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DOE Response to Fukushima Dai-ichi Accident

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Fukushima Dai-ichi Reactors

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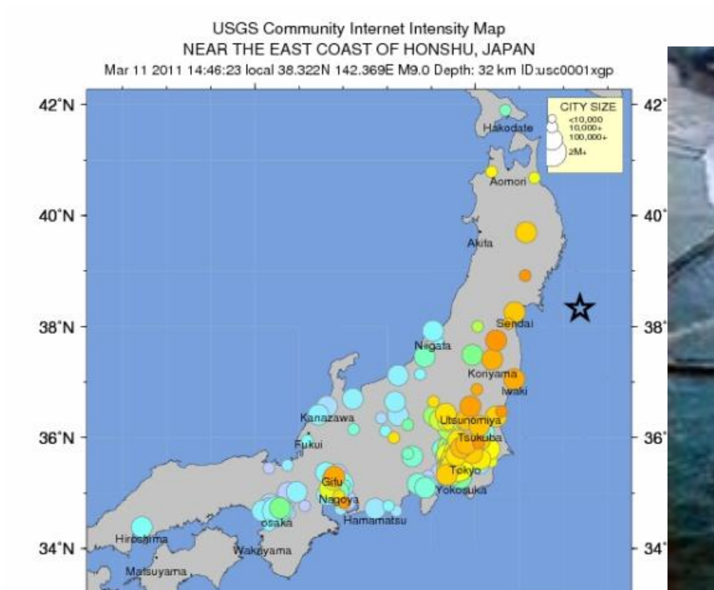
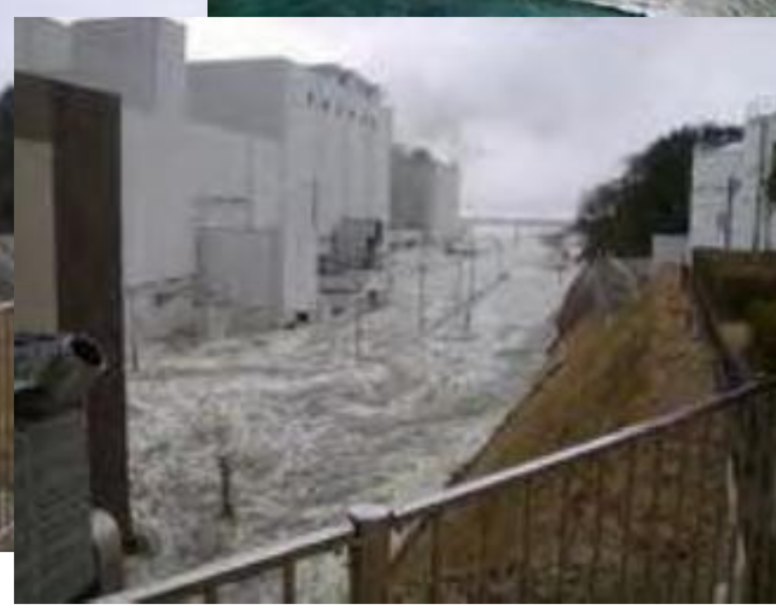
Fukushima Dai-ichi Reactors

Earthquake 3/11





14:36 JST Earthquake

15:41 JST Tsunami

Magnitude: 9.0

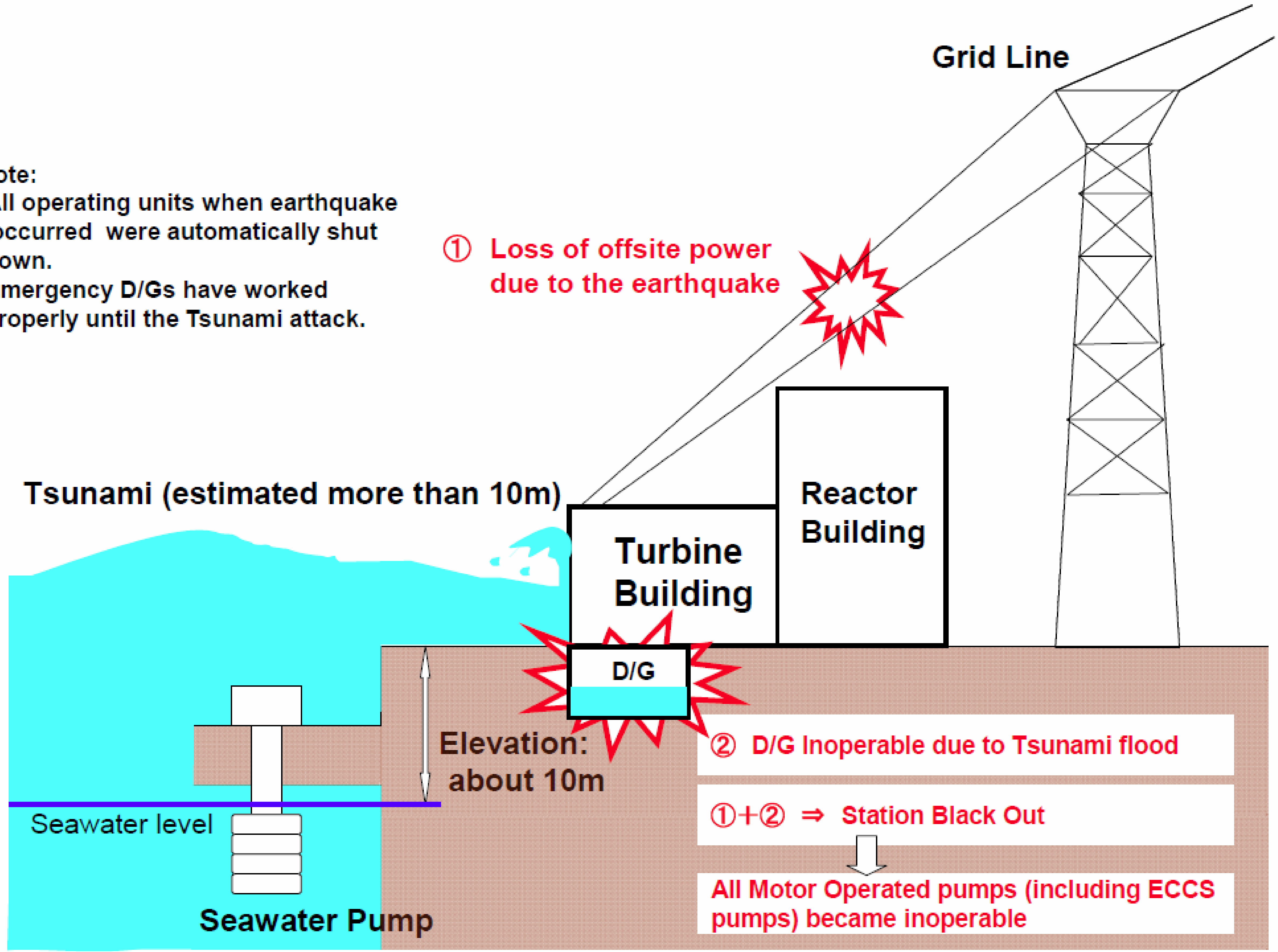
Generated a 14m Tsunami

Many thousands perished

More that 100 thousand people were homeless without food, water, or heat

3-2. Major root cause of the damage

Note:
- All operating units when earthquake occurred were automatically shut down.
- Emergency D/Gs have worked properly until the Tsunami attack.



Accident Sequence for Fukushima Dai-ichi Reactors

- Grid power lost due to the earthquake
- Plant experienced station blackout after emergency diesels were damaged by the tsunami (nearly 1 hour later)
- Eventual loss of batteries and cooling to control steam driven emergency pumps
- Core overheats, cladding oxidizes and melts producing hydrogen
- Hydrogen escapes from containment and explodes/deflagrates in reactors 1, 2, & 3
- Explosion/deflagration in reactor 4 building

Immediate Coordinated Response

U.S.NRC

- Activated its Emergency Operations Center
- Immediately deployed personnel to the U.S. Embassy in Japan to support the Reactor Safety Team (RST)
- Provided expert advice to the U.S. Ambassador and Government of Japan ministers
- Set up and coordinated consortium call that involved NRC, INPO, DOE, and Naval Reactors

INPO

- Organized nuclear industry technical response to assist TEPCO

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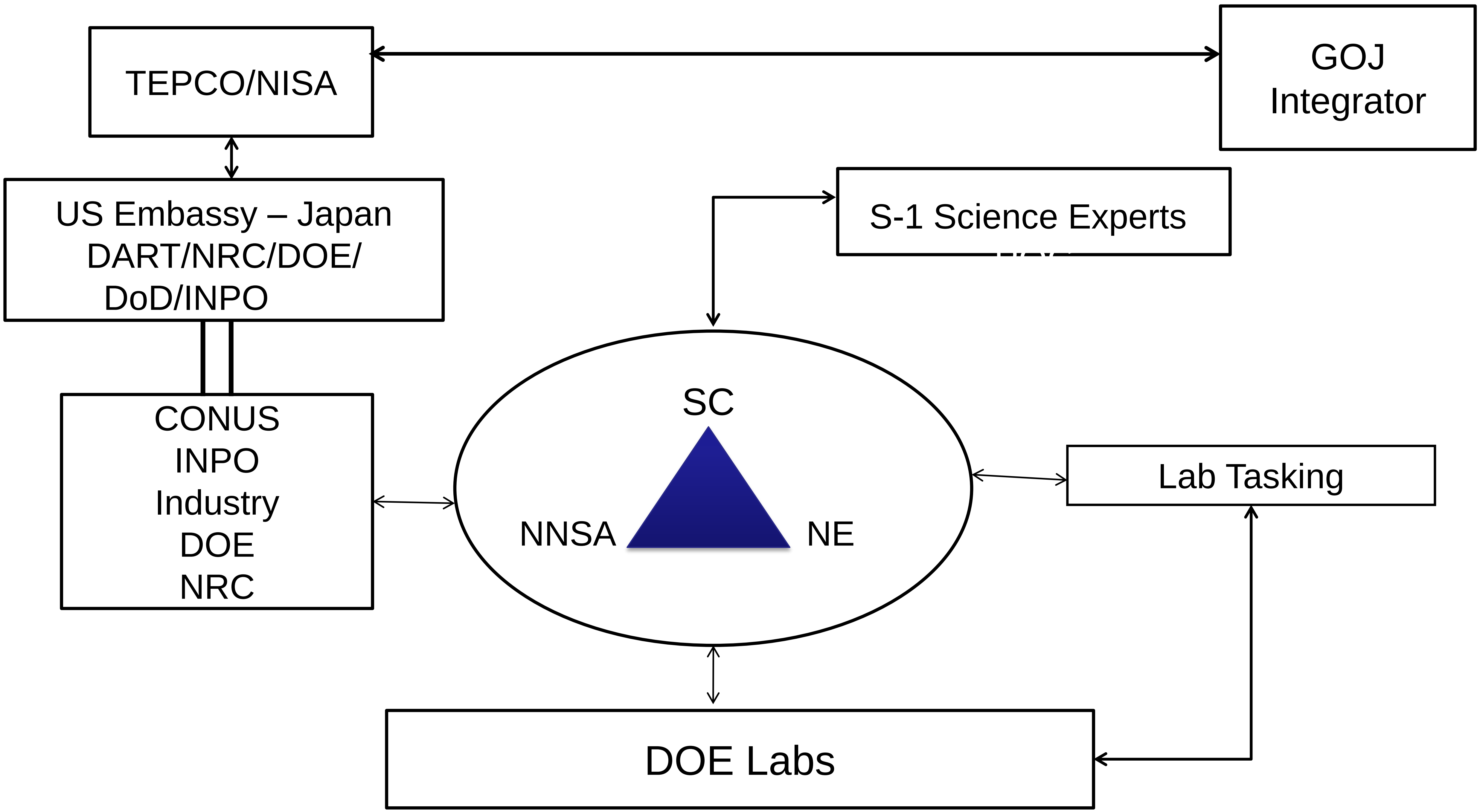
- Activated its Emergency Operations Center focused on monitoring radiation release and impact on U.S. citizens (both in Japan and the U.S.)
- Deployed Airborne Monitoring System aircraft and Consequence Management Response Teams
- Provided additional DOE Embassy reps to the two already assigned to the U.S. Embassy
- Deployed national laboratory reps from INL, PNNL and Sandia to provide technical assistance
- Assigned NE personnel to stand watch in the DOE EOC

DOE Response to Fukushima Events

- During the first several weeks following the Japan earthquake and tsunmai, DOE provided a significant and diverse set of analysis to support the events at Fukushima-Daiichi

- This response involved a broad set of institutions with over 200 people contributing DOE: Offices of NE, SC, NNSA, EM
  - Laboratories: ANL, BNL, INL, LANL, ORNL, PNNL, and SNL
  - Numerous universities
  - Individual consultants – Secretary's external science experts

Nuclear Energy Response Team



Airborne Radiation Monitoring

- **NNSA had primary responsibility to monitor radiological fallout and provide data to USG and GOJ**
- **Deployed airborne monitoring systems**
- **Used NARAC code suite at LLNL to model calculate plume**

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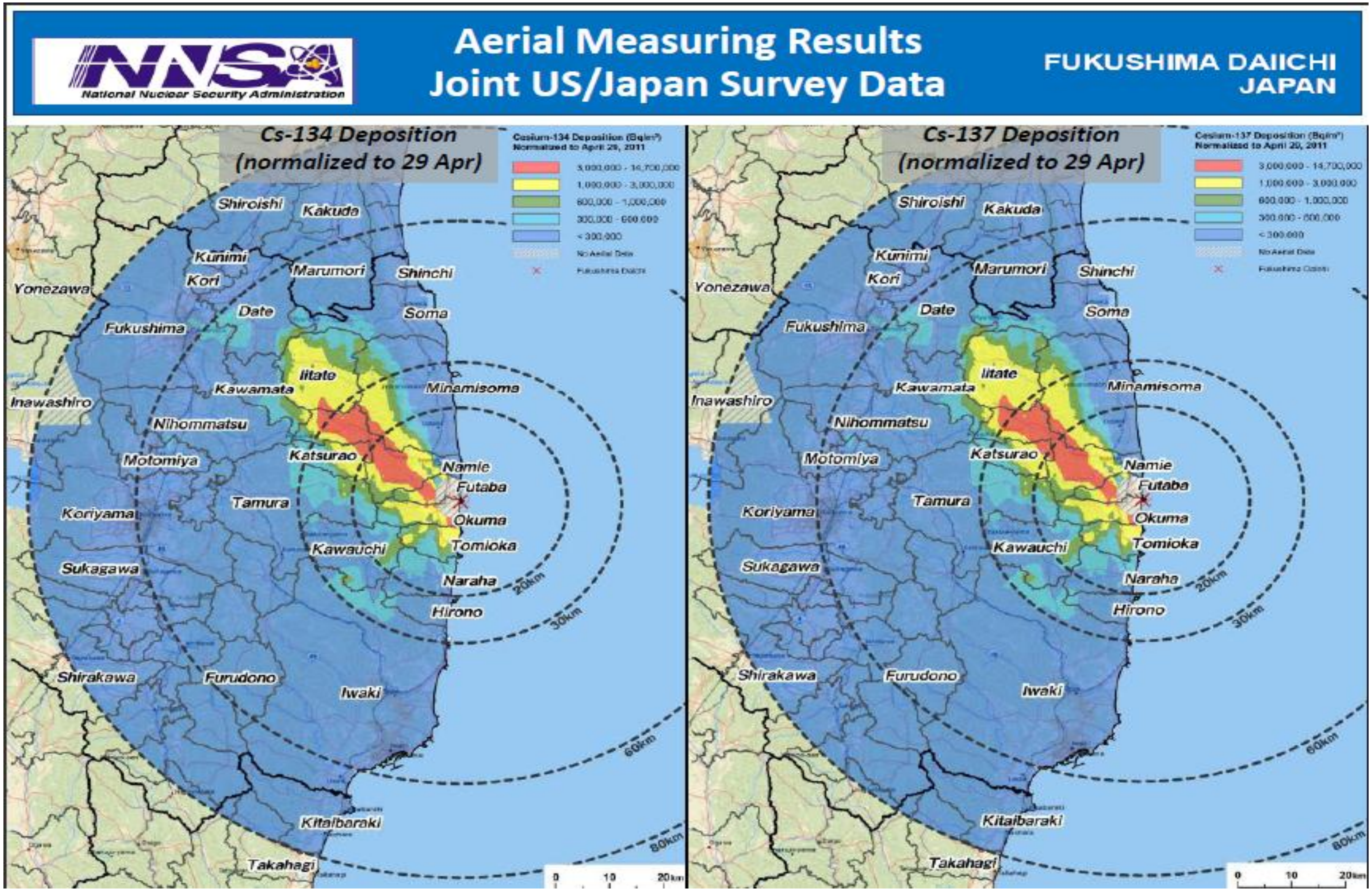
Airborne Radiation Monitoring



Data based on 42 fixed wing and helicopter survey flights at altitudes ranging from 150 to 700 meters between April 6 and April 29

Office of Nuclear Energy Response Team

- **Primary mission**
  - Assess and clarify information for DOE and NE leadership concerning the status of the Fukushima Dai-ichi reactor situation

- **Provide support to NE EOC watch standers**

- **Organized national laboratory analysis activities to support:**
  - White House and USG
  - U.S. Embassy Requests
  - DOE and NE Leadership

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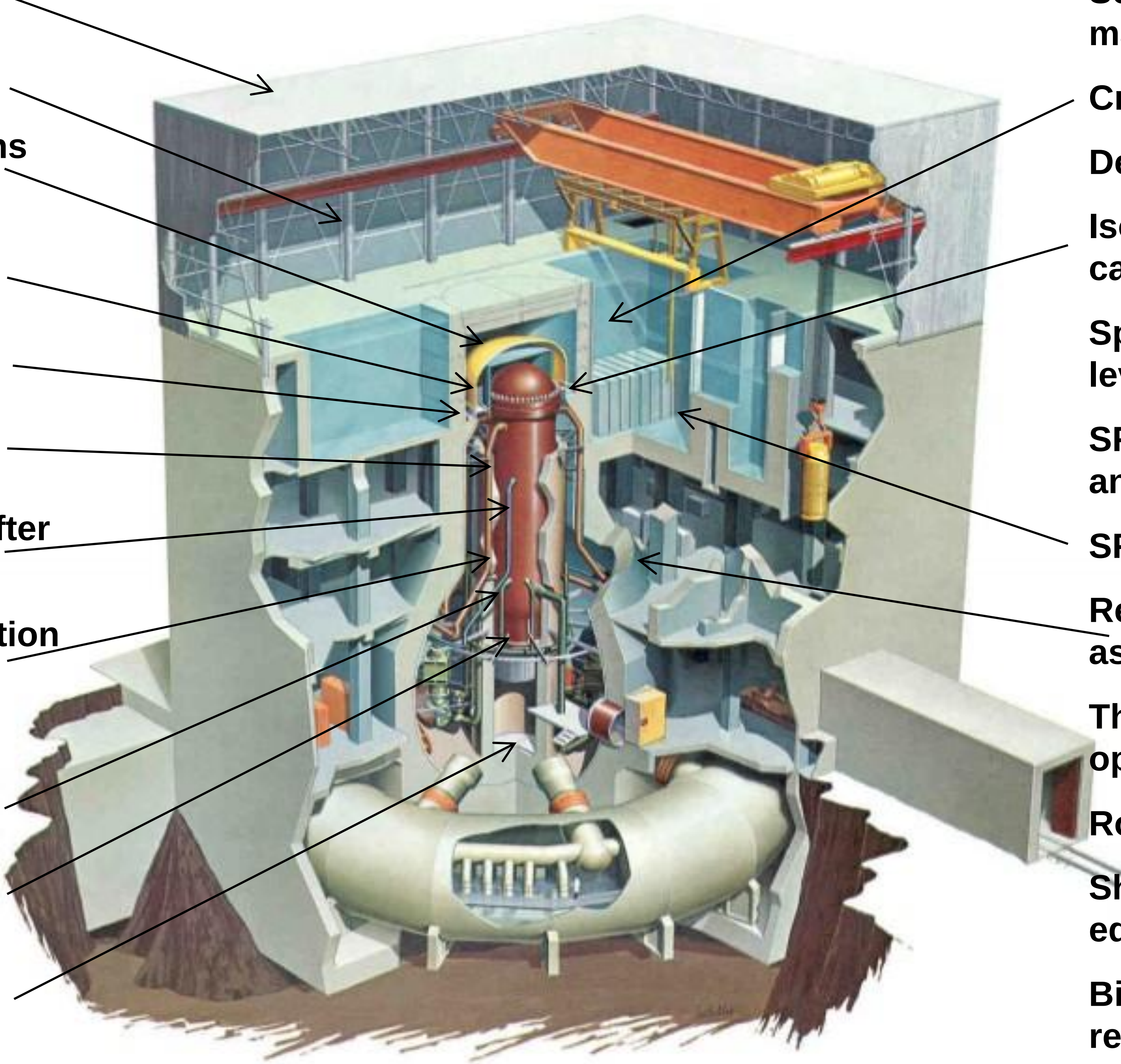
DOE Analysis for Initial and Stabilization Phase



Collection of daily status data and events

Isotopic analysis of releases

H2 production and explosions in reactor buildings

N2 inerting options and processes

Gas inventory calculations

Potential for further H2 production and explosions

Structural analysis of RPV after pressure spikes

Core damage and fuel condition

Sensor data analysis

Water level calculations

Corrosion in sea water solutions

Drywell filling options and water level tracking

Stabilization criteria

Severe accident analysis and management

Criticality determinations

Decay heat calculations

Isotope and radionuclide calculations and releases

Spent Fuel Pool (SFP) water level analysis

SFP hydrogen production and analysis

SFP modeling

Reactor building and SFP dose assessments

Thermal analysis for SFP fill options

Robotics tools for stabilization

Shielding advice for on-site equipment

Bioaccumulation for water releases

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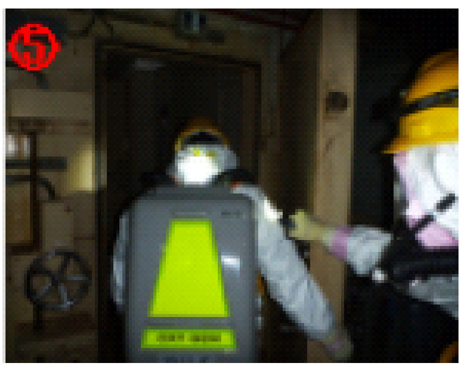
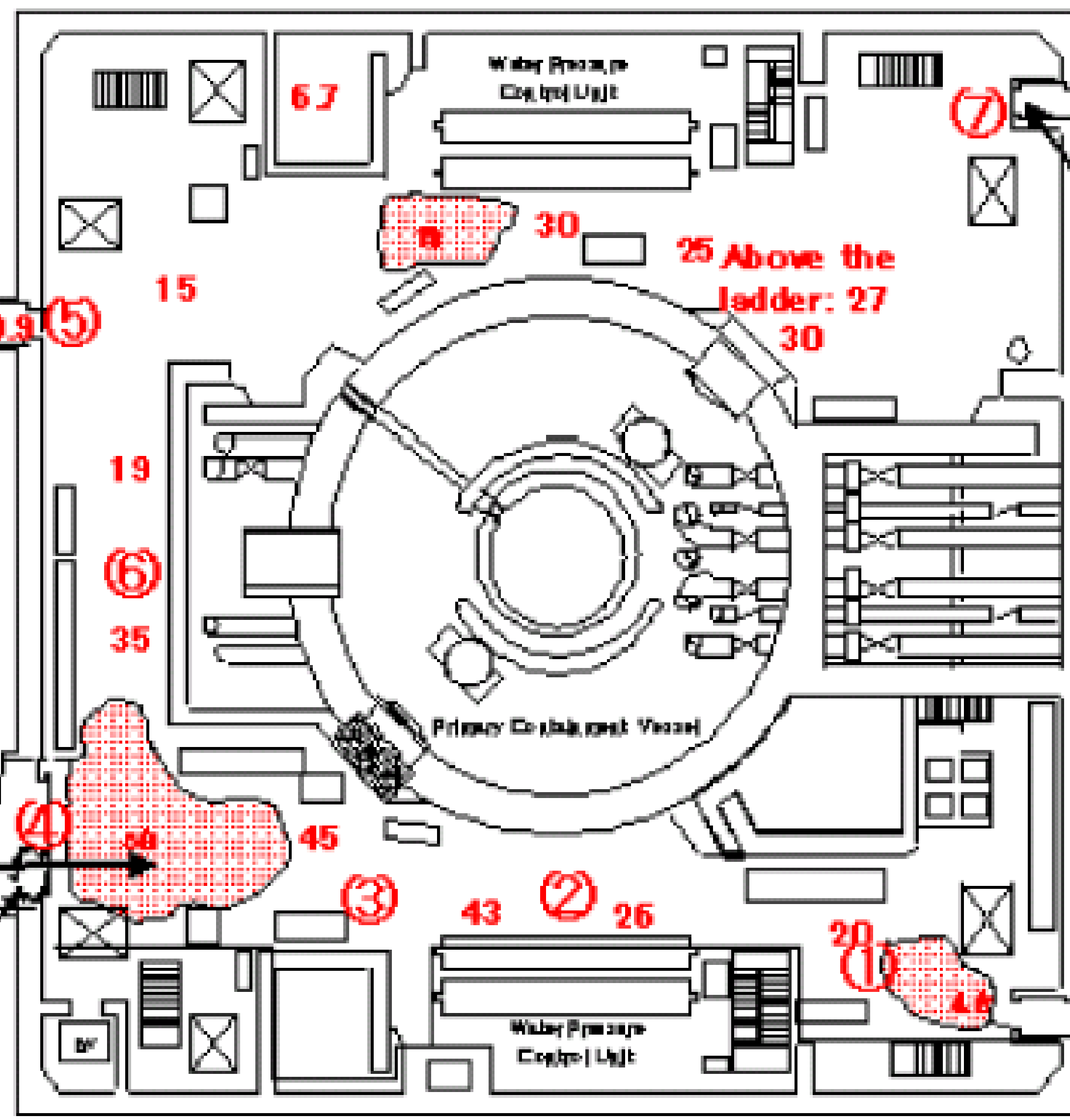
Reactor Building Survey Results Unit 2

- Recent (19 May) survey results for Unit 2 shown below; dose rates in the range of 15 to 45 mSv/hr (1.5 to 4.5 R/hr
- Underscores the difficulty in restarting normal RHR equipment



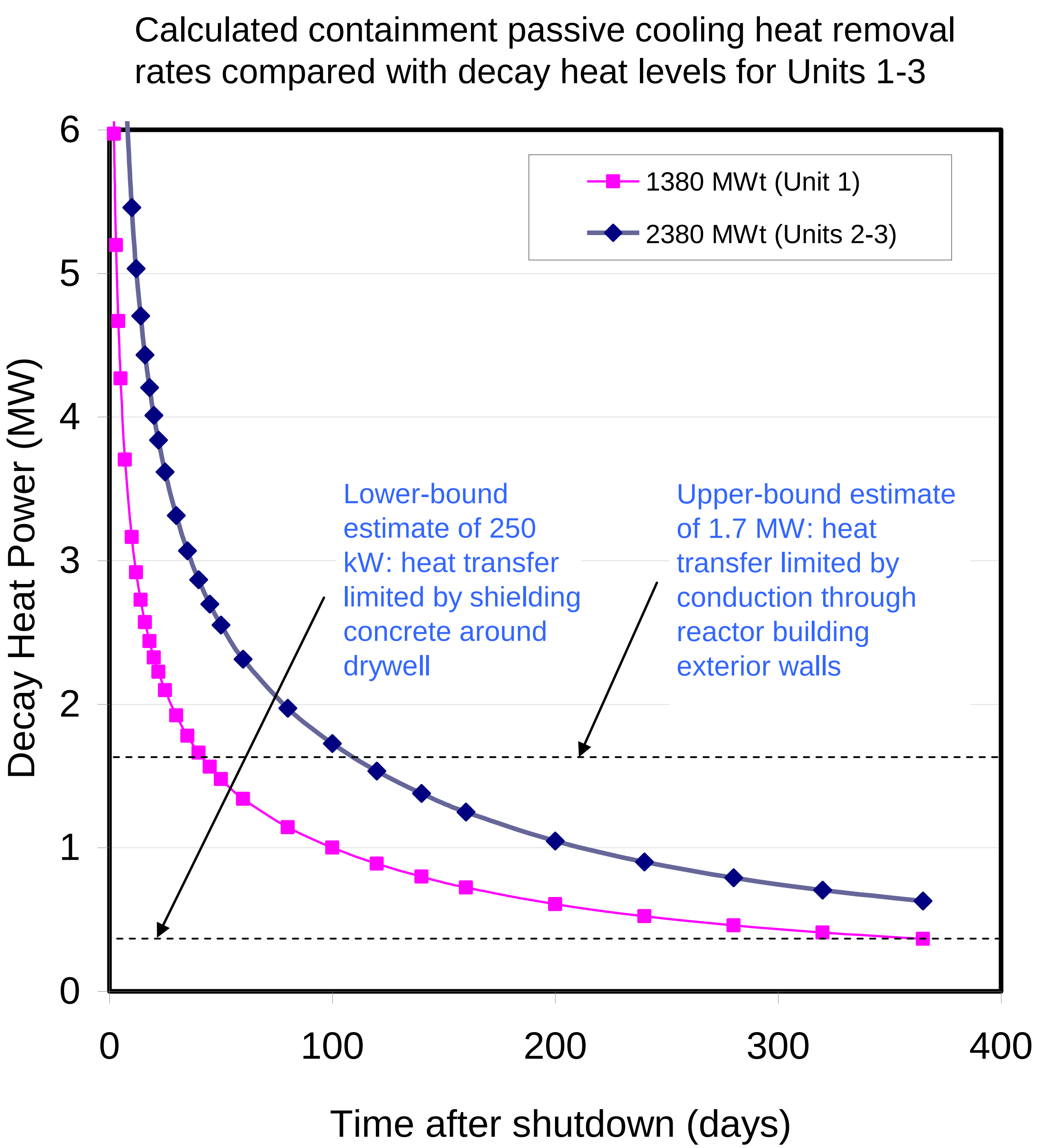
Water dripping found around the upper side of the machine hatch

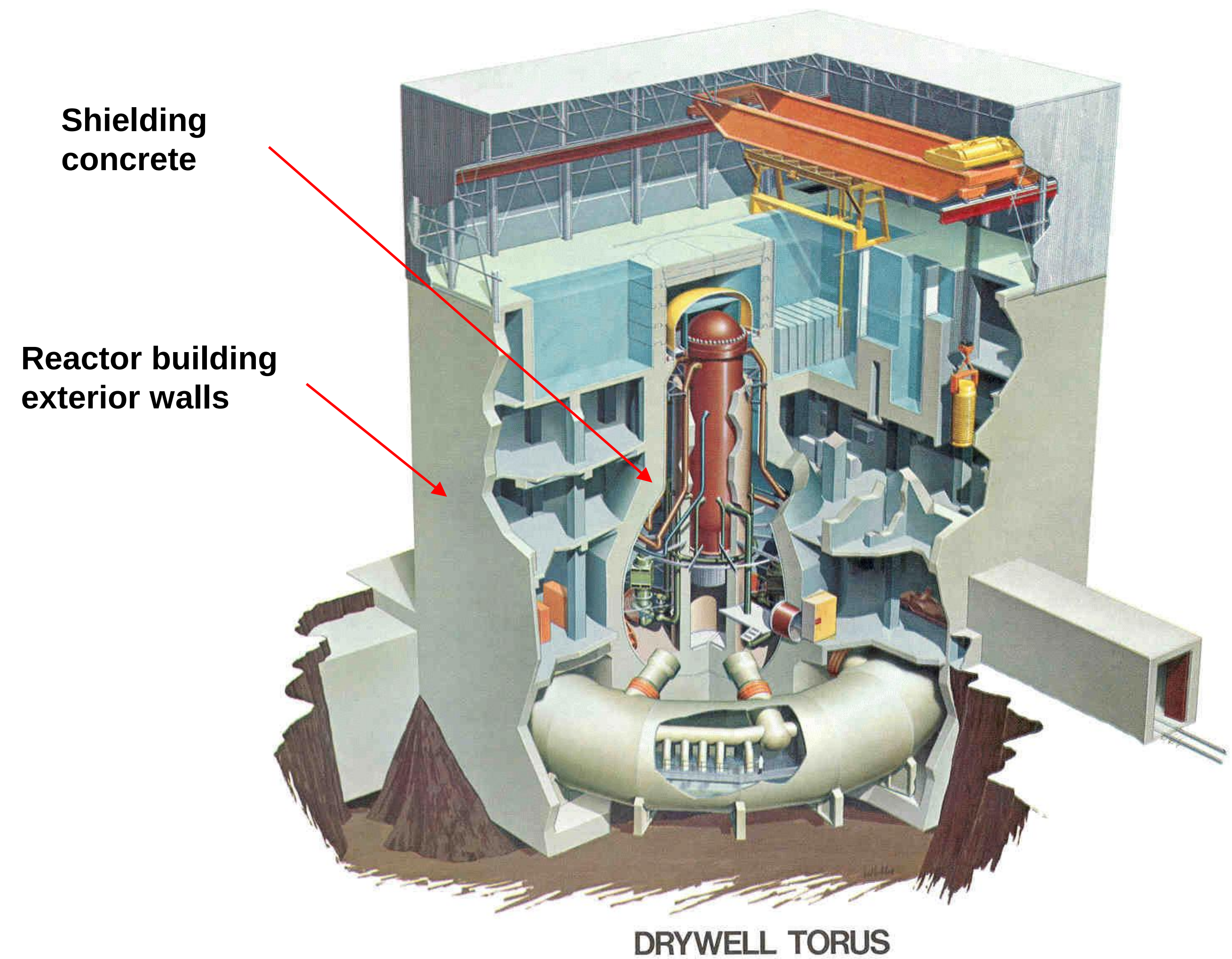
Inside door of the equipment hatch: partly open(approx. 1/3)



Airlock did not open from inside

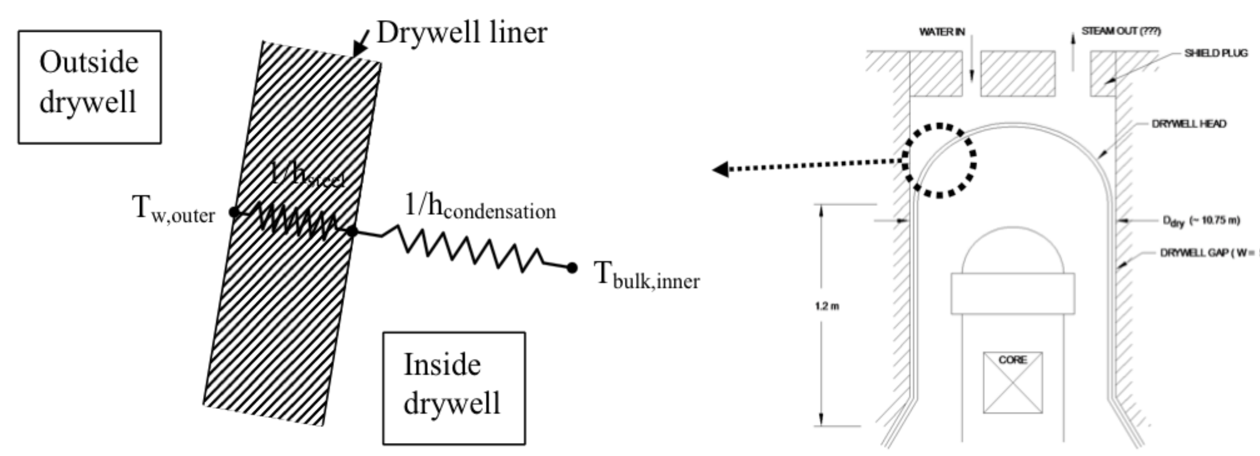
Passive Cooling Assessment

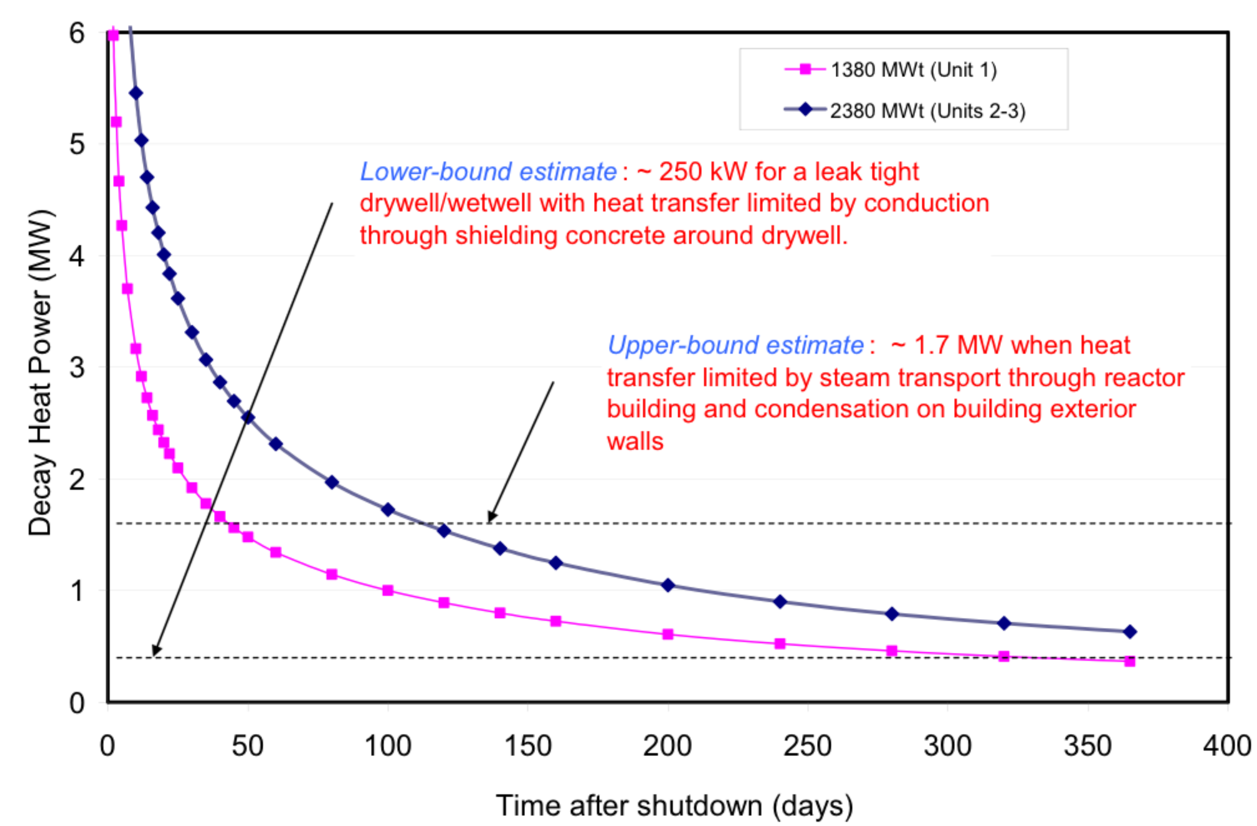




Long-term Decay Heat Removal

- Decay heat cooling would take about 9 months using of passive cooling
- Explored options for accelerated cooling
  - Capture, treatment and reuse of cooling water
  - Alternate cooling approaches





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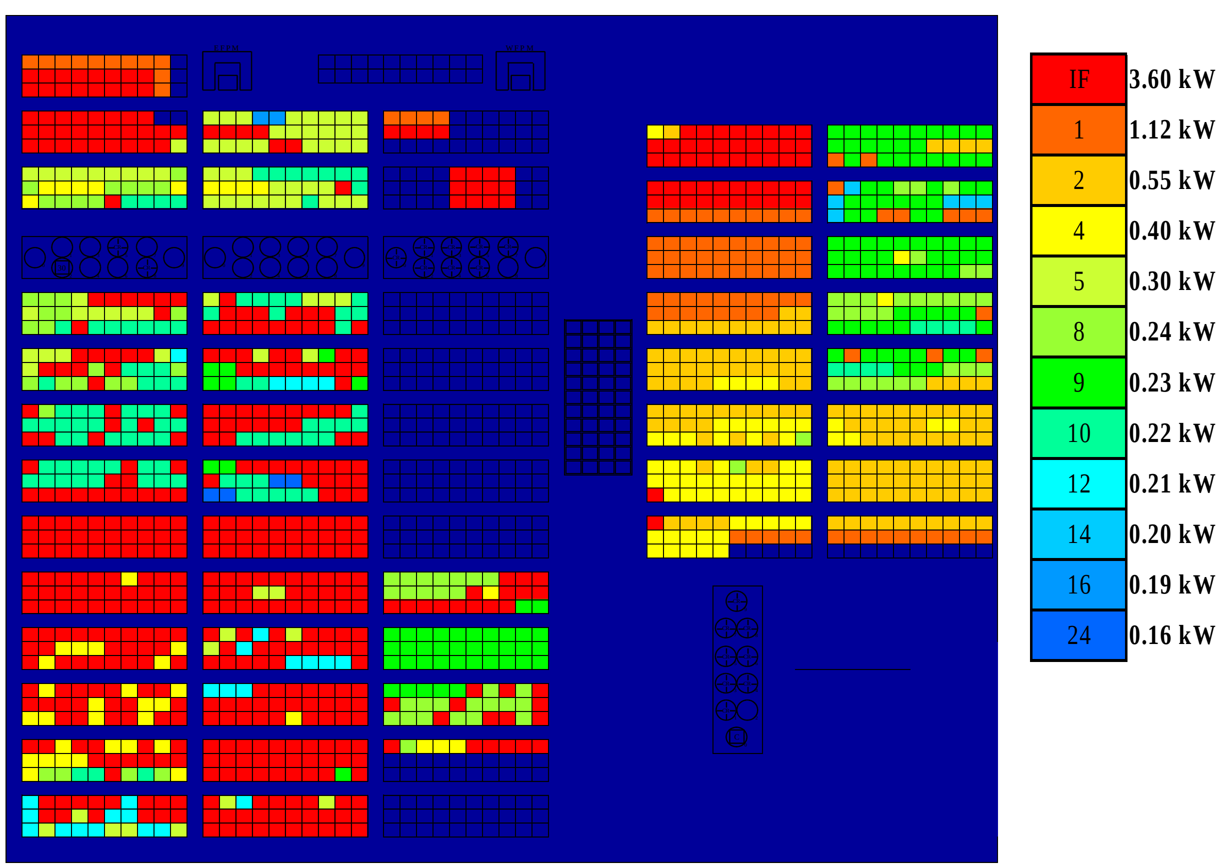
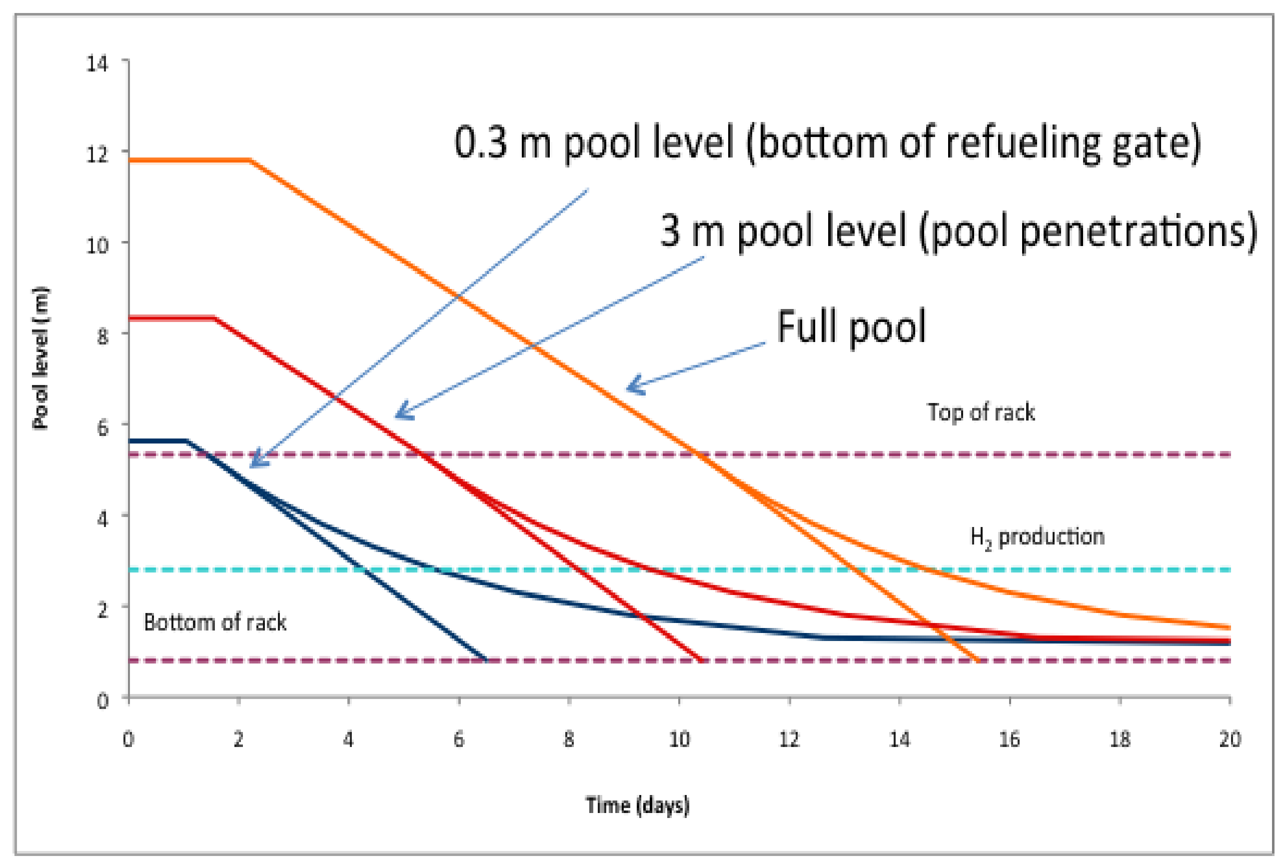
Thermal analysis of pool heatup and boil off

- Models of spent fuel pools developed to predict pool boil off time and to understand hydrogen production
- Used to perform analysis of pool leakage scenarios
- Calculations based on several codes and models to provide range in turn-around time and fidelity

UNIT 4 SFP HEAT GENERATION RATE DISTRIBUTION

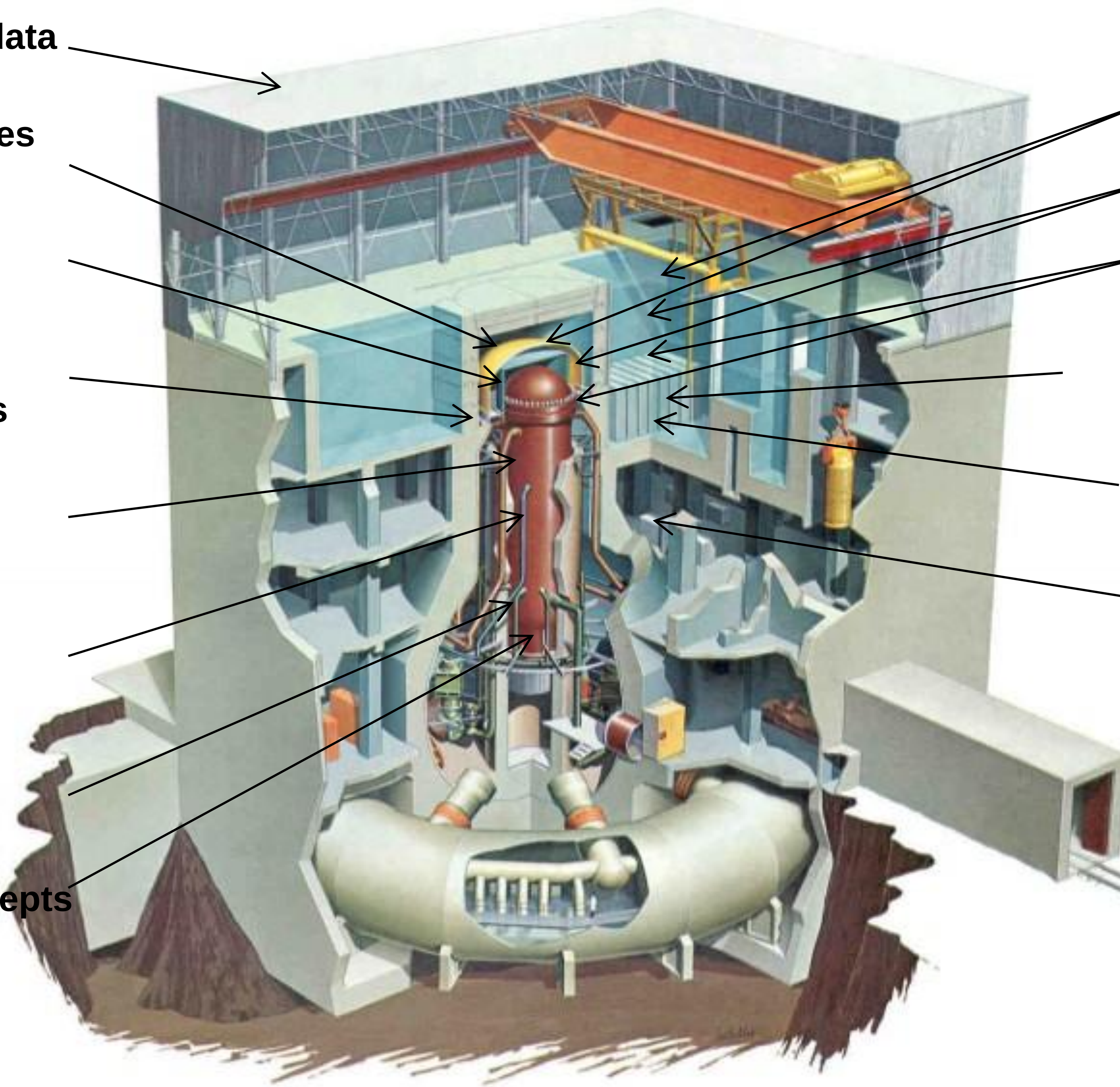


POOL LEVEL FOR VARIOUS SCENARIOS FOR UNIT 4



DOE Analysis for Recovery Phase

- Collection of daily status data and events
- Isotopic analysis of releases
- Passive cooling options
- Dry-well gap cooling
- Potential for further H2 production and explosions
- Clean-up and recycling of reactor coolant
- Core damage and fuel condition
- Corrosion in sea water solutions
- Corrosion Mitigation Concepts
- Leak management



- Severe accident analysis and management
- Criticality determinations
- Decay heat calculations
- Isotope and radionuclide calculations and releases
- SFP modeling
- Thermal analysis for SFP fill options
- Reactor building and SFP dose assessments
- Robotics tools for stabilization
- Shielding advice for on-site equipment
- Bioaccumulation for water releases
- Water clean-up options

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Waste Water Storage & Treatment

- **Significant quantities of water is collecting in the sumps and basements of the reactor and turbine building**
- **Japan government requested U.S. concepts for**
  - **Collection**
  - **Transfer**
  - **Storage**
  - **Treatment of waste water**

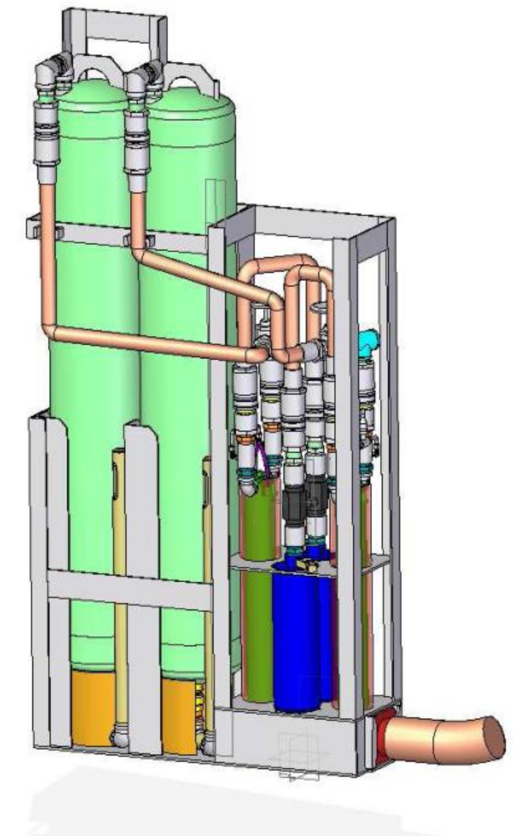
Potential Near-Term Options to Mitigate Contaminated Water in Japan's Fukushima Daiichi Nuclear Plant
April 7, 2011

Hanford Spent Fuel K-Basin

Hanford Spent Fuel K-Basin

Design Options for Water Retrieval and Treatment

- **Currently accumulated sea water**
  - Pump water from basement, tunnels and other locations
  - Treat water for storage/disposal
- **Cooling water**
  - Pump water from reactor vessels or spent fuel basins
  - Treat water for recirculation
- **Skid mounted systems**
  - Pumping/retrieval technologies for liquids and sludges
  - Pre-filters and filters to remove debris and solids
  - Ion exchange resin columns and sorption systems for removal of radionuclides
  - Evaporation systems
  - Treatment equipment contained in large shielded fuel transport casks
- **Utilize DOE-EM cleanup contractor base for expertise**



Conceptual design of a water treatment system deployed in a spent fuel basin

Corrosion rates of RPV steels have been examined in the open literature

- Fukushima-Daiichi plants utilize A533B steel for the pressure vessel (likely based on industry standards, but not confirmed)
- There is little data on this class of steels in salt or concentrated salt solutions as it is not a typical choice for any application
- Some data has been identified (and the search will continue)

Corrosion experience from Millstone unit 1

- **Sept. 1, 1972, the Millstone Unit 1 BWR was undergoing routine startup**
  - **Sea-water was introduced into full flow demineralizers**
  - **High conductivity water entered the reactor vessel via the condensate/feedwater system**

- **Corrosion effects were observed in a matter of hours**
  - **116/120 of the local power range monitors (with very thin walls) were damaged by cracking**
  - **Stress corrosion cracking was observed in other reactor components and considered to be "superficial"**
  - **Subsequent tests at GE found tests produced results more severe than in the actual incident.**

Implications from Millstone 1 experience to Fukushima

- Cracking likely occurred in all units very quickly as seawater was introduced
- However, rapid cracking early in the event may not be sustained, consistent with the disposition of cracks that were deemed superficial to subsequent operation in Millstone
- The observations on carbon steel testing are consistent with other literature results from other industries for this class of alloys

Corrosion Rate for Carbon Steel

- **Initial data for low-alloy steels (LAS) and carbon steels (C-steel) in salt-solutions**

Alloy	Temp. (C)	Solution	Concen.	Other factor	Corrosion rate (mm/y)	Corrosion rate (mils per year)
LAS	25	NaCl	3.5%	--	0.025	1
LAS	25	NaCl	3.5%	--	0.38	15
LAS	25	NaCl	3.5%	H2SO4	3.8	150
C-steel	150	MgCl2	10%	Irrad.	0.07	27
A533B (Davis Besse)	310	Boric acid	High		64	2500

*Davis Besse test data is still most conservative

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Next Steps for DOE-NE

- Continue our Support for the Government of Japan
  - Peer reviews and analysis as requested
- Data collection and accident forensics to support lessons learned
- Continued monitoring of potential accident consequences