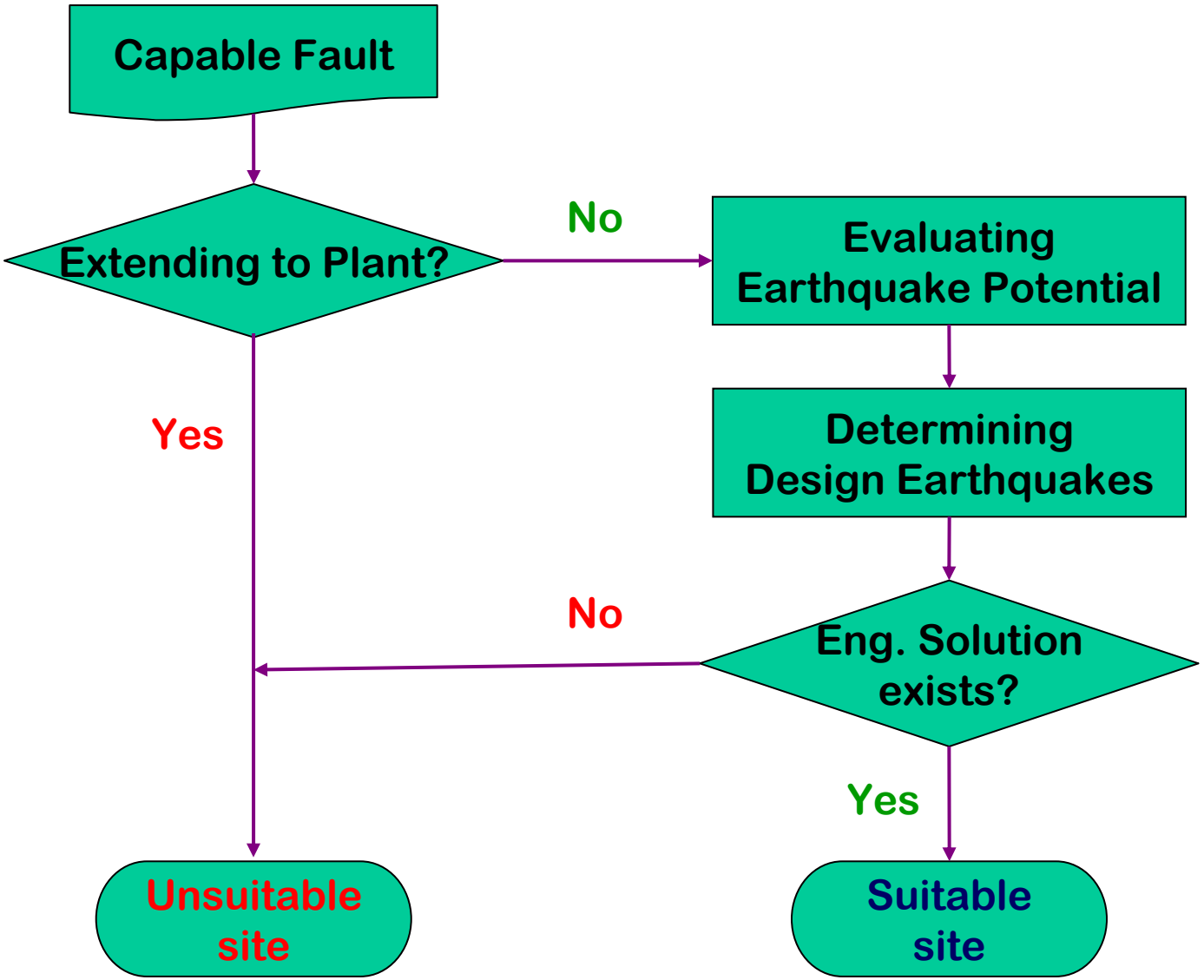
Vibratory ground motion

Surface faulting

Seismic Safety
(Design Earthquake)

Integrity of Foundation
(Site Suitability/Layout)

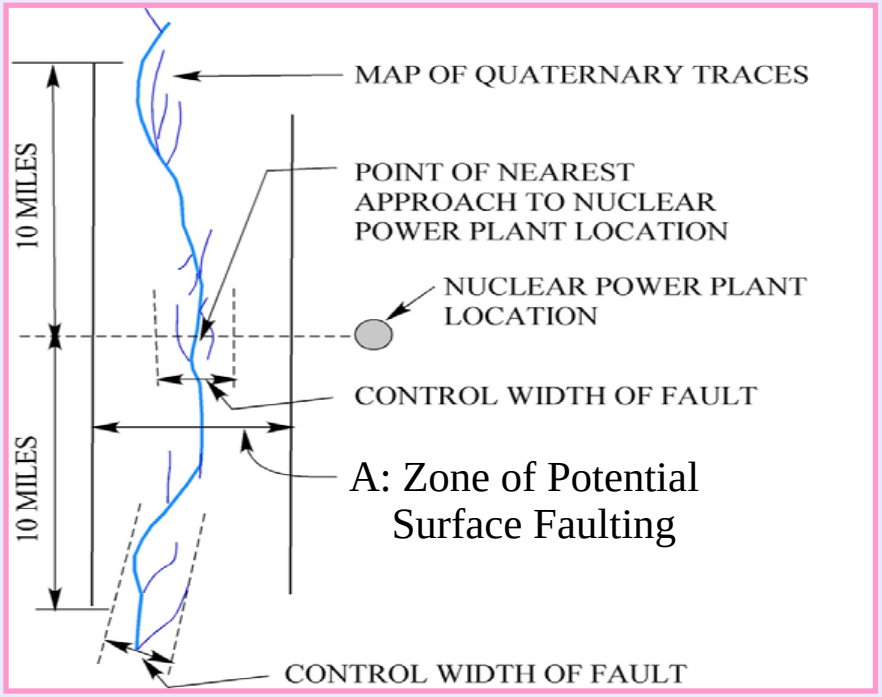
3. Tectonic Hazard Evaluation for Korean NPP Sites



3. Tectonic Hazard Evaluation for Korean NPP Sites

Surface Faulting

- Zone of Potential Surface Faulting
  - Consists of traces of capable fault and Quaternary faults structurally related with the capable fault
  - Minimum width of 800 m must be applied



(Modified from the appendix A to 10 CFR 100)

A: Zone of Potential Surface Faulting

Magnitude of earthquake	A
Less than 5.5	1 x CW
5.5-6.4	2 x CW
6.5-7.5	3 x CW
Greater than 7.5	4 x CW

CW : Control Width

3. Tectonic Hazard Evaluation for Korean NPP Sites

Design Earthquake

☐ Definitions

❍ Safe Shutdown Earthquake (SSE)

- Seismic design for safety related SSCs
- At least 0.1g in peak ground acceleration
- SL-2 in IAEA terminology

❍ Operating Basis Earthquake (OBE)

- Seismic design for continuous operation
- SL-1, IAEA

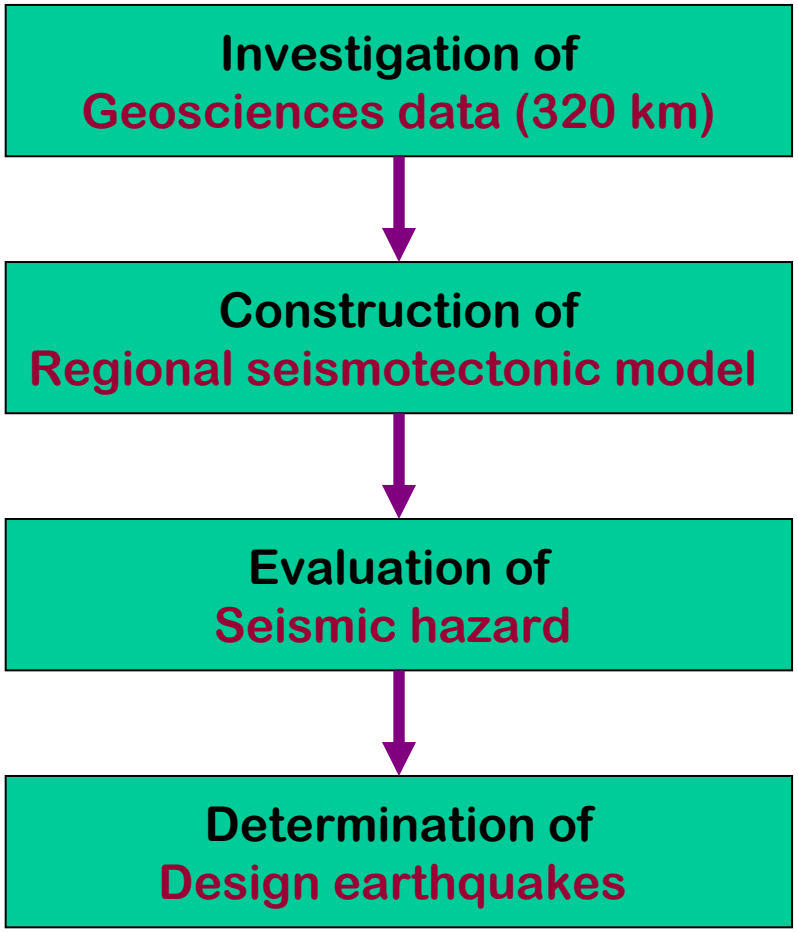
☐ Construction

❍ Design Earthquakes (Des) should be given in response spectra

3. Tectonic Hazard Evaluation for Korean NPP Sites

Design Earthquake

- **Procedure for determining DEs**



3. Tectonic Hazard Evaluation for Korean NPP Sites

Design Earthquake

☐ Investigation of Geosciences Data

- ❍ Geologic data
  - Identification of capable structures: faults, folds, etc.
- ❍ Seismic Data
  - Historical earthquakes: historical documents
  - Instrumental earthquakes: since 1900
  - Site-specific earthquakes: local seismic network
- ❍ Check: reliability, accuracy, completeness

3. Tectonic Hazard Evaluation for Korean NPP Sites

Design Earthquake

☐ Regional Seismotectonic Models

❍ General considerations

- Seismic, geological, and geophysical data are combined to establish regional seismotectonic models.
- It is not desirable to establish seismotectonic models that are more sophisticated than the data support. **REASONAL MODEL!!**

❍ Seismic sources

- Capable tectonic structure
  - Definition: a geological structure capable of generating earthquakes
  - Characterization: location & geometry of geological structure, maximum potential earthquake, earthquake recurrence rate, etc.
- Seismotectonic province
  - Definition: a region where earthquakes diffusely occur, but no specific geological structure is identified to be responsible for those earthquakes.
  - Characterization: similar to that of capable tectonic source

3. Tectonic Hazard Evaluation for Korean NPP Sites

Design Earthquake

☐ Seismic Hazard/Design Earthquakes

❍ Methods

- Deterministic & probabilistic methods
- Korean regulation requires the deterministic method

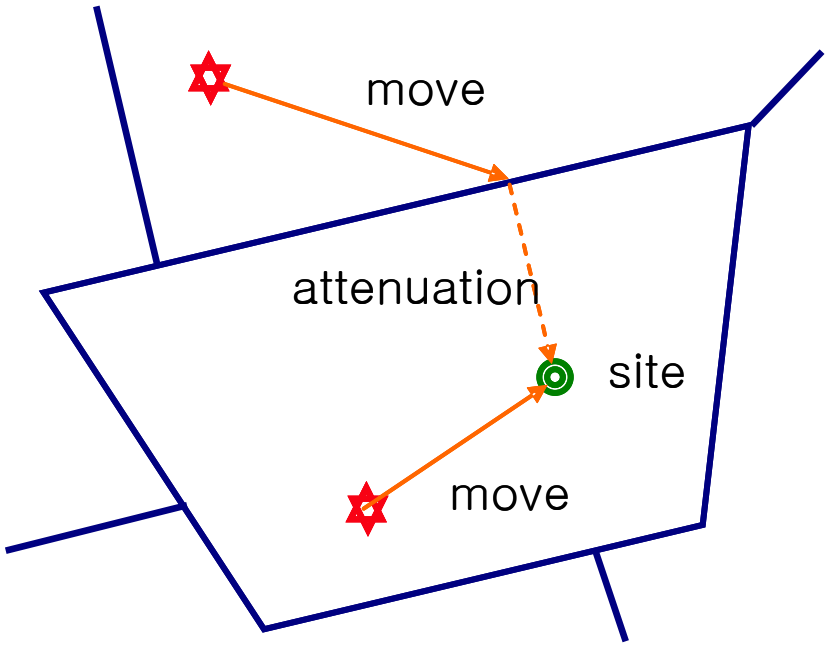
❍ Deterministic method

- Establish a seismotectonic model consisting of capable tectonic structures and seismotectonic provinces (i.e., seismic sources)
- Determine the max. potential earthquake (MPE) for each seismic source
- Locate each MPE at the closest point to the site
- Calculate the ground motion at the site by each MPE by using proper attenuation equation
- Take the largest ground motion among all MPEs (max. site ground motion)

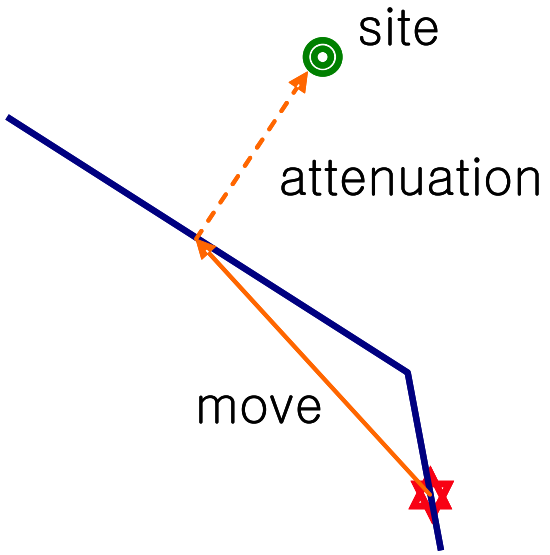
3. Tectonic Hazard Evaluation for Korean NPP Sites

Design Earthquake

– Deterministic method (diagrammatic)



Seismotectonic Provinces



Capable Tectonic Structure

3. Tectonic Hazard Evaluation for Korean NPP Sites

Shin-Kori 3 & 4

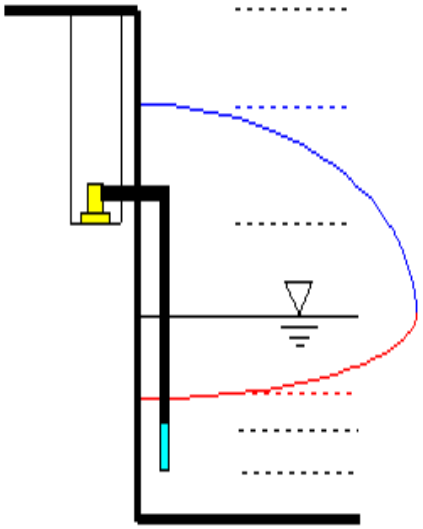
- Nearby capable faults
  - None identified within 8 km
- Max. ground acceleration at site
  - 0.15g
- Wave transmission effect
  - Seismic properties comparable with those of recording sites
  - Massive rocks, no significant topography
- Safe shutdown earthquake (SSE): 0.3g
  - US RG 1.60 spectra anchored at 0.3g were applied
  - Mean annual exceeding probability: 1.06E-4
- Operating basis earthquake (OBE)
  - 0.1g (=1/3 of SSE)

3. Tectonic Hazard Evaluation for Korean NPP Sites

Tsunami Hazards in Korea

- Concerns for Design: Overflow & ESW
- Design Tsunami
  - ✓ Seismic Gap near NE seashore of Japan (M 7.8 of)

Imweon Harbor (1983)



Design Sea Level for Uljin #5,6

	Uljin	Weol-sung	Kori
Run-up (m)	+3.0	+0.50	+0.33
Subsidence (m)	-3.0	-0.49	-0.29

Tsunami effect on the designed sea level of Korean NPPs

4. DEAL WITH UNCERTAINTIES

4.1 Step-wise Safety Confirmation

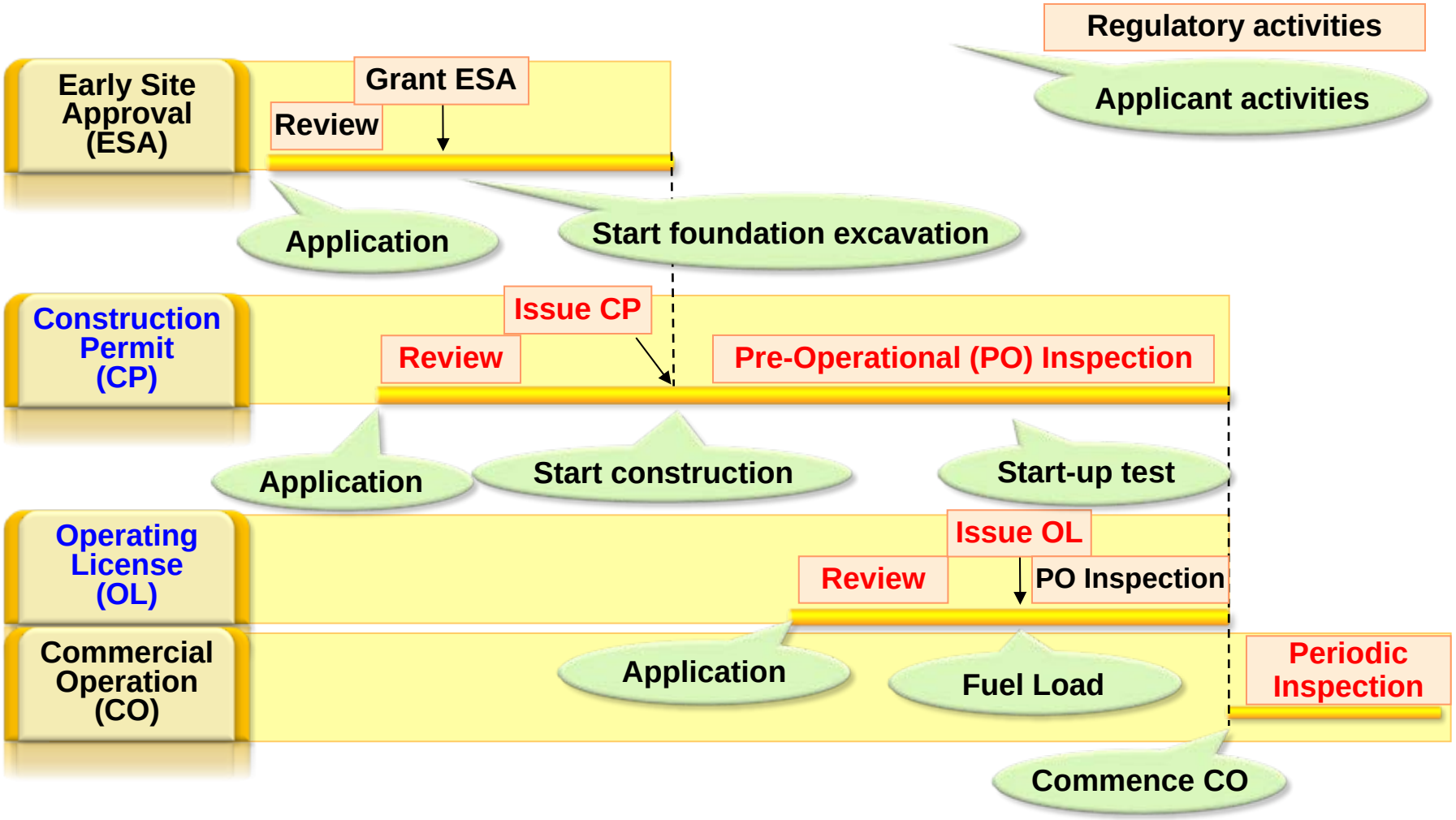
4.2 Double check with Alternative Methods

4.3 Conservative Approaches

4.4 Tectonic Monitoring

4.1 Step-wise Safety Confirmation

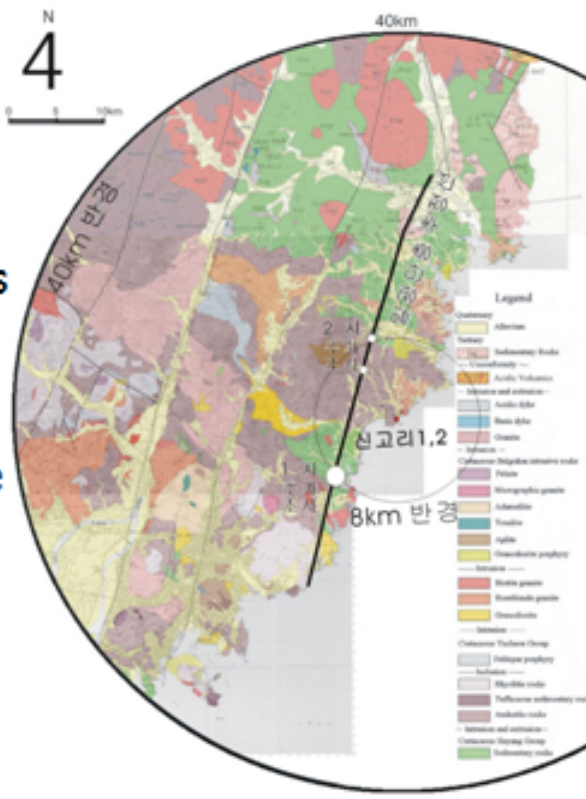
Overall Licensing Process



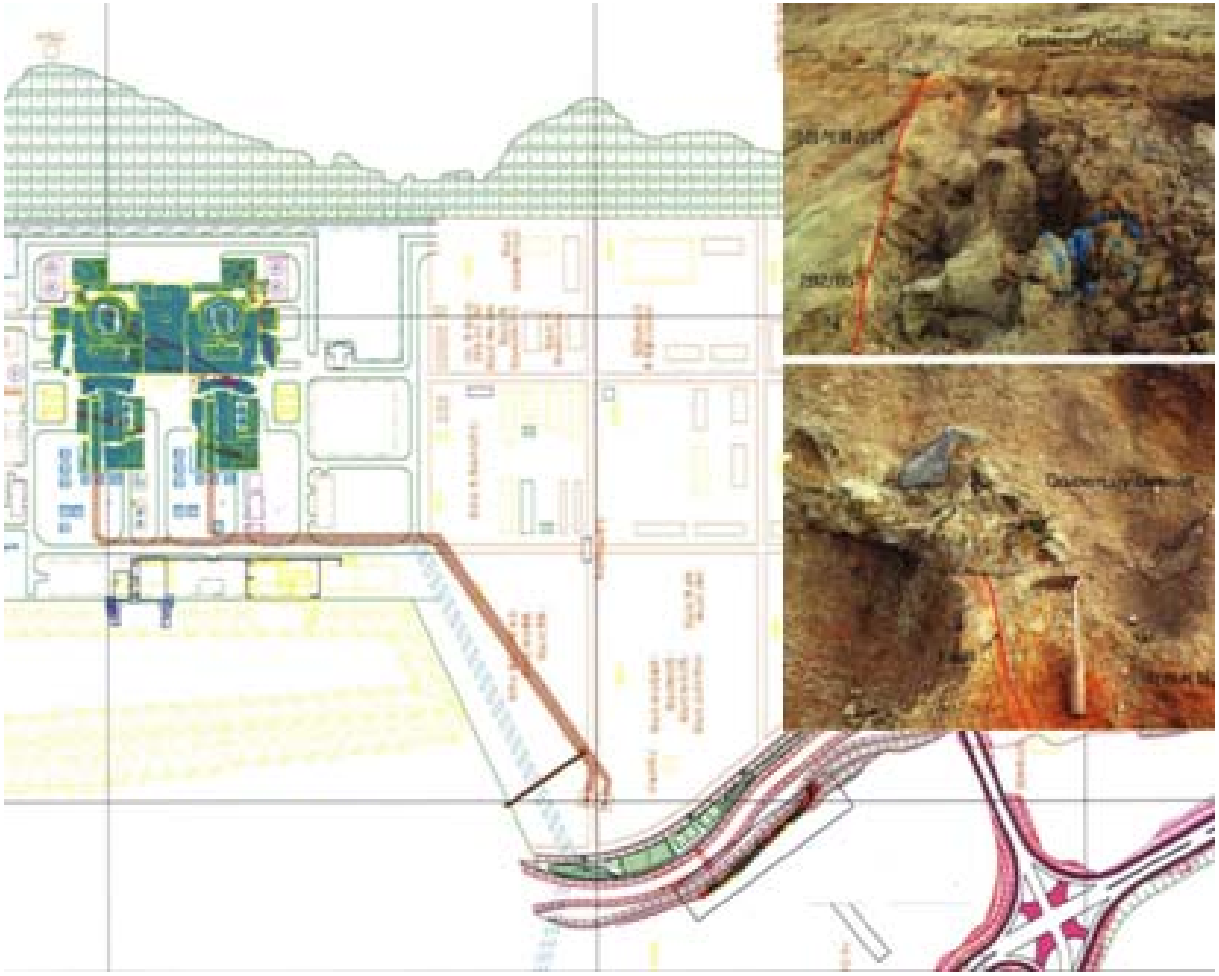
4.1 Step-wise Safety Confirmation

Verification of the Site Geological Stability

- Needed to verify the nature of a fault set expected from boring data at the foundation and any possible Quaternary offset along the faults suspect.
  - KINS has confirmed, through the inspection during the foundation excavation, that there exist several faults newly found at the foundation area but no evidence of offsets of the Quaternary layers at the foundation area, and hence that the site is geologically stable.



4.1 Step-wise Safety Confirmation



4.2 Double Check with Alternative Methods

Design Earthquake

☐ Requirement

❍ Design Earthquake is decided deterministically

☐ Recommendation

❍ Probabilistic Seismic Hazard Analysis (PSHA) evaluates

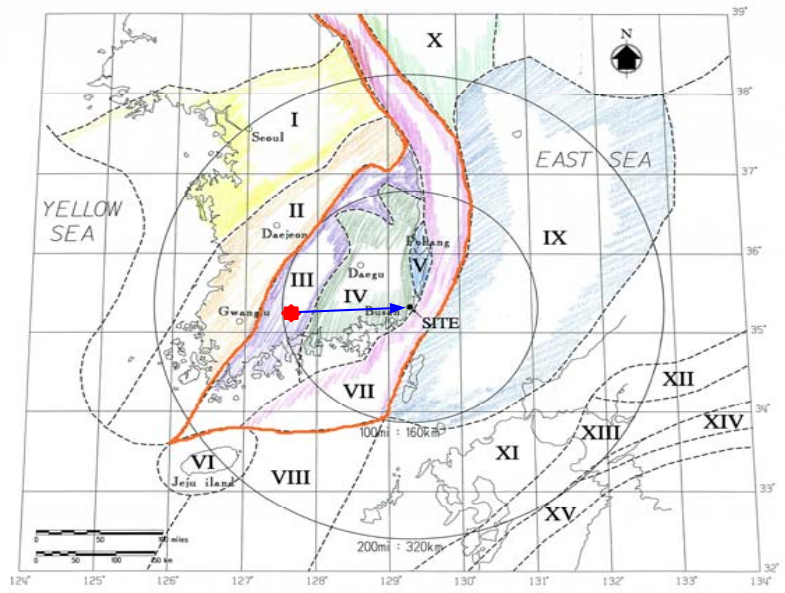
- Earthquake data both from historical and instrumental records
- Magnitude-frequency models and MPEs including the associated uncertainties for each source
- Proper attenuation equations including the uncertainties
- Annual frequency of exceedance for various levels of ground motions: Mean, median, 15^{th}-percentile, 85^{th}-pertiles

4.3 Conservative Approaches

Max. EQ. Potential

TECTONIC PROVINCE	DATE OF MAXIMUM EARTHQUAKES			EPICENTER OR PLACE OF MAXIMUM INTENSITY		DEPTH OF FOCUS (if know) (km)	EPICENTRAL DISTANCE TO SITE (km)	ADJUSTED DISTANCE TO SITE (km)		LIBRARY AND SOURCE	MAGNITUDE (TSUBOI OR RICHTER) OR INTENSITY (JMA or MMI)
	Year	Month	Day	Latitude	Longitude			EPI.	HYPO.		
1. 경기육괴	1978	10	7	36.600	126.700	-	268.4	196.5	NA	KMA	JMA V M = 5.0
2. 옥천습곡대	1978	9	16	36.600	127.900	-	172.6	148.5	NA	KMA	JMA IV M = 5.2
3. 영남육괴	1936	7	3	35.233	127.650	10	174.5	81.3	81.9	SUPP, SHP	JMA V M = 5.0
4. 경상분지	1985 1997	6 6	20 26	35.900 35.800	128.600 129.300	- -	82.0 18.6	12.8	NA	KMA KMA	JMA III M = 4.2
5. 연일분지	1949 1986	10 3	- 17	36.033 35.900	129.383 129.500	- -	36.1 20.3	0	10	SUPP, SHP	JMA III
6. 제주화산대	1996	5	26	33.500	126.000	-	403.3	308.5			
7. 한반도 대륙붕	1982	3	1	37.200	129.800	10	167.4	5.8			
8. 남지나해	1967	5	3	31.000	127.000	-	573.6	206.2			
9. 울릉분지	1950	5	17	37.500	132.000	580	300.1	45.8			
10. 한반도 고기평탄면	1960	10	8	40.000	130.000	650	478.8	190.4			
11. 상군구	1927	3	7	35.700	135.000	10	499.0	203.8			
12. 탐바구	1961	5	7	35.100	134.417	40	453.2	270.9			
13. 료케구	1905 2001	6 3	2 24	34.000 34.100	132.000 132.700	100 -	299.3 344.8	270.9			
14. 일본분지	1904	6	7	40.000	134.000	350	620.5	304.6			

KORI Site



4.3 Conservative Approaches

Eupcheon Fault Monitoring System

➢ Monitoring System for a Fault near the NPP site

- A Quaternary fault of uncertainty
  - Was found near the NPP site & firstly described by a research team of KIGAM in 1998
  - Cut a marine terrace at about 3 km south from the NPP site, with a NE-SW trend
- A detailed fault characterization consists of
  - Geological survey: surface trace, 6 trenches, 52 borings, age dating, onshore & offshore geophysical survey, etc.
  - Safety evaluation: Faulting & Near-field ground motion effect
  - Conclusions: The reactors and safety-related facilities will remain functional at the maximum design earthquake (Mw 6.0, 0.183g) and no potential surface deformation at the site.
- A fault monitoring system (conditional CP)
  - To be installed at the fault and surrounding area
  - Taking into account for the uncertainty and the public concerns

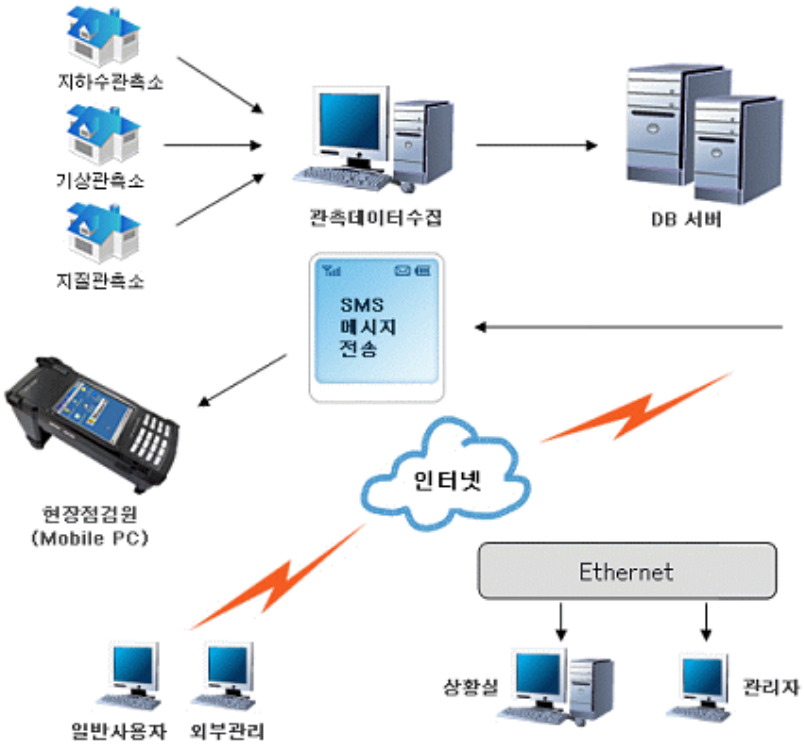
4.4 Tectonic Monitoring

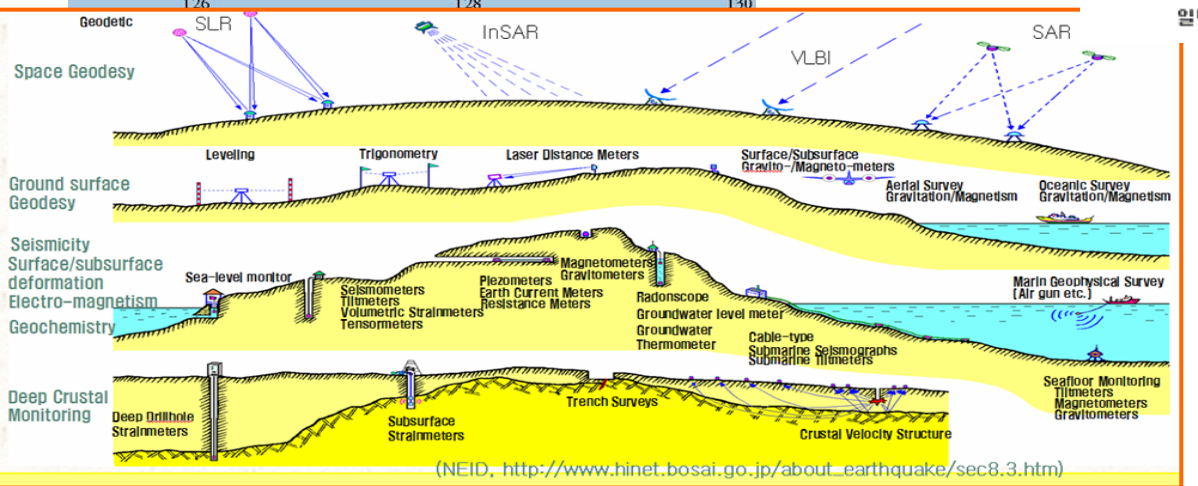
KINS Monitoring Center

- Purpose
  - Establishment of Integrated Site Monitoring Center
    - Development of Techniques & Methods
    - Alarm of unexpected/unusual events at the nuclear sites
  - Public Acceptance through Clear & Open Polity
  - Site-specific Characterization
  - Site-specific Safety Criteria
- Data Comes to the Center
  - Fault Monitoring System at the Shin-Weolsung site
  - Korean Earthquake Monitoring Center
  - Site Monitoring System at the Korean LILRW Repository
  - Geodetic Monitoring System of Other Organizations
    - KIGAM, KMC, etc.

4.4 Tectonic Monitoring

KINS Monitoring Center





(NEID, http://www.hinet.bosai.go.jp/about_earthquake/sec8.3.htm)

5. Conclusions

- **Korean Nuclear Sites are Built**
  - On a stable rock foundation in the Eurasian Plate
  - With low seismicity and tectonic activities
- **Tectonic Hazard Evaluation for Korean NPPs with**
  - Conservative approaches
  - Double check with alternative methods
  - Step-wise safety confirmation
  - Tectonic monitoring, etc.
- **Our experiences in NPP construction should be shared with ANSN member countries**

Thank you very much

KINS