Overview of current understanding of accident progression at Fukushima Dai-ichi

OECD-NEA Workshop on Accident Tolerant Fuels. 10-12 December 2012

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Outline

- **Sequence of key events**
  - **Overview (based on presentation by Dr Okajima, JAEA at June 2012 NSC Meeting)**

- **Types of information available**
  - **examples of measured data**
    - **Station Data , Water level, Pressure, Temperature, Radiation Levels**
  - **examples of analytical studies**
    - **OECD-NEA Benchmark Study on Accident at Fukushima Daiichi (BSAF) Workshops June & November 2012**

- **Qualitative description of accident progression**
  - **key phenomena**
  - **role of fuel & clad design (qualitative)**

Outline of Accident Progression (Common to Units 1-3)

Automatic reactor shutdown due to earthquake, loss of off-site power supply

Dependency on emergency power was inevitable.

- Emergency diesel generator started up and power supply was secured.
- Reactor was cooled by core cooling system.

Start-up / Shutdown operations for IC･RCIC were going on.

Most of electric systems including emergency diesel generators and switchboards were unavailable due to tsunami.

(Only one of emergency air cooling DGs in Unit 6 maintained its function)

Cooling sea water pumps installed along the coast were also unavailable. (Loss of ultimate heat sink)

Station Blackout

(On March 13, Unit 5 received power supply from Unit 6 on emergency basis.)

Motor operated pumps etc. were unavailable. (Emergency cooling was carried out by emergency condenser IC in Unit 1, reactor core isolation cooling system [RCIC] in Unit 2, and RCIC and high pressure core injection system HPCI in Unit 3.)

Soaking / depletion of battery, depletion of compressed air, etc.

Many on-site works were necessary due to difficulty of measurement / control / communication.

Shutdown of core cooling system

Unit 1 has lost its function at an early phase. Due to this reason, there was only short time to address the situation.

Fuels were exposed and melt down while cooling was not conducted.

Serious degradation of Containment led to the release of radioactive materials into environment.

Water injection from fire protection system (Alternative water injection)

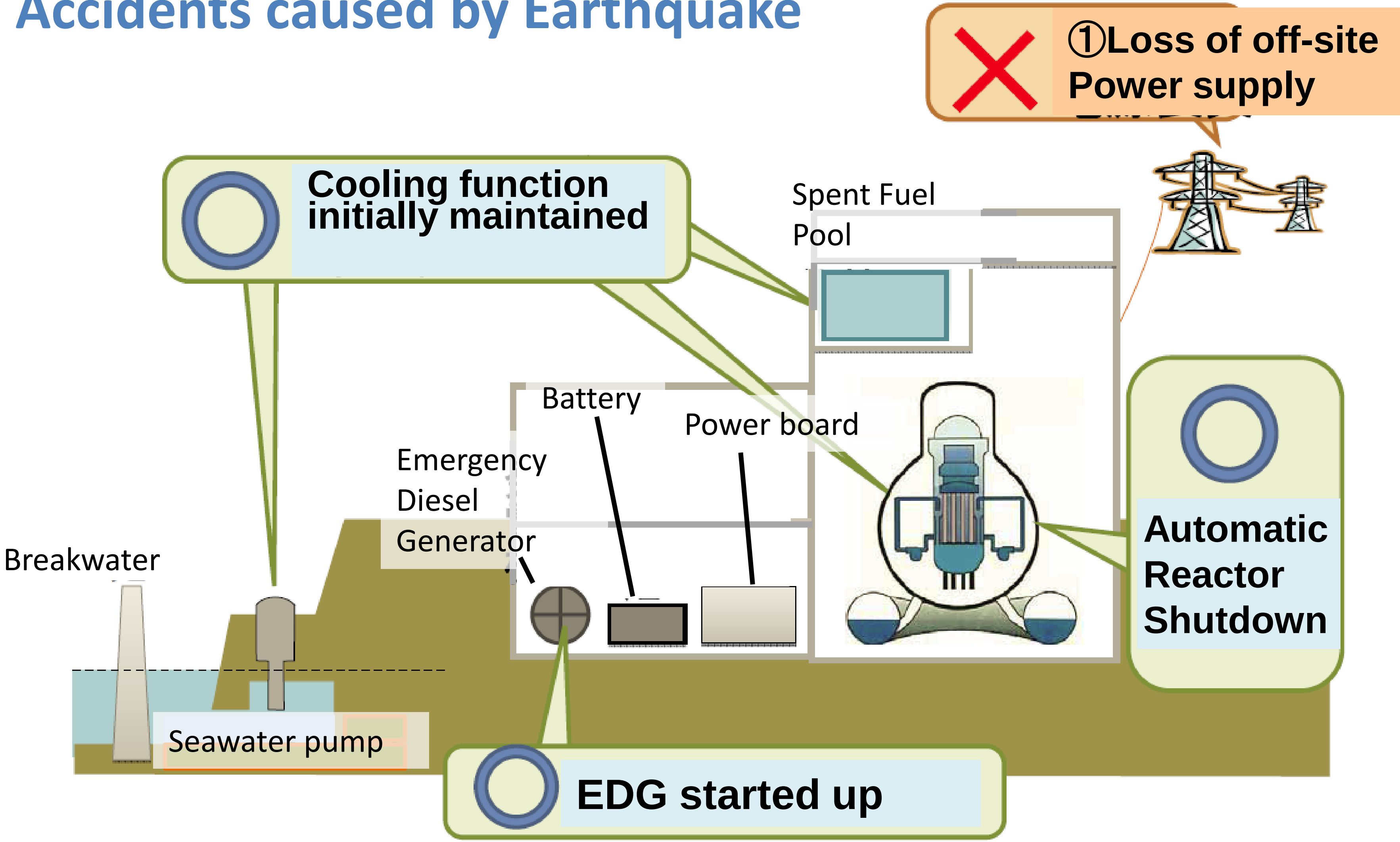
The exposure time of fuels is considered to be prolonged due to insufficient reactor depressurization (reactor depressurization operation for containment, reactor containment depressurization [vent]) to the pressure lower than the fire extinguishing pump head.

Hydrogen generated through zirconium – water reaction. Explosions that seemed to be hydrogen explosion occurred in reactor buildings at Units 1, 3 and 4. (Pressure in the pressure suppression chamber in Unit 2 dropped simultaneously with the Unit 4 explosion.)

- The explosions deteriorated work performance in the surrounding areas.
- Water leakage from containments / buildings were observed.

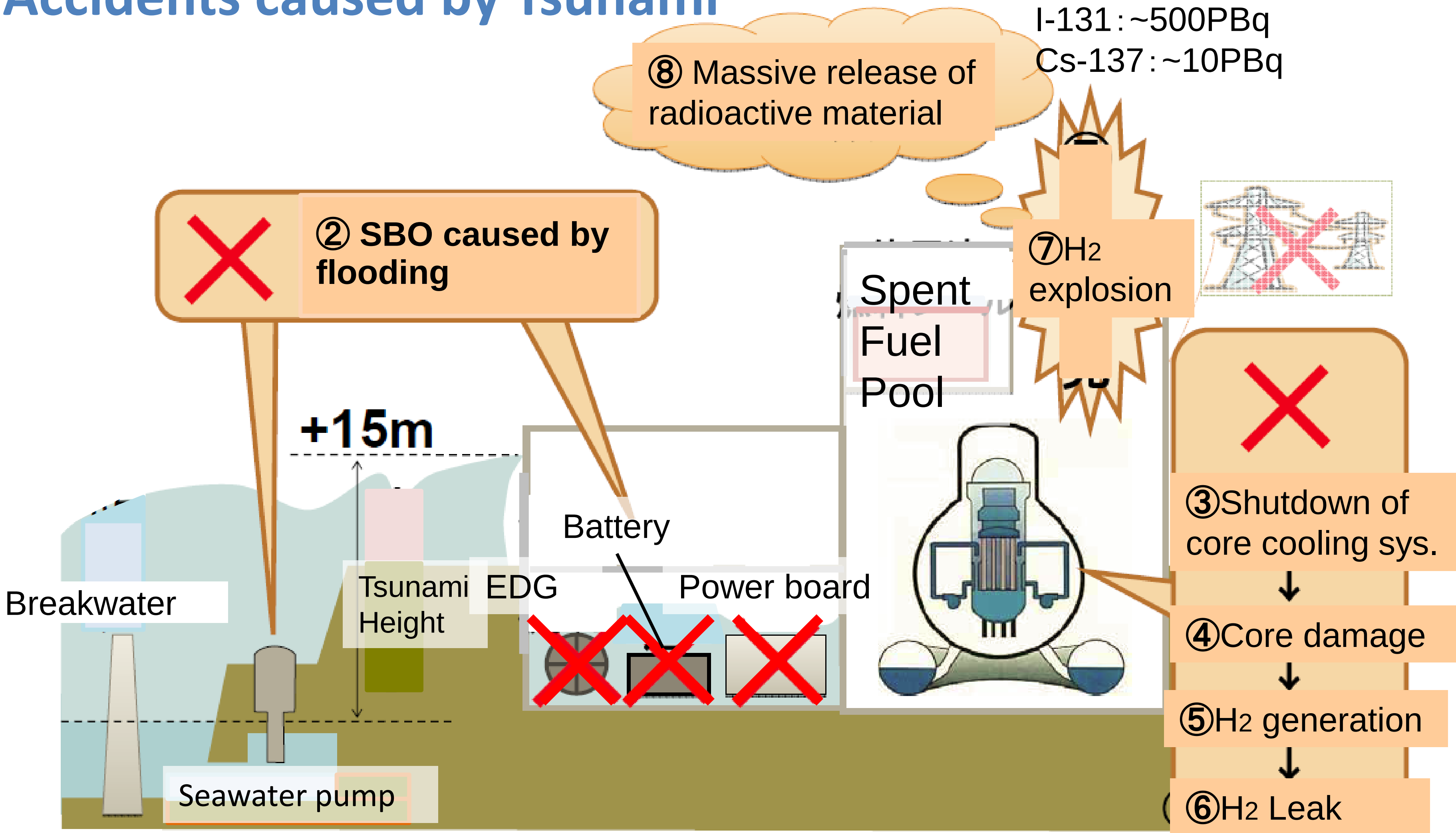
Referred from Cause and Countermeasures, NISA, March 2012

Accidents caused by Earthquake



Referred from Judgement about Safety for restart of Oi unit ¾, METI, May 1, 2012

Accidents caused by Tsunami



Referred from Judgement about Safety for restart of Oi unit ¾, METI, May 1, 2012

Types of Information available

- **During accident**
  - ✓ SBO resulted in operators being unable to get readouts of instruments on the control panel and hence could not know what condition the reactors were in. (Reactor Power, Pressure, Temperature, Water height and flow rate, etc.)
  - ✓ To know the reactor conditions, they made many attempts to connect with the signal lines to obtain the readouts. Finally they succeeded to obtain a few readouts and some limited measurement data was available in the time leading up to full recovery of the power supply.

- **Analysis and evaluation following accident**
  - ✓ Some conditions still unclear

    e.g. Amount of injected water,

    Position/Amount/Composition of melted fuel (corium/debris)

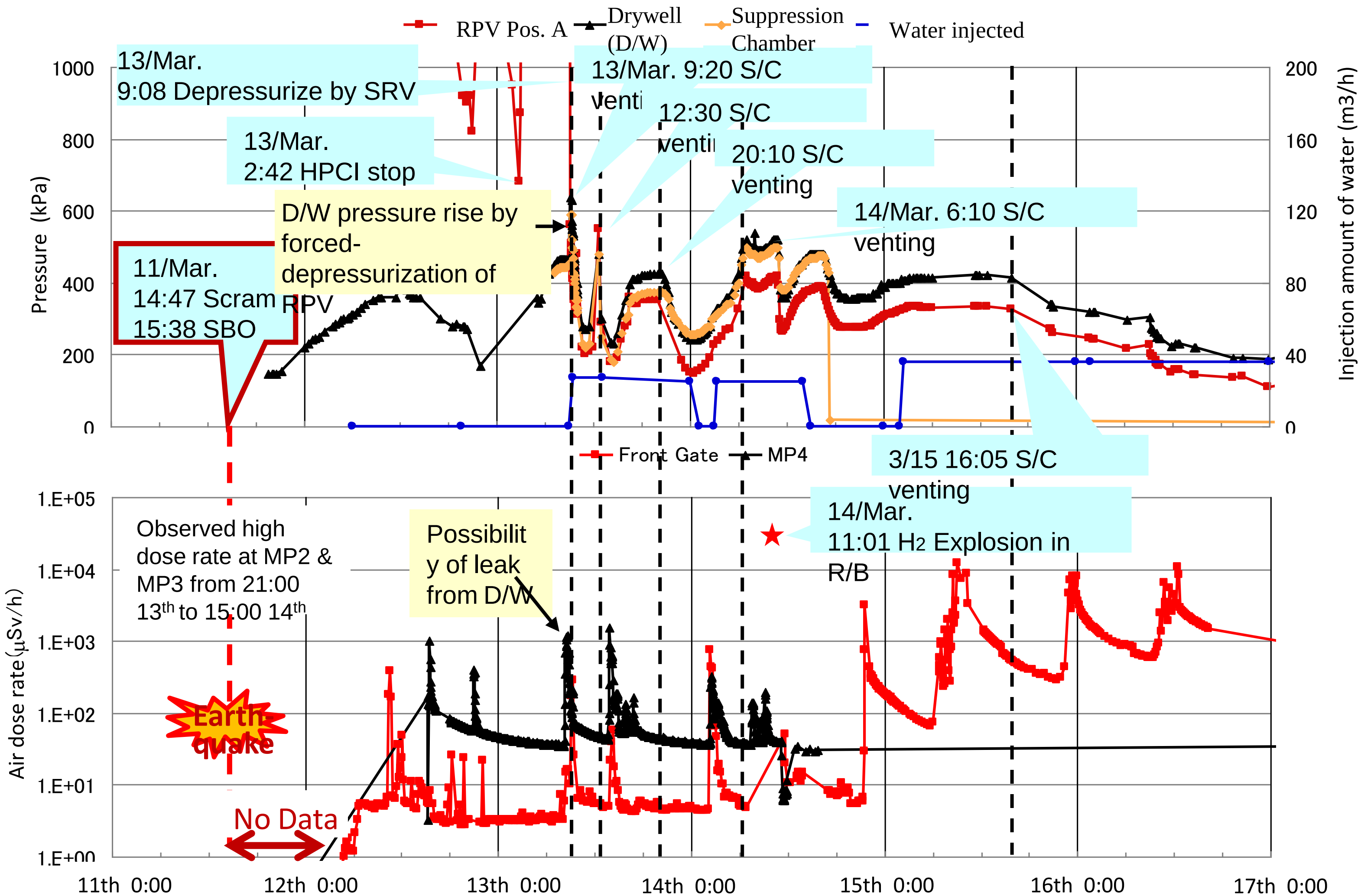
    Integrity (Damaged levels/positions) of structural materials,

    Total amount of radioactive materials released from NPPs

  - ✓ Reasonable reproduction of known thermal-hydraulic/fuel/plant behavior

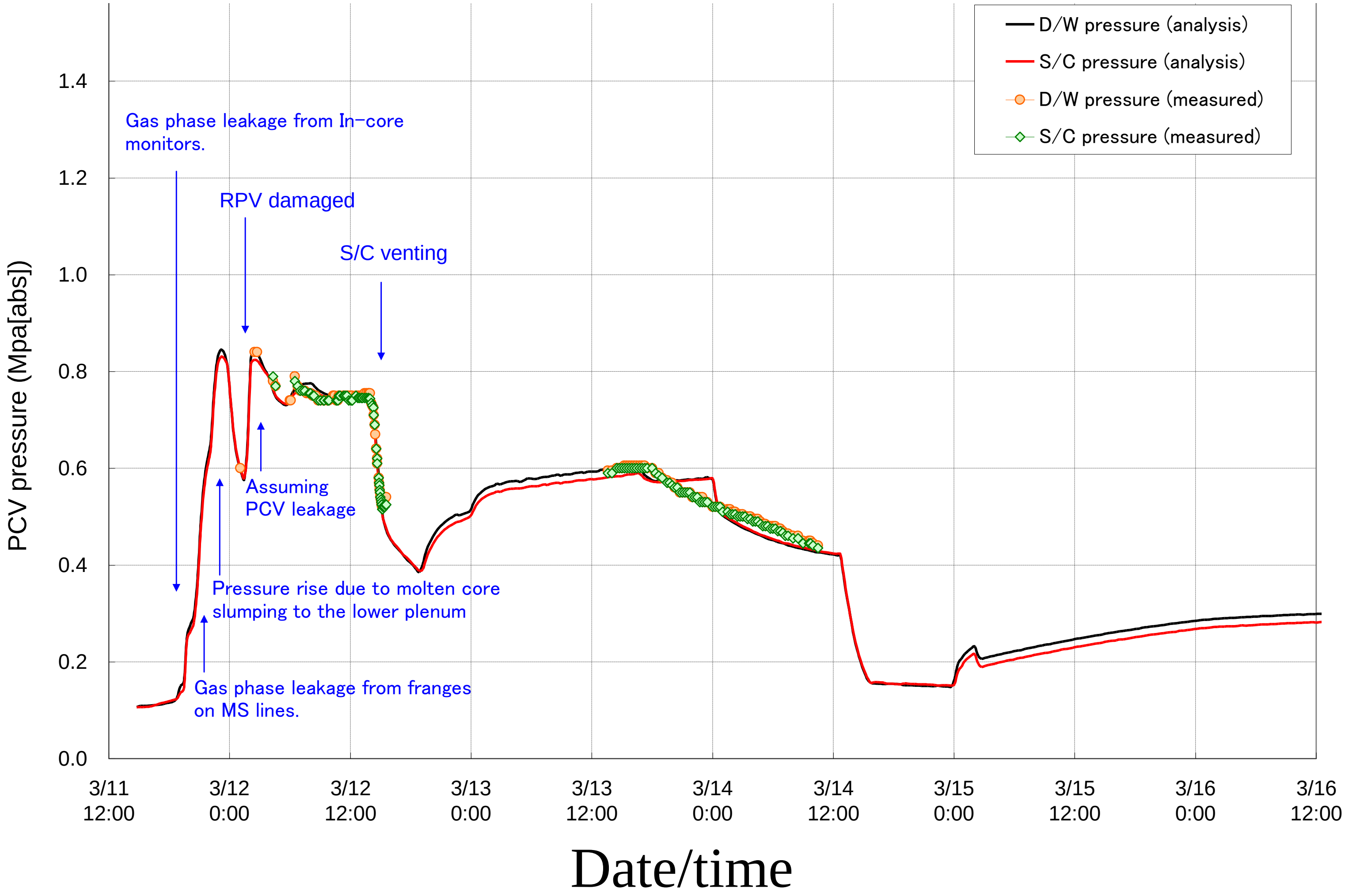
Examples of raw data obtained in SA of 1F NPS unit 3

- Reactor pressure, Injected water and Dose rate -



Y. Maruyama; "Activities of Analysis Related to Fukushima Daiichi NPP Accident and Plan for Severe Accident Analysis at JAEA," Workshop on TEPCO Fukushima Daiichi NPP Accident Analysis (June 18-20, 2012, OECD/NEA HQ, France)

Examples of raw data: PCV Pressure



Additional information from benchmark study (1)

- OECD-NEA Benchmark Study of the Accident at the Fukushima Daiichi NPS (BSAF) project
- Objectives:
  - analyse and evaluate accident progression
  - improve SA analysis methods and models
- Initial workshop June 2012 (at NEA Offices)
- 1st Management Board Meeting & 2nd Workshop held in Tokyo 6-8 November 2012
- Currently 8 participating countries
  - Japan, France, Germany, Korea, Russia, Spain, Switzerland, USA
- Project is providing valuable additional (and corrected) data from plant measurements

Additional information from benchmark study (2)

- Start-up activity has included PIRT analysis identifying and ranking key phenomena.

- In area of fuel heat-up and melting these phenomena include:
  - Core water level change
  - Fuel/cladding interaction
    - Including Zr-water reaction facilitation by water flow in gap
  - Physical properties of core materials
    - Including melting points and eutectic for fuel pellet materials and zircaloy
  - Heat transfer properties
  - Fuel/coolant interaction
  - Oxidation reaction between corium and water

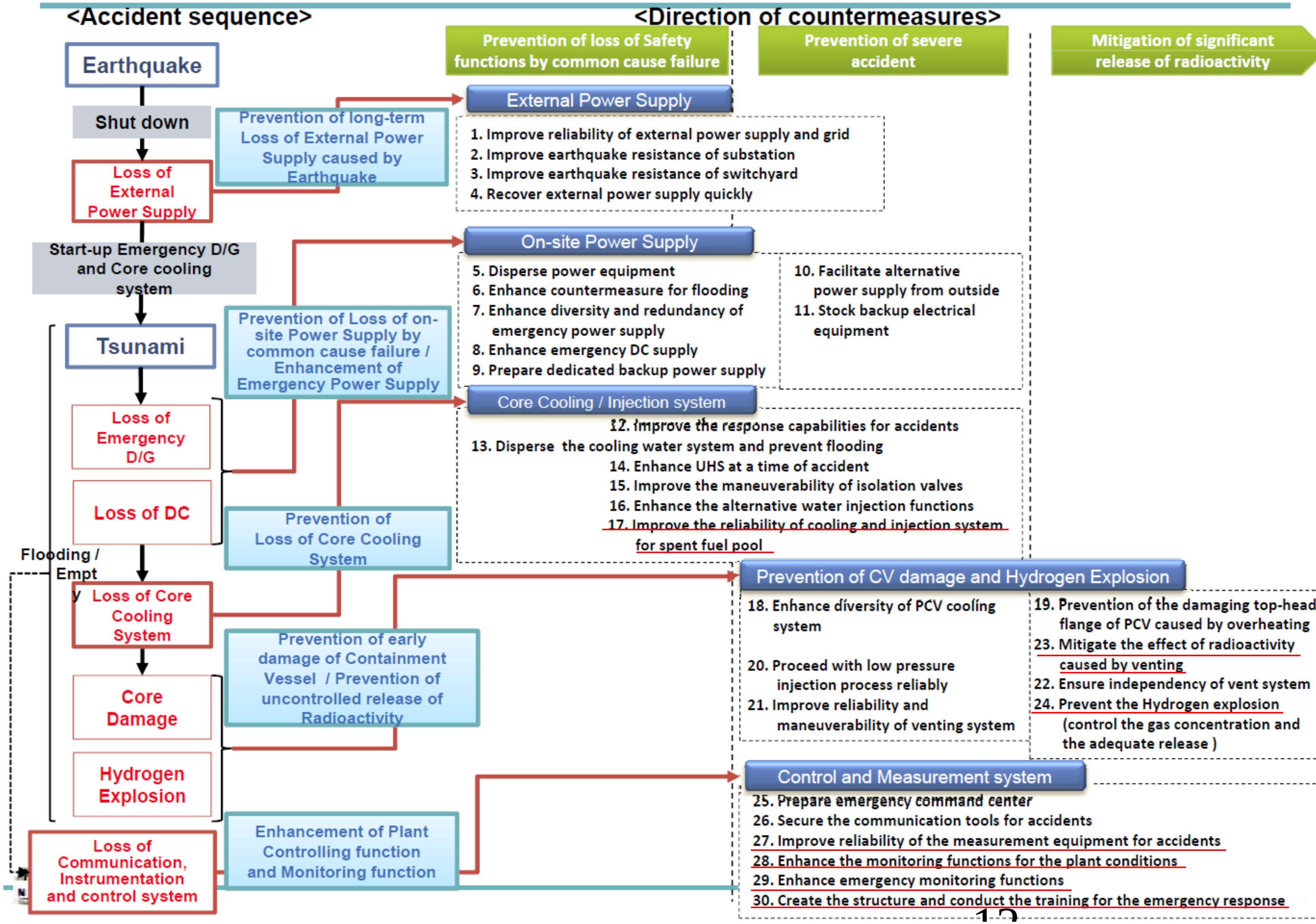
- Several of these phenomena are ranked as ‘high importance’ and with the State of Knowledge as ‘unknown’ or ‘partially known’

- Based on (limited) plant data and extensive modelling analysis, we have a detailed qualitative description of the Fukushima Daiichi accident

- Further analyses are being carried out to provide more quantitative descriptions needed to inform recovery plans and improve safety at other plant

Technical Knowledge about Fukushima Accident

Direction of Countermeasures determined by Gov. and TEPCO Council



Referred from Cause and Countermeasures, NISA, March 2012

Key conclusions from JAEA presentation to NSC

- **Design study for new NPPs enhanced the safety performance**
  - ✓ Development of new materials / new concepts for safety
- **Transfer knowledge / technical skills to next generations**
  - ✓ Necessary to develop persons who have abilities to overview and understand the nuclear plant and the various conditions/situations and to predict well the plant behaviors.
  - ✓ In present there is few opportunities for them to have practical exercises because of few reactor constructions.

Closing remarks from JAEA presentation

- *The presentation was mainly strengthen the actions/countermeasures related to Fukushima accident. However, nuclear scientific technical research activities are essential and wide. These activities contribute to not only the study related to safety regulation but also the nuclear energy system development with new concepts in future.*

- *It is important to develop the new systems such as the reactor enhanced safety of the radiological supremeness which do not cause any release in large quantities to environment.*
- *International cooperation becomes more important to solve the problems described above.*
- *Considering few construction opportunities of new reactor, development of simulation technologies, for example virtual reactor program, would be useful to accumulate scientific knowledge about reactor system and behavior and to cultivate human resources capable of dealing with accidents.'*

Conclusion

- Clear that fuel behaviour played important role in progression and outcome of the Fukushima accident
- Key phenomena/ fuel characteristics:
  - Hydrogen production (through Zr – water reaction)
  - Time to melting (melting point, heat transfer)
- More generally ability of fuel to retain fission products is highly desirable