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Fukushima Daini

A comparison of the events at Fukushima Daini and Daiichi

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The authors are responsible for the content of this report.

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The Fukushima Daini Site

- 12 km south of Daiichi
- Operator TEPCO
- Four Units
  - 1.100 MW (el) each
- Building started 1975
- Last grid connection 1987
- Type BWR 5
- Containment
  - Mark II/Mark II Improved

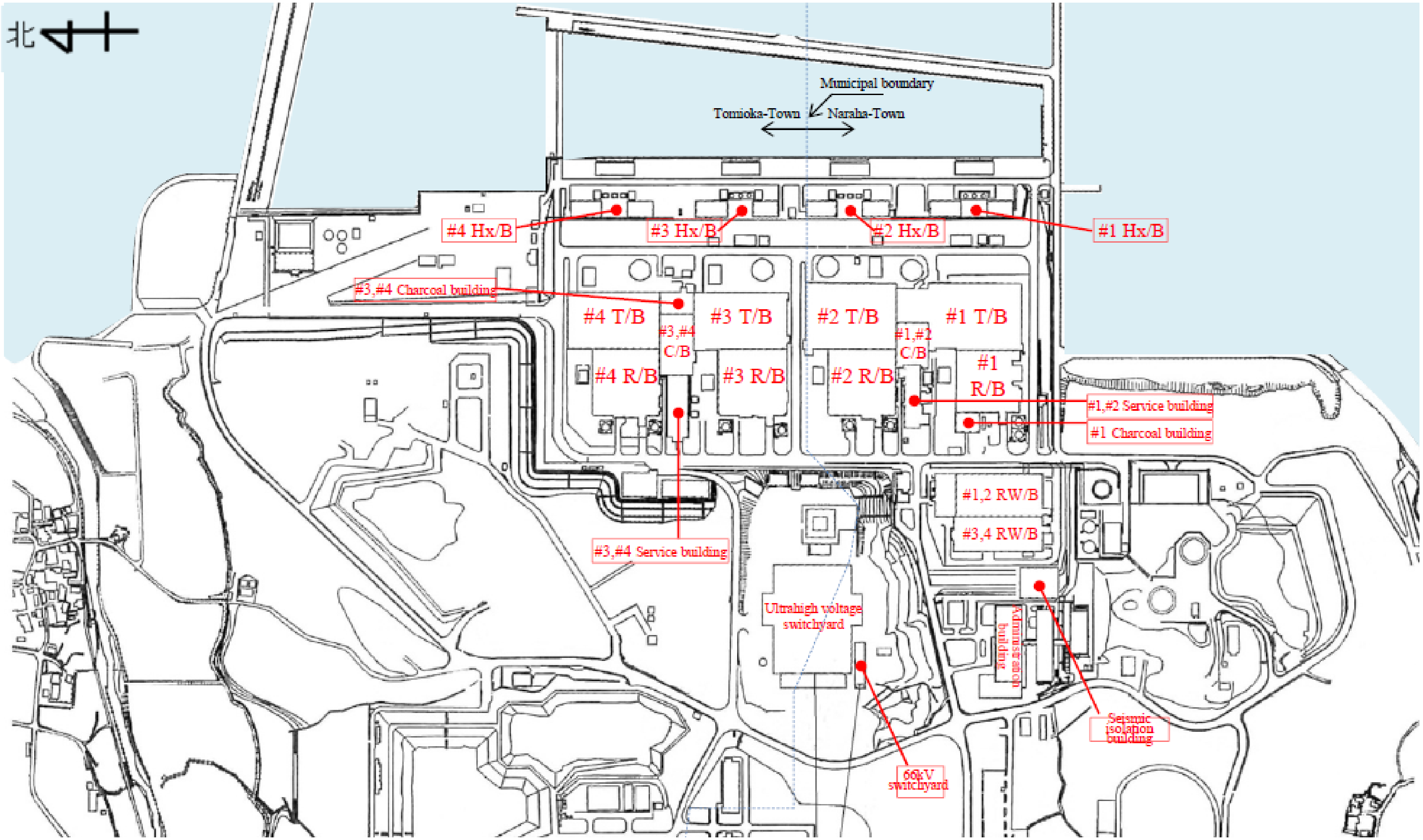
Source: TEPCO

Fukushima Daini - Buildings

Among others each reactor unit consists of

- a Reactor Building (R/B) with annex (R/B Annex),
- a Turbine Building (T/B) and
- two Seawater Heatexchanger Buildings (Hx/B).

Fukushima Daini - Buildings



Source: <GoJ 2012>, Attachment II-5-3

Fukushima Daini – Process Systems

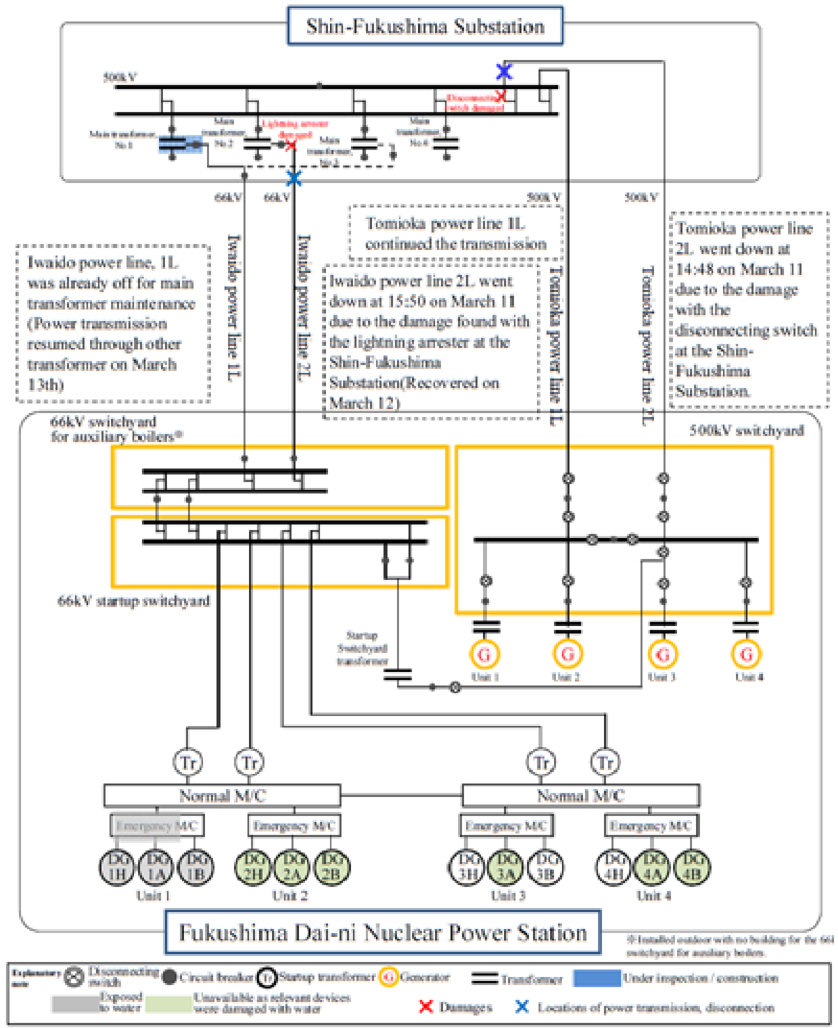
System	Redund.	Function	Support	Power	Sources
RCIC	1	High Pressure Safety Injection		Main Steam, DC	CST, S/C
HPCS	1	High Pressure Safety Injection	HPCSC, HPCSS	ED/G H	CST, S/C
LPCS	1	Low Pressure Safety Injection	RHRC A/C, EECW A	ED/G A	S/C
ADS	18	Depressurisation of RPV		DC	
RHR	A	Low Pressure Safety Injection, Cooling	RHRC A/C, EECW A	ED/G A	RPV, S/C, SFP
	B	Low Pressure Safety Injection, Coolin	RHRC B/D, EECW B	ED/G B	RPV, S/C, SFP
	C	Low Pressure Safety Injection	RHRC B/D, EECW B	ED/G B	S/C
RHRC	A/C	Closed Cooling	RHRS A/C	ED/G A	
	B/D	Closed Cooling	RHRS B/D	ED/G B	
RHRS	A/C	Seawater Cooling		ED/G A	Seawater
	B/D	Seawater Cooling		ED/G B	Seawater
EECW	A	Emergency Equip. Cool.	RHRS A/C	ED/G A	
	B	Emergency Equip. Cool.	RHRS B/D	ED/G B	
MUWC		AM-Low Pressure Safety Injection		Auxiliary power	CST
FP		AM-Low Pressure Safety Injection		Auxiliary power, Diesel	Fresh water
FPC	2	Spent Fuel Pool Cooling		ED/G	SFP

Comparison – Fukushima Daini vs. Daiichi Process Systems

- Essentially the same Process Systems
  - 2 High Pressure Safety Injection systems RCIC, HPCS,
  - 2 Low Pressure Safety Injection systems LPCS und RHRC
  - 2 Low Pressure Safety Injection and cooling systems RHR
- Same Accident Management Measures for both plants
  - Alternative Low Pressure Injection by use of MUWC and FP
  - Possibilities for Depressurization of Containment

à No Relevant Differences

Fukushima Daini – Electric Power Supply Systems



Source: <GoJ 2011b>

Fukushima Daini – Electric Power Supply Systems

- External Grid connection via Shin-Fukushima sub station
  - Two 500 kV lines
  - Two 66 kV lines
- Emergency Power Supply
  - Three Emergency Diesel Generators A, B and H
    - Two Emergency Diesel Generators (A, B) for Residual Heat Removal System RHR
    - One Emergency Diesel Generator (H) for High Pressure Core Spray System HPCS
  - Electric Power Connection between two units respectively

Comparison – Fukushima Daini vs. Daiichi Electric Power Supply Systems

- Both Plants had several external grid connections
  - Daini: four lines to Shin-Fukushima
  - Daiichi: six lines, one of it to Tohoku grid via different sub station

  à Relevant Difference: Daiichi generally higher robustness

- Emergency Power Supply
  - Daini: three emergency diesel generators for each unit (two of if for cooling, one for high pressure coolant injections), all water-cooled
  - Daiichi: two emergency diesel generators for each unit (twelve in total, three of it air-cooled)

  à Relevant Difference: Daiichi generally higher robustness

The Event – Earthquake

- Before the earthquake:
  - All four units at steady state power
  - One external grid line in revision, three lines available
- March 11, 2011, 14:46
  - Earthquake of Magnitue 9 (Momentum-Magnitude)
  - 183 km distance to epicenter
  - Seismic intensity at Daini: 6(upper) on JMA
  - Original Design Basis of the Plant : 3.7 m/s^2 (PGA)
  - Re-evaluation 2006: up to 6.1 m/s^2
  - Maximum measured values at the Site : 3.05 m/s^2
- 14:48: all four units automatically shutdown

The Event – Earthquake

- After the earthquake:
  - Two lines of external grid connection lost
  - One line of external grid still operational
  - External electric power supply available for the whole event (even long-term)
  - Heat removal from reactors to main heat sink
  - No (relevant) damage to emergency safety systems

Comparison – Fukushima Daini vs. Daiichi Earthquake

- Design
  - Earthquake design basis: for both plants about 0.4-0.5 g PGA

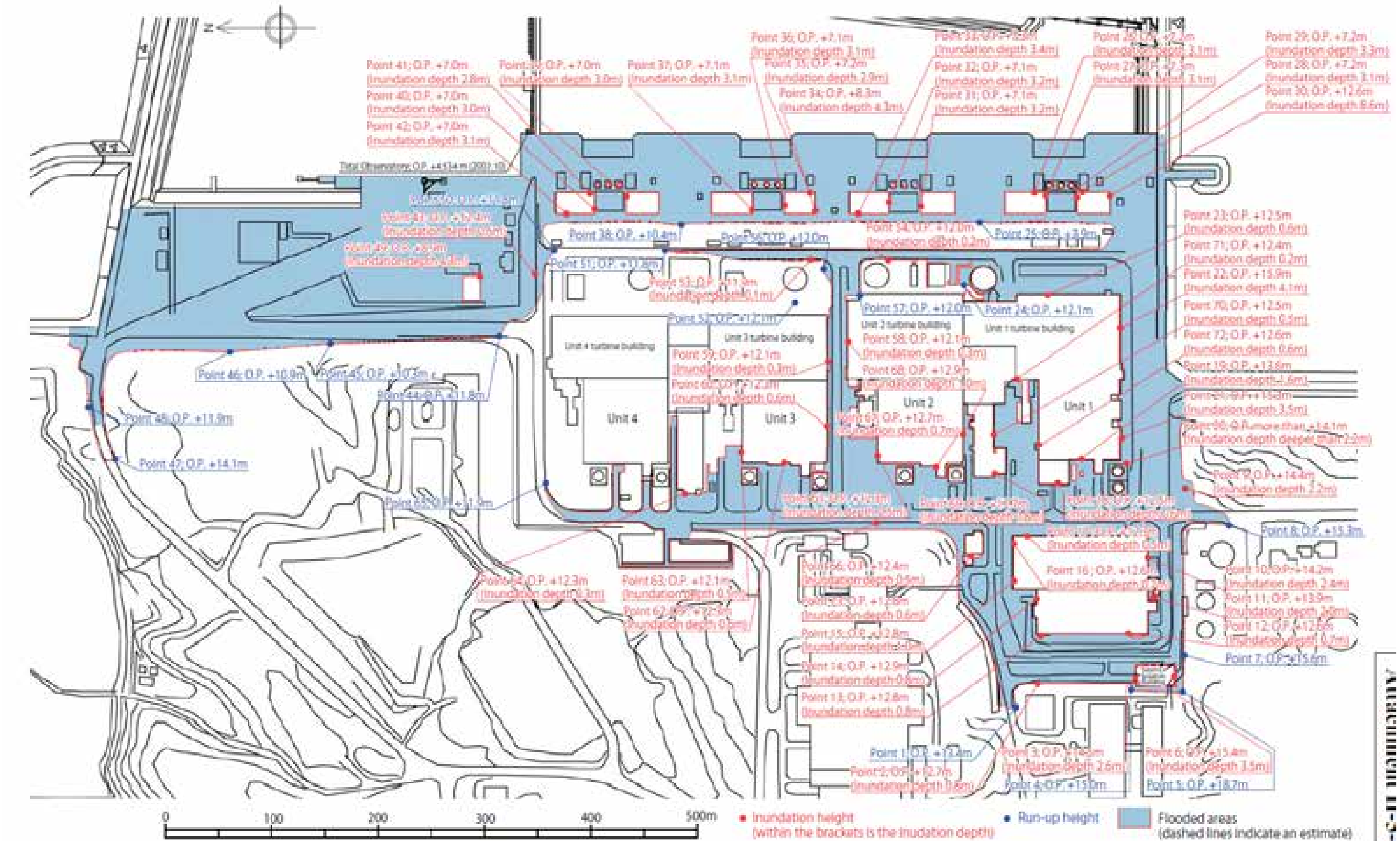
  à No Relevant Differences
- Earthquake
  - Fukushima Daini max. approx. 65% of design basis PGA
  - Fukushima Daiichi max. approx. 125% of design basis PGA
  - Daiichi: total loss of external grid connection, thus
    - Immediate loss of main heat sink
    - Loss of electric power supply of operation systems (MUWC)

  à Relevant Difference: Significantly lower intensity and consequences of Earthquake at Daini

The Event – Tsunami

- 15:22 : Tsunami arriving at the site
  - Until 17:44 Tsunami waves arrive at site
  - Original design basis: O.P. +3.1 m
  - Re-evaluation 2002: O.P. +5.2 m
  - Maximum Tsunami height off site: O.P. +9.1 m
  - Seawater Heatexchanger Buildings at O.P. +4 m
  - Reactor Buildings at O.P. +12 m
  - Runup Water at unit 1 up to O.P. +15.9 m

The Event – Tsunami



Source: <GoJ 2012>, Attachment II-5-6

The Event – Availability of electric power supply (ED/Gs)

Table 3-3: Availability of ED/Gs in Fukushima Daini after the Tsunami

Unit 1		Unit 2		Unit 3		Unit 4	
Line	**Location**	**Line**	**Location**	**Line**	**Location**	**Line**	**Location**
1A	R/B Ann. 2 UG	2A	R/B Ann. 2 UG	3A	R/B Ann. 2 UG	4A	R/B Ann. 2 UG
1B	R/B Ann. 2 UG	2B	R/B Ann. 2 UG	3B	R/B Ann. 2 UG	4B	R/B Ann. 2 UG
1H	R/B Ann. 2 UG	2H	R/B Ann. 2 UG	3H	R/B Ann. 2 UG	4H	R/B Ann. 2 UG

Source: <GoJ 2012>, Attachment II-5-7

Red: direct damage due to flooding, Orange: unavailable due to loss of cooling

The Event – Availability of electric power supply (Equipment in Hx/B)

Table 3-6: Availability of equipment in Hx/B in Fukushima Daini after the Tsunami

Unit 1		Unit 2		Unit 3		Unit 4	
North	South	North	South	North	South	North	South
RHRC-Pumps							
(B)	(A)	(A)	(B)	(A)	(B)	(A)	(B)
(D)	(C)	(C)	(D)	(C)	(D)	(C)	(D)
RHRS-Pumps							
(B)	(A)	(A)	(B)	(A)	(B)	(A)	(B)
(D)	(C)	(C)	(D)	(C)	(D)	(C)	(D)
EECW-Pumps							
(B)	(A)	(A)	(B)	(A)	(B)	(A)	(B)

Source: <GoJ 2012>, Tabelle II-5-1

Red: direct damage due to flooding, Orange: unavailable due to loss of cooling

The Event – After the Tsunami

- Unit1, 2 und 4
  - Electric Power Supply available
  - Total loss of Seawater Cooling Systems: no heat removal to ultimate heat sink possible
  - Temperature increase in condensation chamber
  - RPV injection with RCIC
- Unit 3
  - Electric Power Supply available
  - One train of cooling systems available without interruption

Comparison – Fukushima Daini vs. Daiichi Tsunami

- Design
  - Chile-Event: both plants at about O.P. +3.1 m
  - Re-evaluation to O.P. +5.2 m (Daini), O.P. +5.4-6.1 m (Daiichi)

  à No Relevant Differences

  - Seawater Heatexchanger Buildings (Daini) vs. seawater pumps in the open (Daiichi)

  à Relevant Difference: Daini higher robustness

  - Plant Site at O.P. +12 m (Daini), O.P. +10 m (Daiichi, Units 1-4)

  à Relevant Difference: Daini higher robustness, but not attributable to design basis against tsunamis

Comparison – Fukushima Daini vs. Daiichi Tsunami

- Tsunami Impact
  - Maximum Height at Fukushima Daini +9.1 m
  - Maximum Height at Fukushima Daiichi +13.1 m
  - At Daini no massive flooding of plant site
    - No direct impact to Emergency diesel generators (apart from one in Unit 1)
    - P/C and M/C in R/B not damaged
    - External power supply available
    - I&C and operational systems (MUWC) are supplied with electricity

à Relevant Difference: Significantly lower intensity and consequences of Tsunami at Daini

The Event – Measures taken by Plant Personnel

- Unit 1, 2 and 4
  - Continuous control and prognosis of relevant plant parameters (pressure RPV/PCV, temperature and water level condensate chamber)
  - Purposeful Depressurization of RPV to prepare for Low Pressure Coolant Injection with operation system (MUWC)
  - D/W- and S/C-spay to lower pressure in containment
  - Test of Low Pressure Coolant Injection, fast RPV-Depressurization, intermittend Low Pressure Coolant Injection to keep water level constant
  - Preparations for Depressurization of PCV
- Unit 3
  - Continuous availability of one train of residual heat removal system RHR
  - Until March 12, 12:15 „cold shutdown“

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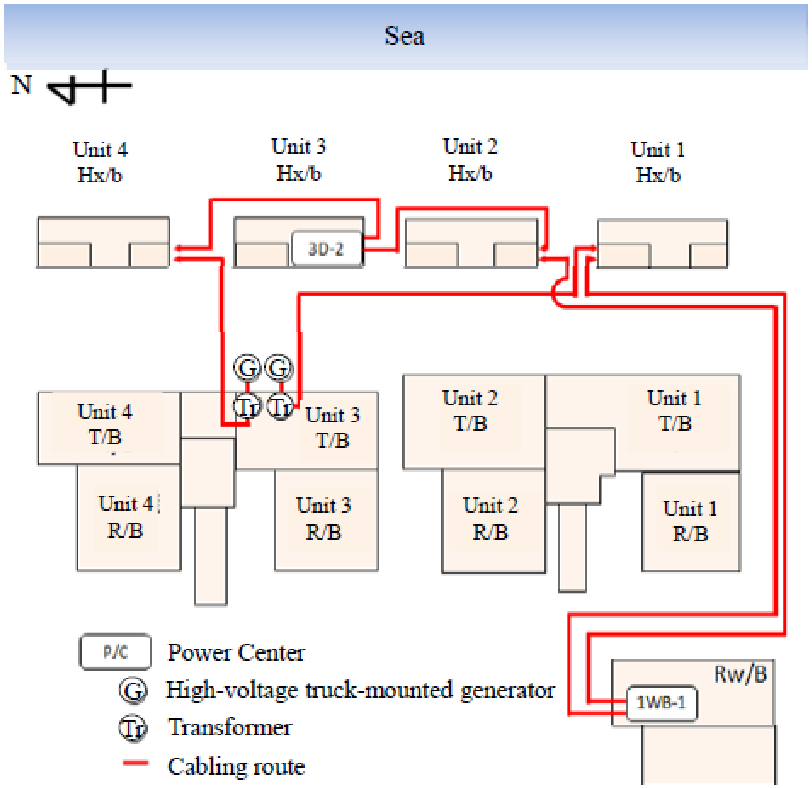
The Event – Recovery of power supply



- Cleanup of streets until March 13
- Installation of 900 m cable from Rw/B to Hx/b Unit 2 on March 12
- Installation of mobile generators
- Additional cable to other Hx/B
- In total 9 km of cable

Source: TEPCO

The Event – Recovery of cooling functions

- Recovery of cooling systems
  - Procurement of motors from other plants
  - Replacement or repair of motors and pumps in RHRC/RHRS
- Restart of RHR
  - Unit 1: March 14. 1:24
  - Unit 2: March 14, 7:13
  - Unit 4: March 14, 15:42
- Until March 15 all four units achieve „cold shutdown“
- Since March 16 RHR also used for SFP-Cooling

Comparison – Fukushima Daini vs. Daiichi Measures taken by Plant Personnel

- Central Measures taken by Plant Personnel:
  - Coninuous control and prognosis of relevant plant parameters
  - Early preparation, test and startup of low pressure coolant injection to ensure RPV cooling and
  - Recovery of heat removal from Containment
- Essential prerequisites for successful implementation of measures:
  - Availability of external power supply
  - Availability of I&C functions
  - Availability of operation systems as part of Accident Management

Conclusions I

- Differences in Design basis Daini/Daiichi
  - Daini: higher robustness of seawater systems (nevertheless total loss)
  - Daiichi: higher robustness of power supply (nevertheless total loss)
- Intensity and consequences of earthquake as well as tsunami in Daini significantly lower than in Daiichi
- Prerequisites for successful implementation of AM measures in Daini significantly better than in Daiichi
  - Continuous availability of external power supply
  - Availability of I&C
  - Availability of operation systems for AM

Conclusions II

- Options to increase plant safety
  - Increase robustness of operation systems and
  - Design of accident management equipment against external events
- Central Cause of Difference between a INES 7 vs. INES 3 event:
  - Lower impact of earthquake and tsunami, but not differences in the design basis of the plants à Luck

Thank you for your attention!

Do you have any questions?