"Paleoseismological Investigations in the Site Evaluation for Nuclear Power Plants - Lessons learned from the Kashiwazaki-Kariwa NPP case"

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2. The 16 July 2007 Earthquake, Japan
   - Effects on the region
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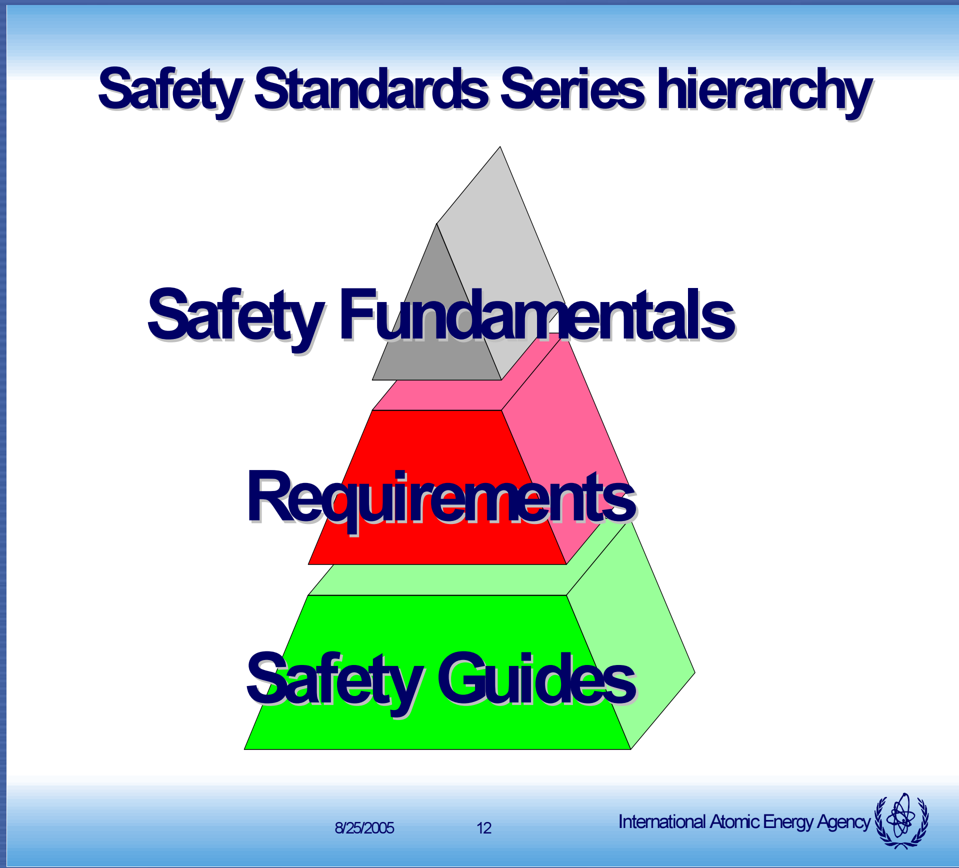
IAEA SAFETY STANDARDS - SEISMIC SAFETY

The IAEA safety standards are the result of a consensus based process in relation to the best/good practices already available in Member States.

An internationally recognized set of standards on seismic safety since late 70s'.



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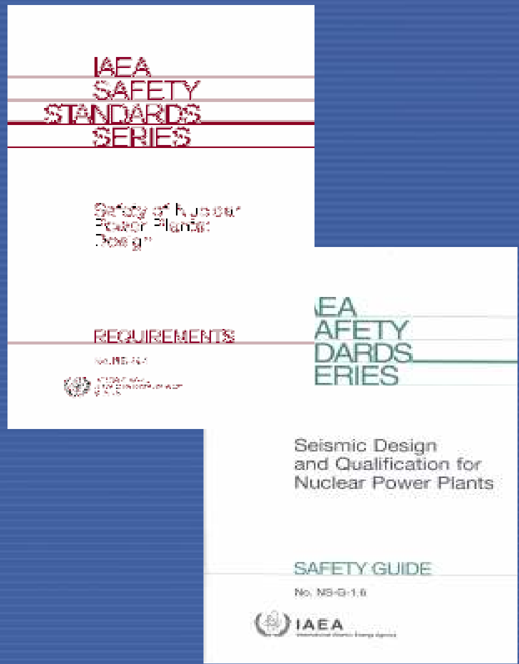
IAEA SAFETY STANDARDS - SEISMIC SAFETY

SITE EVALUATION

Seismic Hazard

DESIGN

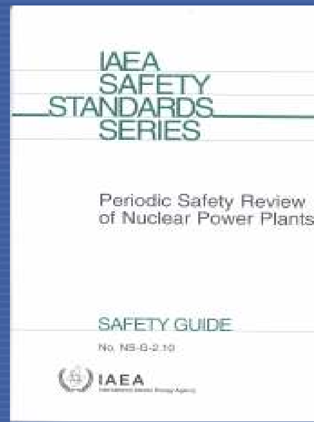
new installations



Seismic Design and Qualification

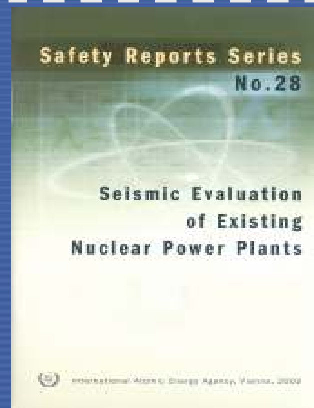
OPERATION

operating/existing installations



Periodic Safety Review

DS 383 Seismic Evaluation of Existing Nuclear Installations



The complete lifetime of the installation *(t)*

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IAEA SAFETY GUIDE ON SEISMIC HAZARD EVALUATION

Seismic <u>hazards</u>: seismic input for the design or the evaluation of a nuclear installation at a given site:

1. **Vibratory ground motions,**
2. **Geological and other hazards:**
   - **potential for (and the rate of) fault displacement at/near the surface which could affect the acceptability of the site,**
   - **liquefaction phenomena,**
   - **….and others.**

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IAEA SAFETY GUIDE ON SEISMIC HAZARD EVALUATION

Two basic objectives:

- **Confirmation of site acceptability: surface fault displacement**
- **Derivation of seismic design basis: vibratory ground motion parameters for plant design.**

1. **A comprehensive and integrated Database - in 4 scales of investigations:**
    - **Geological, geophysical, geotechnical Database**
    - **Seismological Database.**
2. **Integration of all data in a regional Seismotectonic Model**
3. **Evaluation of vibratory ground motion hazard**
4. **Potential for surface faulting at the site**
5. **Minimum 0.10g peak ground acceleration**

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SEISMIC HAZARD EVALUATION – SCALES OF INVESTIGATIONS

Geological, Geophysical and Geotechnical Database

Site vicinity

Objectives:
- Neotectonic fault history
- Potential for surface faulting

Near regional scale

Objectives:
- Detailed seismotectonic characterization
- Latest faults movements

Regional scale

Objectives:
- General geodynamic setting
- Characterization of geological features
- Delineation of seismogenic sources

Site area

(~1 km²)

Objectives:
- Permanent ground displacement
- Dynamic properties of foundation materials

5 km
(maps scale 1:5 000)

~25 km
(maps scale 1:50 000)

>150 km
(maps scale 1:500 000)

A need for application of increased efforts

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IAEA SAFETY GUIDE ON SEISMIC HAZARD EVALUATION

- The general approach to seismic hazard evaluation should be directed towards reducing the uncertainties at various stages of the process.
- Experience shows that the most effective way of achieving this is to collect a sufficient amount of reliable and relevant data.
- There is generally a trade-off between the time and effort needed to compile a detailed, reliable and relevant database and the degree of uncertainty.
- 'Site specific data' (e.g. geological data) vs 'imported' data (e.g. attenuation relationships).

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- Seismic hazard studies include a **multidisciplinary body of experts**: geologists, seismologists, geophysicists, engineers, and other experts.
- The experts should rationally and systematically **interpret the implications of available data.**
- Differences in expert viewpoints and interpretations of available data and their implications will result in **epistemic uncertainties**, which should be adequately accounted for, whether the analysis is deterministic or probabilistic.
  - **Expert opinion should not be used as a substitute for generating new data**

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Specific recommendations on new topics, particularly, in the use of paleoseismology:

- The feedback from the IAEA review services confirmed the need for a 'solid' database, including paleoseismological studies, before proceeding with analysis.
- Paleoseismology, i.e. the study of the geological record of past earthquakes, provides a crucial link between historical seismology and neotectonic studies. This will be even more important in cases where historical data is deficient.

Type and span of data

TYPE OF DATA	TIME FRAME (approx.)	LOWER MAGNITUDE THRESHOLD (approx.)	TIME RESOLUTION
Local networks	10- 20 years	1	second
Modern instruments	30-40 years	2	second
Early instruments	100 years	4	second/minute
Historical	from few centuries to few millennia (*)	3(**)	from minute to year
Archaeological data	from few centuries to a few millennia (*)	5	year
Paleoseismological data	10,000 years	6	century
Neotectonics data	100,000 years		millennium

(*) depending on history of the Country
(**) depending on time period, seismic activity of region and according to cultural and socio-economic historic context.

Table 1

Type of data for the reconstruction of long term seismic history

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Characterization of seismogenic structures

Paleoseismology:

. . .

“ 4.22. Earthquakes produce effects on the environment which are also described in the intensity scales.

Some of these effects (e.g., faulting, liquefaction, coastline uplift) can be used to recognize past earthquakes.

The study of the geological record of past earthquakes is referred to as paleoseismology.

Paleoseismological studies may be particularly useful in areas where historical earthquake records are lacking.

Characterization of seismogenic structures

- **Palaeoseismic studies should be performed for the following purposes:**
  - **Identification of seismogenic structures** based on the recognition of effects of past earthquakes in the region.
  - **Improvement of the completeness of earthquake catalogues for large events,** using identification and age dating of fossil earthquakes; for instance, trenching across the identified capable faults may be useful in estimating the amount of displacement and its recurrence (using age dating of the encountered sediments).
  - **Estimation of the maximum potential earthquake of a given seismogenic structure,** typically on the basis of the displacement per event (trenching) as well as of the cumulative effect (landscape geomorphology).
  - **Calibration of probabilistic hazard analyses,** using the recurrence intervals of large earthquakes.

POTENTIAL FOR SURFACE FAULTING AT THE SITE

- During the selection and evaluation process of a site for a nuclear installation, the potential of fault displacement (or surface faulting) at the site area is a critical issue for the acceptability of the site.
- If such potential exists, the site should be considered as unsuitable and other site should be selected.
- Therefore, one of the main objectives of the site evaluation studies is to determine that fault displacement phenomena will not occur at the site, i.e. that no capable faults exist at the site area.

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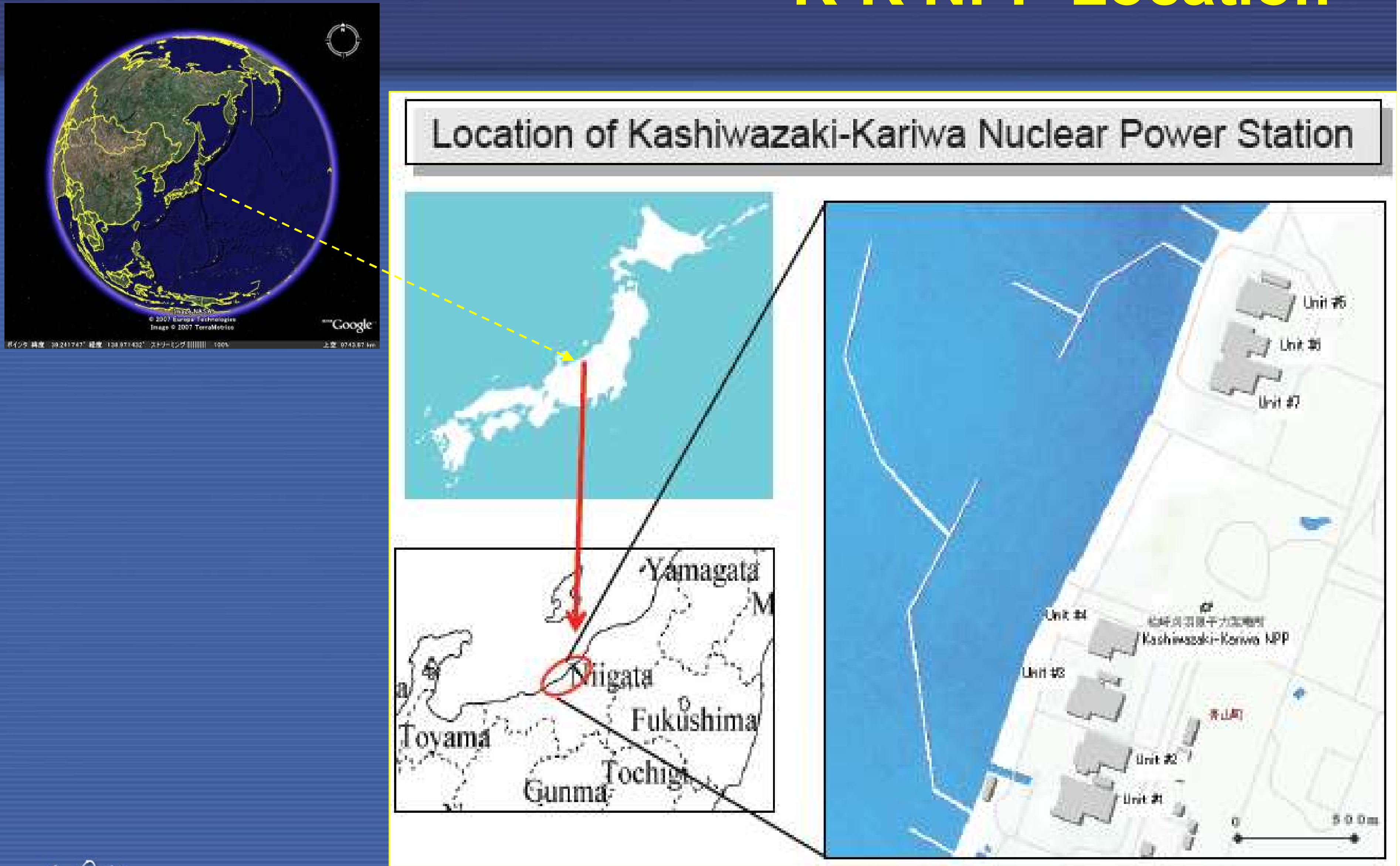
2. The 16 July 2007 Earthquake, the *"Niigataken Chuetsu-oki Earthquake (NCO)"*, Japan, and the Kashiwazaki-Kariwa NPP (K - K NPP).

K-K NPP Location



THE EARTHQUAKE

"NIIGATAKEN-CHUETSU OKI" – MAIN SHOCK:

- Magnitude: 6.8 M_{JMA} (6.6 Moment Magnitude)
- Epicentre: N37.5 , E138.6
- Time: 16 July 2007, 10:13(JST), i.e. 10:13 in the morning
  National Holiday in Japan, 120 staff in plant (1000).
- Depth: 17 km
- Distance to KK NPP:
  - Epicentre: 16 km
  - Hypocentre: 23 km

Total output

8,212 MW

Biggest NPP in the world

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NCO EARTHQUAKE - EFFECTS ON THE REGION

For Citizens

-Number of Death: 15

-Number of Injury: 2,315

For Houses

-Complete Collapse: 1,319

-Half Collapse: 5,621

-Partially Damaged:34,659

For Lifeline as of Jul.16

-Electricity Loss: 25,192 house holds: restored: 3days

-City Gas Loss: 34,200 house holds: restored 42days

-City Water Loss: 61,532 house holds: restored 15days later

Observation Records on R/B Base Mat

Gal:cm/s/s

Observation point				Observed Maximun Acc.			Design value	
				NS	EW	UD	NS	EW
Unit1	R/B	1-R2	B5F(Base Mat)	311	680	408	274	273
Unit2	R/B	2-R2	B5F(Base Mat)	304	606	282	167	167
Unit3	R/B	3-R2	B5F(Base Mat)	308	384	311	192	193
Unit4	R/B	4-R2	B5F(Base Mat)	310	492	337	193	194
Unit5	R/B	5-R2	B5F(Base Mat)	277	442	205	249	254
Unit6	R/B	6-R2	B5F(Base Mat)	271	322	488	263	263
Unit7	R/B	7-R2	B5F(Base Mat)	267	356	355	263	263

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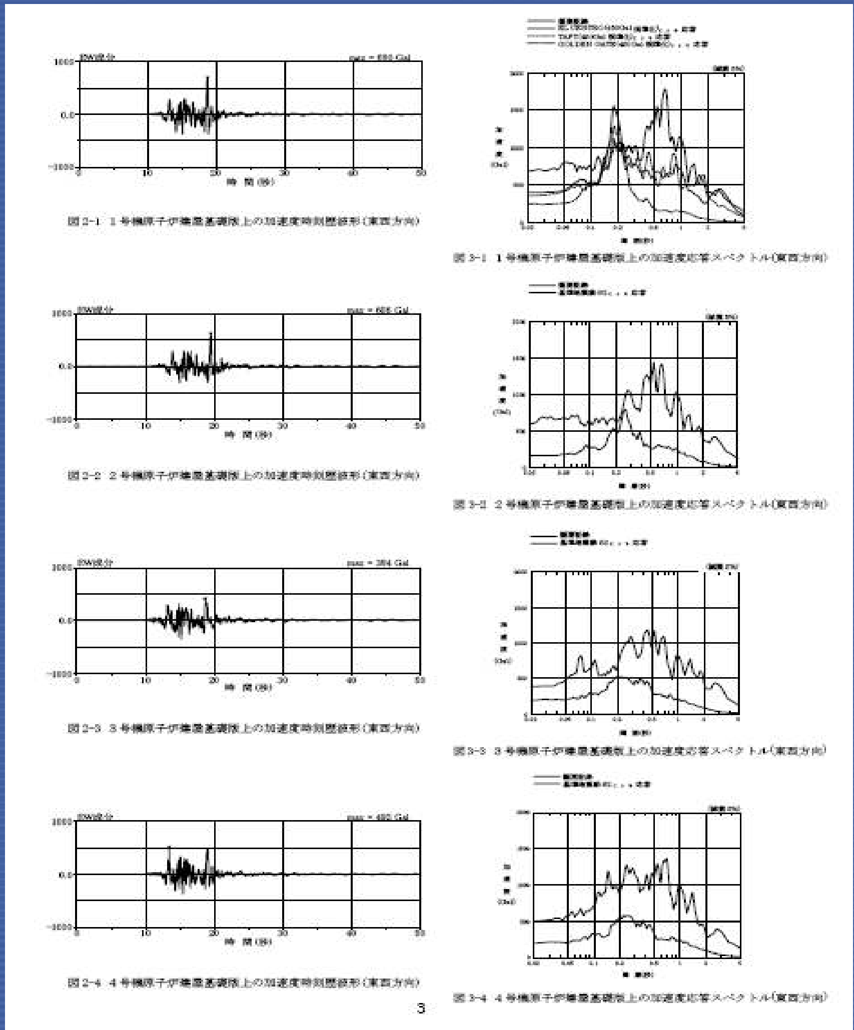
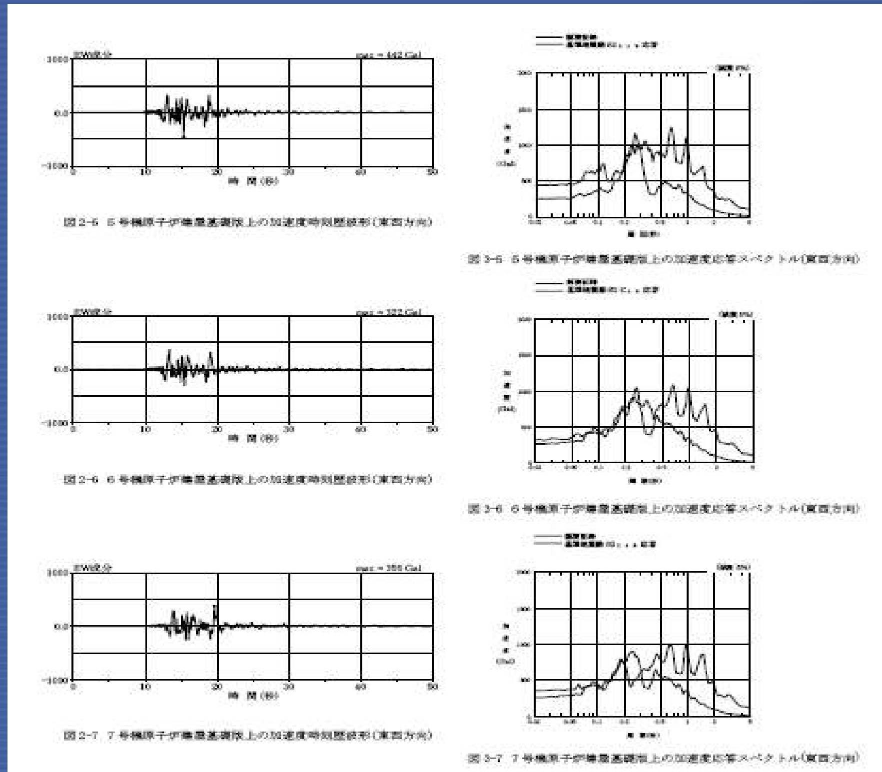
Seismic Wave and Response Spectrum (Acceleration)





Observation — Design (S_2)

On the Foundation of R/B

Earthquake Effects at the Plant:
Fire at in-house (non-safety) electrical transformer

The fire was extinguished after 2 hours.

Root cause: soil subsidence of the base of the secondary connection bus bar with respect to the transformer foundation.

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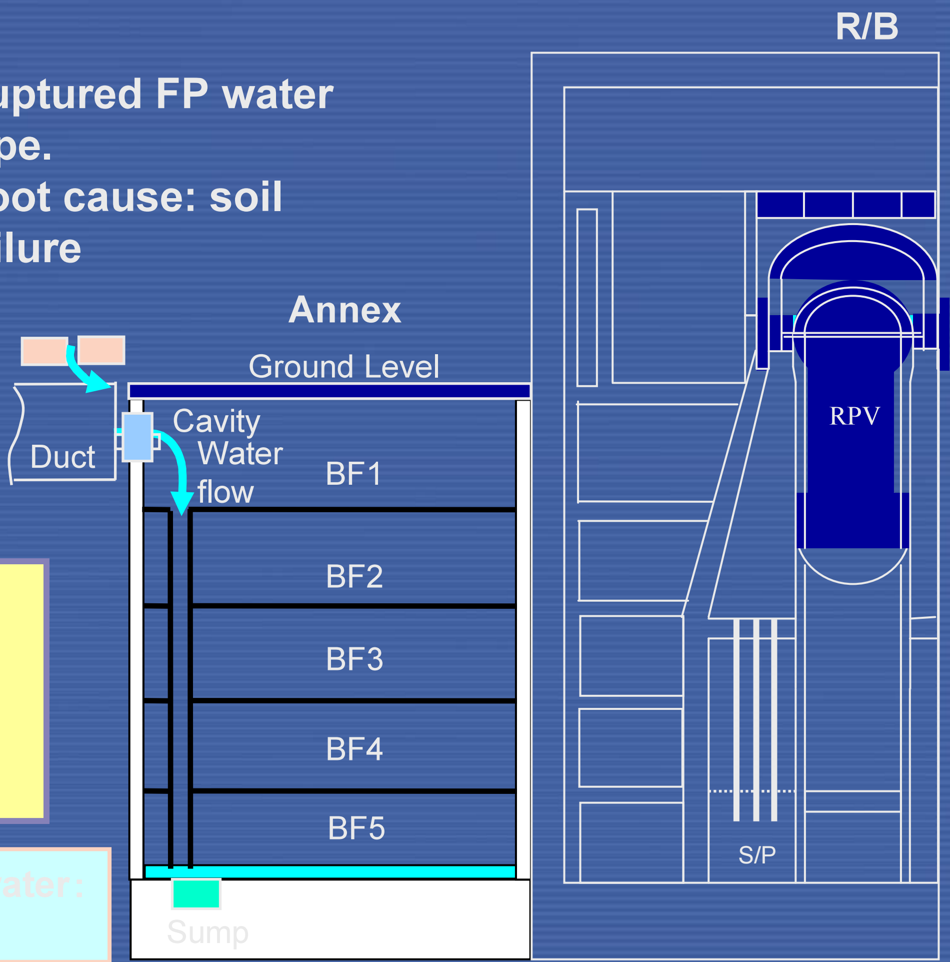
Earthquake Effects at the Plant:
Rupture of Fire Protection Water Pipe

Ruptured FP water pipe.
Root cause: soil failure



The flooding affected radioactive waste processing equipment on BF5 of the Annex.

Amount of leaked water: approx. 2000m^3

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Earthquake Effects at the Plant:
Non-safety related *Class B & C and Other SSCs*

Service Roads


Near Switch Yard


Near Unit 5

Ground Subsidence


Light Oil Tank Yard

IAEA Involvement – K-K NPP

1. "*Seismic Safety Expert Mission - Preliminary Findings and Lessons Learned*", August 2007.
2. "*Follow up Mission in relation to the Findings and Lessons Learned*", January/February 2008.
3. "*Experts Meeting in relation to the Geological and Geophysical investigations*", May 2008.
4. "*Experts Meeting in relation to the New Revised Seismic Hazard Assessment for the K-K NPP site*", June 2008.
5. "*IAEA International Workshop on Lessons Learned from Recent Strong Earthquakes*", Kashiwazaki, Japan, June 2008.
6. Presentations in international meetings.

PLANT PERFORMANCE

- **Satisfactory plant (systems, structures and components) behaviour during and after the earthquake**
- **Fundamental Safety Functions preserved:**
  - **very small and insignificant releases observed**
- **Design basis ground motions (S2) largely exceeded:**
  - **Seismic Hazard: ground motions, used for estimating dynamic response, were underestimated.**
  - **Conservatism in the seismic design criteria used (equivalent static approach) compensate the uncertainties in the data/methods at the time of design that led to the above mentioned underestimation in the hazard assessment.**

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RECOMMENDED ACTIONS

- Seismic hazard re-evaluation: including identification and characterization of capable/active faults at the site area, and evaluation of soil failures and local tectonic features
- Detailed check of integrity and operability of all safety systems (under way). Issue of hidden damage
- Re-evaluation of seismic safety in relation with the new seismic hazard
- Potential interaction between large ground motions and accelerated ageing

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Surveys conducted after July 2007 Earthquake

- Sea Area• •

- Sonic Prospecting Survey
- Submarine Topographic Survey

Survey area of approx. 140km parallel to the shoreline and approx. 50km toward the offing

•from Aug. 27, 2007 until Nov. 8, 2007• •

- Land Area• •

- Seismic Prospecting Survey
- Geological Survey
- GPS Surveying

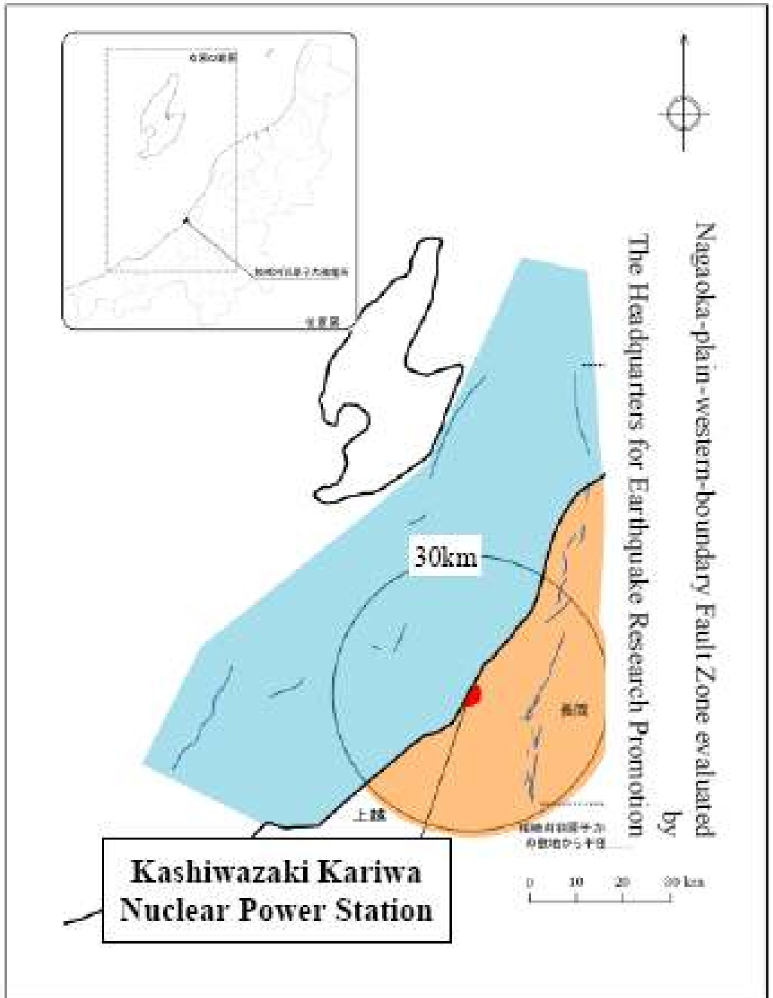
Land area within a 30 km radius from the power station and along Nagaoka-plain-western-boundary Fault Zone

(from Sep. 20, 2007 until Apr. 9, 2008)

- Site and Site Environs• •

- Boring Survey
- Surveying
- Subsurface Investigation

•from Sep. 18, 2007 until Mar. 25, 2008)



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ACTIVE FAULTS AND FOLDS

4. Sado-shima-eastern-boundary Flexure • • approx. 37km

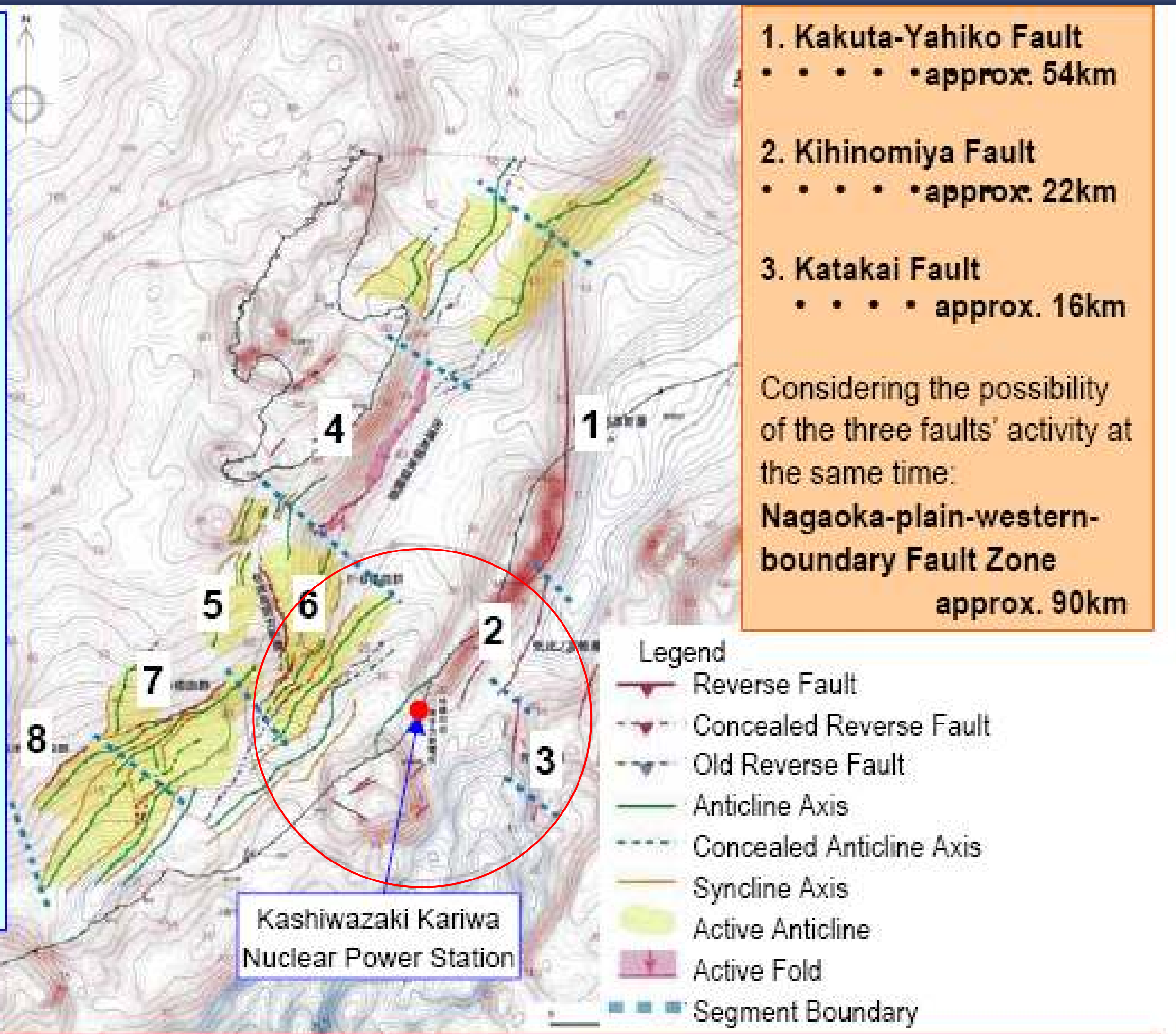
5. Sado-shima-southern Fault • • • • • • approx. 29km

6. F-B Folds Band approx. 34km

7. F-D Folds Band approx. 30km

8. Takada-oki Fold Band • • • • • • approx. 25km

Considering the possibility of the these faults' activity at the same time:
Takada-oki & F-D Folds Bands • • • • • approx. 55km• •



1. Kakuta-Yahiko Fault • • • • •approx. 54km

2. Kihinomiya Fault • • • • •approx. 22km

3. Katakai Fault • • • • approx. 16km

Considering the possibility of the three faults' activity at the same time:
Nagaoka-plain-western-boundary Fault Zone approx. 90km

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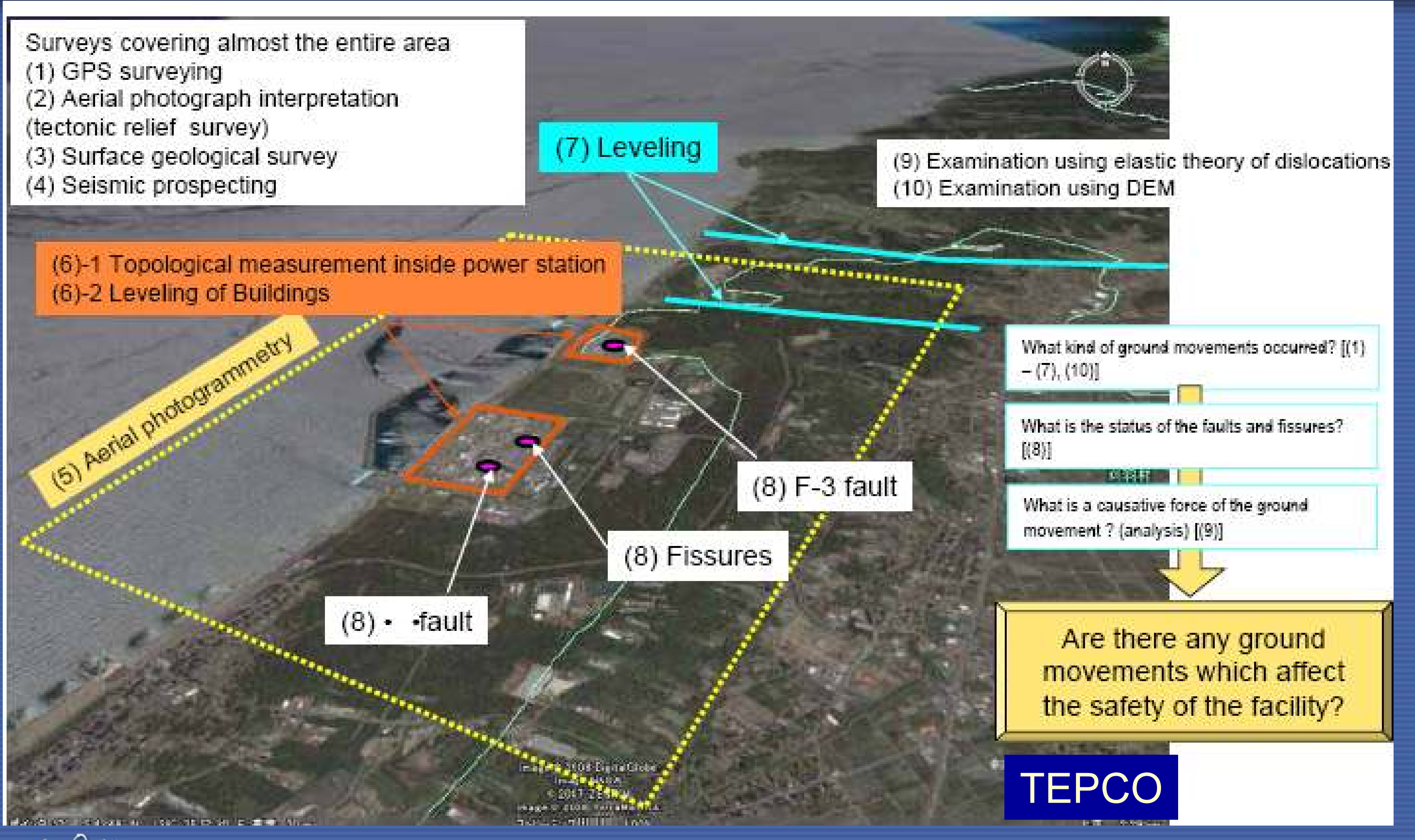
Surveys to identify ground movements



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Geological investigations at the site area

Shaft for β fault

Boring Core storage

Seismic reflection profiles

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Revised New Seismic Hazard at the K-K NPP Site

- The following faults were taken into consideration upon determining the design-basis seismic motion.

Active fault		Length of fault	Scale of earthquake [*1]		Angle of inclination [*2]	Notes
F-B fault		About 34km[*3] (About 27km)	34km	M7.0	Southeastern inclination 35•	As a conservative approach, the total length of the fault was identified as about 34km.
Nagaoka Plain Western Boundary Fault Zone	Kakuda-Yahiko fault	About 54km	91km	M8.1	Western inclination 50•	As a conservative approach, these faults were assumed to move together.
	Kihinomiya fault	About 22km				
	Katagai fault	About 16km				
F-D fault • •		About 30km	55km	M7.7	Southeastern inclination 35•	As a conservative approach, these faults were assumed to move together.
Takada-oki fault		About 25km				

Note 1: With regard to the F-B fault, the scale of magnitude was determined by the scale of the assumed fault surface
• •between the magnitude and the size of the fault surface at the hypocenter of the Niigata-Chuetsu-Oki earthquake.
• • • •magnitude was determined by the length of ground surface faults using the formula of Matsuda (1975).
Note 2: Angle of inclination: the inclination of fault surface against the horizontal surface.
Note 3: The length of the fault, according to our survey, is 27km, but taking a conservative approach, it is assumed to

Assessment currently under review

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Seismic motion	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Niigataken Chuetsu-oki Earthquake (observed on the foundation of reactor building)	680	606	384	492	442	322	356
Response to the design basis seismic motion Ss (on the foundation of reactor building)	829	739	663	699	543	656	642
The peak value of the design basis seismic motion Ss (on the free surface of base stratum)	2,280				1,156		

The value represents the larger value among horizontal ones (south-north and east-west). (Unit: Gal)

Lessons Learned - Seismic Hazard

- A large amount of work has been performed in order to understand the earthquake of July 2007 and to assess the possibility of future earthquakes that may affect the plant. This involved geophysical, geological, geodetic and seismological investigations, both onshore and offshore.
- Many specialized and highly recognized Japanese institutions are taking part in these investigations.
- Considering the complexity of the problem it will be a challenge to bring together all this information and interpretations within a coherent integrated framework.
- The investigations clearly document the occurrence of both horizontal and vertical (uplift, from W to E) coseismic crustal deformation at the site.

CONTENTS

- IAEA Safety Standards
- The July 2007 Earthquake, Japan.
- **Concluding Remarks**

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CONCLUDING REMARKS

- Earthquakes provide valuable "lessons learned" – the major steps of progress in earth sciences and earthquake engineering have always occurred after major earthquakes.
- For Japan, the Great Kanto Earthquake of 1923 and the Kobe Earthquake of 1995 provided many lessons to earth scientists and engineering community and established milestones for scientific and technical progress and development.
- The NCO Earthquake of July 2007 is a similar event that will constitute a milestone for the progress of the seismic safety for NPPs.

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CONCLUDING REMARKS

- **Common cause events** –i.e. earthquakes- can have a great impact to **multi-unit sites**.
- **Public perception** about the seismic safety of nuclear installations: when an earthquake happens affecting a nuclear power plant, damage may occur in non-safety related structures, systems and components, as it occurs to facilities outside the plant site. A ‘success’ story is not perceived as such.

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CONCLUDING REMARKS

- **New approaches and methodologies**, (e.g. probabilistic safety assessment for the hazard and the facility capacity evaluation).
- **Newly defined seismic hazards** are much higher than the original design values, and seismic risk has become an important contributor to the total plant risk. Recorded ground motions higher than 1g (pga) .
- IAEA has contributed significantly to assist Member States in this subject for more than 20 years. Our related Safety Standards today reflect properly the developments of the scientific, regulatory and industry communities. They are being updated to reflect lessons learned from recent strong events.

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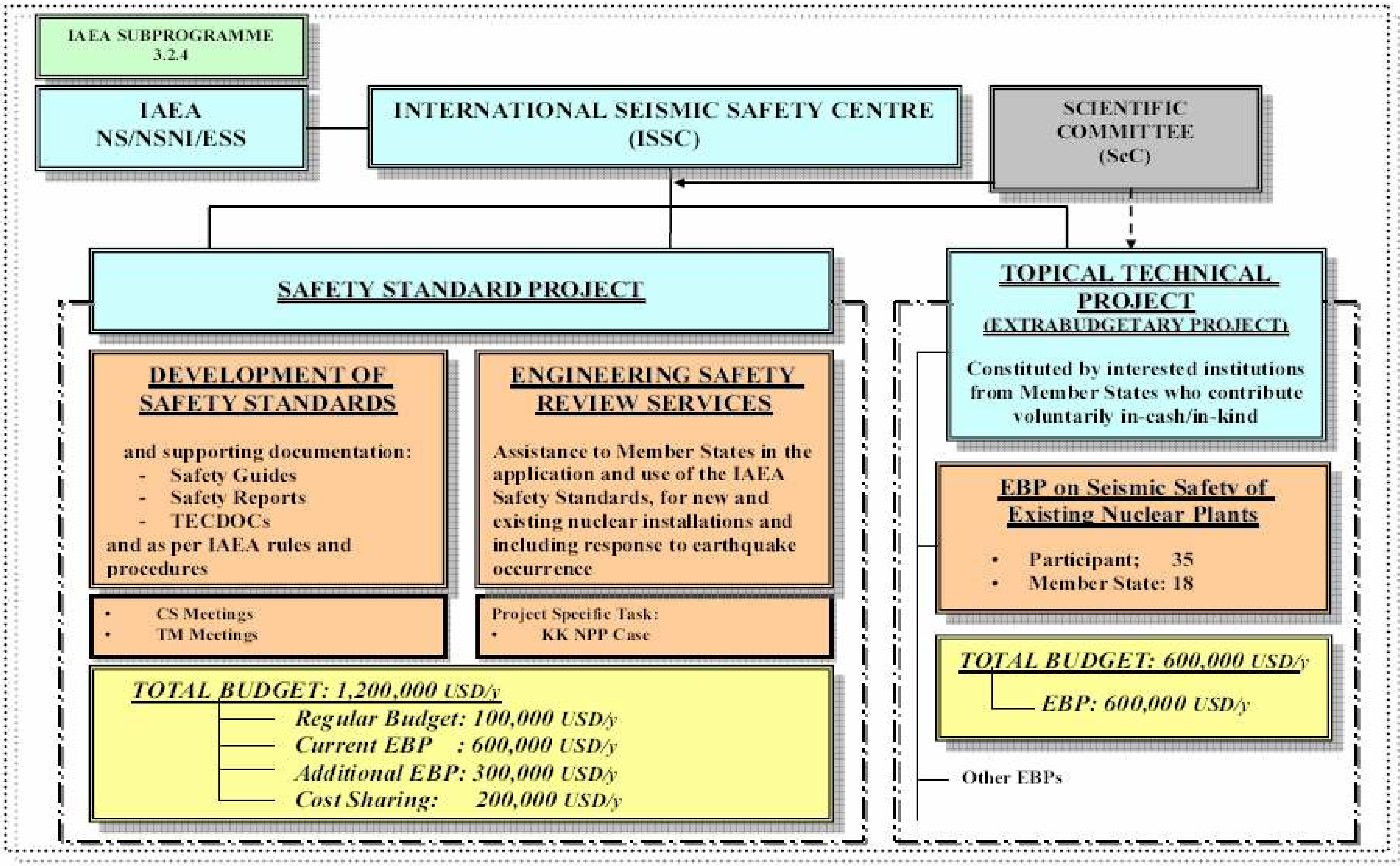
INTERNATIONAL CENTRE for SEISMIC SAFETY

CONCEPTUAL FRAME OF *"INTERNATIONAL SEISMIC SAFETY CENTRE (ISSC)"*



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Thank you for your attention

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