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Ensuring Safety: Role of PRA for Rare Event and Unlikely Event

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Contents

- Fukushima Dai-ichi Accident
- Lessons-Learned
- How to Ensure Safety
- Unknowns
  - Black Swan and White Raven….White Snake
- PRA Standard Development
- Comprehensive Risk Assessment
- Conclusions

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Summary of Fukushima Dai-ichi Accident

- Radiation Exposure of Fukushima Residents (for 4 months after the accident)
  - 99 out of 25,520 exceed 10mSv (public), maximum 25.1mSv
  - 48 out of 147 exceed 10mSv (workers in nuclear facilities)
- Confusion in evacuation, food and water control
- Contamination of land is significant

- If emergency preparedness works, they should have been mitigated
  - Exposure limitation in emergency situation
  - Radioactivity control in food and drinks
  - Mitigation measure of significant radioactive release

The Tsunami Caused Station Blackout (SBO) and Loss of Ultimate Heat Sink

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Off site power	X (0/6/7)	X (0/6/7)	X (0/6/7)	X (0/6/7)	X (0/6/7)	X (0/6/7)
Emergency DG	X	X	X	-	(X)	(X)
	X	(X)	X	(X)	(X)	O
						(X)
Metal clad (6.9kV)	X	X	X	X	X	(X)
	X	X	X	X	X	O
		X		X		(X)
Power center (480V)	X	O	X	-	X	O
	X	O	X	O	X	O
		X		X		O
DC battery	X	X	O	X	O	O
	X	X	O	X	O	O
Ultimate heat sink	X	X	X	X	X	X

Crossroad in Fukushima Dai-ichi Accident

- Earthquake - Practically no damage on safety functions at 14:46, March 11
- Tsunami - Loss of multi-functions (not only safety but logistics) at 15:42
  - Station blackout (SBO)
  - Loss of ultimate heat sink (LUHS)
  - Loss of instrumentation and control
  - Loss of communication and information (lighting, computer, mobile phone, paging)
  - Loss of off-site external assistance
  - Fear on aftershock and another tsunami
- Hydrogen Explosion on Unit 1 at 15:36, March 12
  - Loss of accident management
  - Loss of accessibility
  - Loss of habitability
  - Fear on the next explosion

Recovery from Disaster

- The staff always considered priority; to select the best action on the worst unit
- Knowledge-base management
  - Mobile equipment
  - Car batteries
- Information is helpful for good decision making
  - Helicopter flight confirmed water in the spent fuel pool on March 16
- External support started (Self-Defense Force, Fire Management Agency, etc)
  - Core cooling using fire engines
  - Spent fuel pool cooling using concrete pump vehicles

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Lessons Learned

- We can manage things, even in very serious situations
- Flexibility, knowledge-base and imagination really work in beyond design basis event
- Agreement with society is important to make preparation for emergency practicable
- Justification of nuclear and acceptance of risk are inseparable
- Risk is uncertainty– PRA deals with uncertainty

Lessons from Japanese Government Report

- The most important basic principle in securing nuclear safety is "defense in depth"
  - Strengthen preventive measures against a severe accident (8)
  - Enhancement of response measures against severe accident (7)
  - Enhancement of nuclear emergency responses (7)
  - Reinforcement of safety infrastructure (5)
  - Thoroughly instill a safety culture (1)

Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, The Accident at TEPCO's Fukushima Nuclear Power Stations (June 2011)

Recommendations for Enhancing Reactor Safety in the 21st Century

- *Clarifying the Regulatory Framework (1)*
- *Ensuring Protection (2)*
- *Enhancing Mitigation (5)*
- *Strengthening Emergency Preparedness (3)*
- *Improving the Efficiency of NRC Programs (1)*

The Near-Term Task Force Review of Insight from the Fukushima Dai-ichi Accident, JULY 12, 2011

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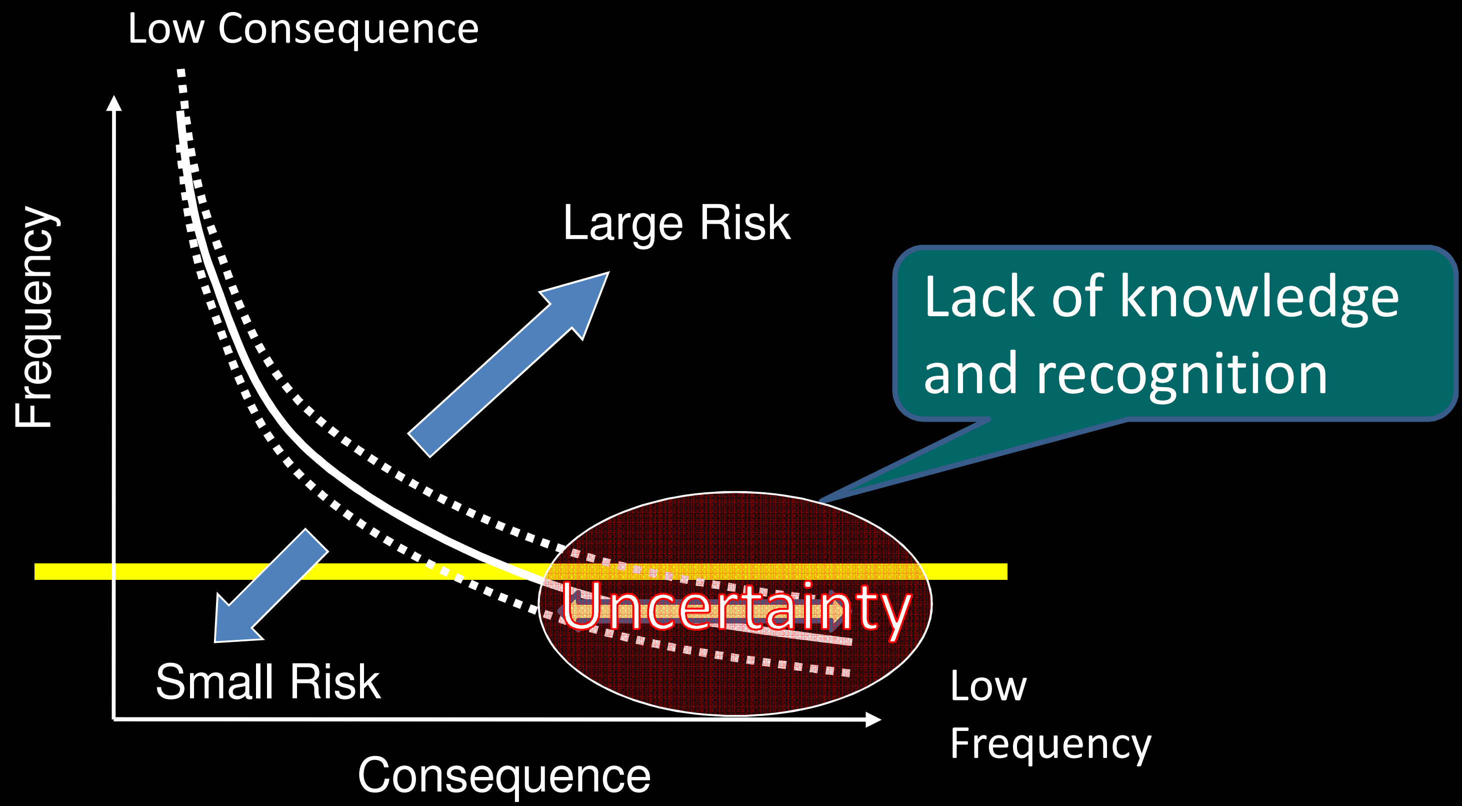
How to Ensure Safety…
Risk Model - in Mathematical Form

$$\text{Risk} = \text{Frequency} \times \text{Consequence}$$

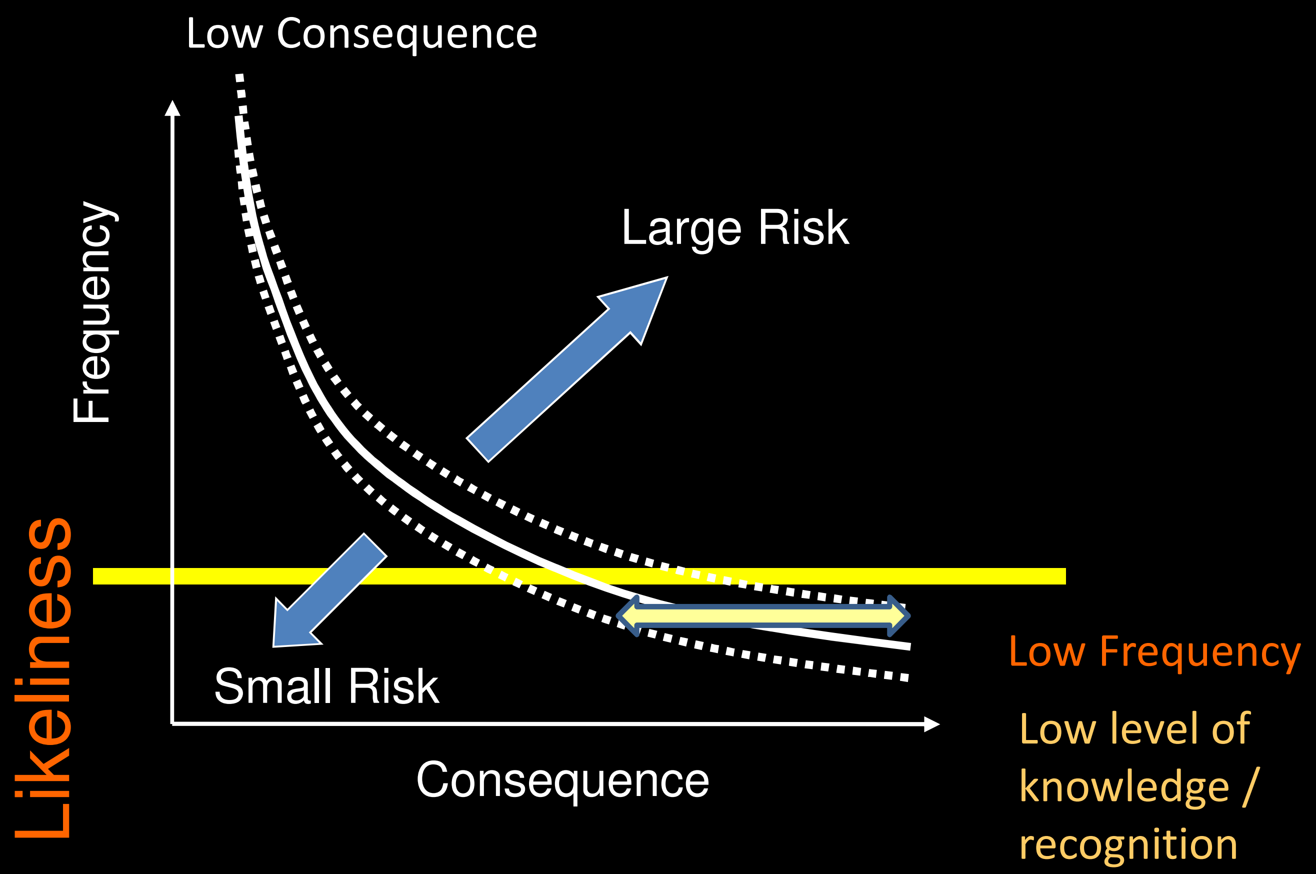
- To ensure safety, suppress the risk to low level
  - Reduce Frequency
  - Mitigate Consequence
- It works only If we know the frequency precisely and we control the consequence

Frequency and Consequence; Which Is More Important?



Large risk means large uncertainty

Low Frequency: What Does It Mean?



Low frequency means less information (ignorance)

Approach to Ensure Safety – Limit the Risk

- Risk is not "frequency" times "consequence"
  - Risk comes from uncertainty which we cannot be free from
  - We must be prepared for uncertainty and overcome ignorance
- Approach to prepare for uncertainty and to limit the risk is : Defense-in-Depth
- What causes the risk?
  - Source term or radioactive material: fission product causes the risk
- Who sustains the risk?
  - Public health and safety and environment sustain the risk

Goal: What Is Hazard? Who Should be Protected?

- Identify Hazard Source
  - Radioactive materials
- Define Safety Objective
  - Health and property of public and environment
- Keep Hazard and Public Separate

3^{rd} Defense : Objective Is the Goal

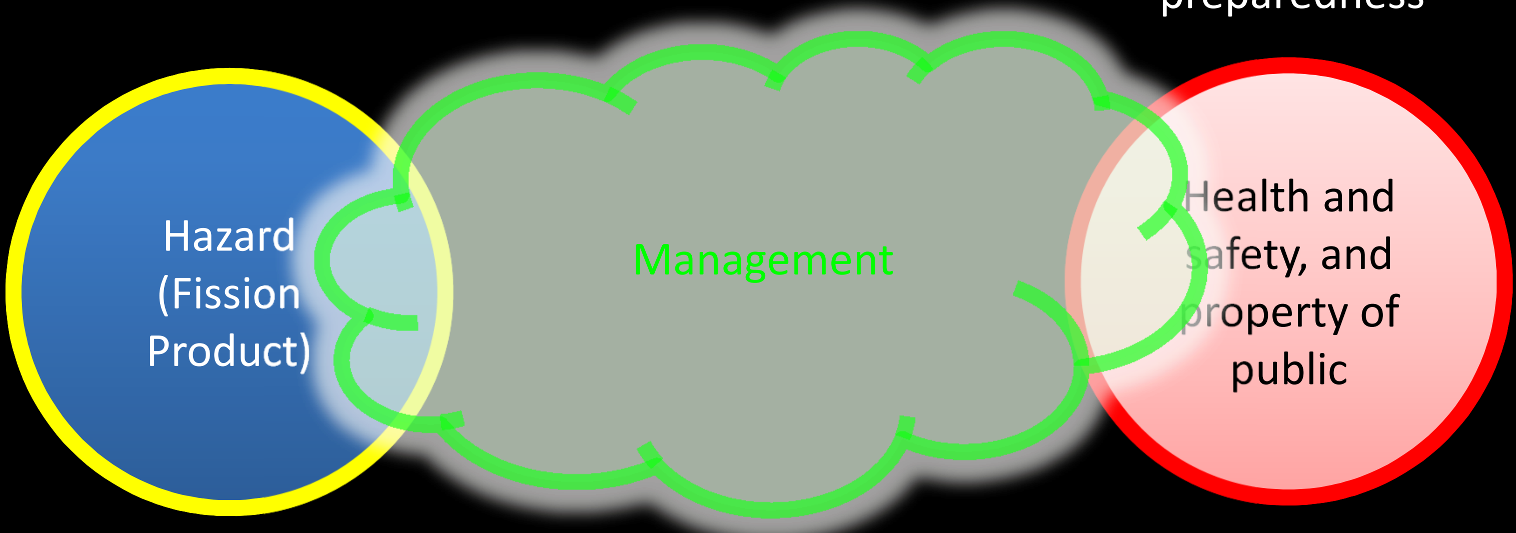
- To protect public is most important
- Emergency response is scenario-less
  - Scenario is unpredictable
  - 1^{st} defense depends on scenario
- Flexibility and knowledge-base action works
  - Management system
  - Drill and education
  - Safety culture

2nd Defense Is Flexible and Broad

1st Defence
Prevention

2nd Defence
Mitigation

3rd Defence
Emergency preparedness



No Severe Accident

Contain Fission Product

Respond to Emergency
Barrier / Distance / Time

Purpose of the 2nd defense is ambiguous
Boundaries are overlapped

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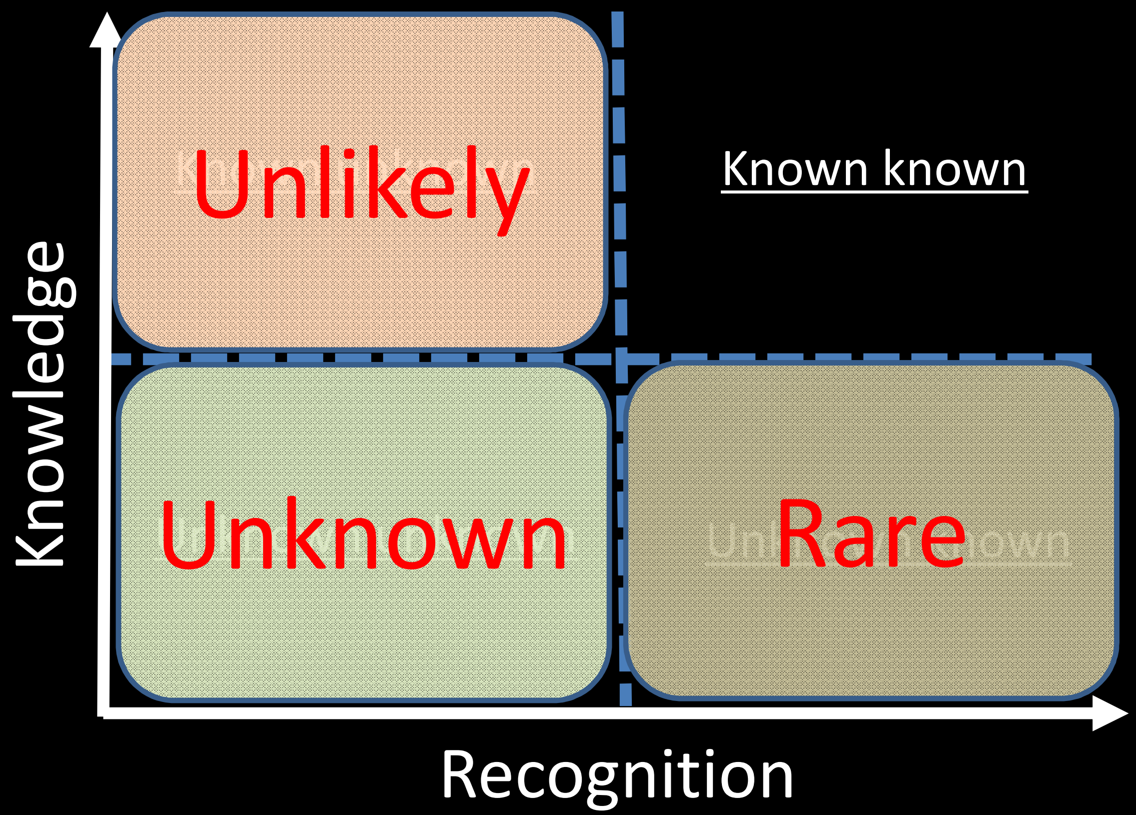
“Absolutely Unlikely” Is Impossible

- Black Swan / White Raven

Black Swan (N. Taleb, 2007)

White Ravens (Hempel's Ravens)

Four Categories of Undesirable Event



Two Beyond-Design-Basis Type: Unlikely Event and Rare Event

Precursor is Messenger of Safety

- White Snake (Iwakuni City, Yamaguchi, Japan)

Messenger of God

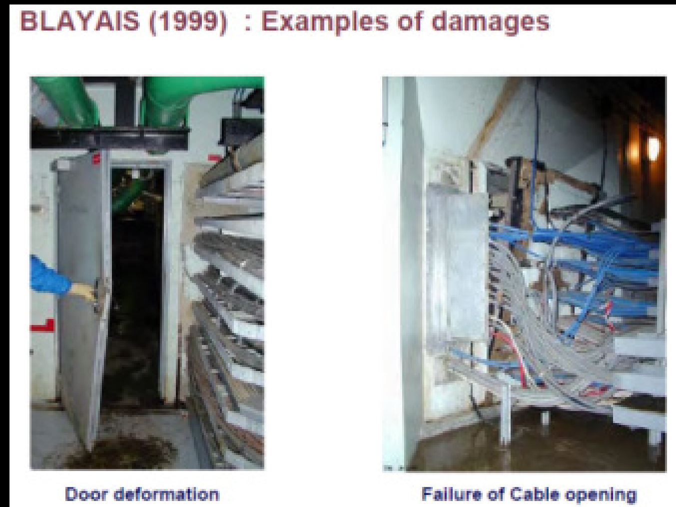
- Appearance of unknowns is messenger of safety

We know white raven / black swan, then, be prepared for them

Known Unknown Becomes Reality

Earthquake and tsunami in the Indian Ocean off Sumatra : Kalpakkam NPP

Flooding: Le Blayais NPP, France



Fort Calhoun NPP: Missouri River Flooding in 2011, USA

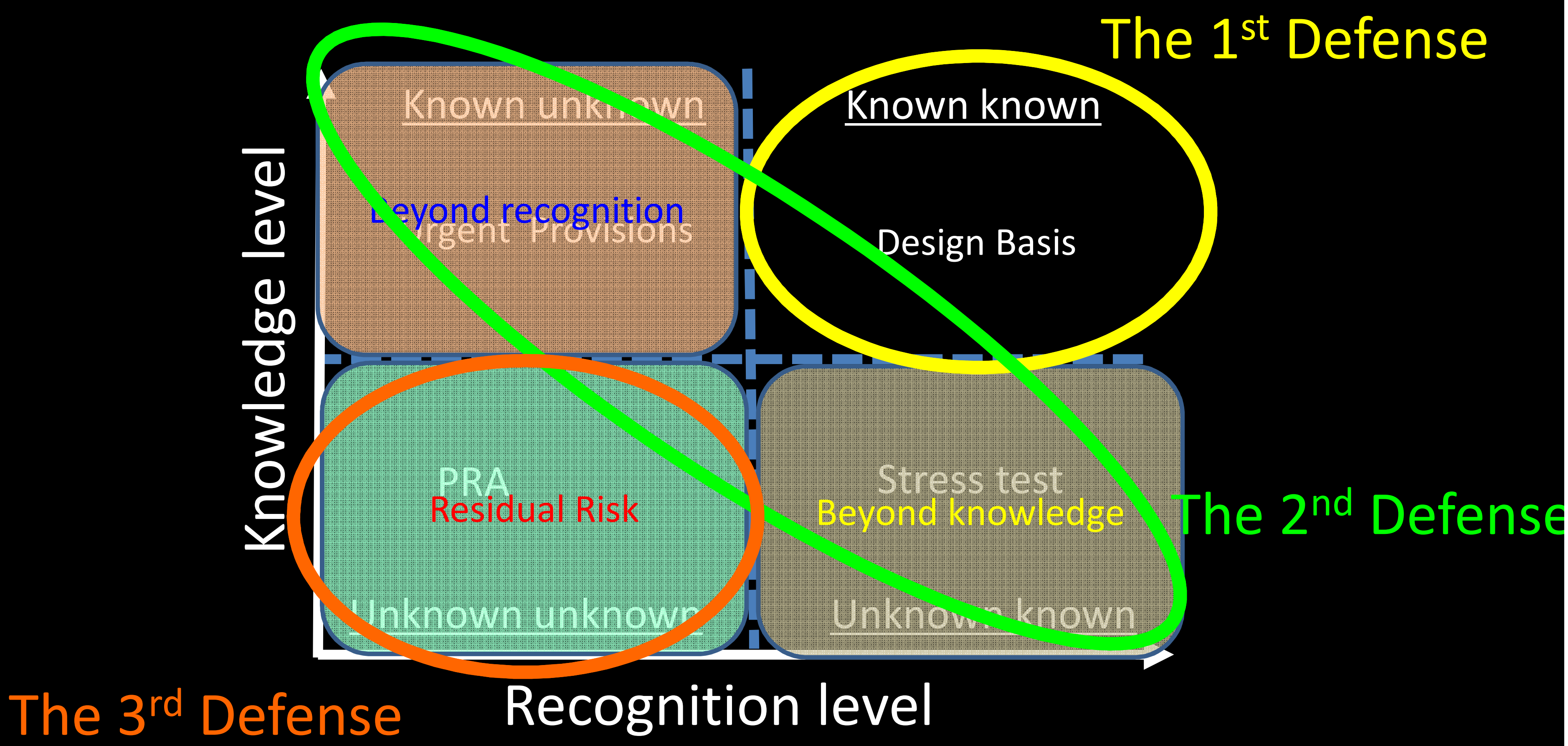
To Prepare for Unknown High Consequence Event

- Low Frequency High Consequence Event（Rare Event）
  - We recognize the event but it is rare. We do not collect knowledge
  - Although frequency is very low, we should have at least knowledge on:
    - Cliff edge, weak link, safety margins, practical preparedness
  - Stress test (comprehensive safety evaluation)
- Low Likelihood High Consequence Event（Unlikely Event）
  - Event is unlikely and we do not understand the importance
  - We should imagine unknown scenario and investigate every possibility
    - Accident sequence precursors (Empirical / Factual)
    - Probabilistic Risk Assessment (Deductive / Eliciting)

Identification and Preparation for Unknowns

- “Known Known” is already considered
  - Design basis
- “Unknown Unknown” becomes “Knowns”
  - PRA find out sequences (Unknown Known)
    - BWR containment vessel failure (SBO scenario): hardened vent
  - Unexpected event becomes reality (Known Unknown)
    - Small LOCA and human error (TMI)
    - SBO+LUHS (Fukushima Daiichi) by tsunami
- “Unknown known” is investigated in detail (stress test)
- “Known unknown” is protected (provisions)

Role of Stress Test, PRA and Provisions



How to Deal with the Residual?

Do We Accept Residual Risk?

IAEA Fundamental Safety Principles
Facilities and activities that give rise to radiation risks must yield an overall benefit.

Justification is the action of declaring or making righteous in the sight of God (Oxford Dictionary of English)

Be ready to accept risk under justification
But continue to reduce / optimize risk

正義の女神、ユースティティア（Justitia）

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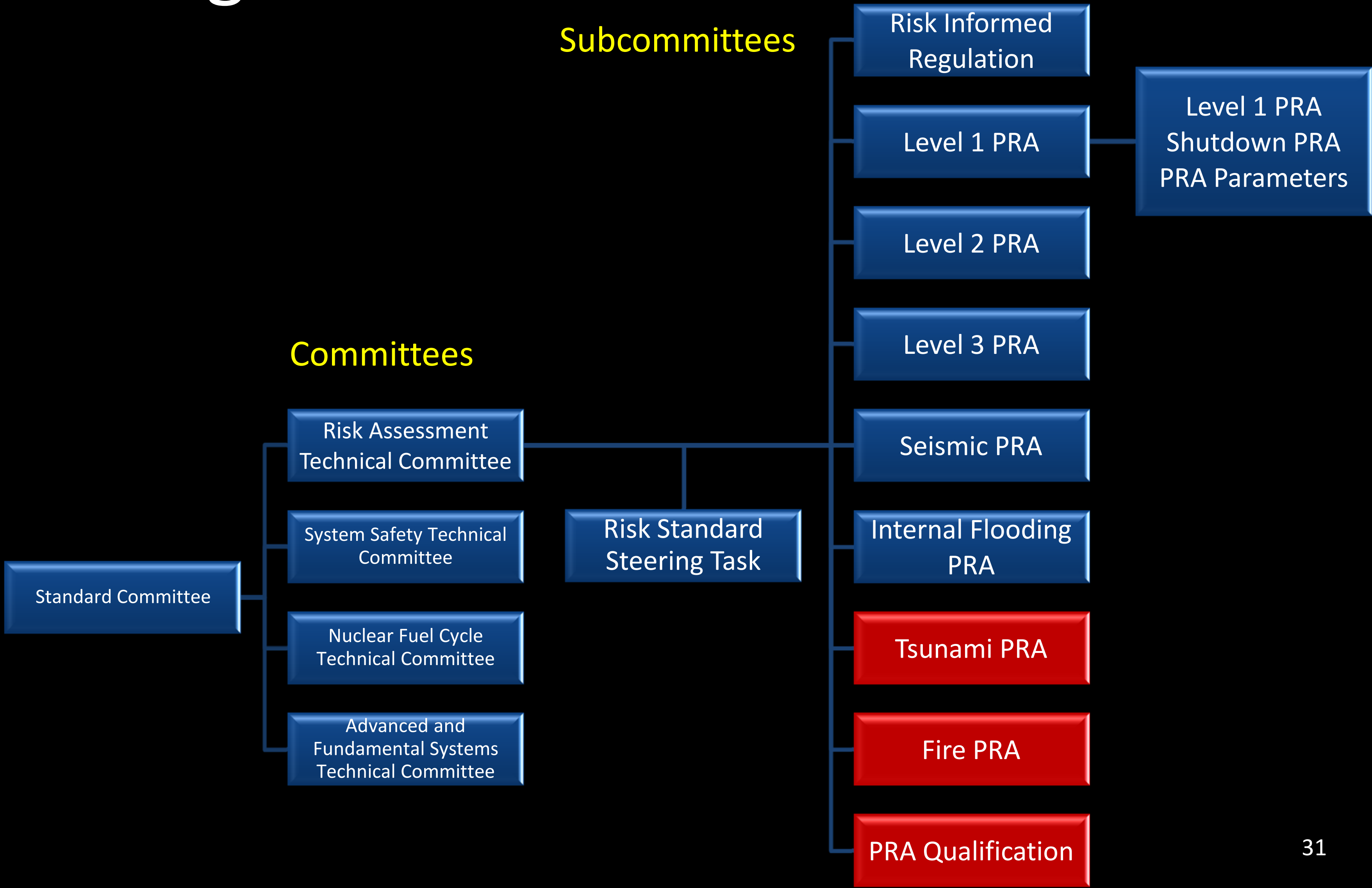
Lessons Learned #27

Effective Use of PSA in Risk Management

- PSA has not always been effectively utilized in the overall reviewing processes or in risk reduction efforts at nuclear power plants. While a quantitative evaluation of risks of quite rare events such as a large-scale tsunami is difficult and may be associated with large uncertainty, Japan has not made sufficient efforts to improve the reliability of the assessments by explicitly identifying the uncertainty of these risks.
- Considering knowledge and experiences regarding uncertainties, the Japanese Government will further actively and swiftly utilize PSA in developing improvements to safety measures including effective accident management measures based on PSA.

Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations -, June 2011

Atomic Energy Society of Japan Organizations for PRA Standards



Atomic Energy Society of Japan PRA Standard Line-up

Standard	Issuance
Level 1 PRA	March 2009 (under revision)
Level 2 PRA	March 2009
Level 3 PRA	March 2009
Shutdown Level 1 PRA	February 2002 (revised in November 2011)
Seismic PRA	September 2007 (under revision)
PRA Parameter Estimation	June 2010
Use of Risk Information	October 2010
Tsunami PRA	December 2011
Internal Flood PRA	November 2012
Tsunami PRA Usage Example	To be published
Terms and Definitions Used in PRA	January 2012

Earthquake Experience and NPPs Affected

- Hyogo-Ken Nambu Earthquake
  - (January 17, 1995, Magnitude 7.3)
- Miyagi-Oki Earthquake Onagawa NPP
  - (August 16, 2005, Magnitude 7.2)
- Noto Peninsula Earthquake Shika NPP
  - (March 25, 2007, Magnitude 6.9)
- Niigata-ken Tyuetsu-Oki Earthquake K-K NPP
  - (July 16, 2007, Magnitude 6.8)
- Suruga-Bay Oki Earthquake Hamaoka NPP
  - (August 11, 2009, Magnitude 6.5)
- We have overcome the earthquake threat, but….may be unbalanced consideration on external events

PRA Standard Updates

- Japanese regulatory authority required utilities to implement emergency safety measures for currently operating NPPs on March 30, 2011
- Additional vital power and alternative equipment for cooling have been equipped
- Risk reduction effect is to be quantified of the measures
- Emergency measures have to be taken into account not only in tsunami PRA, but internal level 1 PRA and seismic PRA

- Tsunami PRA development (completed)
- Level 1 PRA standard and seismic PRA standard update so that the up-to-date safety level are appropriately evaluated (in progress)

Premises in Tsunami PRA

- Initiator is a tsunami caused by earthquakes
- NPP is in power operation when the earthquake occurs
  - No direct effect by earthquakes
    - Supported by Kashiwazaki (2007) and Fukushima, Onagawa and Tokai (2011)
    - Sensitivity analysis on off-site power
  - According to earthquake and/or tsunami alarms, the reactor is in safe shutdown
  - Earthquake does not influence safety function of NPP. Safety-related SSCs for the reactivity control, core cooling, and containment of the fission products are all intact

Direct Effect of Earthquake and Tsunami on March 11

	Fukushima #1 Unit 1-4	Fukushima #1 Unit 5-6	Fukushima #2	Onagawa	Tokai
Plant status at EQ occurrence	Full power Full power Full power Shutdown	Shutdown Shutdown	Full Power Full power Full power Full power	Full power Start-up Full power	Full Power
Off-Site Power	0/6 Earthquake	0/6 Earthquake	1/4 Earthquake	1/5 Earthquake	0/3 Earthquake
Emergency DG	No Tsunami	Unit 5 No Unit 6 1/3 Tsunami	Unit 1 No Unit 2 No Unit 3 2/3 Unit 4 1/3 Tsunami	Unit 1 OK Unit 2 1/3 Unit 3 OK Tsunami	2/3 Tsunami
Heat Sinl	LOHS by Tsunami	LOHS by Tsunami	LOHS by Tsunami	LOHS by Tsunami	LOHS by Tsunami

Earthquake and Tsunami Coupling

- Earthquake 3-7km/s while Tsunami 50-100km/hour (time lag)
- Coupling of earthquake and tsunami
  - Supporting systems and equipment which may fail at relatively low intensity earthquake
  - Added equipment and structures to enhance the water-tightness
  - Emergency measures (equipment and procedures) for may not be seismically qualified

External Event Coupling Effect

- Seismic experience of secondary failure
  - In Onagawa NPP a fire was induced by the earthquake in a transformer in 2011 earthquake off the Pacific coast of Tohoku
  - In Kashiwazaki-Kariwa NPP, the Tyuetsu Offshore Earthquake triggered a fire of a station service transformer of in 2007
  - Spent fuel pool sloshing
- Seismic-induced fire and seismic-induced internal flooding of especially non-safety grade equipment are probable
- Several external events are mutually interactive
  - Internal flooding PRA standard mentions earthquake-induced flooding is out of scope
- Some external events may induce multiple failures and/or another external event

Other Unresolved Issues Level 2 PRA and Level 3 PRA

- Tsunami PRA standard deals with level 1 PRA for reactors in power operation
- AESJ has developed level 2 PRA standard and level 3 PRA standard for internal events
  - They can be applied to external event as well
  - Necessity to develop standards for level 2 PRA and level 3 PRA for external events
  - Consideration if an external event has specific features in terms of the fission product release, containment performance and the emergency responses

Other Unresolved Issues Shutdown PRA

- In Fukushima Dai-ichi Accident:
  - Units 4, 5 and 6 are in shutdown for refueling.
  - In unit 4, all the fuel assemblies are unloaded and transferred to the spent fuel pool to replace the reactor vessel shroud
- In shutdown condition
  - Some safety systems may be out of service
  - Water-tight doors and openings may not be closed
- Practical and efficient tsunami protections is to keep the safety-related SSCs away from the tsunami water
  - Dry site concept, water-tight structure, water-resist and water-proof SSCs
  - During shutdown situations, they may not work

- Is shutdown PRA for external events necessary? Yes, probably.

Other Unresolved Issues
Risk Assessment of Spent Fuel Pool

- Spent fuel pool risk is an safety concern
- Inventory of the fuel and fission products may be larger than in the reactor core
- Decay heat in the spent fuel pool is quite small and the maintenance of water level is enough for cooling
- Do we need to estimate the spent fuel pool risk in the framework of the PRA?
- In the Fukushima Dai-ichi accident
  - Difficulty in spent fuel pool cooling comes from hydrogen explosion
  - Accessibility were extremely deteriorated
  - Spent fuel pool risk may be well controlled by management
- Technological requirement, quantification methodology, and data are not enough to complete spent fuel pool PRA but the risk is controllable

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Other Unresolved Issues
Comprehensive External Event PRA

- External event PRA
  - Necessary if occurrence frequency and/or consequence significant
  - Internal flooding PRA and fire PRA standards are under development
  - Other external events?
- Concurrency of multiple external events
  - Priority on combined PRA of earthquake and tsunami
    - Seismic failure of anti-tsunami SSC, loss of function or deterioration of infrastructure such as power supply system and communication system
    - Deterioration of the accessibility for the operators and workers is to be considered in case that the human recovery actions are taken into account.
  - Combinations of earthquake and internal flooding and fire
  - Other combinations?

Comprehensive External Event PRA Impact Based Approach

- Nuclear power plant should be designed safe for postulated events, that are “likely” and “influential”
- All possible “influential” events are considered in PRA regardless of the likelihood
  - We cannot tell an event is likely or unlikely precisely
- Provisions for influential but unpostulated events have varieties according to event characteristics
- Selection of influential unpostulated event is based on impact and tolerability
  - Frequency of event, capacity of plant, isolation capability
  - Practical and effective metrics is “Risk”

Procedure for External Hazard and Risk Assessment

- Comprehensive survey of external hazard
- Risk potential of external hazard
- Risk-significance of external event
- Available quantitative evaluation methodology
- Protection and management against external hazard

Identify external hazard
- Natural event / Man-made event
- Single event / Multiple event

→

Categorize external hazard
- Frequency
- Distance
- Grace period
- Influence

→

Select risk assessment approach
- Screening
- Bounding analysis
- Margin analysis
- DSA
- PRA

Identification of Possible Natural Hazard

- Japanese Diet Report
  - Natural disaster for 416-1995
  - Secondary disaster included
- ASME/ANS standard
  - Natural event
  - man-made event
- IAEA NS-R-3
  - Natural event
  - man-made event

List of Potential External Hazard

External hazard		Phenomena
Natural hazard	Earthquake and tsunami disaster	Earthquake / Subsidence / Ground uplift / Ground crack / Soil discharge / Liquefaction / Landslide / Debris flow / Mountain slide / Cliff failure / Flooding / Tsunami / Fire
	Volcano disaster	Volcanic bomb / Volcanic lapillus / Pyroclastic flow / Lava flow / Debris flow / pyroclastic surge / Blast wave / Ash fall / Flooding / Tsunami / Forest fire / Volcanic gas stagnation / Cold weather by volcanic gas / Boiling water / Earthquake / Mountain collapse
	Meteorological calamity	Storm(wind / fire / avalanche / sandblasting) / Wind wave/Tidal wave / Abnormal elevation of sea level / Intense rainfall (immersion / flooding / Debris flow / flash flood / mountain slide / landslide / cliff failure / High tide water / Seiche / Wind wave / Fog and mist / Heavy snow (dead weight / avalanche) / Snowstorm / Heavy snow (flooding) / Snowmelt (mountain slide / landslide) / Lighting strike (current / fire) / Hail / Frost / Tornado / River blockage by ocean water / Water level declination in lake and river / Drought / High temperature / Low temperature (freeze) / Abnormal change in ocean current
	Others	Forest fire / Coastal erosion / Biological event / Meteor / High tide / Toxic gas / River channel change
Man-made event		Airplane crash / Artificial satellite / Transport accident / Ship impingement / Turbine missile / Industrial or military facility accident / Pipeline accident / Abnormal gas eruption cased by boring / Oil spill / Chemical substance release from onsite storage facilities / Flooding and wave by failure of flood control structure

Underlined hazards typed in red are from ASME/ANS Standard, IAEA NS-R-3

Selection Criteria of External Event Yes / No / Uncertain

- C-1: Current PRAs practice cover the external event?
- C-2: Licensing evaluations cover the event and show it is not influential and dominant
- C-3: Occurrence frequency definitely small
- C-4: Distance of hazard and NPP is kept large enough
- C-5: Hazard progression (time scale) is slow enough
- C-6: Influence on NPP is small enough

- If one or more of C-2 to C-6 is yes, PRA is not required
- If one or more of C-2 to C-6 is uncertain, select appropriate risk assessment method
- If all of C-2 to C-6 is no, PRA is required

Hazard – Criteria (EQ, Tsunami, Volcano)

外的ハザードの種類		外的ハザード	【基準1】当該の事象は既存のPRAにおいて評価される事象か	【基準2】既存評価(設置許可等)結果を利用して、プラントの安全性が損なわれることがないことが確認できるか	【基準3】発生頻度が極めて小さいことが明確か	【基準4】当該のハザードの影響が及ぶ範囲内に、プラントが存在しないことが確認できるか	【基準5】ハザードが進展していくタイムスケールが、プラントの寿命に比べて十分長いか	【基準6】ハザードが到達したと想定しても、炉心損傷につながる起因事象を引き起こさないことが明らかか	外的ハザード事象の分類結果(定量的リスク評価の実施要否) A:定量的リスク評価不要:基準2~6のいずれかが○ B:不確実さ確認の上で判断を行う:基準2~6に○はないがいずれかが△ C:定量的リスク評価要:いずれも×
自然災害	地震・津波災害	地震動	○(地震PRA)	△	×	×	×	×	B (ただし、基準4の不確実さが大きいため、定量的リスク評価が必要) → 地震PRA
		地盤沈下	×	×	×	×	×	×	C
		地盤隆起	×	×	×	×	×	×	C
		地割れ	×	×	×	×	×	×	C
		泥湧出	×	×	×	z	×	×	C
		液状化現象	×	×	×	×	×	×	C
		地滑り	×	△	×	×	×	×	B
		土石流	×	×	×	×	×	×	C
		山崩れ	×	×	×	×	×	×	C
		崖崩れ	×	×	×	×	×	×	C
		洪水	×	△	×	×	×	×	B
		津波	○(津波PRA)	△	×	×	×	×	B (ただし、基準4の不確実さが大きいため、定量的リスク評価が必要) → 津波PRA
		火災	×	×	×	×	×	×	C
	火山災害	火山弾(大きな噴石)	×	×	×	△(活火山からの距離次第)	×	×	B
		火山礫(小さな噴石)	×	×	×	△(活火山からの距離次第)	×	×	B
		火砕流	×	×	×	△(活火山からの距離次第)	×	×	B
		溶岩流	×	×	×	△(活火山からの距離次第)	×	×	B
		土石流	×	×	×	△(活火山からの距離次第)	×	×	B
		火砕サージ	×	×	×	△(活火山からの距離次第)	×	×	B
		爆風	×	×	×	△(活火山からの距離次第)	×	×	B
		降灰	×	×	×	×(広範囲に影響が及ぶ可能性がある)	×	×	C
		洪水	×	△	×	△(活火山からの距離次第)	×	×	B
		津波	×	△	×	△(活火山からの距離次第)	×	×	B
		火災(山林火災)	×	×	×	△(活火山からの距離次第)	×	×	B
		火山ガス滞留	×	×	×	△(活火山からの距離次第)	×	○	A
		火山ガスによる冷害	×	×	×	△(活火山からの距離次第)	×	×	B
		熱湯	×	×	×	△(活火山からの距離次第)	×	×	B
		地震	×	△	×	△(活火山からの距離次第)	×	×	B
		山体崩壊(崩落)	×	×	×	△(活火山からの距離次第)	×	×	B

Hazard – Criteria (Natural Phenomena)

外的ハザードの種類		外的ハザード	【基準1】当該の事象は既存のPRAにおいて評価される事象か	【基準2】既存評価（設置許可等）結果を利用して、プラントの安全性が損なわれることがないことが確認できるか	【基準3】発生頻度が極めて小さいことが明確か	【基準4】当該のハザードの影響が及ぶ範囲内に、プラントが存在しないことが確認できるか	【基準5】ハザードが進展していくタイムスケールが、プラントの寿命に比べて十分長いか	【基準6】ハザードが到達したと想定しても、炉心損傷につながる起因事象を引き起こさないことが明らかか	外的ハザード事象の分類結果（定量的リスク評価の実施要否） A:定量的リスク評価不要:基準2～6のいずれかが○ B:不確実さ確認の上で判断を行う:基準2～6に○はないがいずれかが△ C:定量的リスク評価要:いずれも×
自然災害	気象災害	暴風（風）	×	△	×	×	×	×	B（ただし、基準4の不確実さが大きいため、定量的リスク評価が必要）→ 地震PRA
		暴風による火災	×	△	×	×	×	×	B
		暴風による雪崩	×	×	×	×	×	×	C
		暴風による砂嵐	×	×	×	○	×	×	A
		風浪・高波	（○）（影響は津波に包含される）	×	×	×	×	×	C（ただし、津波PRAに包含）
		海水位の異常な上昇	（○）（影響は津波に包含される）	×	×	×	×	△	C（ただし、津波PRAに包含）
		豪雨（浸水）	（○）（影響は津波に包含される）	×	×	×	×	×	C（ただし、津波PRAに包含）
		豪雨による洪水	×	△	×	×	×	×	B
		豪雨による土石流	×	×	×	×	×	×	C
		豪雨による鉄砲水	×	×	×	×	×	×	C
		豪雨による山崩れ	×	×	×	×	×	×	C
		豪雨による地滑り	×	△	×	×	×	×	B（ただし、基準4の不確実さが大きいため、定量的リスク評価が必要）→ 津波PRA
		豪雨による崖崩れ	×	×	×	×	×	×	C
		高潮	（○）（影響は津波に包含される）	△	×	×	×	×	B
		静振	（○）（影響は津波に包含される）	×	×	○（プラント周辺に湖・ダムが無い場合）	×	×	A
		風津波	（○）（影響は津波に包含される）	×	×	×	×	×	C（ただし、津波PRAに包含）
		霧	×	×	×	×	×	○	A
		豪雪による荷重	×	△	×	×	×	×	B
		豪雪による雪崩	×	×	×	×	×	×	C
		吹雪	×	×	×	×	×	○	A
		豪雪による洪水	（○）（影響は津波に包含される）	△	×	×	×	×	B
		融雪による山崩れ	×	×	×	×	×	×	C
		融雪による地滑り	×	△	×	×	×	×	B
		落雷（電流）	○（外部電源喪失起因事象で考慮）	△	×	×	×	×	B
		落雷による火災	×	△	×	×	×	×	B
		降雹	×	×	×	×	×	○	A
		霜	×	×	×	×	×	○	A
		竜巻	×	×	×	×	×	×	C
		海氷による川の閉塞	（○）（影響は津波に包含される）	×	×	○（プラント周辺に河川が無い場合）	×	×	A
		湖若しくは川の水位下降	×	×	×	○（プラント周辺に河川が無い場合）	×	×	A
		旱魃	×	×	×	×	○	○	A
		夏の高温	×	×	×	×	×	○	A
		氷結（低温）	×	△	×	×	×	○	A
		海流異変（原因は黒潮）	×	×	×	×	×	○	A

Hazard – Criteria (Natural Phenomena and man-made event)

外的ハザードの種類		外的ハザード	【基準1】当該の事象は既存のPRAにおいて評価される事象か	【基準2】既存評価(設置許可等)結果を利用して、プラントの安全性が損なわれることがないことが確認できるか	【基準3】発生頻度が極めて小さいことが明確か	【基準4】当該のハザードの影響が及ぶ範囲内に、プラントが存在しないことが確認できるか	【基準5】ハザードが進展していくタイムスケールが、プラントの寿命に比べて十分長いか	【基準6】ハザードが到達したと想定しても、炉心損傷につながる起因事象を引き起こさないことが明らかか	外的ハザード事象の分類結果（定量的リスク評価の実施要否） A:定量的リスク評価不要:基準2～6のいずれかが○ B:不確実さ確認の上で判断を行う:基準2～6に○はないがいずれかが△ C:定量的リスク評価要:いずれも×
自然災害	その他の災害	森林火災	×	×	×	×	×	×	B （ただし、基準4の不確実さが大きいため、定量的リスク評価が必要） → 地震PRA
		海岸浸食	(○)(影響は津波に包含される)	×	×	×	○	×	A
		生物学的事象	×	×	×	×	○	×	A
		隕石	×	×	△	×	×	×	B
		満潮	(○)(影響は津波に包含される)	×	×	×	×	○	A
		毒性ガス	×	×	×	×	×	○	A
		河川の流路変更	×	×	×	○(プラント周辺に河川が無い場合)	○	×	A
人為災害		航空機落下	×	△	×	×	×	×	B
		人工衛星	×	×	△	×	×	×	B
		輸送事故	×	×	×	×	×	×	C
		船舶の衝突	×	×	×	×	×	×	C
		タービンミサイル	×	○	×	×	×	×	B （ただし、基準4の不確実さが大きいため、定量的リスク評価が必要） → 津波PRA
		産業又は軍事施設事故	×	×	×	○(10km圏内に当該施設が無い場合)	×	×	A
		パイプライン事故	×	×	×	○(10km圏内に当該施設が無い場合)	×	×	A
		ボーリング工事の影響によるガス異常噴出	×	×	×	○(10km圏内に当該施設が無い場合)	×	×	A
		油流出	×	×	×	×	×	×	C
		サイト内の貯蔵庫からの化学物質放出	×	×	×	×	×	×	C
		治水構造物の破損による洪水及び波	(○)(影響は津波に包含される)	×	○	○(周辺に治水構造物が無い場合)	×	×	A

Concept of Event Selection

Criterion 1

Criterion 2

Safety evaluation by PRA or Design

Frequency

Criterion 3

Occurrence of natural hazard

Separation

Criterion 4

Physical Distance

- Volcano

Criterion 5

Large grace time

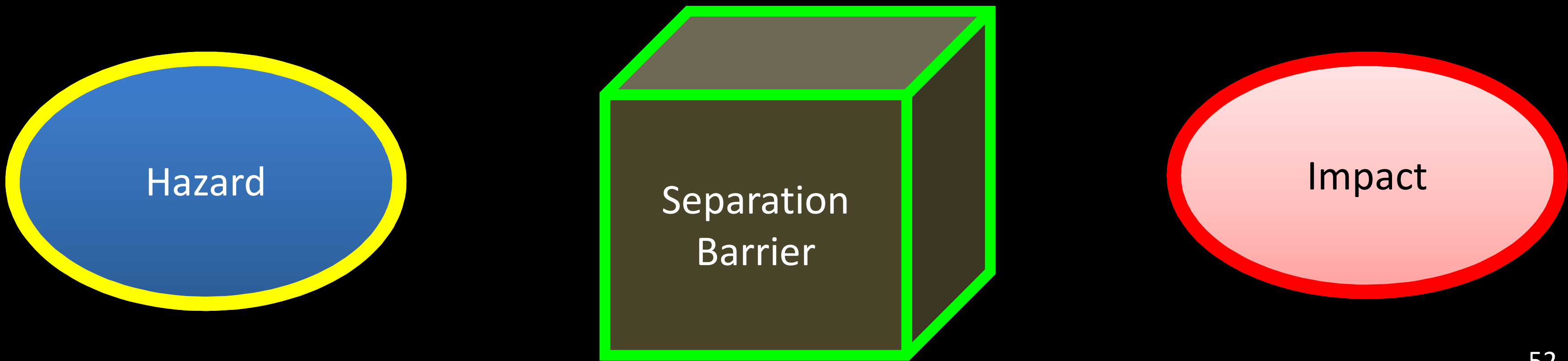
- Geological change
- Drought

Consequence

Criterion 6

Little impact

- Fog
- Frost



Conclusions

- Good management and knowledge lead us to the right way at crossroads
- Preparation for Uncertainty (Unpostulated scenarios)
  - Defense-in Depth
  - Unlikely Event and Rare Event
- Being prepared for three types of Unknowns
  - Stress test covers rare event : Unknown known
  - Appropriate back-fit prepares for : Known unknown
  - PRA deal with unlikely event : Unknown unknown
- External PRA Standard Development at AESJ