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Perspectives on the safety of nuclear facilities

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The views expressed here are of my own and do not necessarily reflect those of JAEC nor the government

Outline

1. Basic safety issues
2. Lessons learned and recommendation derived
3. Examples for potential countermeasures and technologies to be applied
4. Improvement of nuclear safety in Japan
5. Mitigation of social and mental effects of the people affected

Reference of 1-3: Y.Oka and. D.Bittermann, "Chapter 12, Implications and Lessons for Advanced Reactor Design and Operation", Reflections on the Fukushima Daiichi Nuclear Accident, Jan 2015 Springer

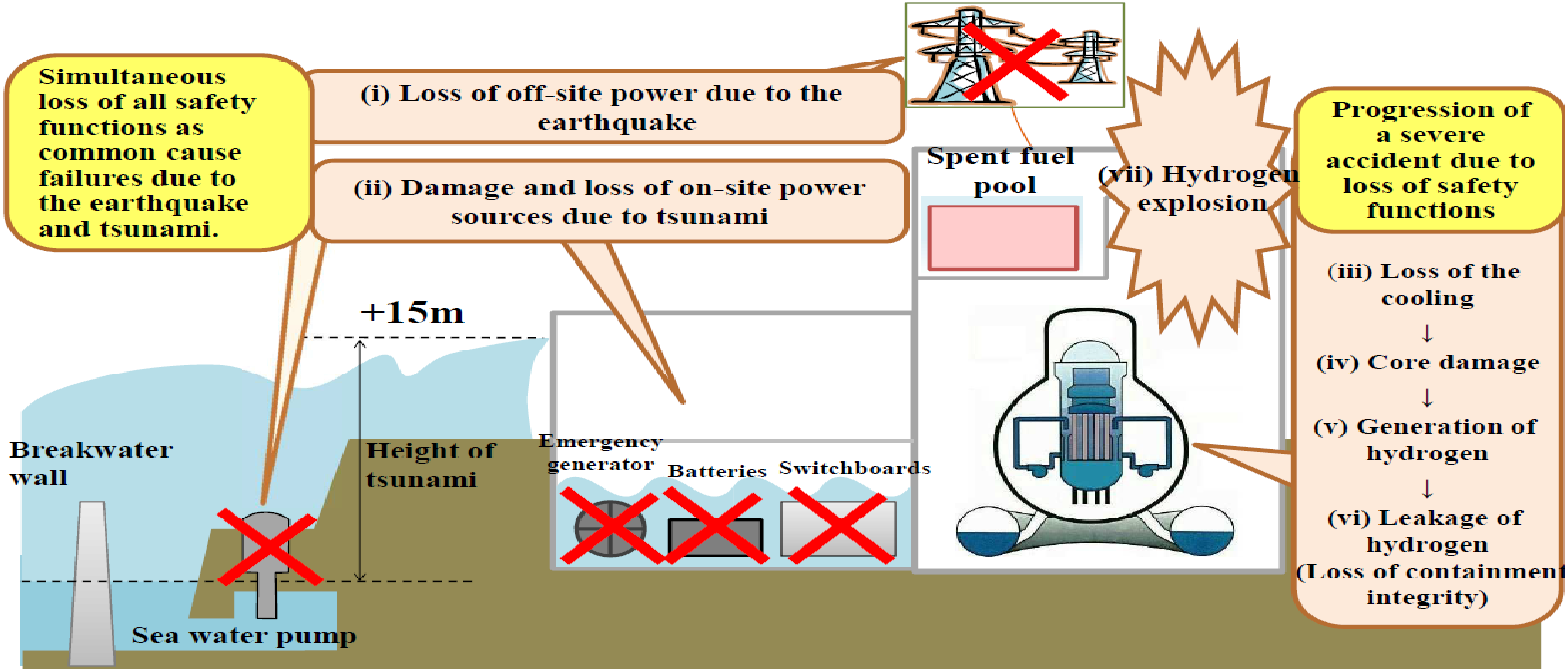
The levels and the main means of action for the defense-in-depth safety concept

INSAG10 level	Goal	Main means of action
1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
2	Control of abnormal operation and failures	Control, limiting and protection systems and other surveillance features
3	Control of accidents within the design basis	Engineered safety features and accident procedures
4	Control of severe conditions including prevention of accident progression and mitigation of the consequences of a severe accident	Complementary measures and accident management
5	Mitigation of the radiological consequences of significant external release of radioactive material	Offsite emergency response

Safety Culture

- INSAG-4 definition: *Safety culture* is that assembly of characteristics and attitudes in organizations and individuals which establishes that as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance.
- NRC definition: A good *safety culture* in a nuclear installation is a reflection of the values, which are shared throughout all levels of the organization and which are based on the belief that safety is important and that it is everyone's responsibility.

TEPCO Fukushima-Daiichi NPP accident



NRA (2013) New regulatory requirement for Light- water nuclear power plants outline- August 2013 Nuclear Regulatory Authority, http://www.nsr.go.jp/english/e_news/data/13/0912.pdf

Natural hazards

Lessons:

The safety systems did not lose function by the earthquake. The height of the tsunami was, however, underestimated.

Recommendation:

It is necessary to develop imagination of natural hazards and its combinations that may potentially cause severe accidents.

Emergency power supply

Lessons

The external power of the TEPCO Fukushima Daiichi plants was lost by the failure of transmission lines by the earthquake. The emergency DGs and some batteries were flooded. Both AC and DC power were lost. The capacity of the remaining batteries was exhausted. The safety systems and instrumentation systems lost their functions.

Recommendation

It is necessary to enhance the reliability of both AC and DC power supply against external events and provide sufficient power in case of severe accidents. Incase that they are lost, alternative power supplies need to be provided for the plant.

Loss of heat sink

Lessons

- Loss of ultimate heat sink is the important lesson of the accident as well as loss of emergency power. Damage of seawater pumps by the tsunami caused multiple failures of functioning pumps and heat exchangers that need cooling for operation and dumping heat into the sea.

Recommendation

- Provision of protective measures like e.g. bunkering of important components and/or alternative cooling devices as well as the water source is necessary.

Hydrogen detonation

Lessons

- The reactor building of unit 1,3 and 4 were destroyed by hydrogen detonation. The building of unit 2 was not destroyed, because the blow- out panel of the reactor building dropped down by the detonation of unit1.The hydrogen detonation of the unit1 building scattered the debris on the site and made preparation of securing activities of unit 2 and 3 difficult.

Recommendation

- The provision against hydrogen leakage at severe accidents should be elaborated and the respective measures should be performed.

Measurement at severe accidents

Lessons

- Important reactor parameters such as water level, pressure and temperature was not able to be measured due to the loss of DC power after the tsunami. The water level, the most important safety parameter of LWRs was measured erroneously after core melt down because of the change of the reference water level by evaporation.

Recommendation

- Important reactor parameters as well as radiation level, radioactivity and hydrogen concentration in PCV need to be measured for management of severe accidents

Recommendations and requirements derived from lessons learned

New regulatory requirements and improvements in Japan

- Enforcement of resistance against earthquake and tsunami
- Reliability of power supply
- Measures to prevent core damage by postulating multiple failures
- Measures to prevent failure of containment vessel
- Measures to suppress radioactive material dispersion
- Strengthen command communication and instrumentation
- Consideration of natural phenomena in addition to earthquakes and tsunamis, for example volcanic eruptions, tornadoes and forest fires
- Response to intentional aircraft crashes
- Consideration of internal flooding
- Fire protection

Examples for potential countermeasures and technologies to be applied

- External events
- Design of buildings, systems and components
- Severe accident issues

External events

General approach

Common countermeasures proposed for all external events are:

- Develop an approach to regulate hazards from extreme natural phenomena
- Periodically redefine and reanalyse the natural event design basis

External events in most cases lead to a combination of initiating events like e.g. earthquake and tsunami or earthquake and fire. Such combined effects have to be systematically considered for the design.

One proposal is as follows:

- Extending even further the in-depth safety approach to any type of hazards, in particular external ones, and accounting for any mode of combination of them;
- Systematically include the design extension conditions (beyond design basis accidents) in the defence-in-depth approach at the design stage.

Need for future studies and development (external events)

- Development of approaches to natural hazard definition, techniques and data, and development of guidance on natural hazards assessments, including earthquake, flooding and extreme weather conditions;
- Development of guidance on the assessment of margins beyond the design basis and cliff-edge effects for extreme natural hazards;
- Development of a systematic approach to extreme weather challenges and a more consistent understanding of the possible design mitigation measures;
- Development of the approach for assessment of the secondary effects of natural hazards, such as flood or fires arising as a result of seismic events;
- Enhancement of PSA for natural hazards and development of methods to determine margins and identify potential plant improvements;
- Overall enhancement of PSA analysis, covering all plant states, external events and prolonged processes, for PSA levels 1 and 2.

Earthquake

- It is proposed from several organizations to increase the seismic design criteria for the evaluation and assessment of beyond design external events.
- In Japan NRA strengthened the examination of active faults. The basic earthquake ground motion (EGM) should be determined taking the three dimensional underground structures which may amplify the EMG. The safety-class structures and buildings should not be built on the active faults. Strengthening the seismic design of the plants is conducted after the approval of NRA.

Tsunami
Actual Japanese NRA requirements

- The standards set by the Japanese NRA define a “Design Basis Tsunami” as one which exceeds the largest ever recorded. It requires protective measures such as seawalls. The standards also require “structure, systems and components (SSCs)” for tsunami protective measures to be classified as class S, the highest seismic safety classification to ensure that they continue to prevent inundations even during earthquakes.
- The examples of multi- layered protection measures against tsunami are installation of a seawall to prevent site inundation and installation of water- tight doors to prevent the flooding of buildings.

Seawall to prevent site inundation

NRA (2013) New regulatory requirement for Light- water nuclear power plants outline- August 2013 Nuclear Regulatory Authority, http://www.nsr.go.jp/english/e_news/data/13/0912.pdf

Design of buildings, systems and components

1. Sites with more than one reactor

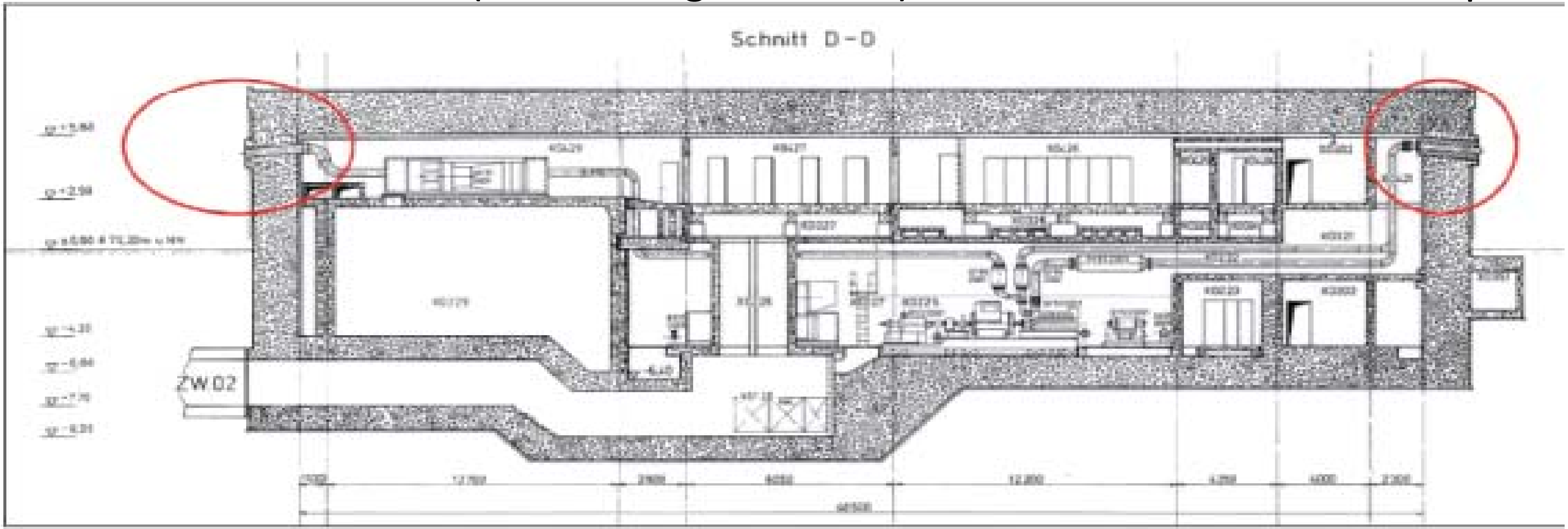
- Strict separation of safety related systems and components
- Provision of a plant arrangement which prevents common cause failures for safety related systems and components

2. Off-site and on-site electricity supply

In case of an external event like an earthquake, the off-site electricity supply is very difficult or even impossible to maintain. The way to substitute off-site electricity supply is mainly to provide mobile power supply systems or addition of diesel generators or other power sources like e.g. gas turbines. These components must be protected against external events by bunkering or e.g. located at positions which cannot be affected by e. g. tsunami waves.

Bunkered emergency feed building for recent German PWRs

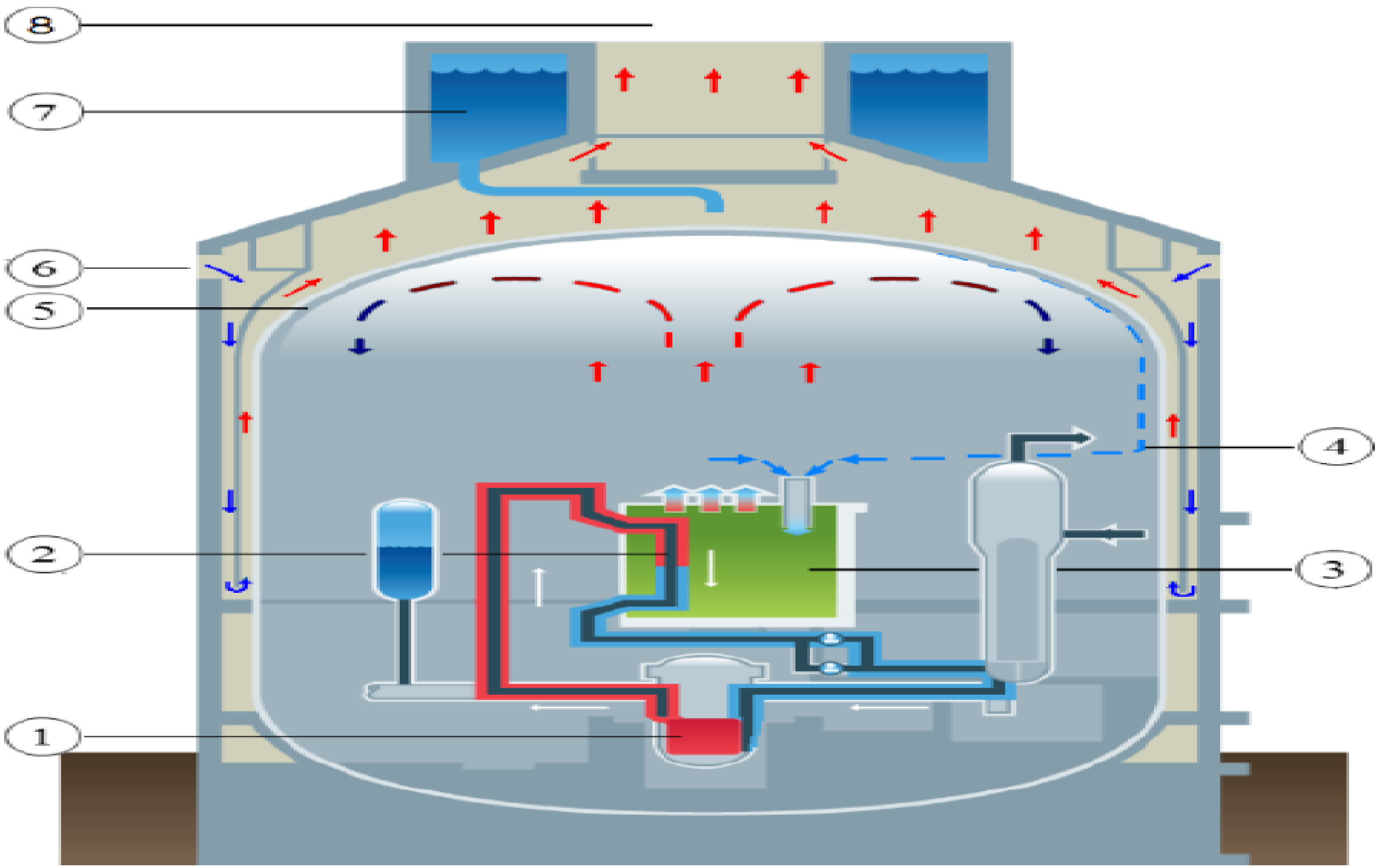
- Recent German PWRs are equipped with a second fourfold emergency power supply (emergency diesel sets). These second emergency cooling systems can cool the reactor core (via steam generators) as well as the fuel element pool



Source : Y.Oka and. D.Bittermann, "Chapter 12, Implications and Lessons for Advanced Reactor Design and Operation", Reflections on the Fukushima Daiichi Nuclear Accident, Jan 2015 Springer

Passive components and systems using natural forces

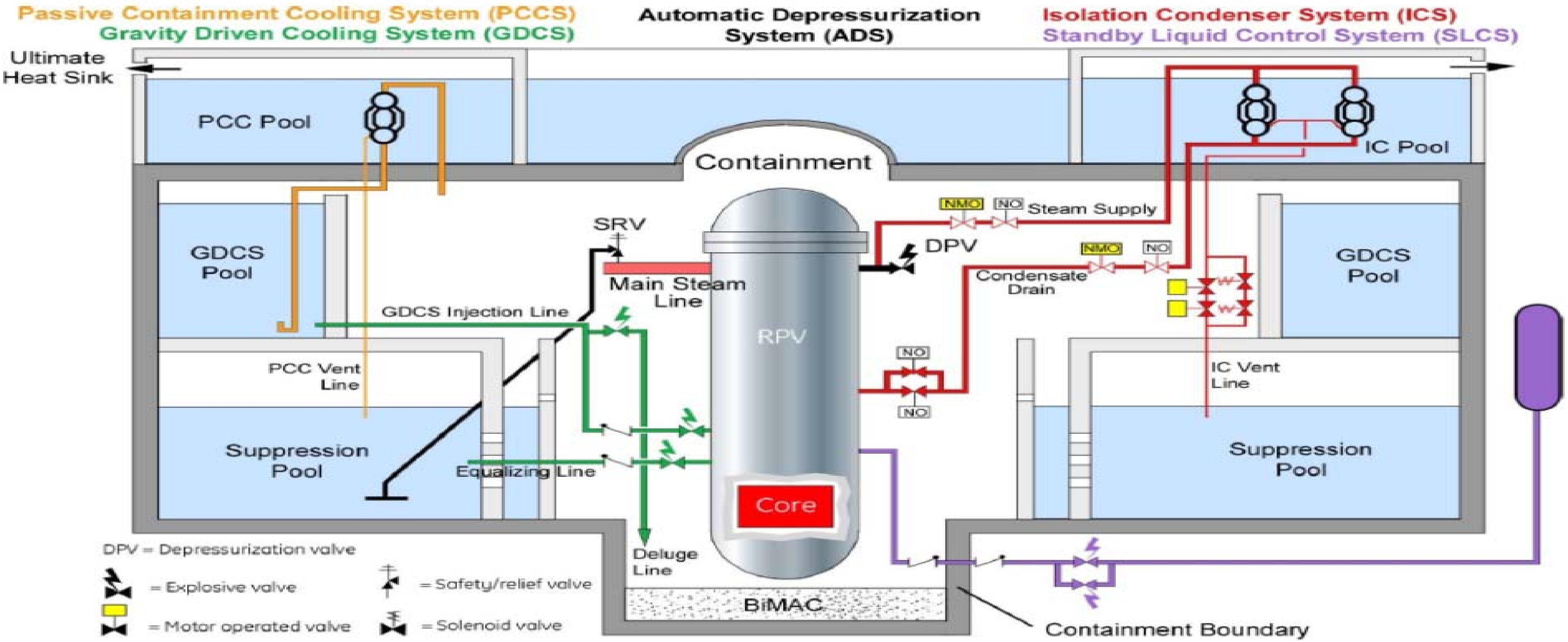
Passive containment cooling system (AP1000)



1: Core,
2: PRHR,
3: IRWST,
4: Gutters,
5: CV,
6: Louvers,
7: PCCWST,
8: Atmosphere

Source: Vereb F, Winters J, Schultz T, Cummins E, Oriani L (2012) The AP1000 nuclear power plant innovative features for extended station blackout mitigation , Proceedings of ICAPP'12, Chicago USA, June 24-28, 2012, paper 12063

Passive Safety Systems (ESBWR)



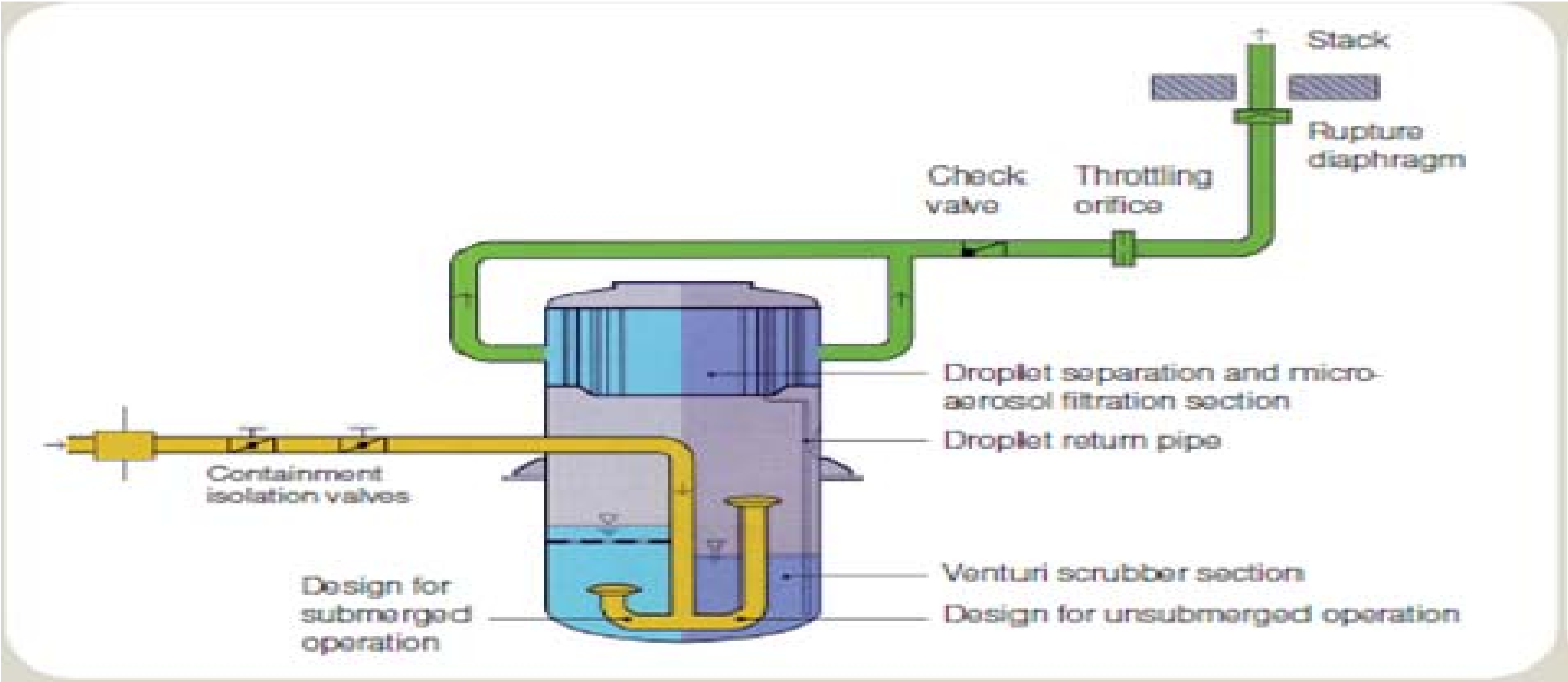
Barrett A. J. and Marquino W (2012) ESBWR response to extended station blackout and loss of all AC power, Proceedings of ICAPP'12, Chicago, USA, June 24-28, 2012)

Mitigation measures against severe accidents

Hydrogen mitigation
Passive auto catalytic recombiner

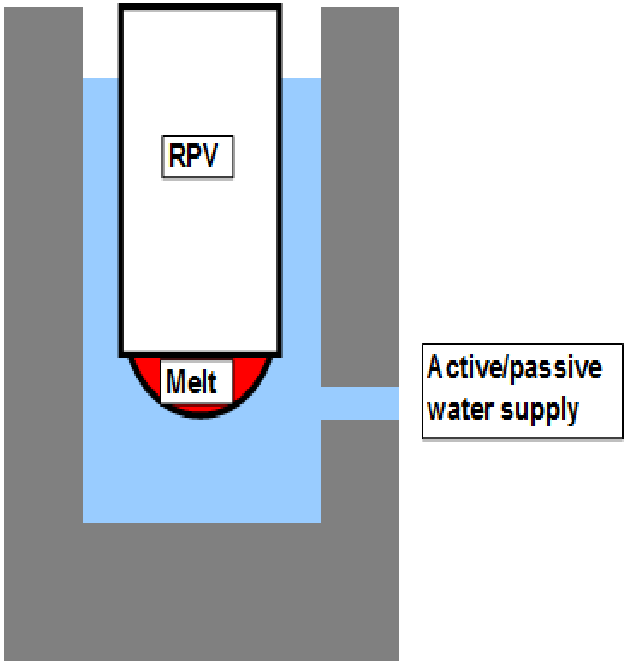
Source : Y.Oka and. D.Bittermann, "Chapter 12, Implications and Lessons for Advanced Reactor Design and Operation", Reflections on the Fukushima Daiichi Nuclear Accident, Jan 2015 Springer

Containment venting systems
Venturi scrubber



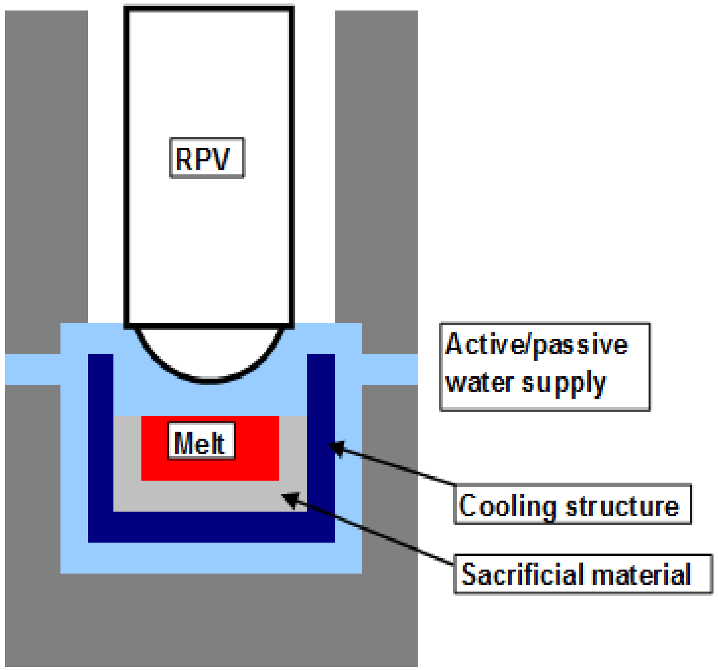
Source : Y.Oka and. D.Bittermann, "Chapter 12, Implications and Lessons for Advanced Reactor Design and Operation", Reflections on the Fukushima Daiichi Nuclear Accident, Jan 2015 Springer

Melt stabilization measures



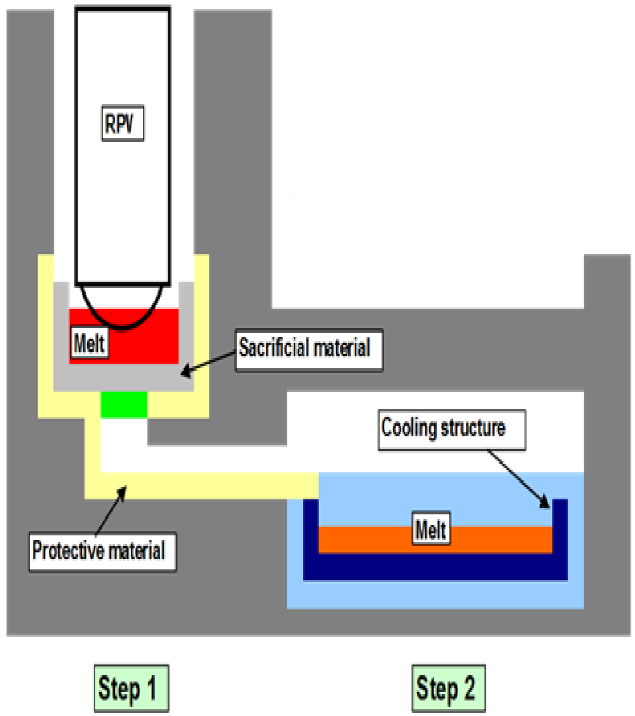
In- vessel retention

AP-1000



Ex- vessel retention

VVER-1200



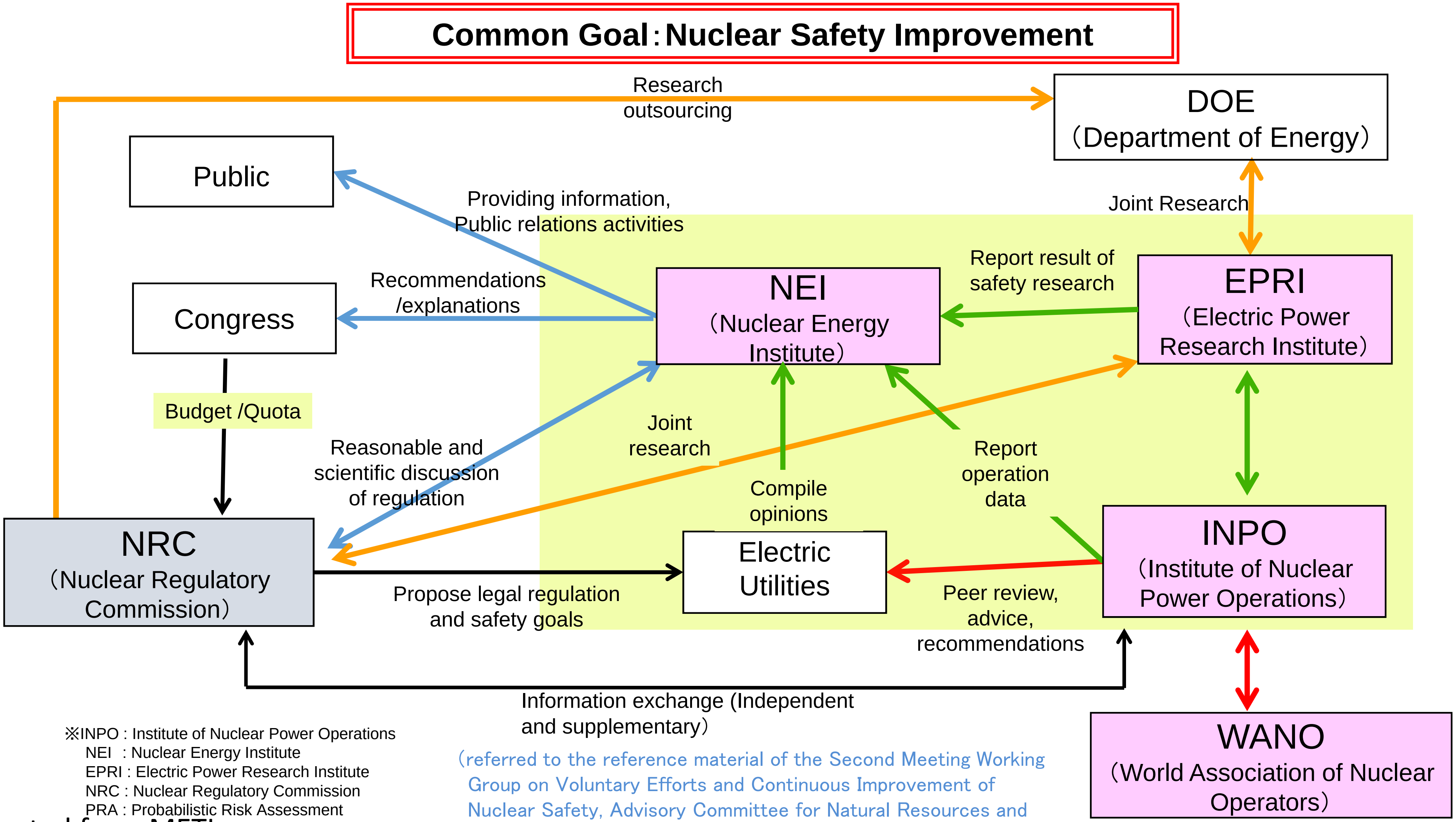
Core catcher concept
EPR, ATOMEA,
European ABWR (no need
of separate spreading chamber)

Source : Y.Oka and. D.Bittermann, "Chapter 12, Implications and Lessons for Advanced Reactor Design and Operation", Reflections on the Fukushima Daiichi Nuclear Accident, Jan 2015 Springer

Safety improvement in Japan

1. Established independent nuclear regulatory agency (NRA)
2. Started voluntary safety improvement by utilities/ industries

Voluntary Safety Improvement Mechanism in US Industry



※INPO : Institute of Nuclear Power Operations
NEI : Nuclear Energy Institute
EPRI : Electric Power Research Institute
NRC : Nuclear Regulatory Commission
PRA : Probabilistic Risk Assessment

（referred to the reference material of the Second Meeting Working Group on Voluntary Efforts and Continuous Improvement of Nuclear Safety, Advisory Committee for Natural Resources and Energy April 23, 2013 ）

Adapted from METI

Japanese effort for Voluntary Safety Improvement

JANSI（Japan Nuclear Safety Institute）
NRRC（Nuclear Risk Research Center）

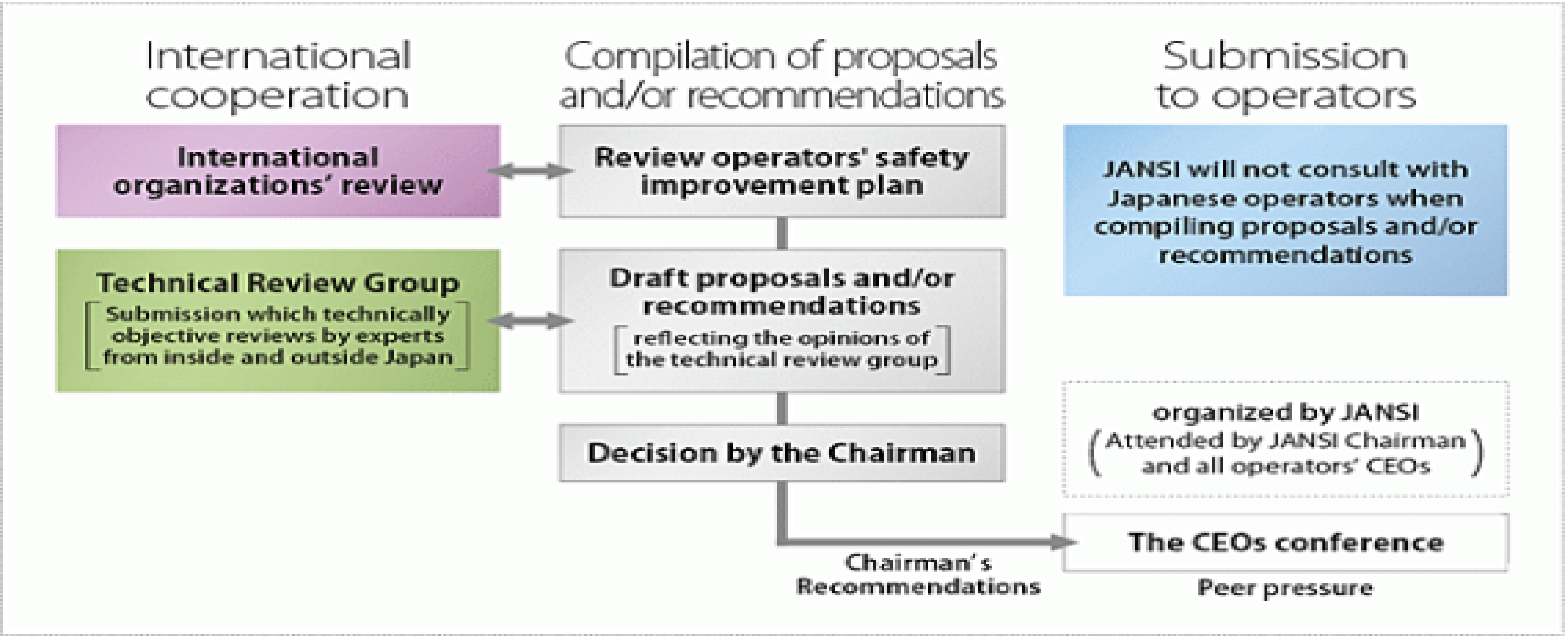
Japanese Nuclear Industry

Electric Utilities：the Federation of Electric Power Companies of Japan, 9 utilities, Japan Nuclear Fuel Limited, Central Research Institute of Electric Power Industry etc…

Manufacturers：Mitsubishi Heavy Industries, Ltd., Hitachi, Ltd., Toshiba Corporation, The Japan Electrical Manufacturers' Association, fuel manufacturers etc…

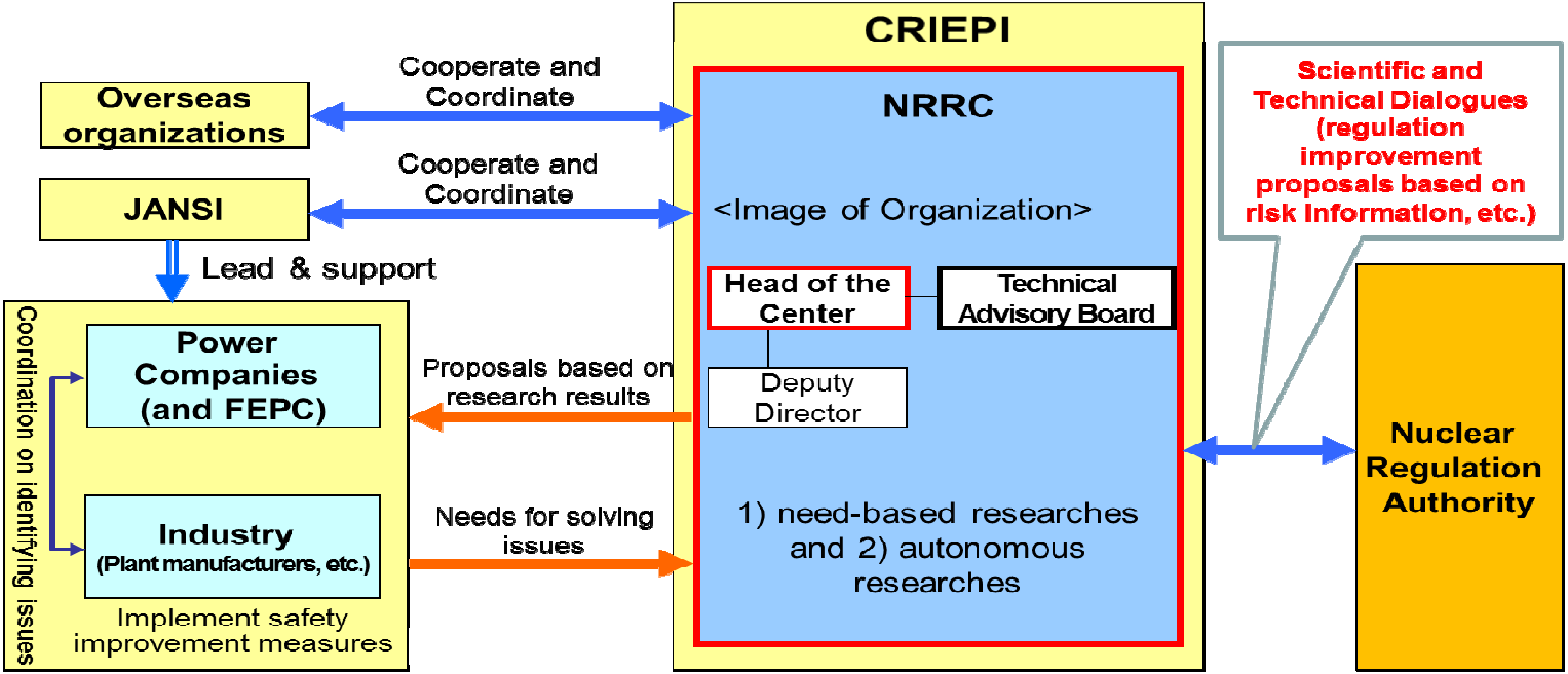
Japan Atomic Industrial Forum, Inc.(JAIF) etc.

Structure of Japan Nuclear Safety Institute (JANSI)



Source: JANSI HP http://www.genanshin.jp/english/association/establishment.html

Structure of the Nuclear Risk Research Center (NRRC)

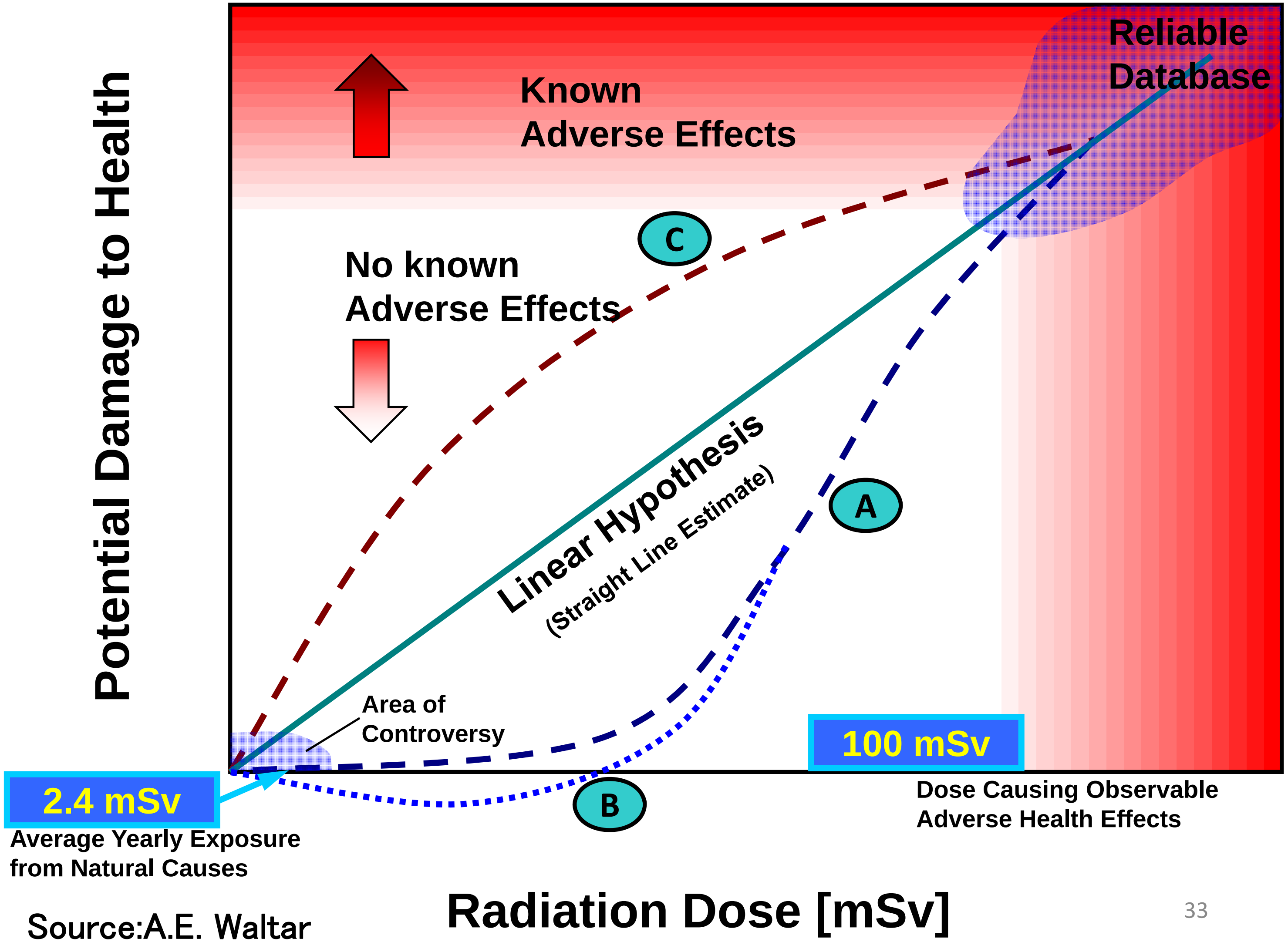


(Source: N20's presentation Material, Hirobumi KAYAMA, "the Current Nuclear Energy Policy" as of November 3, 2014)

Mitigation of mental and social impact of the people affected

Health effect of low level radiation

- Acute health effect occurs above threshold (high) dose.
- Linear non-threshold model (linear hypothesis) is used for estimating latent health effect (cancer) at low dose



Source:A.E. Waltar

Health implications of radiation exposure of the public resulting from FDNPS accident (UNSCEAR 2013 Report, Appendix E)

- “No discernible risk”: An increased incidence of effects is unlikely. Consequences are small relative to the baseline risk and uncertainties.
- The most important health effects would appear to be on mental and social well-being as a consequence of the evacuation and their displacement to unfamiliar surroundings, and the fear and stigma related to radiation exposure. For example more than 50 hospitalized patients died either during or soon after the evacuation, probably because of hyperthermia, dehydration or deterioration of underlying medical problems. Upward of 100 elderly people may have died in subsequent months.
- Understanding full heath impact of accident forms an important context for the Committee’s commentary.

UNSCEAR: United nations scientific committee on the effects of atomic radiation

“Maintaining health” should be the goal

- Order of “sheltering” made most people escape from their homes, but those weak in disaster (single elderly people, patients etc.) were left and separated from outside area.
- Displacement worsen health of the evacuees. No working (farming) increases instability of legs, sugar disease, fatness, osteoporosis
- Displacement for avoiding low level of radiation exposure increased other health risks. It is effective, only when other risks do not increase.
- Lack of exercise and fatness increase cancer risk 1.2 times, equivalent to 100-200mSv of exposure.
- Telling only “radiation” risk increased fear of “radiation”. Radiation risk is a part of cancer risk. It is a part of health risk.
- “Maintaining health” should be the goal for avoiding mental and social health effects of nuclear accidents.

Source: Sae Ochi, Energy review pp7-10, April 2015,(in Japanese)

Lessons of risk communication and management of nuclear accidents

- LNT model is a hypothesis, not a scientific fact. But it assumes that risk is NOT zero. Start to tell “no risk” was a wrong way, failed and increased fear of radiation in Fukushima. It is logically impossible to prove “zero risk”. Start to tell “Cancer risk of radiation exposure is NOT zero” looks a good way of risk communication.
- Telling various cancer risks in human life and its uncertainty at low exposure is the way. Cancer risk of low radiation exposure is within the uncertainty.
- Comparing various cancer risks such as radiation, chemicals, etc. is necessary, but will be not enough to manage mental and social effects.
- “Maintaining health” is good goal for managing the problems and taking actions at severe nuclear accidents.

Thank you for your attention