

Current status of design basis earthquake level for nuclear power plant sites in several countries

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Abstract

According to strict criteria step by step for site selection, design, construction and operation, the seismic safety of nuclear power plant (NPP) sites in South Korea are secured by considering design basis earthquake (DBE) level capable of withstanding the maximum ground motions that can occur on the site. Therefore, it is intended to summarize DBE level and its evaluation details for NPP sites in several countries.

Similar but different terms are used for DBE from country to country, i.e. safe shutdown earthquake (SSE), design earthquake (DE), SL2, Ss, and maximum calculated earthquake (MCE). They may differ when applied to actual seismic design process, and only refer to approximate comparisons. This script used DBE as a representative term, and DBE level was based on horizontal values.

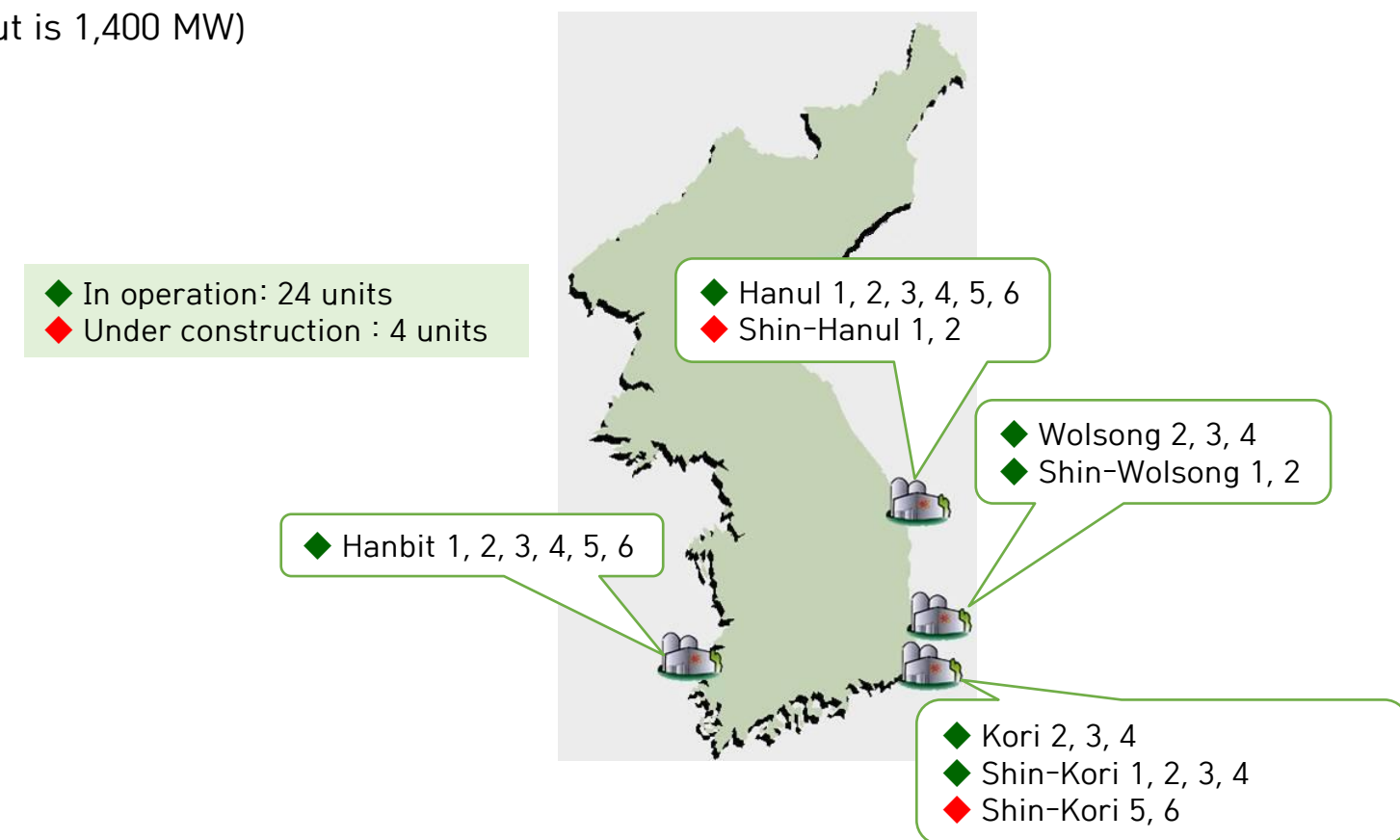
The DBE level of NPP sites depends on seismic activity of the area. Japan and Western United States, where earthquakes occur more frequently than South Korea, have high DBE values. The DBE level of NPP sites in South Korea has been confirmed to be similar or higher compared to that of Central and Eastern United States and Europe, which have similar seismic activity.

Terms (from <http://dx.doi.org/10.5772/65853>)

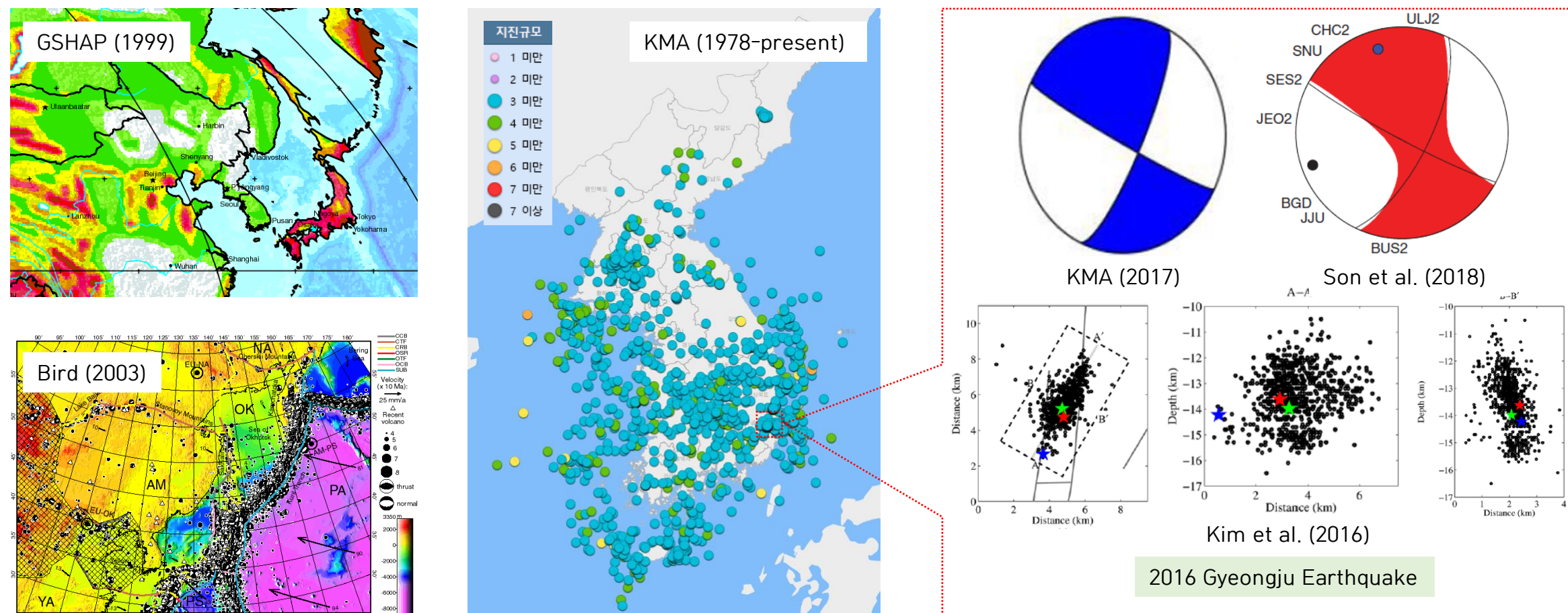
- ◆ **Design basis** refers to the range of conditions and events (i.e. earthquakes and phenomena associated with) taken explicitly into account in the design of a facility, according to the established criteria, such that the facility can withstand them without exceeding authorized limits by the planned operation of safety systems.
- ◆ **Design basis earthquake (DBE)** refers to the earthquakes affecting the plant site effect of those are used in the design of SSCs ensuring the basic safety functions as it is required by the nuclear safety regulations and in compliance with industrial standards. These effects are the vibratory ground motion and surface deformation. The DBE surface deformation is distortion of geologic strata at or near the ground surface by the processes of folding or faulting as a result of various earth forces. Tectonic surface deformation is associated with earthquake processes. The DBE has to be defined at required annual frequency of occurrence (return period) and confidence level. DBE should not result in reactor core melt. The DBE is used as a representative term in this study.

Nuclear Power Plants and Seismic Characteristics in South Korea

- ◆ Nuclear power plants (NPPs) in South Korea
 - South Korea has achieved a remarkable growth in nuclear power since commercial operation of Kori 1 in 1978.
 - South Korea has now 24 operating NPPs : 21 PWRs and 3 PHWRs.
 - Total output of 24 licensed units is 23,250 MW, and the portion of generation capacity in South Korea is 29.0 % (2020).
 - 4 units are now under construction.
 - 4 PWRs (each output is 1,400 MW)



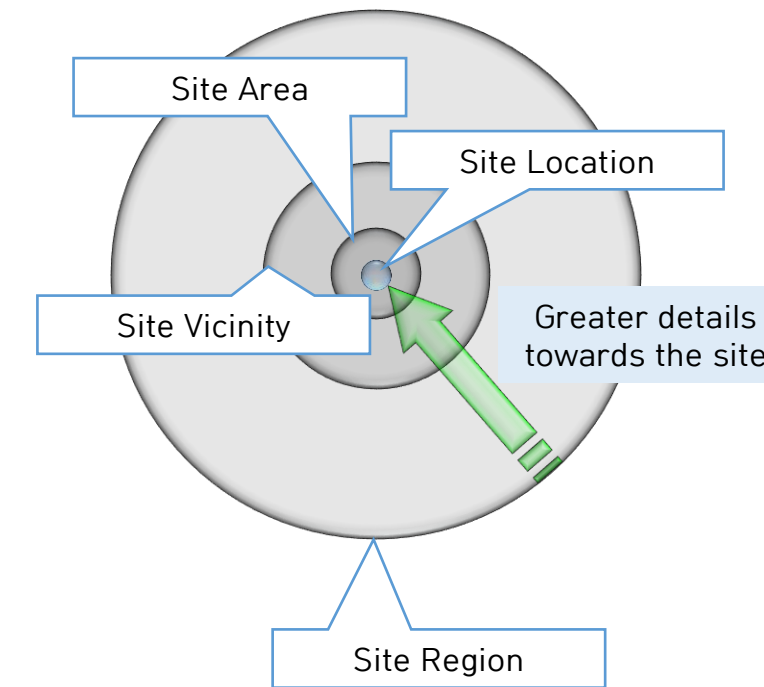
- ◆ Seismic characteristics in South Korea
 - It is located at the far eastern part of Eurasian Plate.
 - It is located within the intra-plate region, several hundred km away from the nearest plate boundary.
 - The earthquakes around the Korean Peninsula show the typical characteristics of intra-plate earthquakes.
 - Low seismicity, relatively smaller magnitude than that of inter-plate earthquakes, spatially irregular epicenters.
 - On 12 September 2016, the largest instrumental event (M_L 5.8) was occurred nearby Gyeongju area (red box in the map below).



Procedures for Determining DBE of NPP sites in South Korea

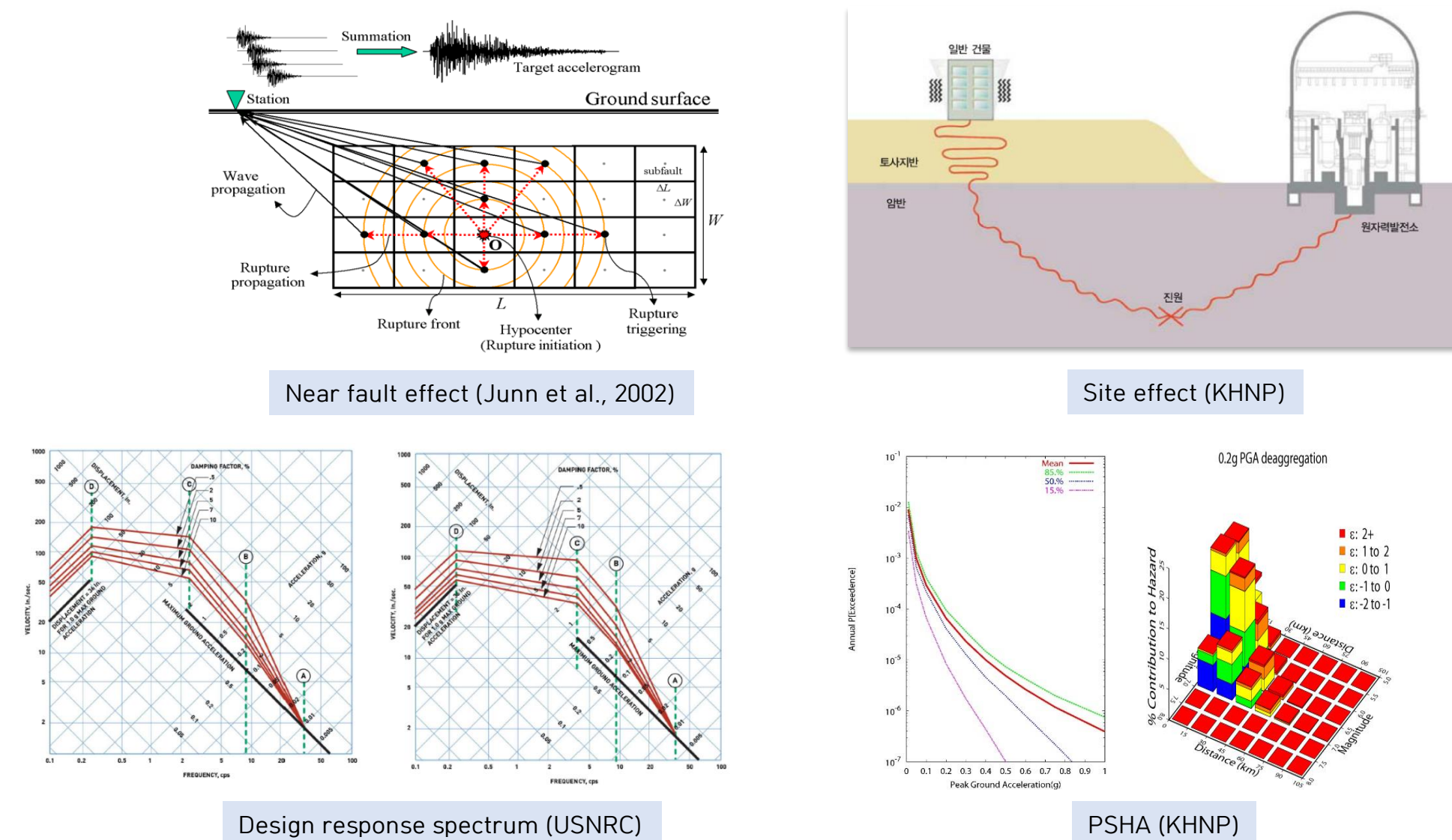
- ◆ Regional and site investigation on geologic and seismic characteristics
 - From geologic, seismic, and geotechnical engineering investigations, ground motions from seismic sources, surface deformations due to capable tectonic structures, foundation material properties and slope stability are evaluated.
 - All evaluation results are reflected in the site design such as DBE, site layout/suitability, improvement of foundation and stabilization of slopes.
- ◆ Seismic source
 - Capable tectonic source : capable fault
 - Seismogenic source : a well-defined tectonic structure or simply a large region of diffuse seismicity
- ◆ Procedure for determining DBE of NPP sites
 - To determine DBE of NPP sites, consideration of all seismic sources within a certain radius from NPP sites is essential.
 - The DBE level should be at least 0.1 g.

- Collection and analysis of past earthquakes within a radius of 320 km from a site
 - historical and instrumental earthquakes
 - magnitude, depth, distance, recurrence interval
 - seismic characteristics, focal mechanism, etc.
 - Analysis of relationships between past earthquakes and tectonic structures
 - faults, folds, etc.
- Establishment of regional seismotectonic models within a radius of 320 km from a site
 - Well-defined tectonic structures, capable tectonic faults and seismotectonic provinces
- Ground motions at a site from each seismic source
 - ground motion model
 - ground motion simulation
 - Site response analysis
- Maximum ground motions and DBE
- Appropriateness of DBE by probabilistic seismic hazard analysis



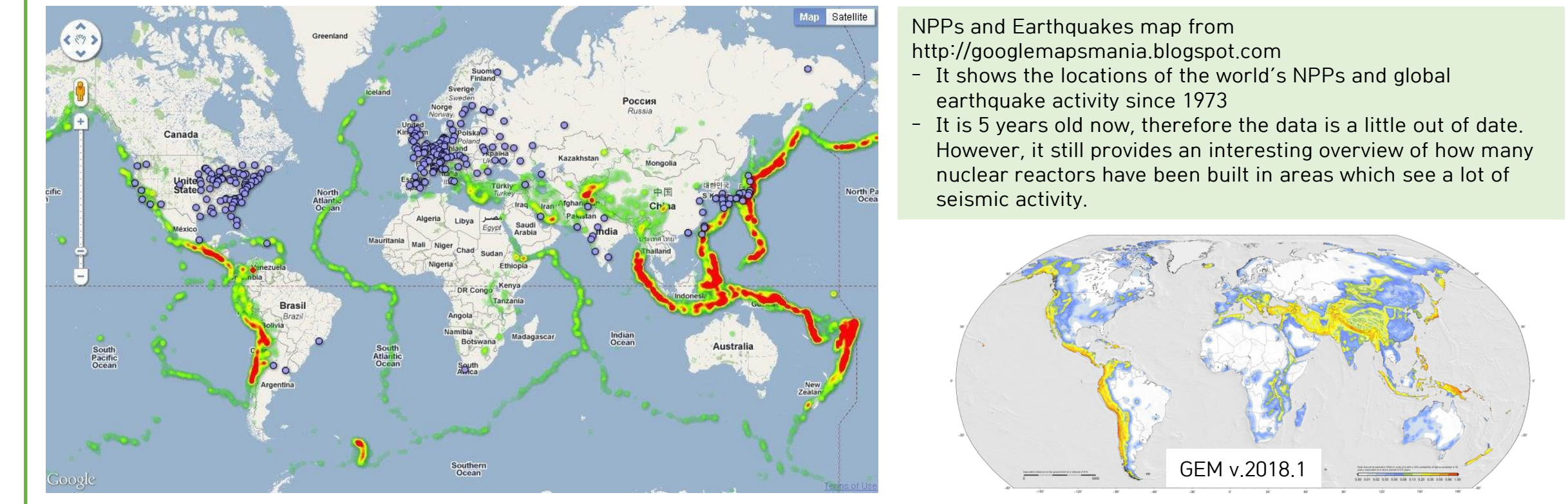
Determination of DBE of a site

- ◆ Deterministic approach
 - Deterministic approach
 - If a province includes the site, the maximum potential earthquake (MPE) is assumed to occur beneath the site.
 - For the other provinces, MPEs are assumed to occur at the nearest point on their boundaries of provinces, then attenuated to the site.
 - In case of a capable tectonic structure, its MPE is assumed to occur at the nearest point on its plane, then attenuated to the site.
 - A capable fault has a significant potential for relative displacement at or near the ground surface.
 - In the case where a capable fault is near the site, the effect of proximity of an earthquake is taken into account.
 - The NPP sites in South Korea are located on the basis rock composed of competent material.
 - Site response analysis
 - The DBE of NPPs in South Korea is determined to be
 - 0.2 g (in case of newly constructed NPPs is 0.3 g) considering MPE ground motions and some safety margin.
 - The ground motions and surface deformations caused by capable faults are also considered in the seismic design of NPPs.
 - DBE should be given in response spectra.
- ◆ Probabilistic approach
 - The uncertainties are originally inherited in the seismic characteristics since faulting and earthquakes are occurred at the deep part of the Earth, but investigation and observation are generally performed at the surface area.
 - Probabilistic seismic hazard analysis (PSHA)
 - Check of the appropriateness of DBE
 - Mean annual exceeding frequency of DBE of NPP sites in South Korea is evaluated to be less than 1.0×10^{-3} , and it meets the criteria of related regulatory guides.



NPPs and Earthquakes

- ◆ The NPPs are designed so that earthquakes and other external events will not jeopardise the safety of the plant. (from <https://www.world-nuclear.org>)
 - It is estimated that, worldwide, 20% of nuclear reactors are operating in areas of significant seismic activity.
 - International Atomic Energy Agency (IAEA) has a safety guide on seismic hazards for NPP sites.
 - Various systems are used in planning, including PSHA, which is recommended by IAEA and widely accepted.



Current Status of DBE Level for NPP Sites in Operation by Country

- ◆ Background
 - The Korean Peninsula is located on the margin of the far east Eurasian plate and in the intraplate region hundreds of kilometers away from the nearest inter-plate boundary. Therefore, it is known as a stable continental region which is characterized by the low seismicity. However, the Gyeongju earthquake occurred on September 12, 2016, the largest one since the Korea Meteorological Administration (KMA) started to observe earthquakes around the Korean Peninsula, and increased public anxiety over the seismic safety of NPPs. Well-defined DBE level allows the NPPs to withstand the maximum ground motions that can occur on the site according to the strict criteria step by step for site selection, design, construction and operation. This study is intended to summarize DBE level and its evaluation details for NPP sites in operation by country.
- ◆ Scope
 - Current status of NPP sites in operation by country
 - Current status of DBE level, simply PGA (peak ground acceleration) for NPP sites in operation
 - Evaluation details of DBE for NPP sites in operation (not described here)
- ◆ Conclusions
 - Summary of current status of DBE level and its evaluation details for NPP sites in operation by country
 - Utilized in the development of technical standards for DBE
 - ◆ The DBE level of NPP sites depends on seismic activity of the area. Japan and Western United States, where earthquakes occur more frequently than South Korea, have high DBE values. The DBE level of NPP sites in South Korea has been confirmed to be similar or higher compared to that of Central and Eastern United States and Europe, which have similar seismic activity.
 - ◆ The DBE of NPP sites in South Korea is determined deterministically, including available seismic data, including historical earthquakes, in accordance with U.S. Federal Act. On the other hand, in relation to the DBE assessment, U.S. allowed DBE to be determined by probabilistic approach, such as estimating uncertainties inherent in DBE. Europe and other countries also require probabilistic approach to be applied or supplemented in the DBE assessment. Therefore, NPPs in South Korea also need to properly prepare for this international trend and upgrade technical standards for evaluating DBE.

Country	Min (g)	Max (g)	No. of opening NPP sites	Country	Min (g)	Max (g)	No. of operating NPP sites
Argentina	0.1	0.26	2	Mexico	0.26	0.26	1
Armenia	0.35	0.35	1	Netherlands	0.08	0.08	1
Belgium	0.1	0.17	2	Pakistan	0.2	0.25	2
Brazil	0.1	0.1	1	Romania	0.2	0.2	1
Bulgaria	0.1	0.1	1	Russia	0.026	0.25	12
Canada	0.3	0.3	4	Slovakia	0.143	0.344	2
China	0.15	0.3	14	Slovenia	0.3	0.3	1
Czech	0.1	0.1	2	South Africa	0.3	0.3	1
Finland	0.1	0.1	2	Spain	0.1	0.2	5
France	0.1	0.3	19	Sweden	0.11	0.15	3
Germany	0.051	0.173	6	Swiss	0.12	0.15	3
Hungary	0.25	0.25	1	Taiwan	0.4	0.4	2
India	0.1	0.3	7	Ukraine	0.05	0.12	4
Iran	0.2	0.2	1	U.K.	0.13	0.25	7
Japan	0.459	2.347	16	U.S.	0.1	0.75	57
South Korea	0.2	0.3	6				

