Accident at TEPCO's Fukushima-Daiichi NPP

Current status, lessons learned, and the future of nuclear energy policy in Japan

Fukushima-Daini-1

Fukushima-Daiichi-4

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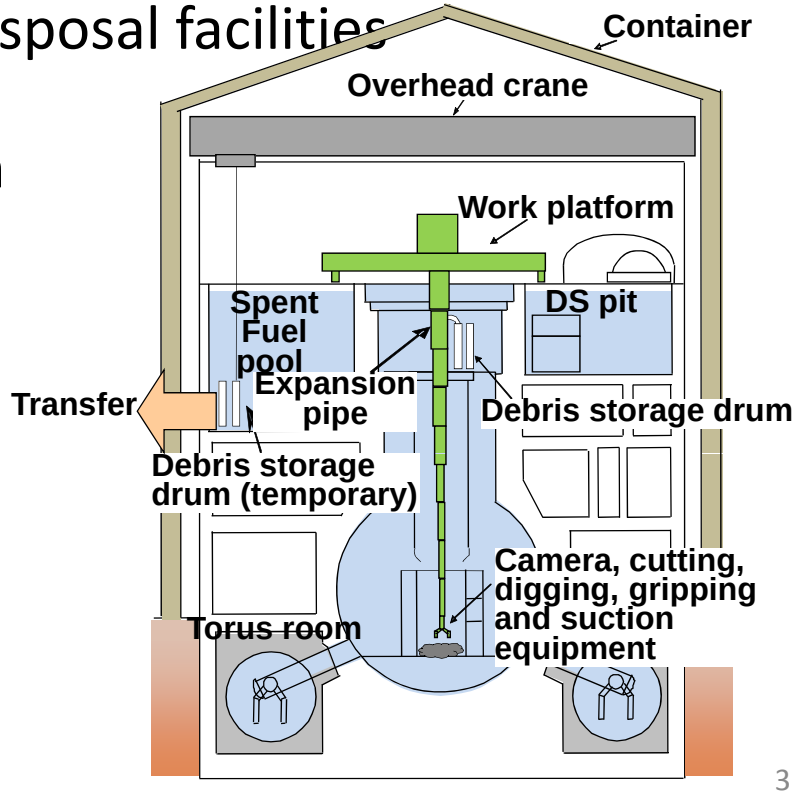
Commissioner, Atomic Energy Commission

Outline

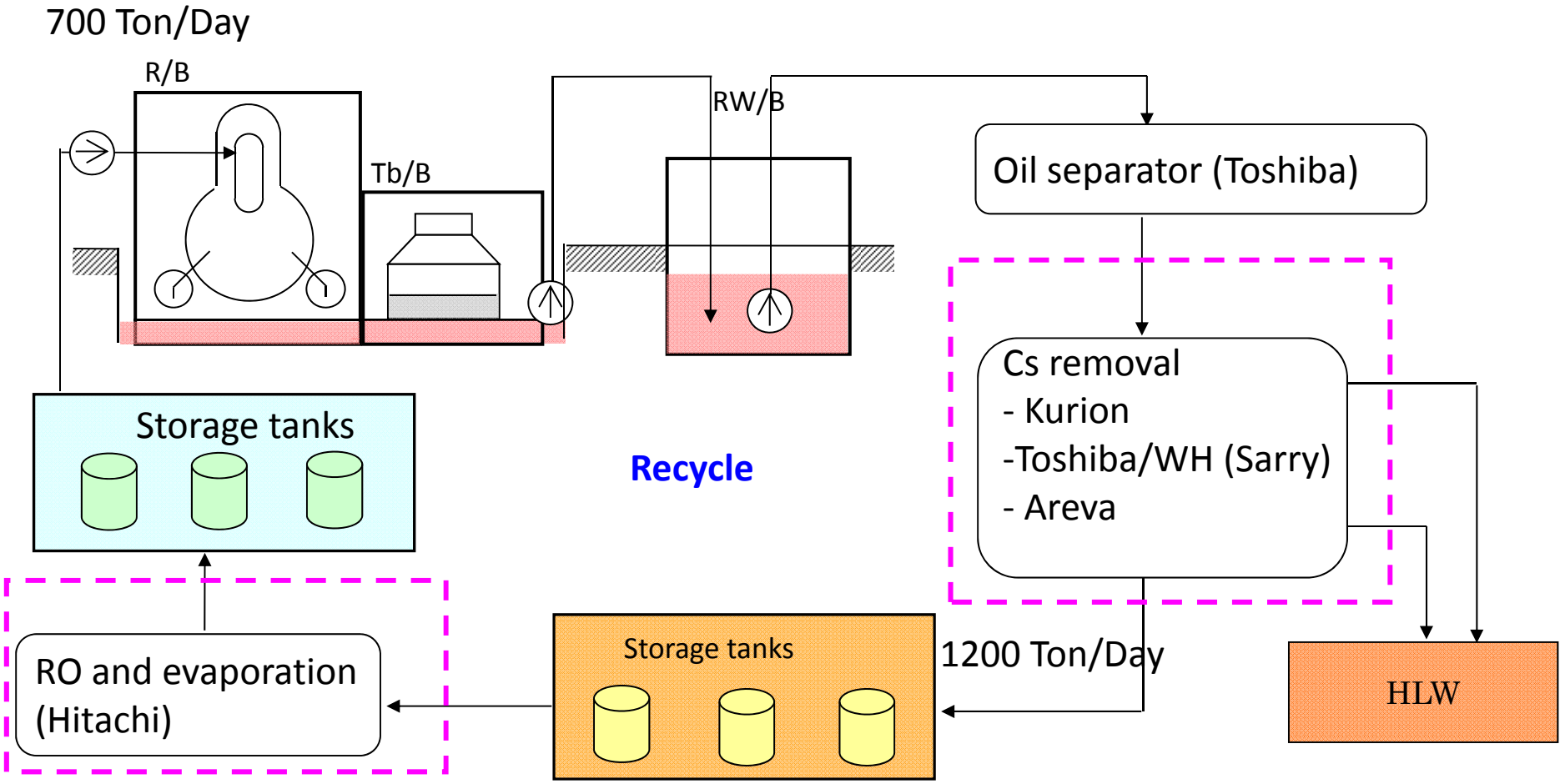
- ✓ ***Current status***
- ***Key Lessons Learned***
- ***Future of NE policy in JAPAN***

Onsite status and medium- & long-term plan

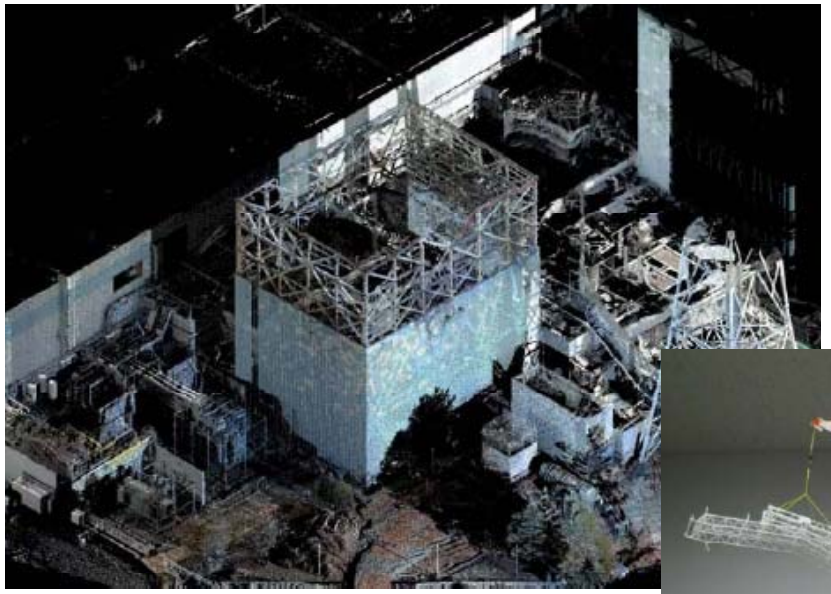
- Stabilization phase ended in 2011 December
- Planned actions
  1. Remove Spent Fuel from the Spent Fuel Pools (start within 2years)
  2. Remove core debris (start within 10years)
  3. Decommission
  4. Dispose generated wastes at final disposal facilities
- Key technology challenges
  - Identify location and configuration of core debris
  - Plug the leaking holes
  - Remove core debris



Maintain debris cooling/ Assure reliable cooling
Water inventory control



Reactor Building Cover



Completed for Unit 1
(2011 October)

Offsite impact:
evacuation, land contamination and exposure

1) **Evacuee: Estimated 146,520** (NAIIC report)

2) **Land contamination, current zoning and decontamination activities**

3) **Estimated radiation exposure:**

- Evaluation of external exposure of residents(evacuees), March 12-July 11: 2012Feb20 report by Fukushima Prefecture
  - ✓ 58%< 1mSv, 99.3%<10mSv (Max. 23mSv), if radiation workers are excluded
  - ✓ High among evacuees *(47.2mSv , if radiation worker is included)*

[SOURCE]
http://www.pref.fukushima.jp/imu/kenkoukanri/231213senryosuikei.pdf,
http://www.pref.fukushima.jp/imu/kenkoukanri/240220siryo.pdf

- Assessment of additional exposure from contaminated food
  - ✓ ~ 0.1mSv/a (tentative estimation for an average Japanese)
    (~0.4mSv/a from natural K-40)

[SOURCE] http://www.mhlw.go.jp/stf/shingi/2r9852000001ip01-att/2r9852000001ipae.pdf

  - ✓ Measured thyroid dose of local residents: yet to be determined

NIRS estimation: max 42mSv *[Source] NIRS symposium, 10-11July2012*

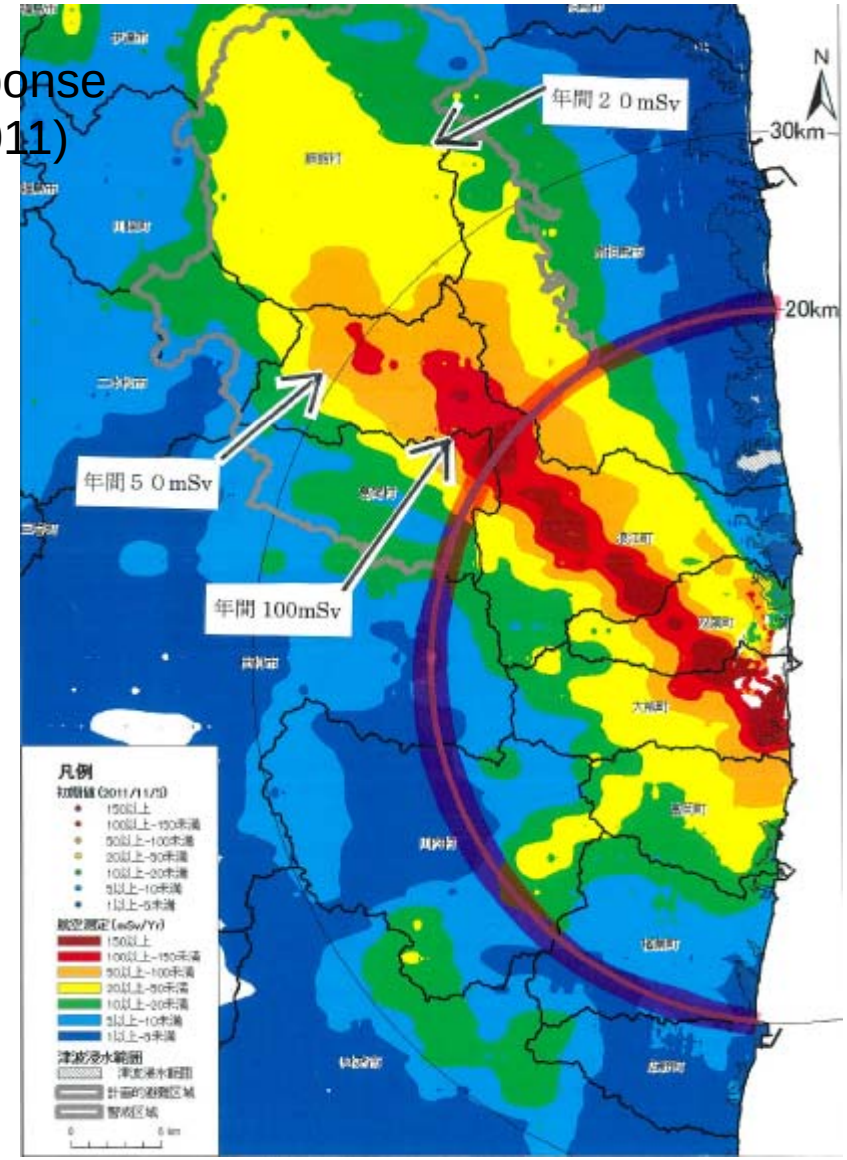
New zoning concept after April2012

Announcement by the Nuclear Emergency Response Headquarters to change zoning (26December2011) after achieving Step II goal at Fukushima NPP

1. To prepare lifting “evacuation” order for areas <20mSv/a by March 2012: Green and Blue zone within 20km radius (decontamination and rebuilding infrastructure)

2. Continued off-limit for areas between above 20 but below 50 mSv/a: Yellow area, but shift to the above 1 after decontamination (decontamination)

2. Designate “areas difficult to return”: above 50mSv/a, applicable for 5 years: Brown and Red (consultation for relocation etc)

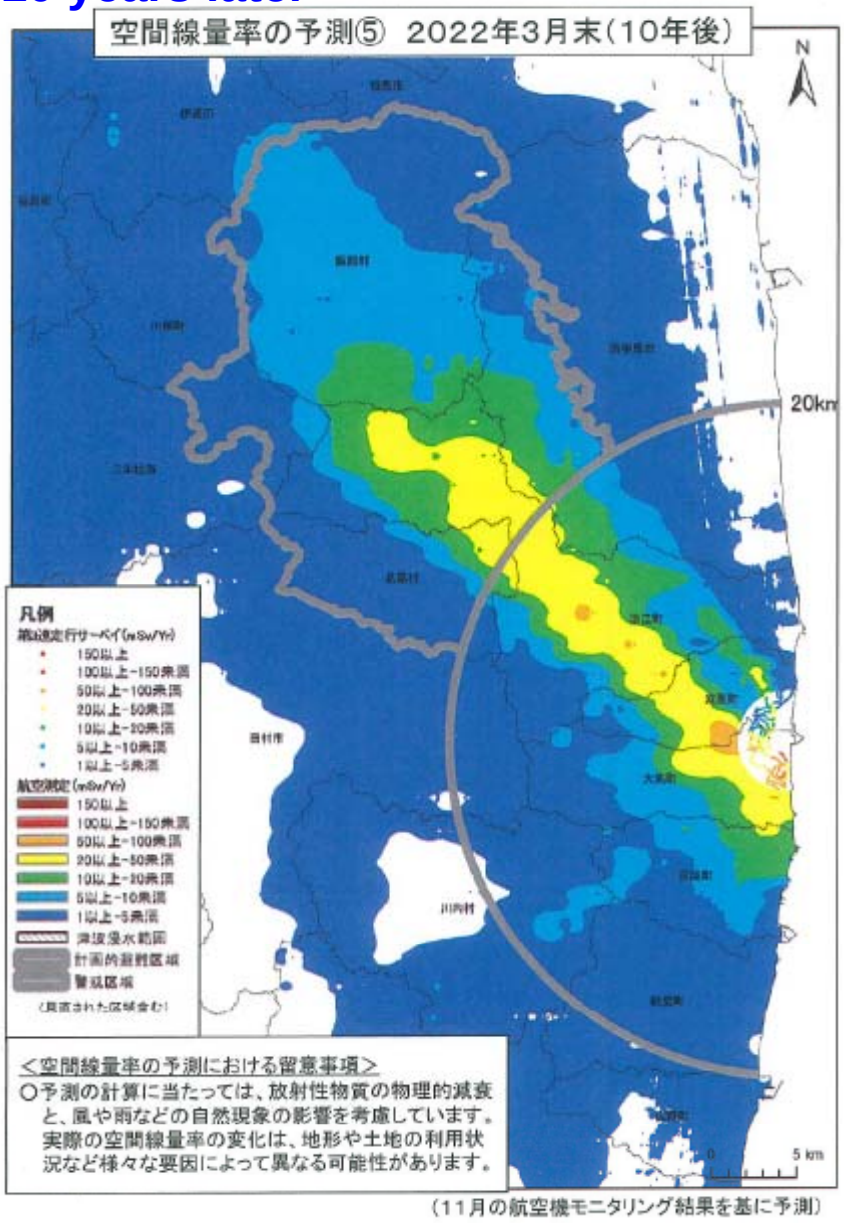


Predicted annual dose (as of 2011Nov5)

[SOURCE] http://www.meti.go.jp/earthquake/nuclear/pdf/111226_01a.pdf

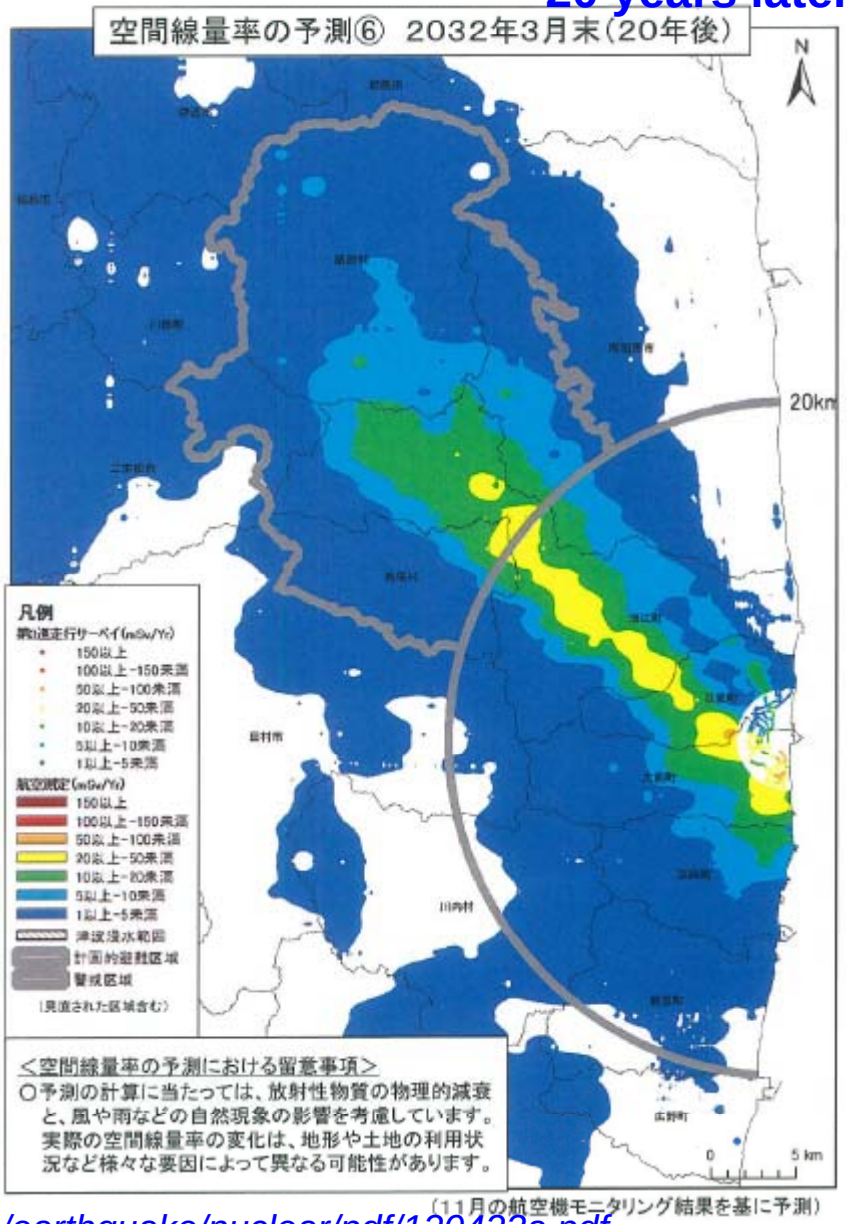
Projections: 10-20 years later, if no decontamination

10 years later



（11月の航空機モニタリング結果を基に予測）

20 years later

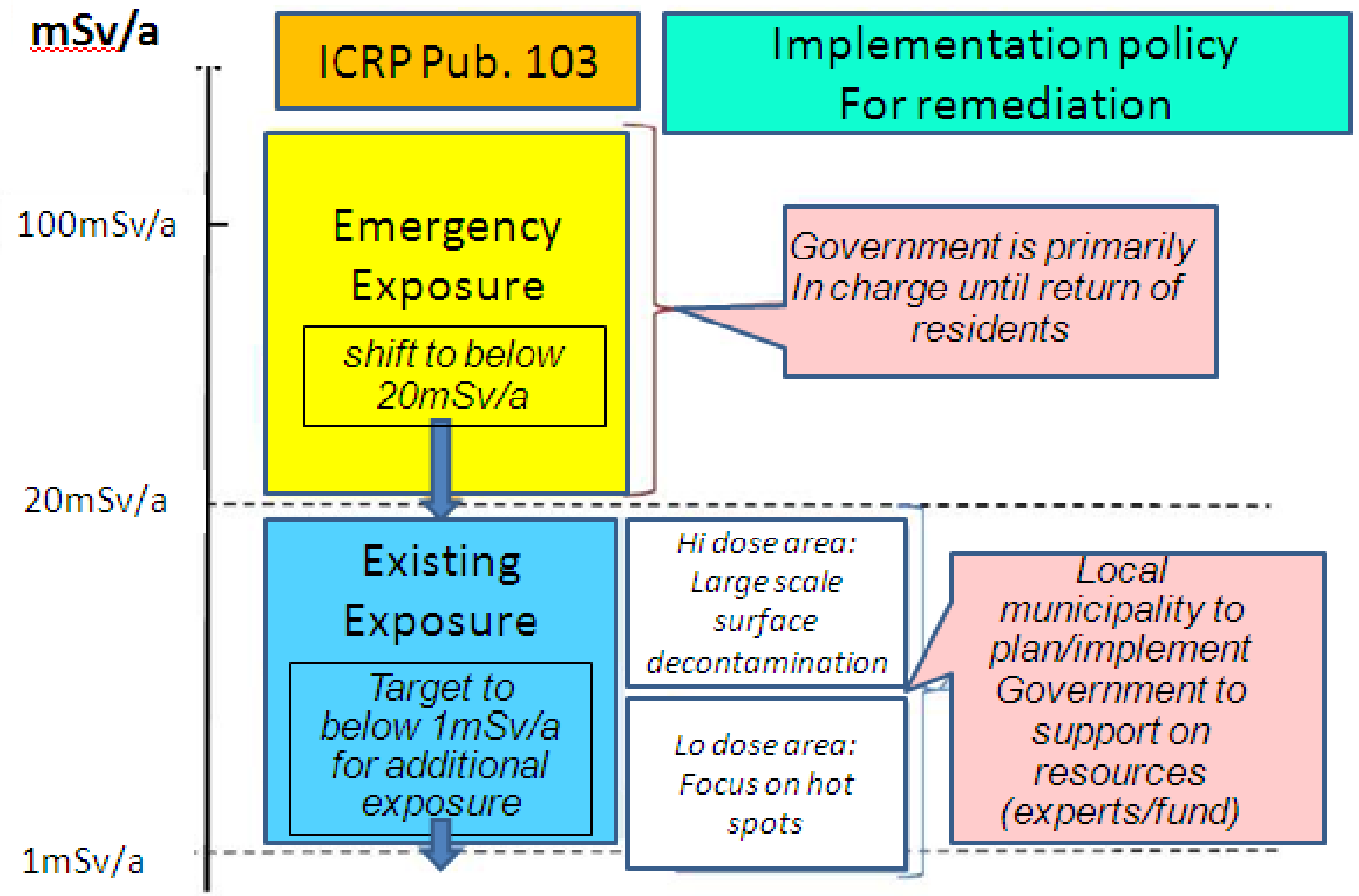


（11月の航空機モニタリング結果を基に予測）

http://www.meti.go.jp/earthquake/nuclear/pdf/120423a.pdf

MoE Decontamination Guideline
[SOURCE]
http://www.env.go.jp/press/press.php?serial=14582

Offsite remediation

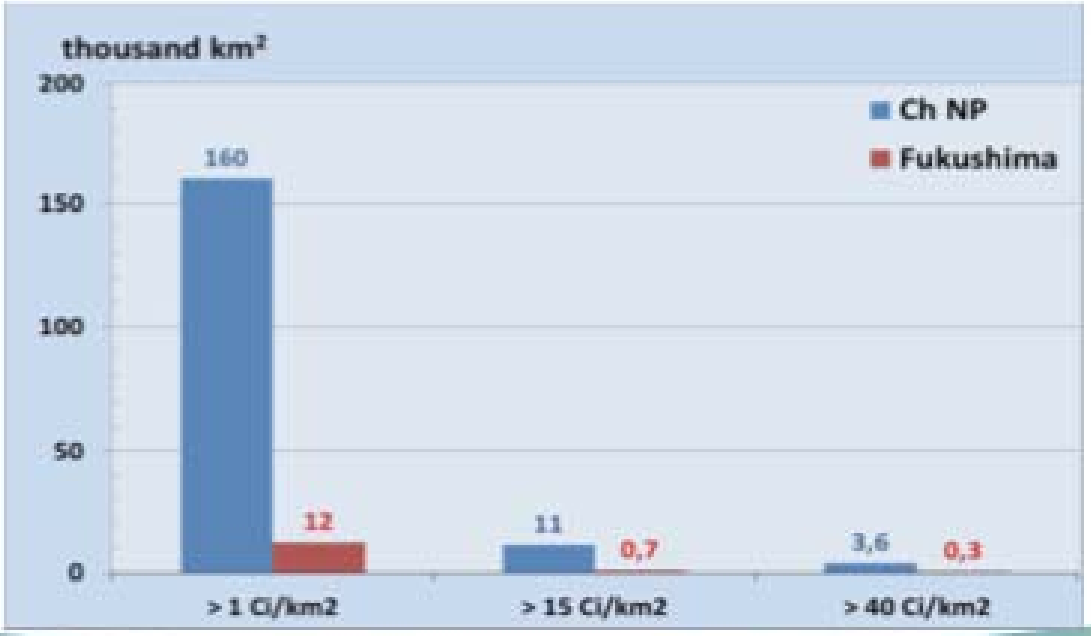


[SOURE] http://www.meti.go.jp/press/2011/08/20110826001/20110826001-4.pdf

Areas of contaminated territories in Russia and Japan as a result of the accidents at ChNPP and Fukushima-1 NPP

Accident	Area of territory contaminated by Cs-137, thous. km²	
	> 15 Ci/km² (555 kBq/m²)	> 40 Ci/km² (1480 kBq/m²)
Fukushima-1	0.7	0.3
Chernobyl NPP	10.95	3.62

[SOURCE] IBRAE



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Economic impact

Fukushima nuclear accident

- Estimated 60B$ damage (decommissioning, land decontamination, compensation (including rumor-induced damage)
- 0.5 JPY/KWhr estimated "accident cost" assuming 40-year operation of all the NPPs in Japan
- Power replacement cost: 30B$/year in case no NPP in operation

3.11 Disaster, as a whole:

Stock: Estimated loss of 160-250 B$ ($=100JPY)

A bit less that 1% loss of non-financial asset (28T$), but often referred as equivalent to 4% of GDP (5.4T$, flow) of Japan

GDP (looking at flow, rather than stock) changes as a result of various factors

- ✓Reduced production (-16% in manufacturing sector)
- ✓Increased import to replace nuclear electricity
- ✓Investment to stock
- ✓Masked by other factors: Reduced export after the Lehman shock, Reduced export due to surge of JPY

Safety improvements, Stress tests

1. NISA Emergency Safety Measures

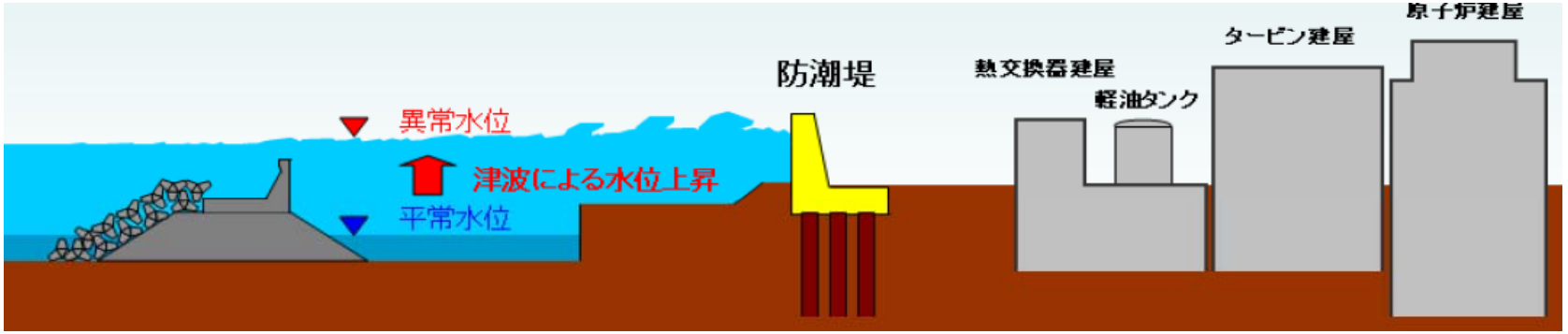
- 30 Directive to each NPP from NISA
- Utility's action plan in response

Short term

- ✓ Ensure emergency power supply and core cooling
- ✓ SAM improvements

Medium-to-Long term

- ✓ Countermeasure against Tsunami
  - → (Example) breakwater wall by 2013



2. Utilities own initiatives: Filtered venting, new JANTI

3. Stress test

- ✓ Phase I: plants ready for restart (assessment of safety margin)
- ✓ Phase II: All plants to determine continued operation or not by comprehensive assessment (PSA)

Changes in nuclear regulatory system

New Act (20June2012)

- Establish Nuclear Regulatory Agency under Ministry of Environment
- Independence in terms of Government Organization Act
- Integration of 3S(safety/security/safeguard) in one Agency
- Five Commissioners

Associated changes in relevant laws:

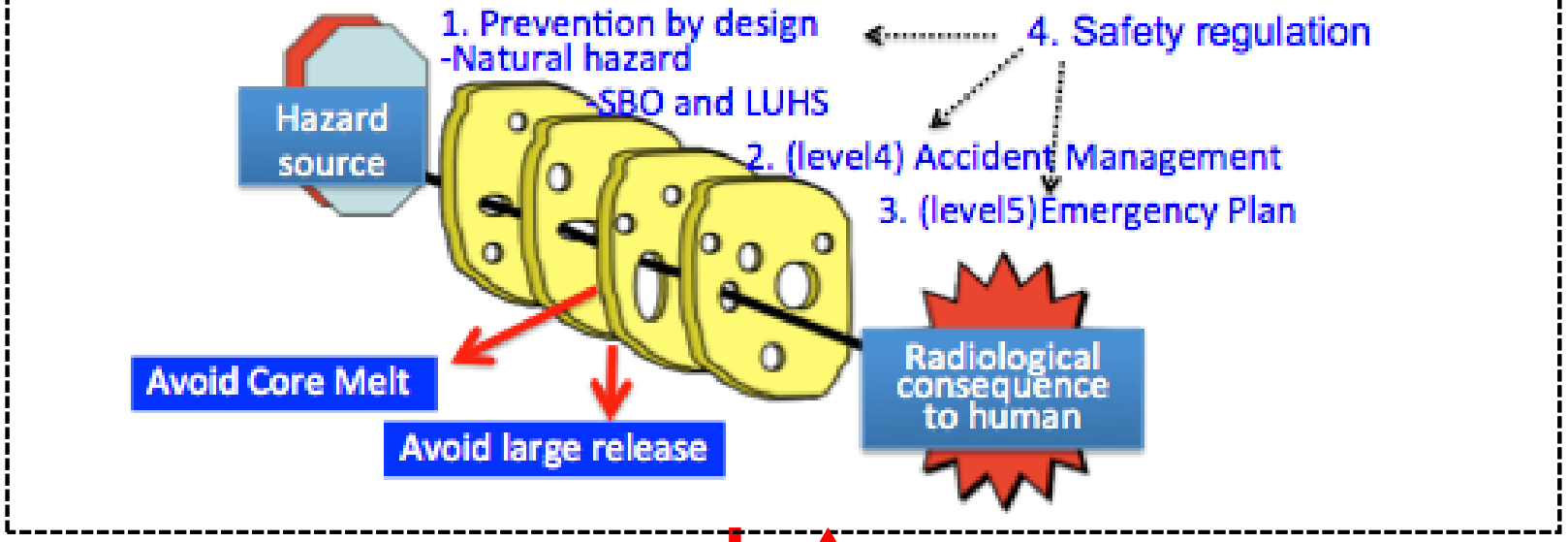
- ✓ Atomic Energy Basic Law
- ✓ Nuclear Reactors regulation
- ✓ Nuclear Emergency
- ✓ Electricity Business Act
- ✓ 40 year life, severe accident measures

Current status

✓ ***Key Lessons Learned***

Future of NE policy in JAPAN

Causal chain of event using Swiss Cheese model

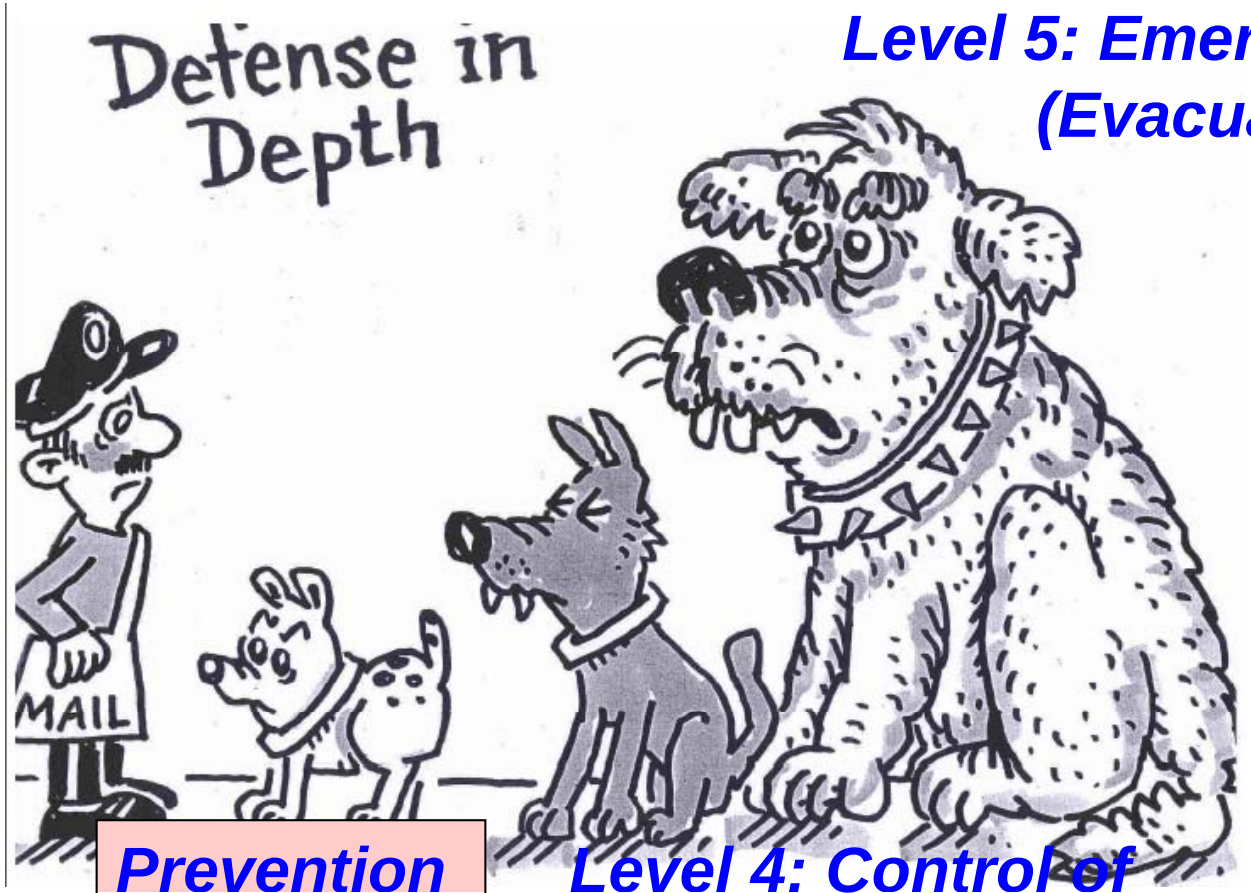


created culture and environment

Company, Management, Government
(including Regulator), Society

underlying factors

Prevention of nuclear accident and Mitigation of radiological consequence from it



Level 5: Emergency Plan (Evacuation)

Level 4: Control of beyond Design Basis conditions

Prevention by design

Level 1）Prevention of failure and abnormal operation

Level 2) Control of abnormal situation

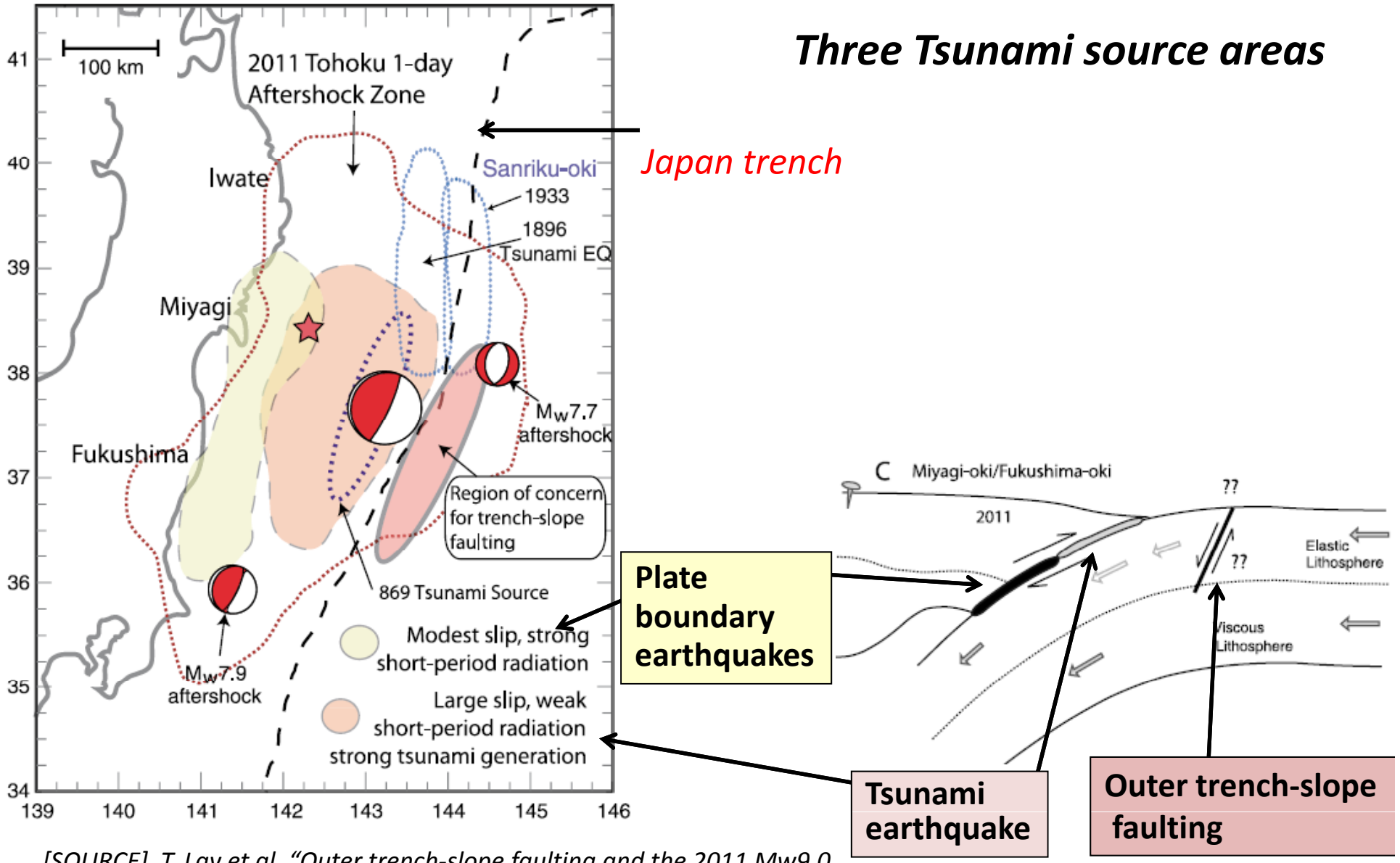
Level 3) Control of accidents within design basis

Key Lessons Learned
A) Design

1. **Protection against natural hazard**

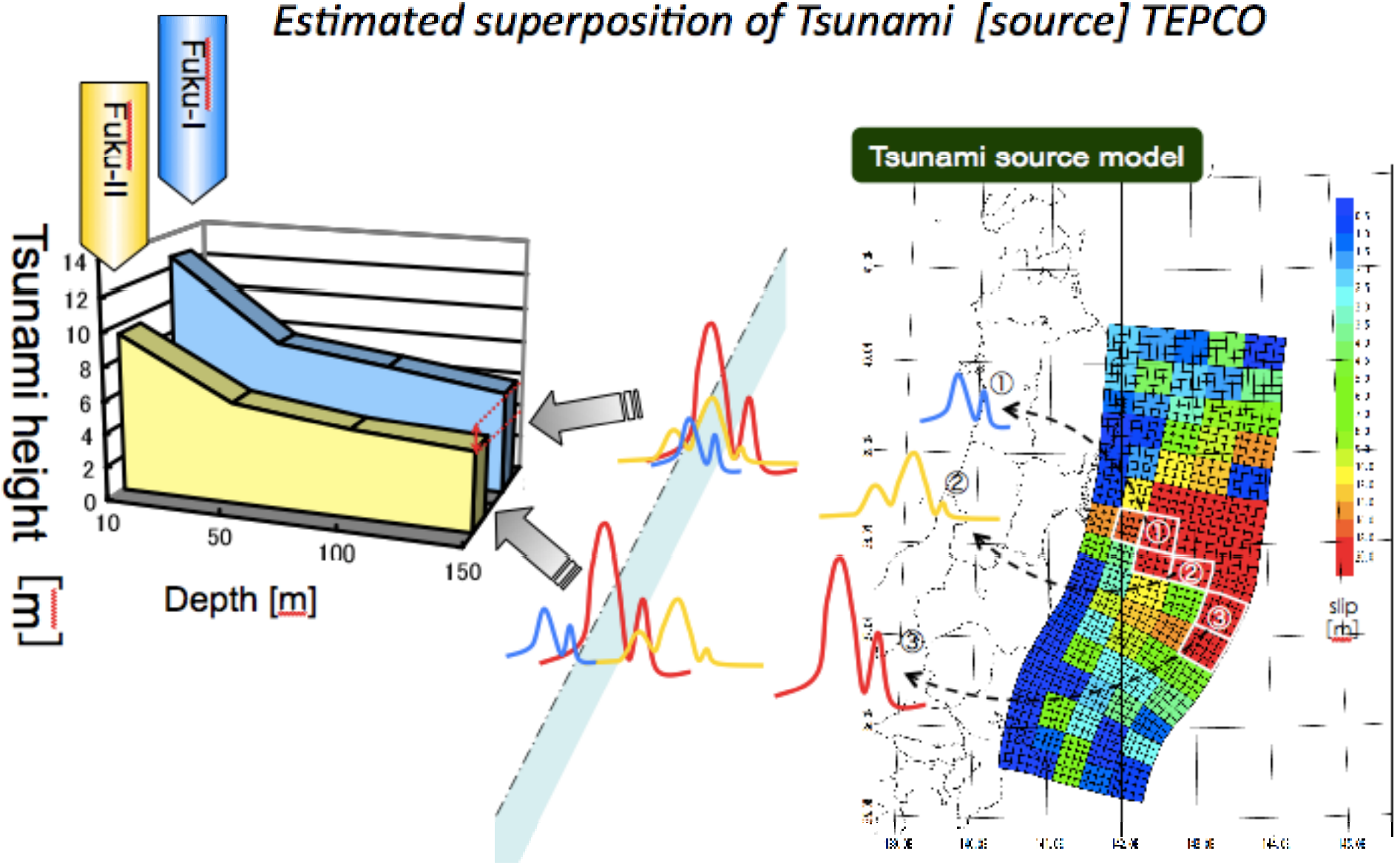
2. **Plant capability to withstand SBO (Station Blackout w/o any AC/DC) and isolation from UHS (Ultimate Heat Sink)**

Three Tsunami source areas



[SOURCE] T. Lay et al, "Outer trench-slope faulting and the 2011 Mw9.0 off the Pacific coast of Tohoku Earthquake", Earth Planets Space, 63, 713-718, 2011

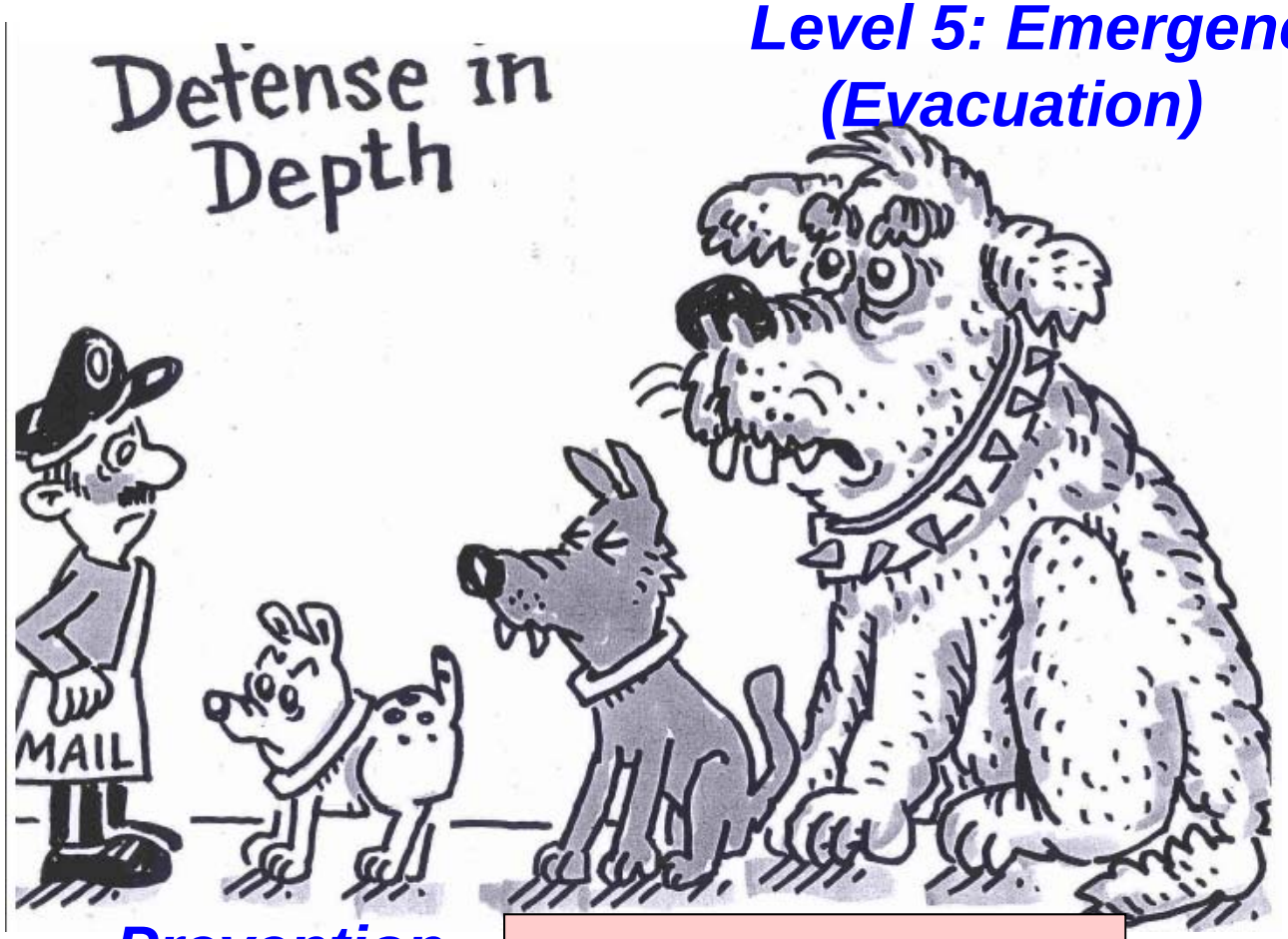
Estimated superposition of Tsunami [source] TEPCO



- Off-Fukushima coast
  - ✓"Tsunami earthquake can occur anywhere along Japan trench"
    or
  - ✓"weak coupling of plates and continuous slip in this region"
    explains historically limited Tsunami record of significant inundation height
- TEPCO'S Tsunami study (2006, 2008)
  - 2008 study: hypothetically assuming M8.3 "off-Sanriku" (North of J trench) earthquake source at off-Fukushima coast result indicated inundation height of 15.7m
  - TEPCO had asked experts review

- Modifications based on flooding analysis by thinking "what happens if the presumed inundation height is exceeded ?" could have changed the whole story

Prevention of nuclear accident and Mitigation of radiological consequence from it



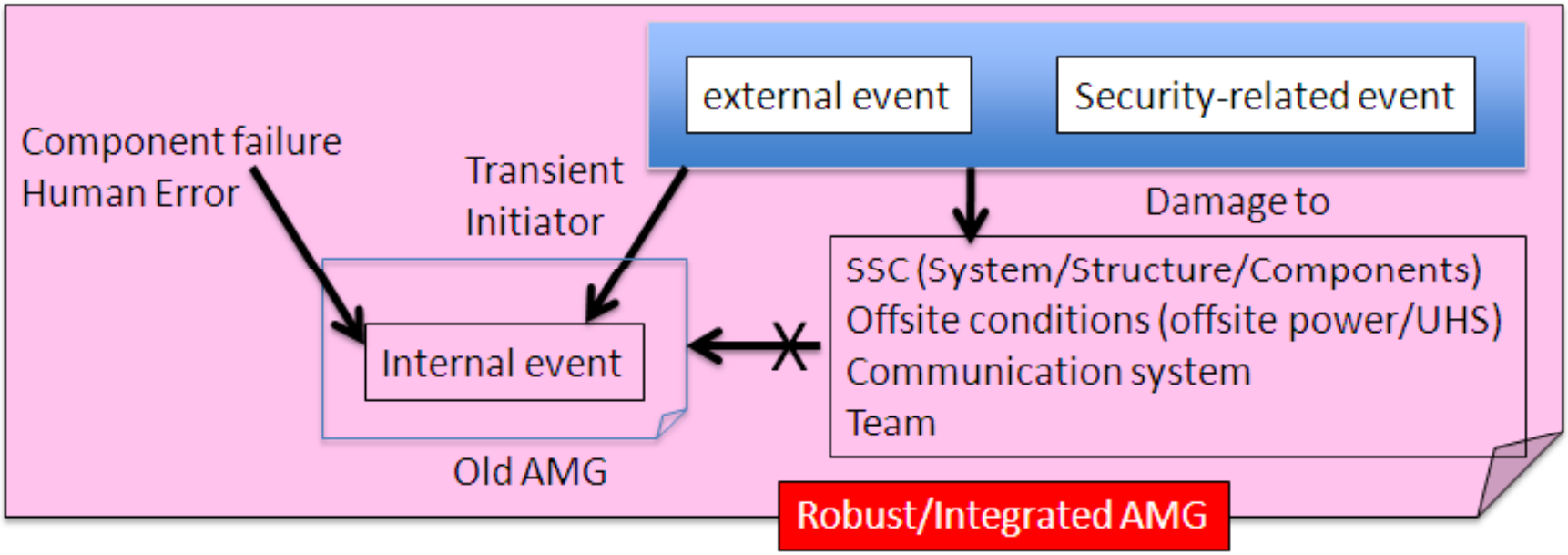
Level 5: Emergency Plan (Evacuation)

Prevention by design

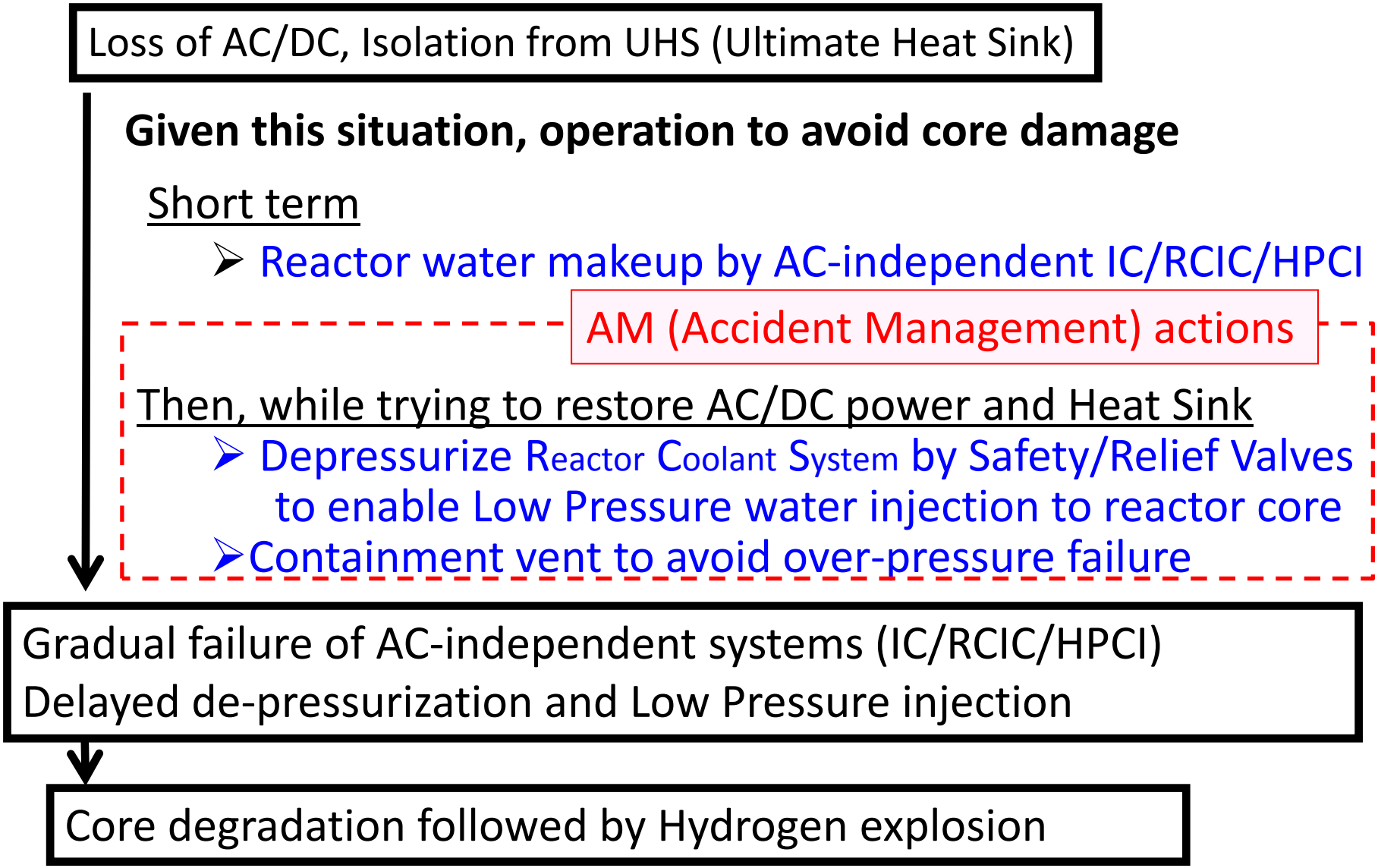
Level 4: Control of beyond Design Basis conditions

Key Lessons Learned
B) Level 4 DinD (Control of beyond DBA condition)

1. AMG not robust enough to be effective/executable under plant damage conditions by high Tsunami



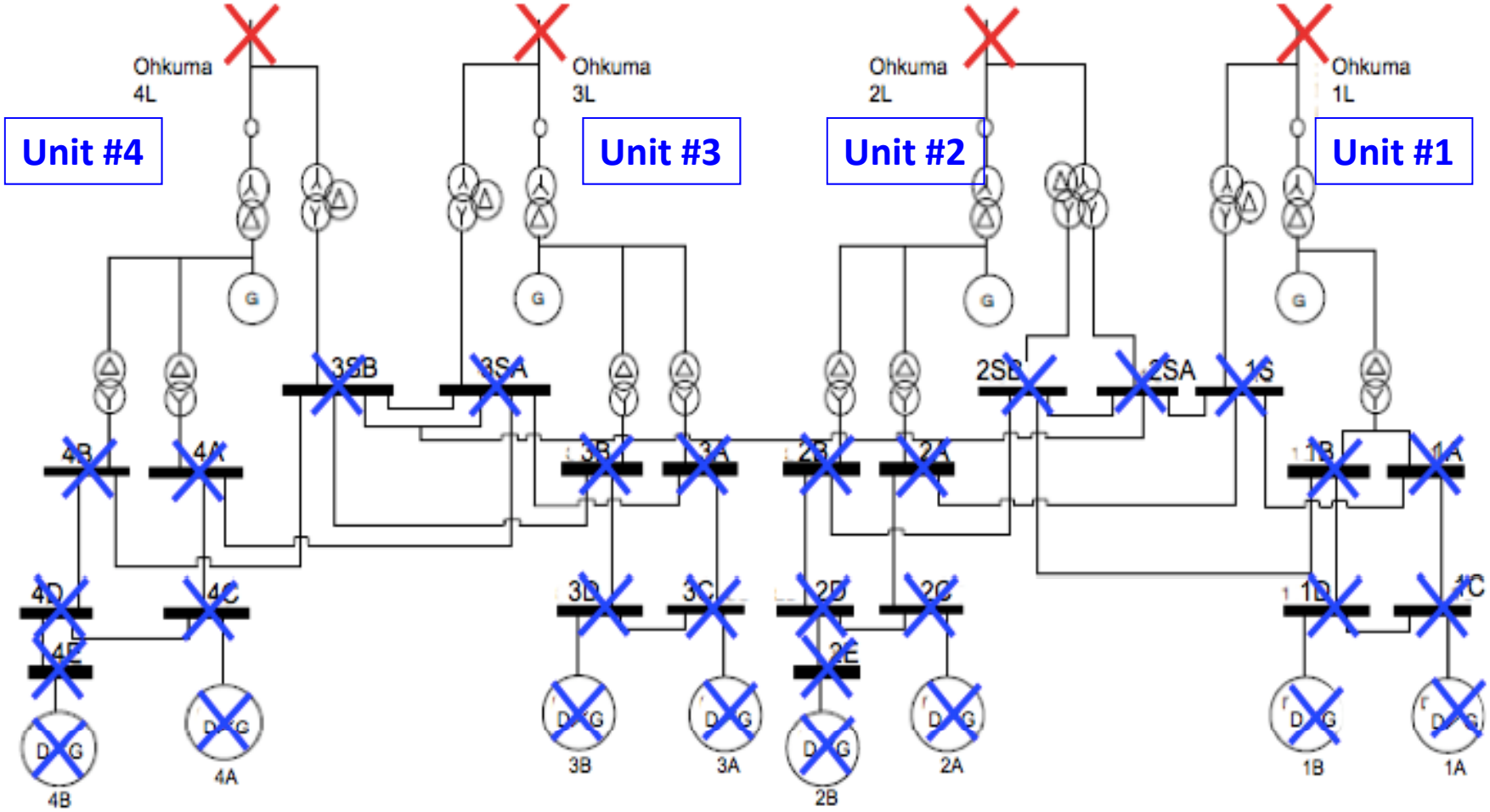
2. Prevention of large release in severe accident condition
   - ✓ Over-temperature failure
   - ✓ Filter-vent to gain higher DF beyond scrubbing venting


Loss of AC/DC, Isolation from UHS (Ultimate Heat Sink)
Given this situation, operation to avoid core damage
Short term
Reactor water makeup by AC-independent IC/RCIC/HPCI
AM (Accident Management) actions
Then, while trying to restore AC/DC power and Heat Sink
Depressurize Reactor Coolant System by Safety/Relief Valves to enable Low Pressure water injection to reactor core
Containment vent to avoid over-pressure failure
Gradual failure of AC-independent systems (IC/RCIC/HPCI)
Delayed de-pressurization and Low Pressure injection
Core degradation followed by Hydrogen explosion

Power supply for Fukushima-Daiichi Unit 1-4 after Earthquake & Tsunami

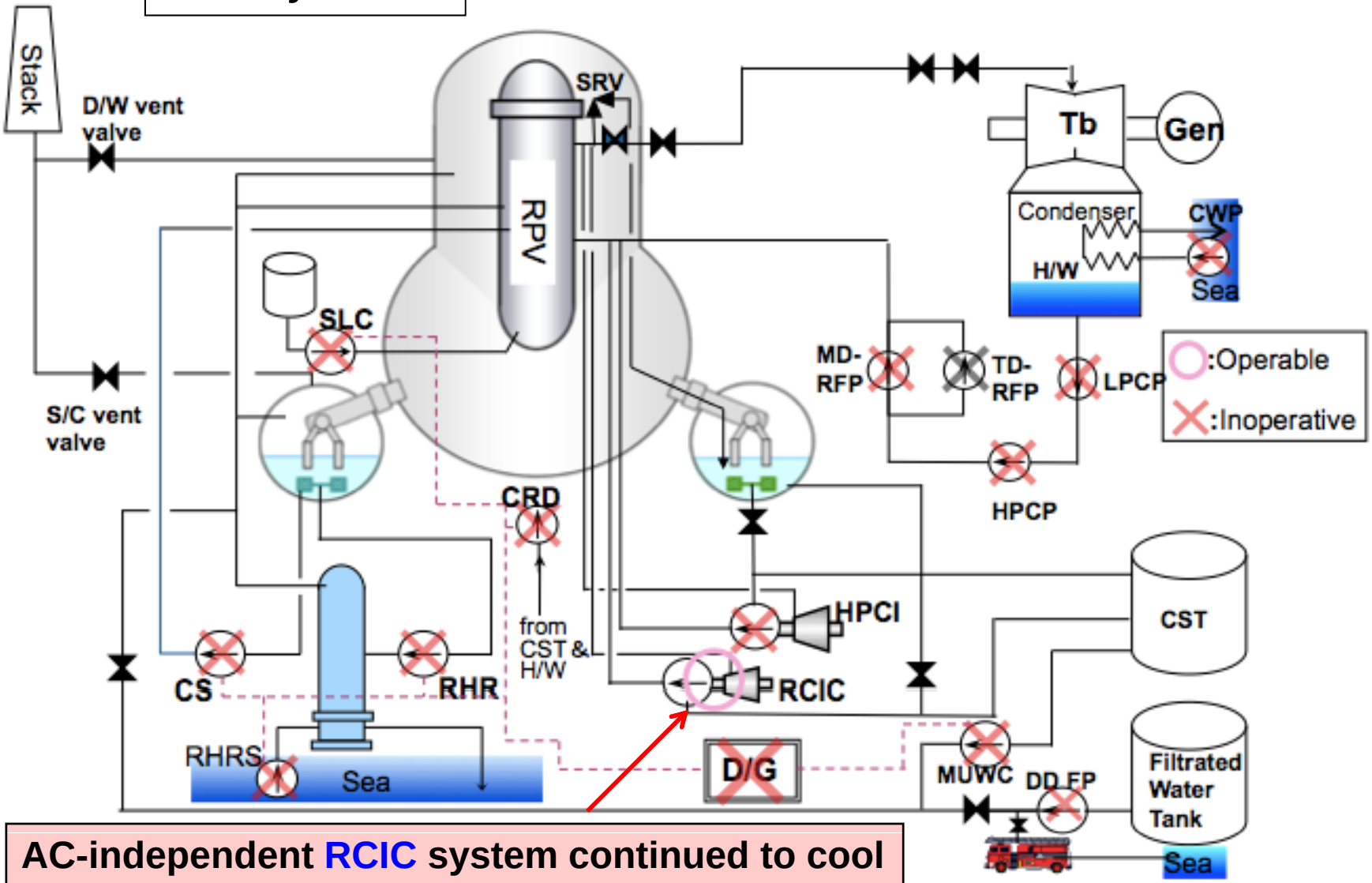
X : inoperable after Earthquake

X : inoperable after Tsunami



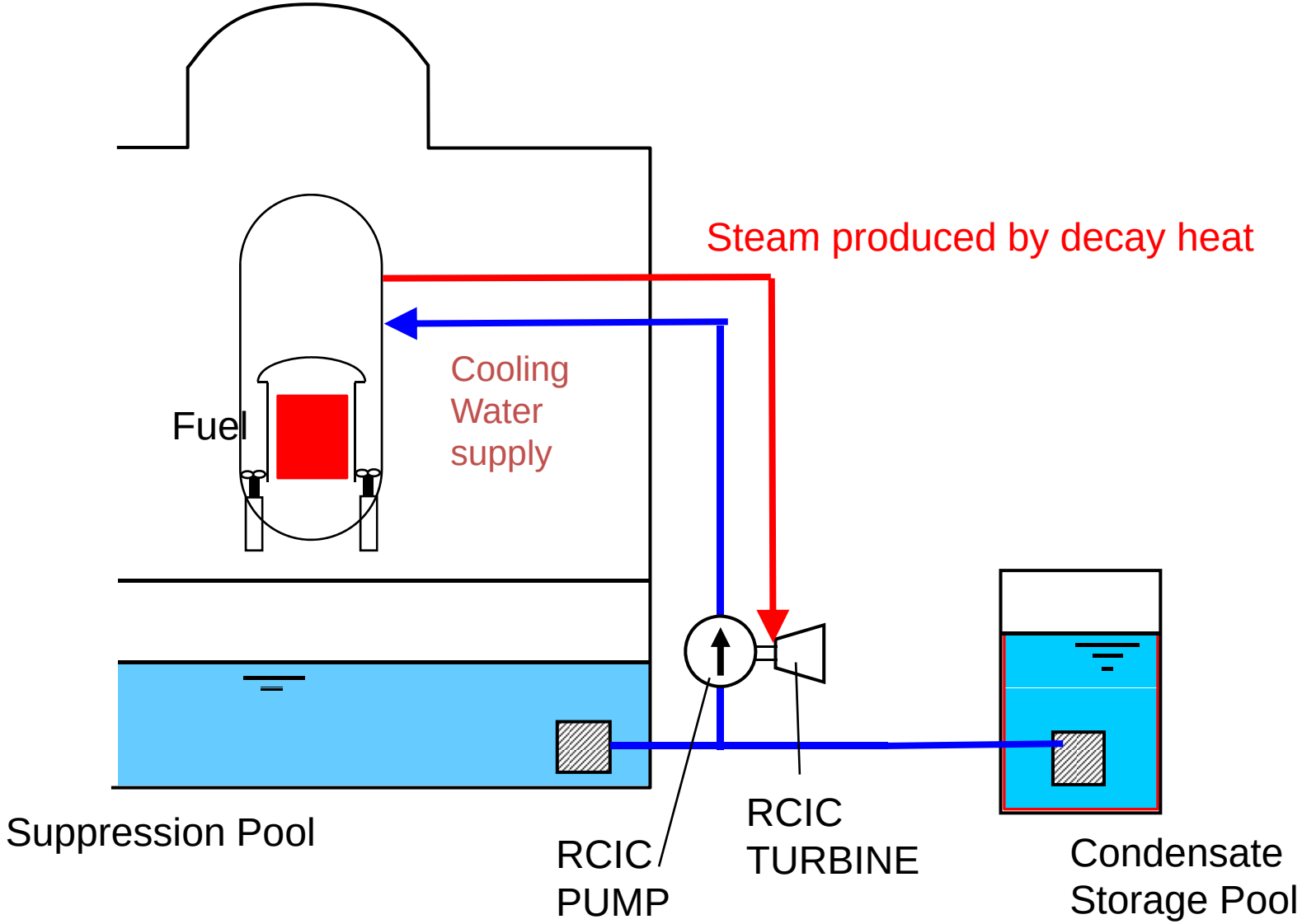
Reactor water makeup systems after Earthquake & Tsunami

Case of Unit 2



AC-independent RCIC system continued to cool the fuel core for about 3 days.

Reactor Core Isolation Cooling System (RCIC)
Utilizes decay heat (independent from AC) to cool fuel



Limited available resources under harsh environment

- Limited available resources and scattered debris/tanks
- Field works risked their lives under devastation/radiation and fear of hydrogen explosions and aftershock (TEPCO report)

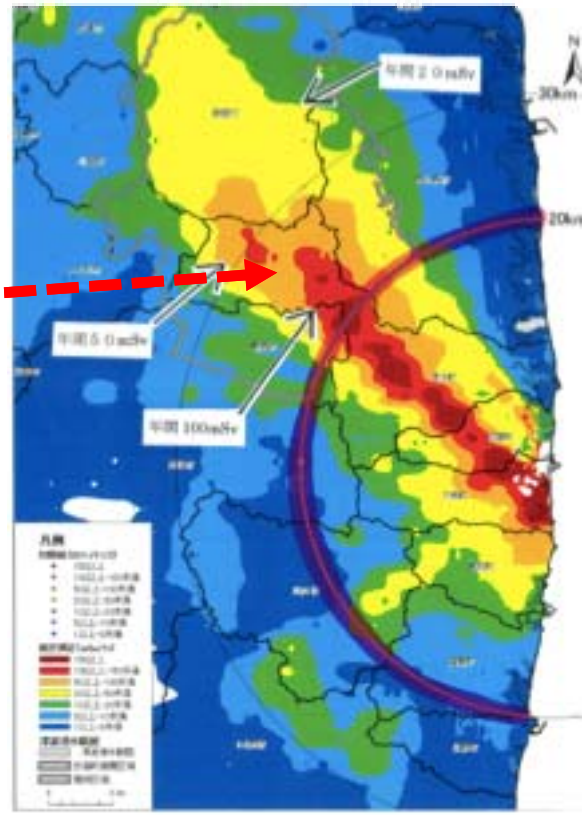
Estimated release fraction to the environment

	Noble gas (Xe-133)	**I-131**	**Cs-137**
Half life	Very short	8 days	30 years
Unit 1	100%	0.9%	0.2%
Unit 2	65%	6%	2%
Unit 3	82%	0.3%	0.1%

[SOURCE] http://www.meti.go.jp/press/2011/10/20111020001/20111020001.pdf

Possibly linked

Land contamination In N-W region

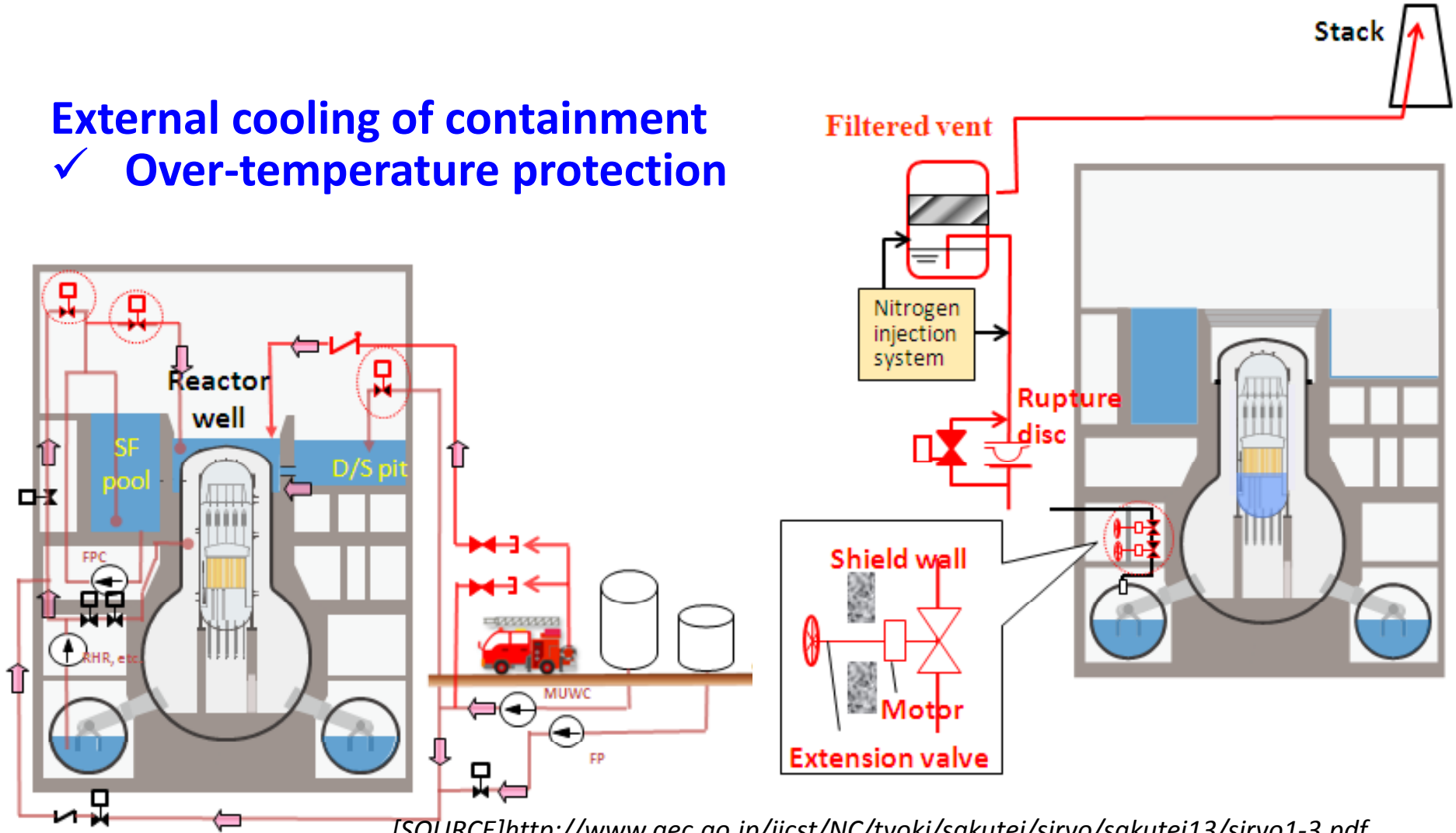


Filtered venting

- ✓ Over-pressure protection
- ✓ Land contamination

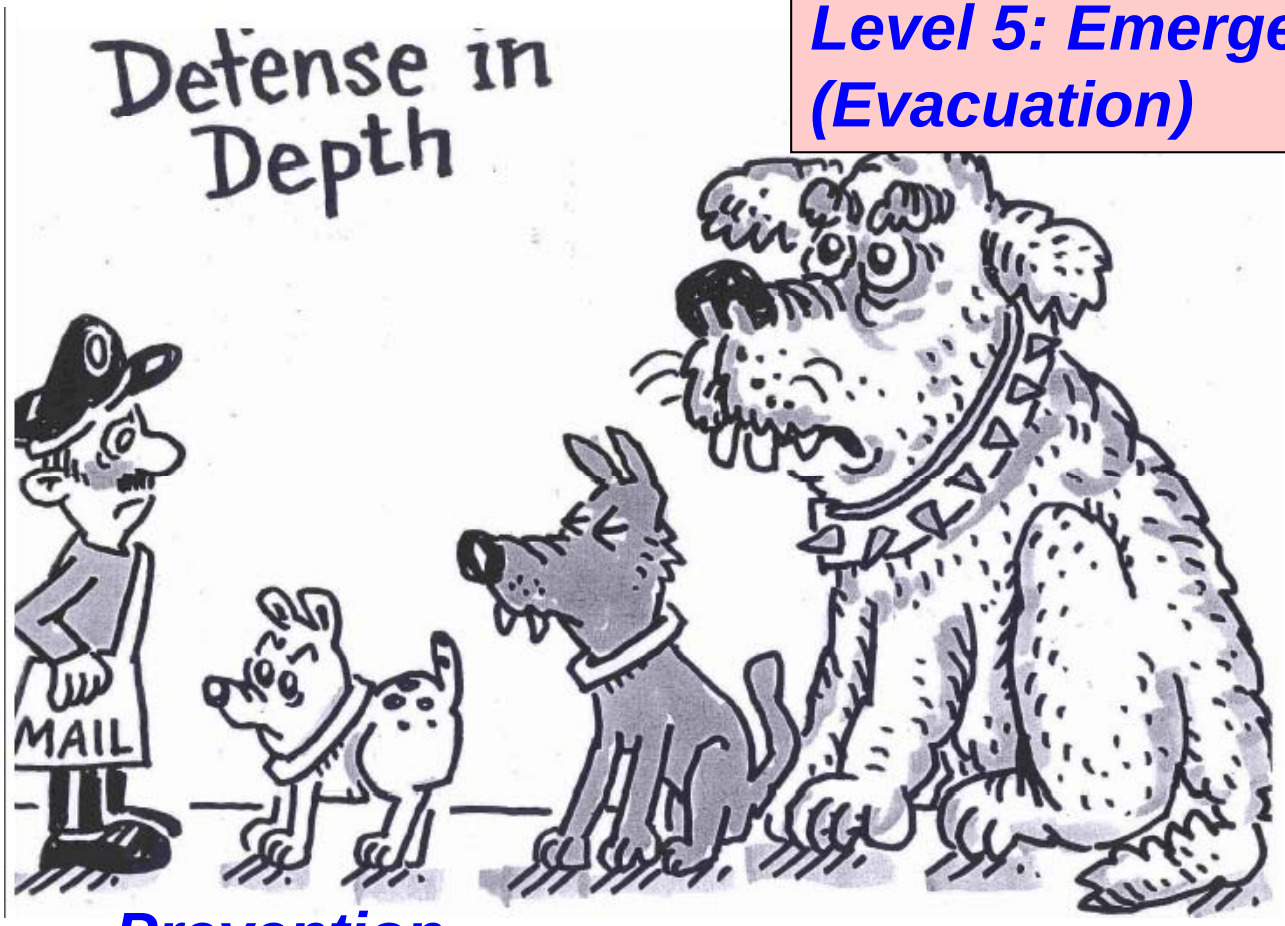
External cooling of containment

- ✓ Over-temperature protection



[SOURCE]http://www.aec.go.jp/jicst/NC/tyoki/sakutei/siryo/sakutei13/siryo1-3.pdf

Prevention of nuclear accident and Mitigation of radiological consequence from it



Level 5: Emergency Plan (Evacuation)

Prevention by design

Level 4: Control of beyond Design Basis conditions

Key LL
3) Level 5: Emergency Plan (and Crisis Management)

Identified problems

- Offsite center's function was lost
- Confusion in implementation of EP (Notice to the public on evacuation, preparation of vehicles, notice on Iodine tablet etc.)
- Delineation of responsibility including PM
- Communication

- *[SOURCE] Accident Investigation Committees' reports (ICANPS interim report, NAIIC final report, NPO report), report from the association of municipalities having NPPs (http://www.aec.go.jp/jicst/NC/iinkai/teirei/siryo2012/siryo19/siryo1-1.pdf)*

Needs to revisit

- ✓Delineation of responsibility, command line, coordination
- ✓Design and function of "offsite center"
- ✓Offsite emergency plan (scope of EPZ, workability)

Further LL

- Regulation (independence to enable safety-first decision making, technical competence)
- Multiple unit installation
- Spent Fuel Pool (location, early transfer to storage casks)
- Accident instrumentation
- System interface and inter-dependence
- Risk management, oversight of safety

Lessons Learned
- Post 3.11 situation -

No production without trust

- ✓ None of the 54 nuclear power plants in Japan are in operation since May 2012
- ✓ 30B$/year for replacement power
- ✓ Government policy to reduce dependency on nuclear

LPHC accident

- ✓ Liability
- ✓ “Consequence” matters

Key issues raised by Diet (Congressional) Investigation Committee [NAIIC]

Report published, 5July2012

[source] *http://naiic.go.jp/wp-content/uploads/2012/07/NAIIC_report_lo_res2.pdf*

- "Manmade" disaster
- This was a disaster "Made in Japan."
  Its fundamental causes are to be found in the ingrained conventions of Japanese culture (our reflexive obedience; our reluctance to question authority; our devotion to 'sticking with the program'; our groupism; and our insularity)
- Highlighted
  1) Organizational issues: Regulatory capture (lack of oversight of safety by regulatory body due to industry lobbying), organizational issue of TEPCO (lack of concern over public health etc0, organizational issue of NISA, and
  2) Deficiency in crisis management system

Key issues raised by major investigation committee reports
Diet (Congressional) Investigation Committee [NAIIC]

- Recommendations

1) Monitoring of the nuclear regulatory body by the National Diet
2) Reform the crisis management system
3) Government responsibility for public health and welfare
4) Monitoring the operators including corporate reform of TEPCO (governance and risk management and information disclosure—with safety as the sole priority)
5) Criteria for the new regulatory body (Independent (from organizations promoted by the government, operator, politics), Transparent, Professional, Consolidated (especially emergency communications, decision-making and control), Proactive)
6) Reforming laws related to nuclear energy
7) Develop a system of independent investigation commissions

Key issues raised by Government Investigation Committee [ICANPS]

Report published, 23July2012 *[source]* http://icanps.go.jp/eng/

- TEPCO & Government trapped by "safety myth" by thinking "severe accident will not happen here"
- Preparedness to combined disaster by natural hazard and consequential nuclear accident
- Paradigm shift (expressed as "changing attitude") in risk management to avoid nuclear disaster
  - ✓ [Comprehensive] mitigation, regardless of its probability of occurrence
  - ✓ Not setting aside residual risk

Key issues raised by Government Investigation Committee [ICANPS]

Recommended

- ✓ Better preparedness
- ✓ Different approach for risk reduction, regardless of its probability of occurrence
- ✓ Institutional framework to ensure in-depth examination of residual risk
- ✓ Need to identify all risk potential from “disaster victims’” point of view
- ✓ Use of new findings/knowledge in disaster prevention
- ✓ Central Disaster Management Council to consider nuclear disaster
- ✓ Comprehensive risk analysis and disaster prevention measures
- ✓ Improvements needed for Severe Accident Management and Crisis Management
- ✓ Role of the PM, prefecture, use of SPEEDI
- ✓ Harmonization with international good practices
- ✓ Functional separation for safety-first decision by regulation
- ✓ Building safety culture
- ✓ Continued investigation into accident causes and damage

Paradigm shift in nuclear safety?

- Before TMI: Accident primarily attributed to component failures→ component reliability
- TMI: Highlighted human factors (man-machine interface) and PSA
- Chernobyl: Highlighted safety culture and Accident Management (4th layer of defense-in-depth)
- Fukushima: ?

Paradigm shift in nuclear safety?

SFEN Annual Convention “Fukushima 1-year later” (March2012)
“New paradigm: resilience and responsible use”

1. How to be prepared to unexpected by enhanced resilience?
   - ✓ Resilience: Capability to Respond, Monitor, Anticipate, Learn in varying conditions to lead to success
   - ✓ A) Organizational and cultural aspect, B) Design (avoiding system interactions and tight coupling), and C) Emergency preparedness (procedure, provisions and team)
2. How to strengthen defense in depth?
   - ✓ Condition to practically eliminate certain phenomenon from design and Accident Management
   - ✓ Enhance independence of each layer from the rest
3. And very basics “operator is primarily responsible for safety”

[SOURCE] E. Hollnagel, IAEA Technical Meeting on Managing the unexpected, 2012 June 24-29

Why only look at what goes wrong?

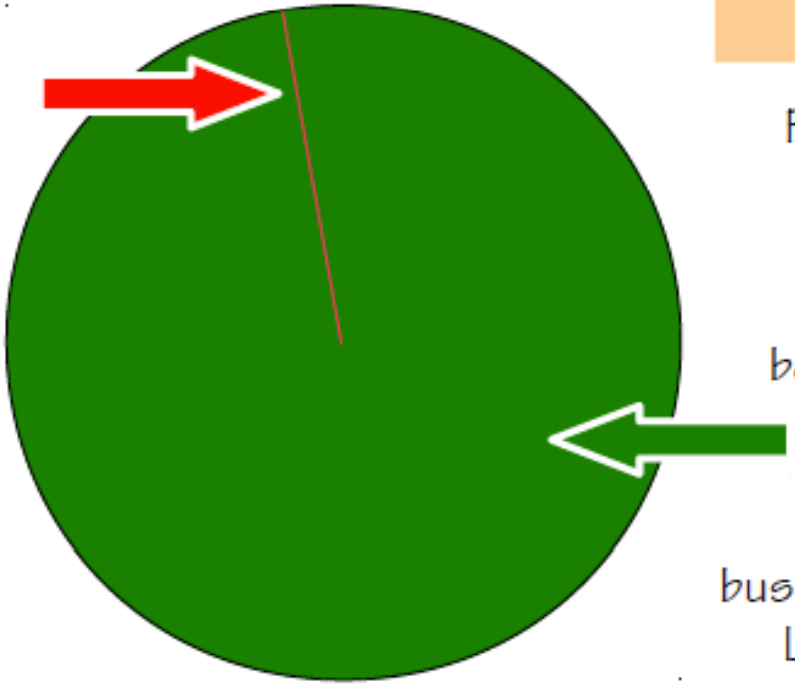
FRAM

Safety-I = Reduced number of adverse events.

Focus is on what goes wrong. Look for failures and malfunctions. Try to eliminate causes and improve barriers.

Safety and core business compete for resources. Learning only uses a fraction of the data available

10^{-4} := 1 failure in 10.000 events



1 - 10^{-4} := 9.999 non-failures in 10.000 events

Safety-II = Ability to succeed under varying conditions.

Focus is on what goes right. Use that to understand everyday performance, to do better and to be safer.

Safety and core business help each other. Learning uses most of the data available

What learning's are universal?
-personal view -

1. *Resilience*
   - ✓ Organization: Capability to Respond, Monitor, Anticipate, Learn in varying conditions to lead to success
   - ✓ Design: Reduced system interactions, Enhanced reliability by "diversity" & "passive" in safety system
2. *Responsibility*
   - ✓ Operator: primarily responsible (*responsible use*)
   - ✓ Government: protect public health and environment
   - ✓ Supported by competence/knowledge/understanding
3. *LPHC risks*
   - ✓ Consequence matters
   - ✓ Comprehensive mitigation, not relying on probability
4. *Interface with society*
   - ✓ Mindful of societal impact and value
   - ✓ No production without trust

Current status

Key Lessons Learned

✓ ***Future of NE policy in JAPAN***

Atomic Energy Commission

- To plan, deliberate and decide on basic NE policy
- Immediate deliverable:
  Long-term Plan for R&D and Utilization of NE

1st Long-term Plan for R&D and Utilization of NE (1956)

- Reliance on domestic uranium resources, while import deficit from outside
- Atomic Fuel Cooperation as a sole reprocessor using indigenous technology
- Research into indigenous enrichment technology
- Domestic fast breeder as a target in light of effective use of resources
- Several NPPs from overseas then domestic production

Emerged policy issues on the use of NE in Japan

- **Is nuclear energy a dependable source of energy?**

Issues includes: risk management, vulnerability of multiple unit installation, economics, liability

- **Is current fuel cycle policy appropriate?**

Issues includes: reprocessing plant, Spent Fuel management, development of fast reactor

- **Is current utility business regulation appropriate?**

- Cabinet's Energy and Environment Committee
- METI's Integrated Energy Committee
- AEC's committee on the "Framework of NE Policy"

AEC activities after 3.11

- **Statements**
- **Medium- and long-term onsite activities**
- **Revision of "framework document" for NE policy**
  - ✓ Suspended after 3.11
  - ✓ Resumed and suspended again (June2012)
- **Evaluation and report to Energy & environment Committee (Cabinet)**
  - ✓ Accident cost
  - ✓ Fuel cycle options
    - Three options (Complete recycle, Direct disposal, Hybrid)
    - Evaluation from various view points (economics, SF and waste, international aspect….)
    - Report emphasized, besides evaluation, four points (SF storage, comprehensive assessment of the nuclear fuel cycle business operation & of FBR programme, international aspect)

Options raised for public consultation

- Three options for power generation portfolio in 2030
- Based on discussions by;
  - ✓ Energy & Environmnet Committee (considering green growth)
  - ✓ Integrated Energy Review Committee
  - ✓ AEC's discussion on "Framework for NE policy"
  - ✓ Central Environment Council on countermeasures against Global Warming
- Mindful of;
  - ✓ Risk management of nuclear power
  - ✓ Reduce dependence on nuclear power
  - ✓ Shift to low carbon economy fully utilizing energy saving, renewable
  - ✓ Economics, energy security, green growth
- To be decided by the end of August

Options raised for public consultation

[SOURCE] Cabinet's Energy & Environment Committee (29June2012)
http://www.npu.go.jp/policy/policy09/pdf/20120629/20120629_1.pdf

	Share of nuclear electricity			
	Year 2010	Year 2030		
	26%	0%	15%	20-25%
Renewable (includes hydro)	10%	35%	30%	25-30%
Fossil share (coal:gas)	63% (1:1.2)	65% (1:1.8)	55%(1:1.5)	50%(1:1.5)
KWhr saving	Base	- 10%	- 10%	- 10%
GHG emission (compared to 1990)	-0.4%*	- 23%	- 23%	-25%
Power Generation Cost [JPY**/KWhr]	8.6	15.1	14.1	14.1
GDP change in Trillion JPY(compared to business as usual (609-636 Trillion JPY**)	Base	- 8~-45	-2~-30	-2~-28

**[SOURCE] Ministry of environment, http://www.env.go.jp/press/file_view.php?serial=18801&hou_id=14564*

*** 1JPY=0.0126 US$ (1.26 US cent), 1Trillion (10^{12})JPY=12 BillionUS$*

Thank you for your attention