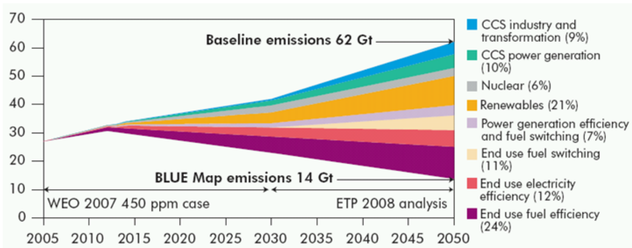
Nuclear Energy in the power generation portfolio in Japan



IEA "Energy Technology Perspective 2008" report: To meet Blue scenario

31May2011, MENA-II, Akira OMOTO, AEC, JAPAN

[Note]

The views expressed here does not represent the official view of the AEC.

Early days of Nuclear Energy in Japan

1953: "Atoms for Peace" address at the UN-GA, December 8
1954: Nuclear research budget JPY235 million
1955: Enacted Atomic Energy Basic Law
with 3 principles
- Strictly for peaceful purpose
- "For the *welfare of human kind* and to *raise national living standards*"
- Three principles – democratic decision-making, independent management, and transparency

1956: Joined the IAEA and established national organs for nuclear energy
- Atomic Energy Commission
- Science and technology agency (Government)
- Japan Atomic Energy Research Institute (JAERI) and The Atomic Fuel Corporation

1957: First criticality by JAERI's first research reactor (JRR-1)
1963: First nuclear electricity (JPDR)
1966 : First commercial nuclear power

JRR-1

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Atomic Energy Commission

- To plan, deliberate and decide on basic NE policy
- Immediate deliverable

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

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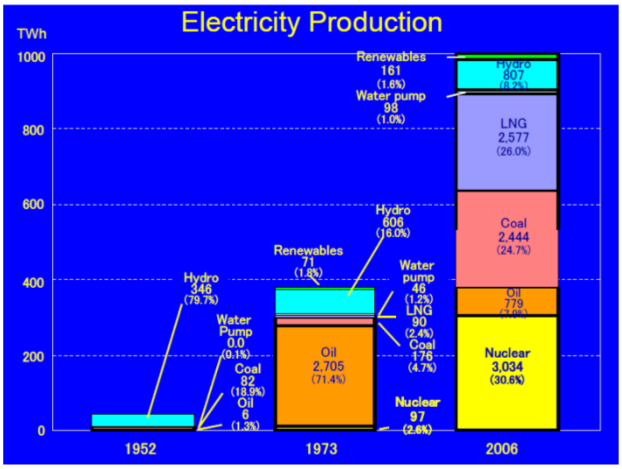
Subsequent deployment of commercial nuclear power plants

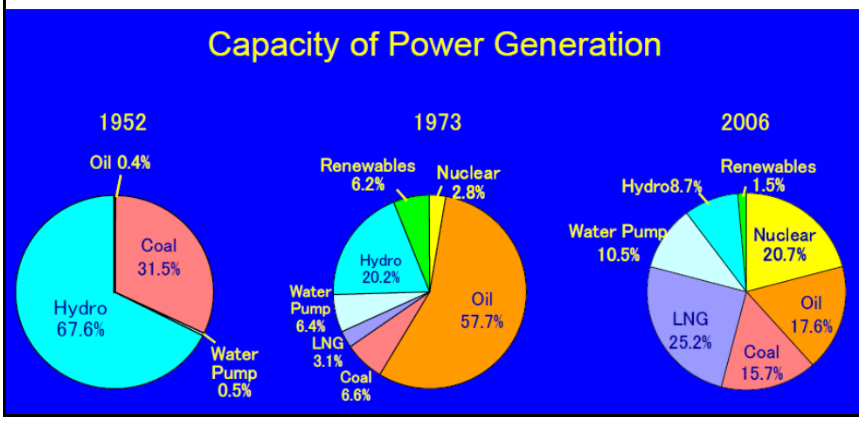
- Meeting growing power demand coming from economic growth
- 5 decades of continuous deployment (54 nuclear power plants)
- Deployment plan accelerated by Arab oil embargo (1973)



Kwhr/capita	500	3500	8000

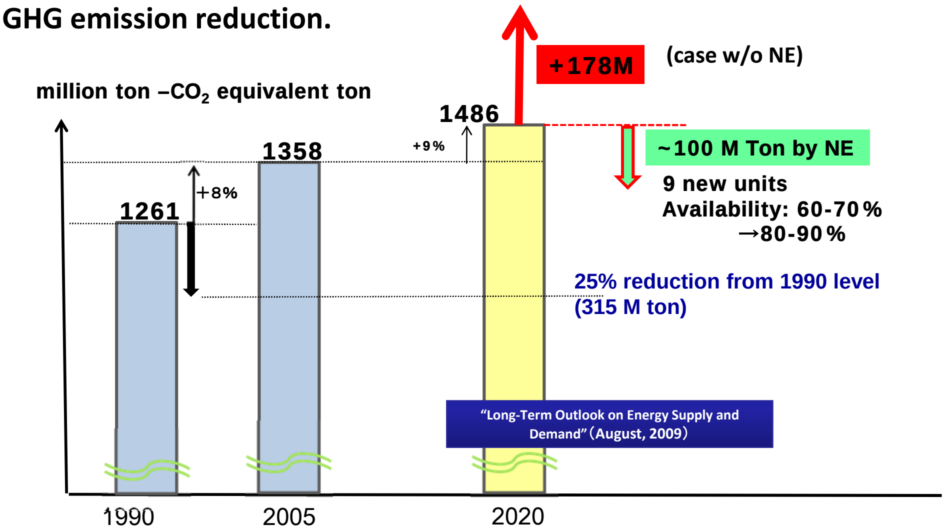
Subsequent deployment of commercial nuclear power plants

- As a resources-poor nation, strong drive in the 1970's and 80's
- ➢ To diversify energy supply sources
- ➢ To enhance supply security
  - Short term: shield of electricity price from fossil cost volatility
  - Long-term : sustainable energy supply
- Eroded concern in the 1990's when fossil price was stable



Drive to low carbon society

Nuclear power was considered by the AEC as an important option for GHG emission reduction.



Emission rate: Nuclear=22g/kWh, Coal-fired=930g/kWh, LNG-fired=434g/kWh

Assume NE(278 TWhr, 29.2%) be replaced by Coal(24.7%) /LNG(29.4%) in today's share ratio

278x10(9)kWh×（660.5g/kWh－22g/kWh）~178 Milliomton-CO_2

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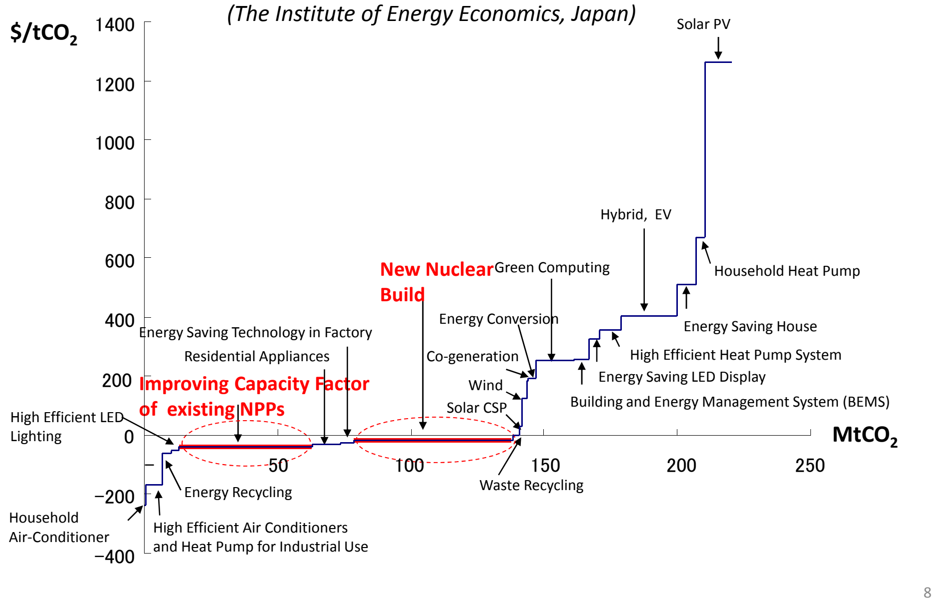
Marginal Abatement Cost curve in Japan

SOURCE: IEEJ report to AEC (23April2010)
(The Institute of Energy Economics, Japan)



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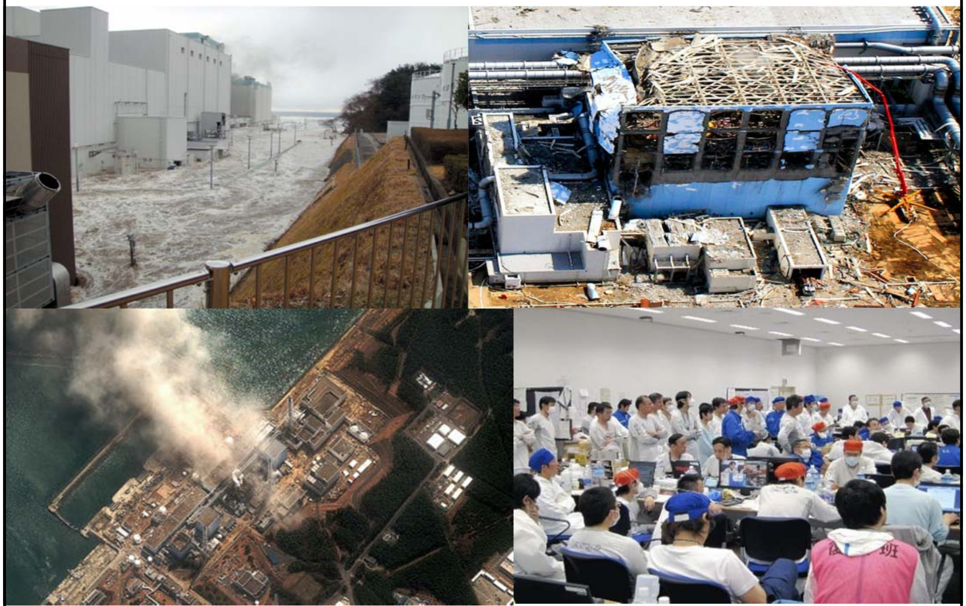
Fukushima Accident : An overview



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[Note]

1. *The information contained here is preliminary and needs to be confirmed by the Accident Investigation Commission to be set up soon by the Government.*
2. *The views expressed here does not represent the official view of AEC nor U of Tokyo nor TEPCO.*

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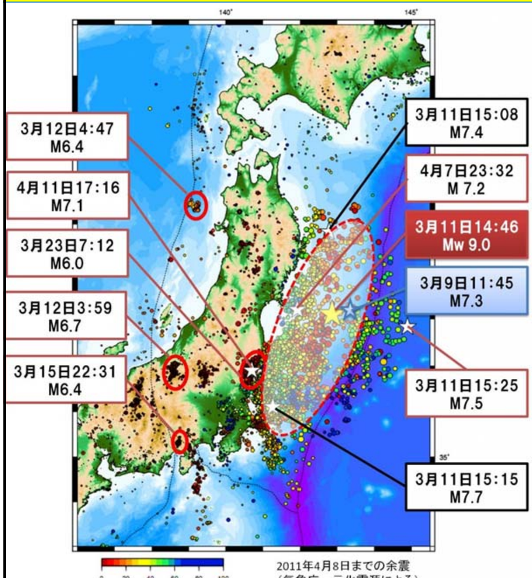
3.11 Earthquake and aftershocks



Statement by the Headquarter for Earthquake Research, *11March2011*

The Earthquake Research Committee evaluated earthquake motion and tsunami for the individual region off-shore of Miyagi prefecture, to the east off-shore south of Sanriku along the trench, and to the south off-shore of Ibaraki prefecture, but occurrence of the earthquake that is linked to all of these regions is "out of hypothesis".

[SOURCE] http://www.jishin.go.jp/main/index-e.html The 2011 off the Pacific Coast of Tohoku Earthquake

http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng/#mesonet
"Earthquake Research Institute, University of Tokyo, Prof. Takashi Furumura and Project Researcher Takuto Maeda"

3.11 Earthquake

Design basis earthquake and observed acceleration (Basement of Reactor/B)

Nr.	MWe	3.11 Observed (max. gal)			Design (Ss) (max. gal)		
		N-S	E-W	Vertical	N-S	E-W	Vertical
1Fuku1	460	460	447	258	487	489	412
1Fuku2	784	348	550	302	441	438	420
1Fuku3	784	322	507	231	449	441	429
1Fuku4	784	281	319	200	447	445	422
1Fuku5	784	311	548	256	452	452	427
1Fuku6	1100	298	444	244	445	448	415

Note 1: **Damage by the earthquake**: Not fully inspected but maybe not significant considering the KK earthquake (2007) where no damage to safety functions even though the observed acceleration exceeded design basis by factor 2-3
(Acceleration will not necessarily be damages indicators)

Note 2: **Scram set points** by acceleration (Basement of Reactor Building)
Horizontal=135-150 gal, Vertical=100 gal

Note 3: Design means new design basis (2009)

3.11 Tsunami

1F1-3 Plant response immediately after the earthquake

14.46 Earthquake followed by Reactor SCRAM, LOOP, EDGs start, IC/RCIC in operation

15.38-41 Tsunami followed by complete (AC/DC) blackout and (mostly) isolation from the Ultimate Heat Sink

http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng/#mesonet

"Earthquake Research Institute, University of Tokyo, Prof. Takashi Furumura and Project Researcher Takuto Maeda"

14 NPPs along the coastal line affected by Tsunami

Onagawa
- Unit1: 524 MW, 1984-
- Unit2: 825 MW, 1995-
- Unit3: 825 MW, 2002-

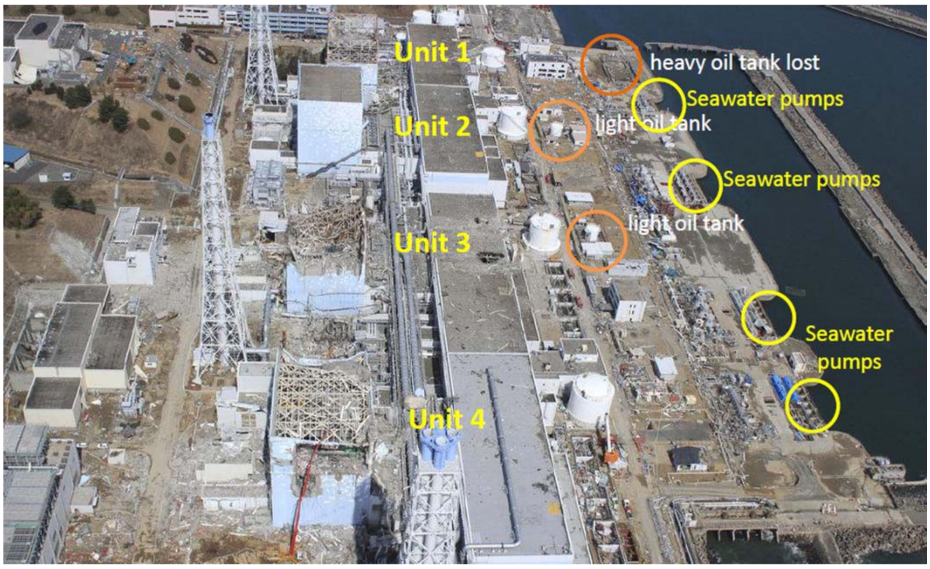
Fukushima Ⅰ
- Unit1: 460 MW, 1971-
- Unit2: 784 MW, 1974-
- Unit3: 784 MW, 1976-
- Unit4: 784 MW, 1978-
- Unit5: 784 MW, 1978-
- Unit6: 1,100 MW, 1979-

Fukushima Ⅱ
- Unit1: 1,100 MW, 1982-
- Unit2: 1,100 MW, 1984-
- Unit3: 1,100 MW, 1985-
- Unit4: 1,100 MW, 1987-

Tokai Ⅱ (1,100 MW, 1978-)

All except for O-2, 1F-4,5,6 were in operation when hit by the 3.11 earthquake

Fukushima Dai-ichi Unit 1-4



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3.11 Tsunami

Unit	Ground Level R/B, Tb/B [m]	Ground Level Intake str. [m]	Tsunami height [m] DB	Tsunami height [m] Mod (2002)	Tsunami height [m] 3.11	Location of Electric Equipment Room (M/C, P/C, Battery)	Type & location of Emergency Diesel Generator SC: Seawater-cooled AC: Air-cooler
1Fuku1,2,3,& 4	10.2	4	3.1	5.7	14-15		1F1.3: 2 SC-EDGs (design) 1F2,4: 1 SC-EDG (design) + 1 AC-EDG (SAM)
1Fuku5	13.2	4	3.1				2 SC- EDGs
1Fuku6							2 SC-EDGs (design) 1 AC-EDG (SAM)
2Fuku1,2,3 & 4	12	7	3.7	5.2			3 SC-EDGs
Onagawa1,2 & 3	14.8		9.1	-	13		3 SC-EDGs
Tokai 2	8.0	3	1.5	4.86	5.1-5.4		3 SC-EDGs

Location info not listed here.

1. ***One of the offsite power lines for 2F stayed alive during & after the Earthquake/Tsunami***
2. ***What mattered was the elevation of air intake/exhaust of EDG room & location of Electric Equipment rooms***

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Fuel damage or not ---- *What made the difference?*

(1) *Elevation vs. Tsunami height*

- *Site ground level → saved Onagawa/Tokai*
- *Elevation of air intake/exhaust of EDG*
- *Location of EDG/EE room/battery*

(2) Availability of power

- *Offsite power (together with SAM under isolation from UHS) → saved 2F site*
- *Air-cooled EDG coupled with the above 1) location/height (together with SAM under isolation from UHS) → saved 1F6*

  - Air-cooled EDG was added for 1F2,4,6 respectively in the 1990's as a part of SAM modifications.
- *1F3/5/6 battery located at a higher elevation, escaped flooding*

(3) Implementation of AMG by using then-available resources

→ saved 1F5, SFPs (makeup water)

NOTE: Availability of UHS commensurate to decay heat level supports quick recovery but does not seem to be a decisive factor.

- 1F5/6 : Use of temporary seawater pump for RHR (units were in refueling outage)

- 2F : continued Rx water makeup under isolation from UHS until March 14th

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Tsunami: NPP Design guidelines and probabilistic study

◆ ***Safety Design Guide (NSC) Nr. 2 [footnote]***

- *"….Anticipated natural hazard includes flood, Tsunami …."*

◆ ***Japan Society of Civil Engineers (JSCE) on Tsunami***

- *Renewed concern over Tsunami by 1983, 1993 Tsunami experiences*
- *2002 guidelines for NPPs from the Nuclear Civil Engineering Committee of JSCE*
  http://committees.jsce.or.jp/ceofnp/system/files/JSCE_Tsunami_060519.pdf

1) *Consideration of Tsunami sources along the plate boundary,* uncertainty analysis and verification by the use of historical record;

…. At the target site, the height of the design tsunami should exceed all the calculated historical tsunami heights.

2) *"….the design tsunami is compared with the historical records …. it is confirmed the height of the design tsunami that is obtained in this paper is twice that of historical tsunamis on an average"*

- *Modification in 2002 based on this guideline*

◆ ***Tsunami Probabilistic Hazard study***

- *Probabilistic Tsunami hazard analysis (TEPCo, ICONE-14, 2006)*
- *Methodology guide from JSCE Nuclear Civil Engineering Com. (2009)*

◆ ***IAEA DS417 (draft)***

- *Includes guide on Tsunami analysis*

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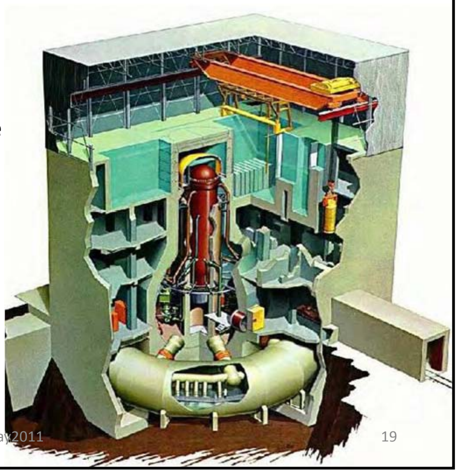
BWR/3,4 generation plant

<u>BWR/3</u> (460MWe, 1Fuku1)

- Mark I Containment (Drywell + Torus-type Suppression Pool)
- SFP on top floor of the R/B
- Isolation condenser for passive core cooling (@Hi Pressure)
- Core Spray system (@Lo Pressure) after depressurization by SRV

<u>BWR/4</u> (784MWe, 1Fuku 2,3,4 &5)

- Mark I Containment (Drywell + Torus-type Suppression Pool)
- SFP on top floor of the R/B
- RCIC (Reactor Core Isolation Cooling) & HPCI (High Pressure Core Injection) (@Hi Pressure)
- CS (Core Spray) & RHR/LPCI (@Lo Pressure) after depressurization by SRV



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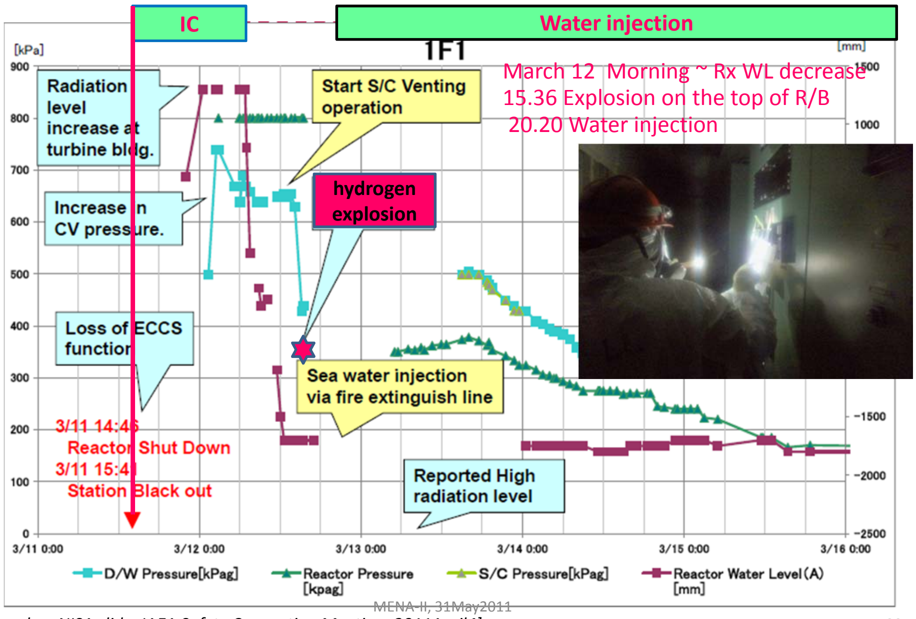
1Fuku1



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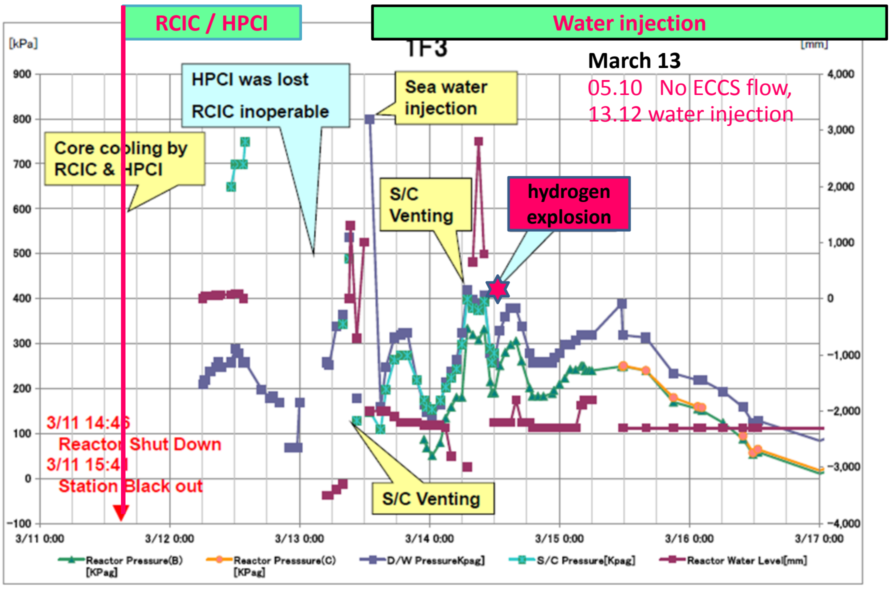
[Based on NISA slide, IAEA Safety Convention Meeting, 2011April4] 20

1Fuku3



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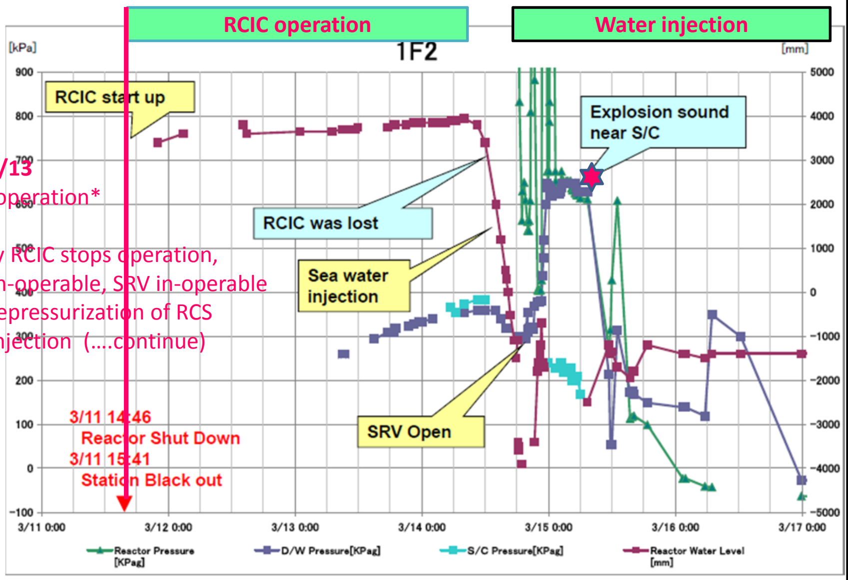
[Based on NISA slide, IAEA Safety Convention Meeting, 2011April4]

1Fuku2



March 12/13
RCIC in operation*
March 14
~midday RCIC stops operation,
HPCI in-operable, SRV in-operable
16.34 Depressurization of RCS
start injection (....continue)

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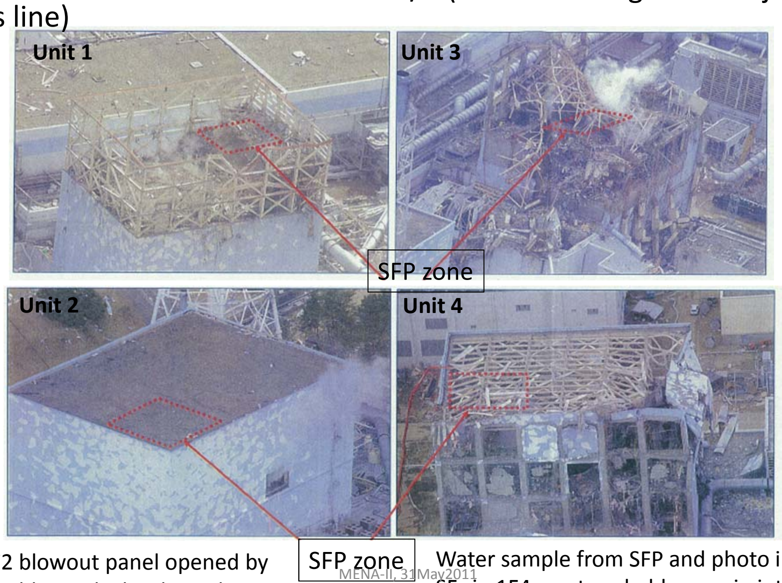
[Based on NISA slide, IAEA Safety Convention Meeting, 2011April4]

Why H_2 explosion right after venting?

Possible Path 1 : Excessive leakage by over-pressure at CV flange/airlocks
Possible Path 2: Vent line→ SGTS→R/B (vent line merge with adjacent unit's line)

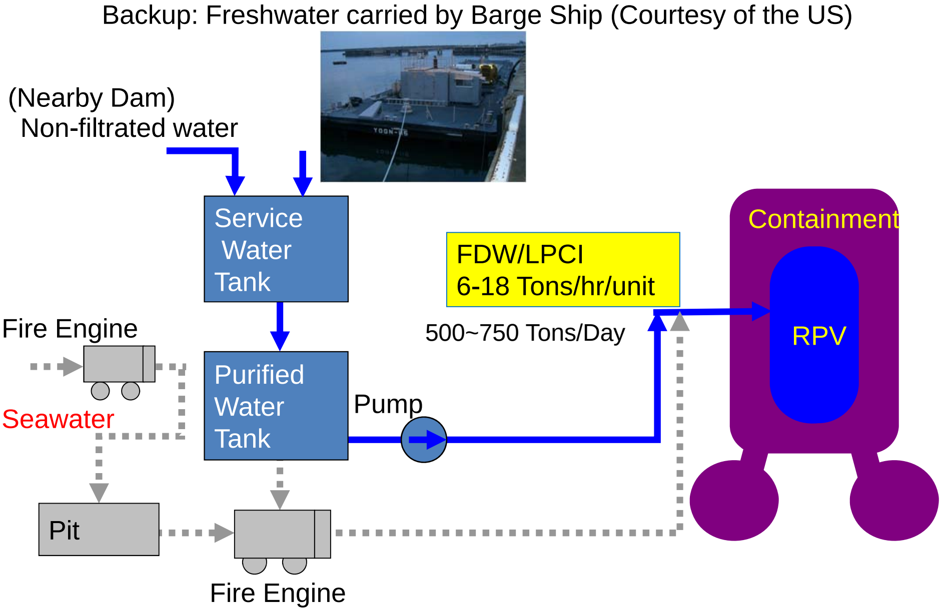


1F2 blowout panel opened by 1F3 blast, which released H_2

Water sample from SFP and photo indicate SFs in 1F4 most probably remain intact

Water Injection to the reactor core

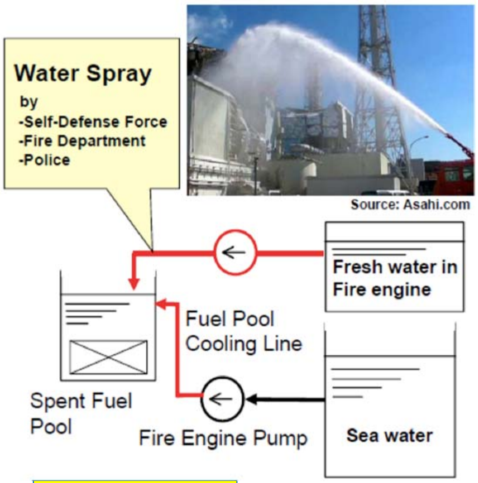
Backup: Freshwater carried by Barge Ship (Courtesy of the US)



[SOURCE] Modified based on NISA, IAEA Safety Convention Meeting, 2011April4

Current : Water Injection Spent Fuel Pool

Used to be



2-5Tons/hr/unit

Current

1F1-3 : Fuel pool makeup using FPC system
- **Use of plant system**
- **No spray**

1F4 : Spray from outside (FPC line is not yet usable)

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Key near-term recovery actions

1. COOLING
   - ◆ Flooding the containment to a certain level & installation of heat exchanger to remove heat, *[challenge] working environment & leakage of water from the containment*
   - ◆ SFP cooling system (rather than spray and evaporation)

2. MINIMIZING AIRBORNE/LIQUID EFFLUENT
   - ◆ Recycling of water recovered from Tb/B through removal of radioactivity (France/US/Japan) and RO (Japan)
     ~1200 Tons/Day treatment
     500~750 Tons/Day treated water return to the reactors
   - ◆ Storage of contaminated water
   - ◆ Installation of R/B cover
   - ◆ Corrosion control (Deaeration of supply water, hydrazine)

3. MINIMIZING RESIDUAL RISKS
   - ◆ Aftershocks (Structural integrity of damaged R/B, Reliability of power/water supply)
   - ◆ Hydrogen

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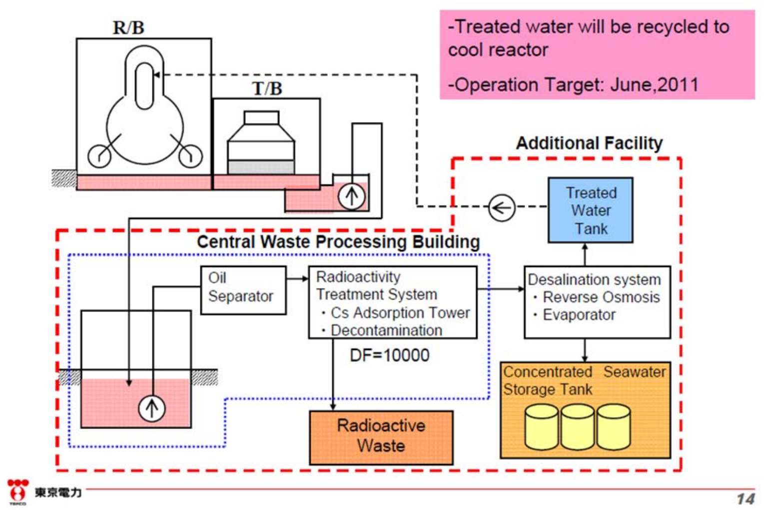
Installation of Water Treatment Facility



Water in the Tb/B is treated and recycled to the reactor for feed. Will balance by 2011/E.

✓Capacity of Treatment facility : 1200 Ton/Day x 6month (7-12) =216,000 Ton

✓Water to be treated : 1-4 Tb/B 87,500 Ton + (500-750) Ton/Daily feed x6month =177,500~22,250 Ton

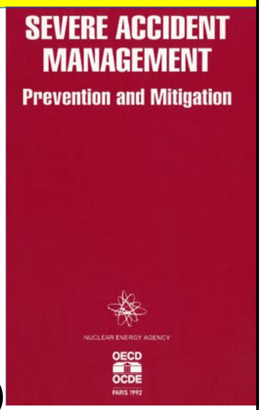
What SAM (Severe Accident Management) was in place?

(OECD/NEA)

In the aftermath of Chernobyl, OECD/NEA organized a series of meetings by SESAM (Senior Expert for Severe Accident Management)

"Severe Accident Management": published in 1992

"Implementing Severe Accident Management in Nuclear Power Plants", published in 1996



(Japan)

- **NSC recommendation for SAM preparation (1992)**
- **SAM study followed by SAM Guide and modifications (hardened vent, injection to RPV and RPV-pedestal region etc)**
- **Technical basis for SAM by Utility/Industry/Academia (NSRI guideline, 1999, http://www.nsra.or.jp/safe/cv/index.html)**
- **Submittal of Utility report to Regulatory body after completion of modifications (2002) and AMG, followed by evaluation by NISA**

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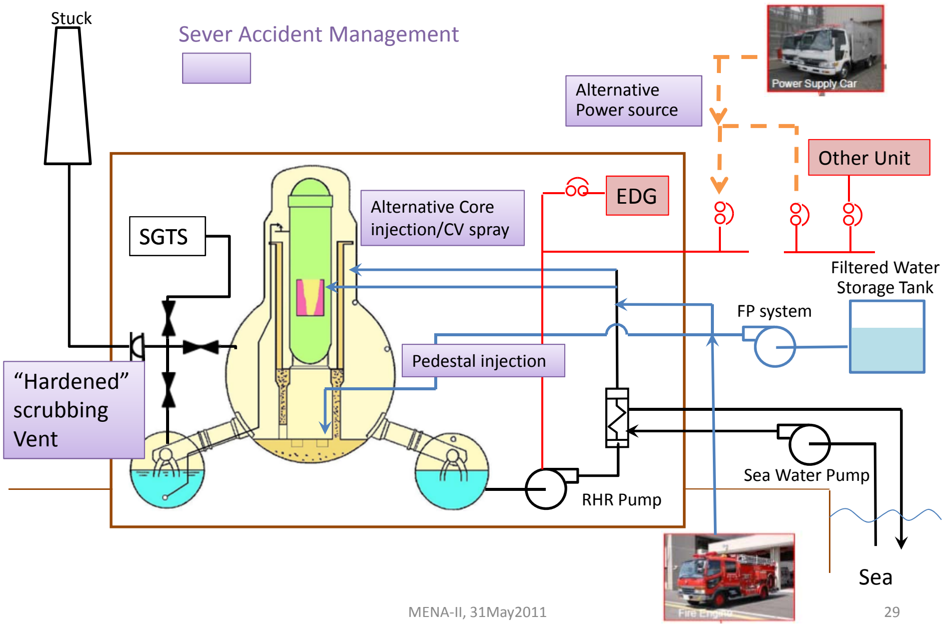
What SAM (Severe Accident Management) was in place?



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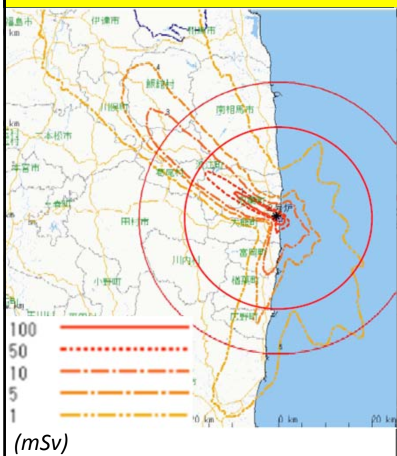
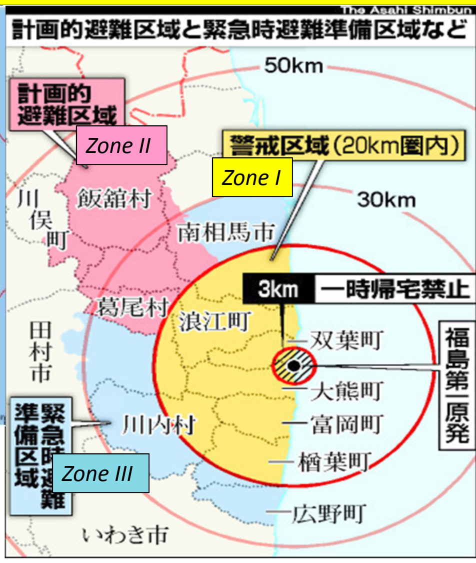
What offsite emergency plan was enacted?



SPEEDI calculation March 11-April24
Cumulative exposure to adult
http://www.nsc.go.jp/info/110425_top_siryo.pdf



Zone I (20km); "evacuation"
Zone II (North-west): "evacuation plan (in a month)"
Zone III (20-30km); "preparedness for evacuation"

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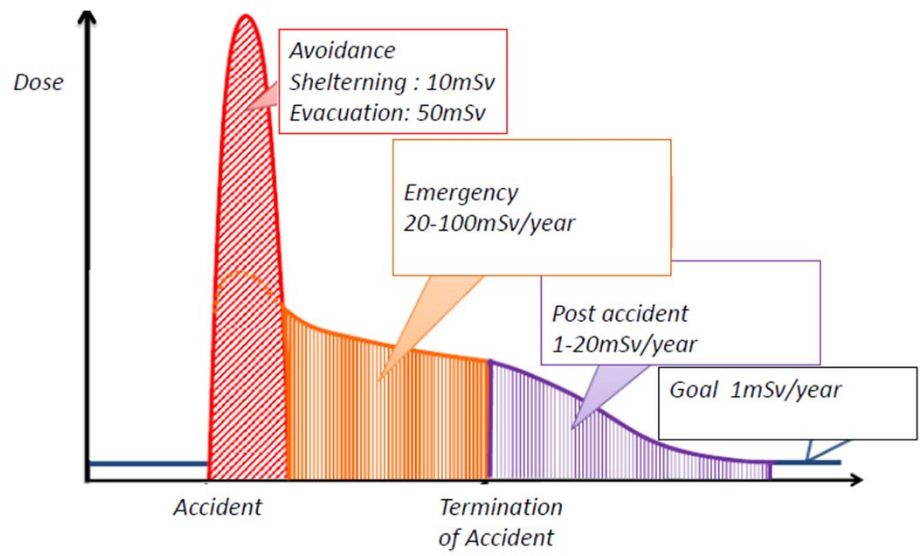

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[SOURCE] NSC, http://www.nsc.go.jp/info/20110411_2.pdf

Why INES level 7? Declared by NSC/NISA on April 13th

Chernobyl: I-131 eq. 5.2 x [10(18)] Bq

Fukushima: I-131 eq. 0.3-0.6 x [10(18)] Bq

Estimated by reverse calculation using SPEEDI and ground contamination (outside) and Severe Accident ST Analysis (inside)

INES 2.2.2.Definition of levels based on activity released

Level 7: An event ….
equivalent to a release to the atmosphere of more than several tens of thousands of tera[10(12)] Bq of I-131
(SOURCE: INES User's Manual 2008 Edition)

The International Nuclear Event Scale
For prompt communication of safety significance

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What Nuclear Liability system in Japan?

1. Basics: Owner/Operator owes unlimited liability for compensation of nuclear damage, irrespective of the cause of accident
2. Two contracts: Owner/Operator-Insurance company (Liability insurance)
   Owner/Operator-Government (Indemnity Agreement)
3. If the compensation amount exceeds 1.2B$ (assuming 100yen/$), Government may come to support contingent on the Diet's decision
4. Not a signatory of Amended Paris nor Amended Vienna agreements nor CSC

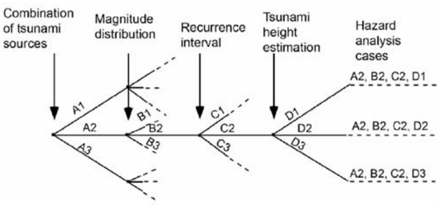
Owner/Operator's insurance	**Indemnification Agreement**	**Government's arrangement**
[Not cover Earthquake, Tsunami, Volcano Eruption]	1) Case of Earthquake, Tsunami, Volcano Eruption 2) Case of unknown cause during normal operation 3) Case of compensation request after 10 years	Case of extraordinary natural disaster or insurrection

What are the potential considerations for future designs and successful implementation of SAM ?

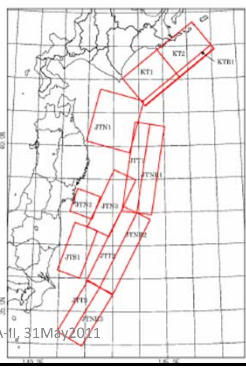
Personal observations

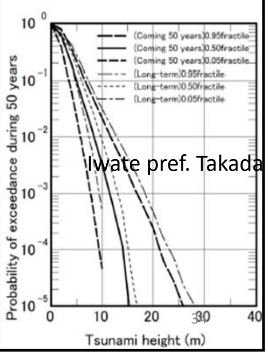
1. Design considerations against natural hazards

- Data compiled by reactor-year for internal events, while by year for natural hazards
- Logic tree and Tsunami hazard curve
- Building layout and elevation of Electric Equipment /EDG rooms
- ERC in robust building (seismic isolation after 2007 earthquake)



[SOURCE} T. Annaka et al, "A method Of Probabilistic Tsunami Hazard Analysis", Earthquake Engineering Symposium, 2006





What needs to be considered for future designs and successful implementation of SAM ?

Personal observations

2. Diversity

a) Diversified Ultimate Heat Sink (UHS) of Residual Heat Removal and Emergency Equipment Cooling Systems

b) Diversified power & water supply: Air-cooled DG, Water from dam

3. Passive safety

a) Heat removal from reactor core/containment/SFP

b) Preparations for "what if onsite recovery actions were disabled"

4. Consideration against extended time blackout

Battery in safe place and recharger of battery by small EDG

What needs to be considered for future designs and successful implementation of SAM ?

Personal observations

5. Improvements of SAM (Severe Accident Management)

a) Review and drill for the "use of all available resources"
- Provisions of Onsite or National Nuclear Crisis Center, under appropriate delineation of responsibility, transportation systems and storage of mobile equipments such as Fire Engines, portable sweater pumps, batteries, remote sensing devices, remote spray system, robotics etc & drill for use

b) Implementation of recovery actions in harsh radiation environment
- Provision of Temporary shielding, Remote handling machine, Remote water spray machine, remote sensing machines and cameras by unmanned plane, and others from National Crisis Center

c) Potential of detonation/deflagration of leaked hydrogen outside of the CV
- vent line pipe and SGTS line pipe
- "hydrogen deflagration/detonation in a BWR R/B" (NE&D 211,27-50)

d) Include "water inventory control" "water leak path analysis" (LWR)

e) Recovery actions: preparation for the worst & "defense in depth"

f) Structure of Emergency Management organization

What needs to be considered for future designs and successful implementation of SAM ?

Personal observations

6. SAM Operational aids

Real-time simulation of plant behaviour as an aid to decision-making from options and assess the current/future risks potentials, backed by precise accident data tracking system by recoding every plant behaviour and remedial actions

7. Accident instrumentation (CV water level etc) and sampling capability

Very limited data available (Rx-SC/DW pres/Rx-SC/DW temp/Rx WL)

8. Offsite management such as the use of exposure prediction system etc

9. Design considerations for **SFP**

- Potential of re-criticality of over-moderated SFP
- Location of SFP (Accessibility, Structural integrity, Aeroplane crash)
- Alternative heat removal method (cooling system and UHS)

10. Amendment of International safety standards and establishing international expert review of design/SAM (vs. national authority to license), global safety goal

For countries considering nuclear power

Personal observations

1. Establishing safety infrastructure (General)

- International support from IAEA (safety standards, guidelines, INIR review, Safety Convention etc), WANO and international networking
- international peer review on safety by experts
- Starting in the process of national/regional infrastructure building; site selection, human resources
- Establishing national safety standards and safety goal consistent with international standards
- Regional Crisis Management Center with mobile equipments (WANO?)

2. Considerations of nuclear liability and compensation mechanism

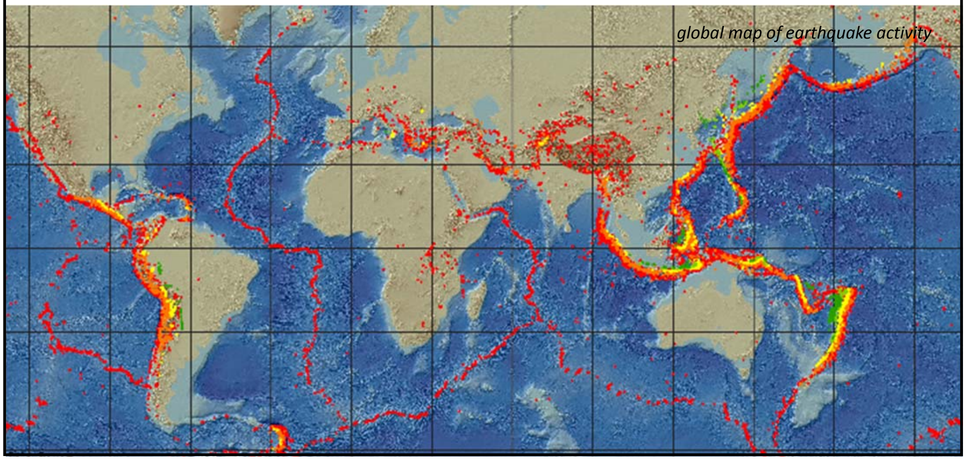
- International scheme (Paris & Vienna Conventions, CSC (Convention on Supplementary Compensation, regardless of nuclear installations on the nation's territories)

For countries considering nuclear power

Personal observations

3. Use of PSA as a tool to check vulnerability of the plant by yourself and to address the vulnerability (owner/operator and regulators)

- External events PSA
- In-house PSA engineers (owner/operator)
- PSA-savvy shift safety engineers (operator)



For countries considering nuclear power

Personal observations

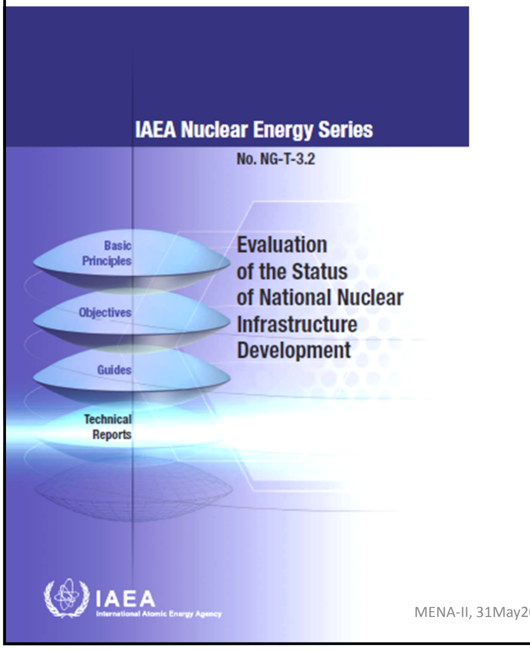
4. Preparedness, preparedness and preparedness

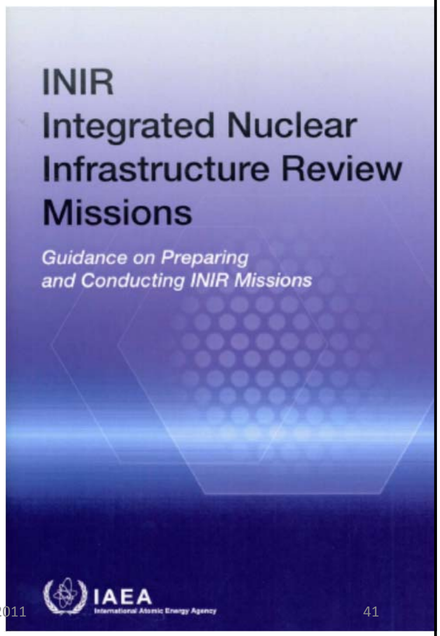
- Do not think "It cannot happen here"
- Emergency Plan
- Government's coordinated emergency management (US: FEMA)
- Protective action guidelines (evacuation/sheltering/ingestion control)
- Drill and establish preparedness for unexpected

5. Transparency in safety for confidence-building in the nation & w/neighbors

40

Infrastructure status self-evaluation & IAEA review mission





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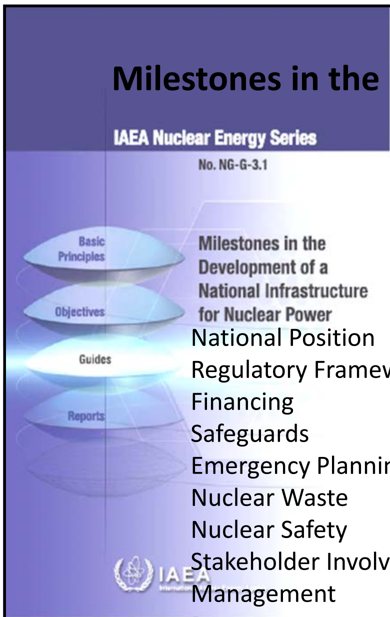
Milestones in the development of infrastructure



Clarifies:

- **19 major issues to consider in infrastructure building**
- **Conditions to achieve the milestone for each issues**

National Position
Regulatory Framework
Financing
Safeguards
Emergency Planning
Nuclear Waste
Nuclear Safety
Stakeholder Involvement
Management
Procurement

Legal Framework
Radiation Protection
Human Resource Development
Security and Physical Protection
Nuclear Fuel Cycle
Environmental Protection
Sites & Supporting Facilities
Electrical Grid
Industrial Involvement

(Nuclear Energy Series NG-G-3.1)

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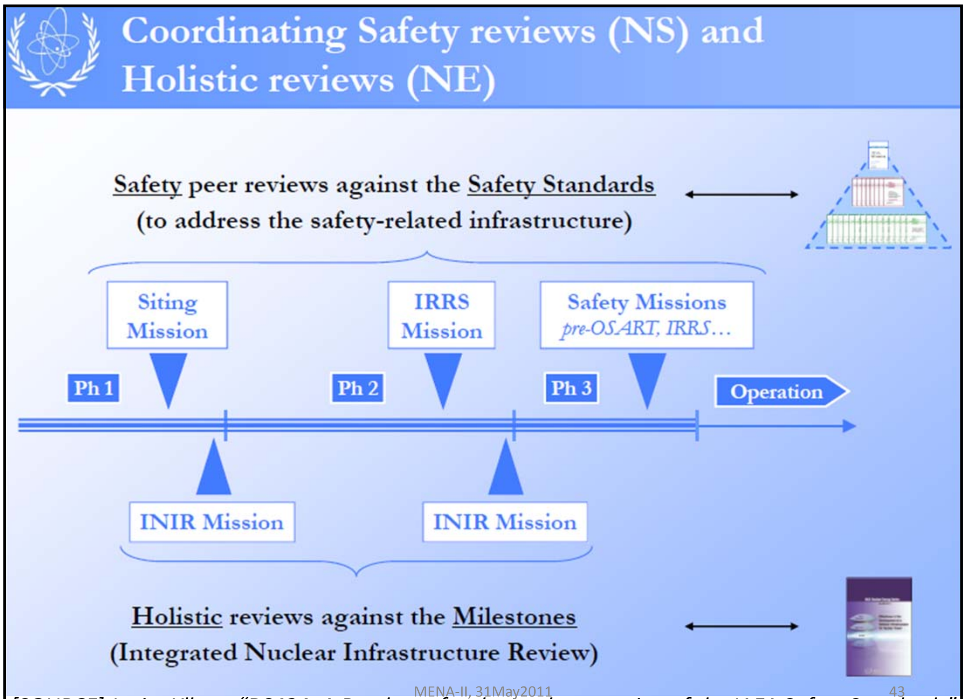

[SOURCE] Javier Yllera, "DS424: A Roadmap for the Implementation of the IAEA Safety Standards"

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