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Cesium Removal and Storage – Update on Fukushima Daiichi Status

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Briefing for Hanford Advisory Board, Tank Waste Committee

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Discussion Topics

- Message – Water treatment activities at Fukushima Daiichi have demonstrated cesium removal and storage technologies and preliminary options for disposition of cesium-loaded secondary wastes have been examined.
- Fukushima cooling system for damaged reactor cores and waste stream cesium content
- Cesium removal systems currently in use.
- Storage system for spent cesium adsorption vessels
- Options for future disposal

- Acknowledgements: data obtained from reports and colleagues at:
  - Tokyo Electric Power Company (TEPCO) and Fukushima Decommissioning Engineering Co. (FDEC)
  - Ministry of Economy, Trade and Industry (METI)
  - International Research Institute for Nuclear Decommissioning (IRID)
  - Japan Atomic Energy Agency (JAEA)
  - Kurion, Inc.
  - AVANTech, Inc.

Current Status of Units 1-4 and Cooling Water System

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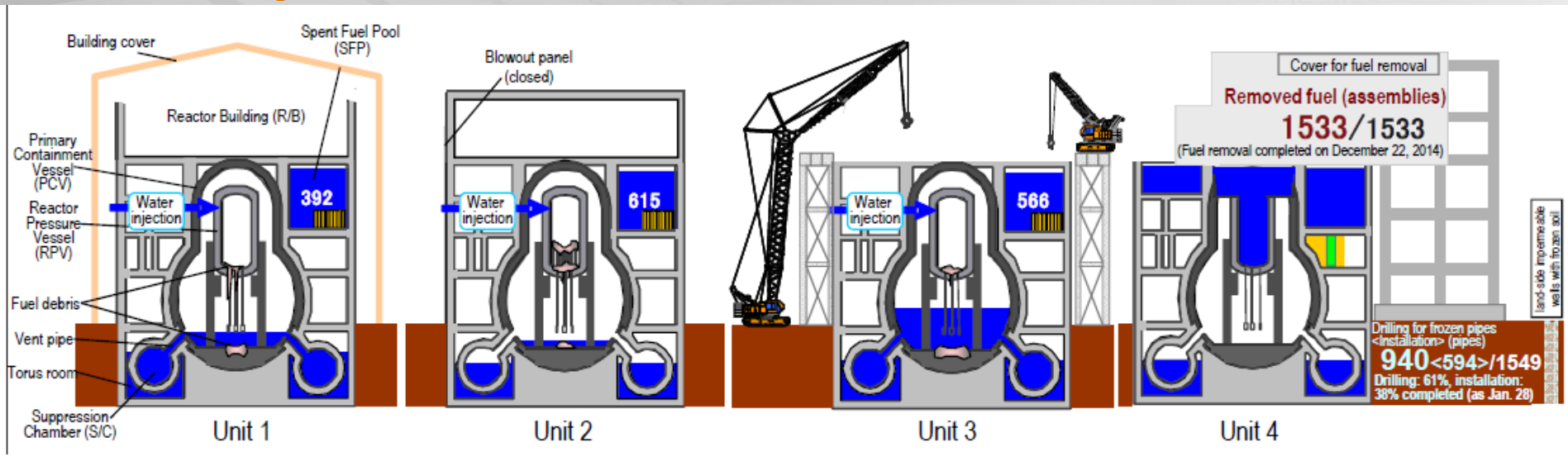

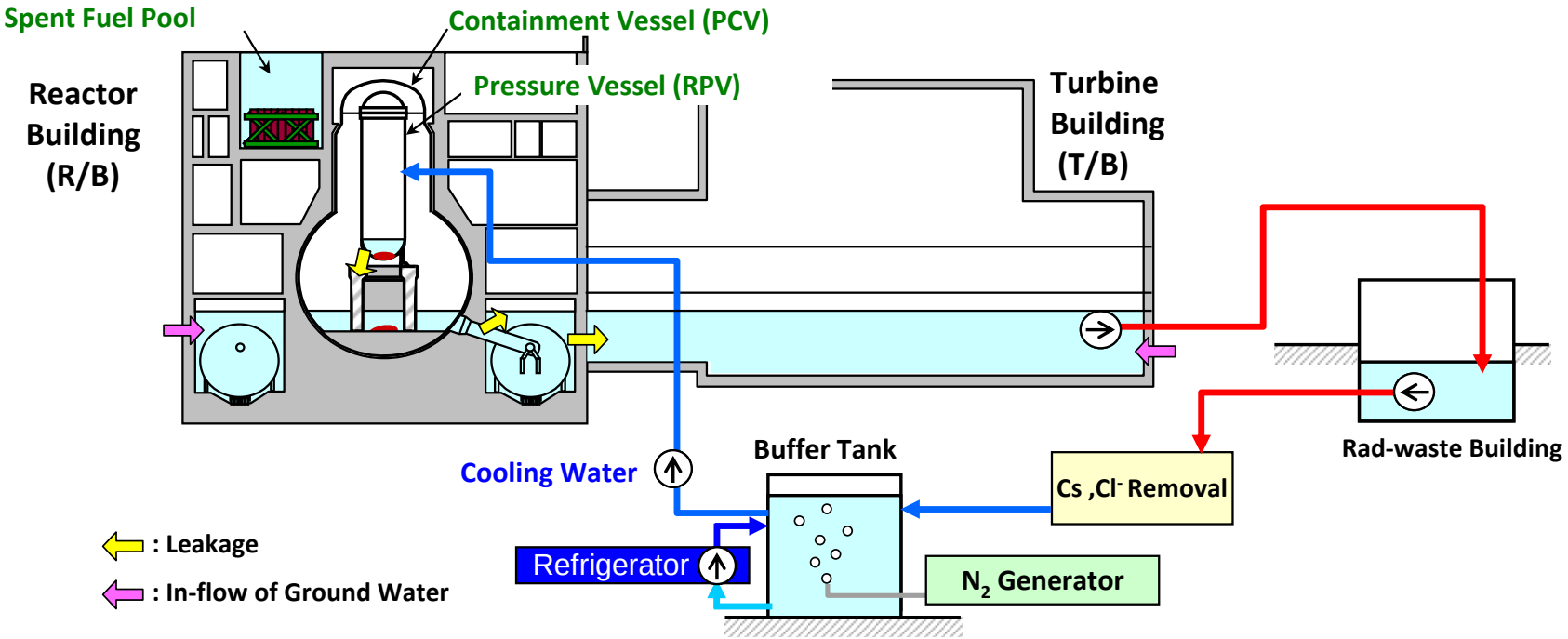

Motivations for Cesium Removal at Fukushima

- 400 m^3/day of excess cooling water (~100 kgal/day)
- High cesium content, 5 x 10^6 Bq/ml (135 µCi/ml) and high dose rate
- By June 2011, storage capacity (radwaste building) was rapidly filling with no viable options
- Removal of cesium would allow multiple storage options and buy time for future treatment to remove less problematic contaminants

- Kurion's cesium removal system was designed, fabricated, and delivered in less than 3 months. It began operating on June 17th.

Comparison of Hanford Tank Waste to Fukushima Cooling Water

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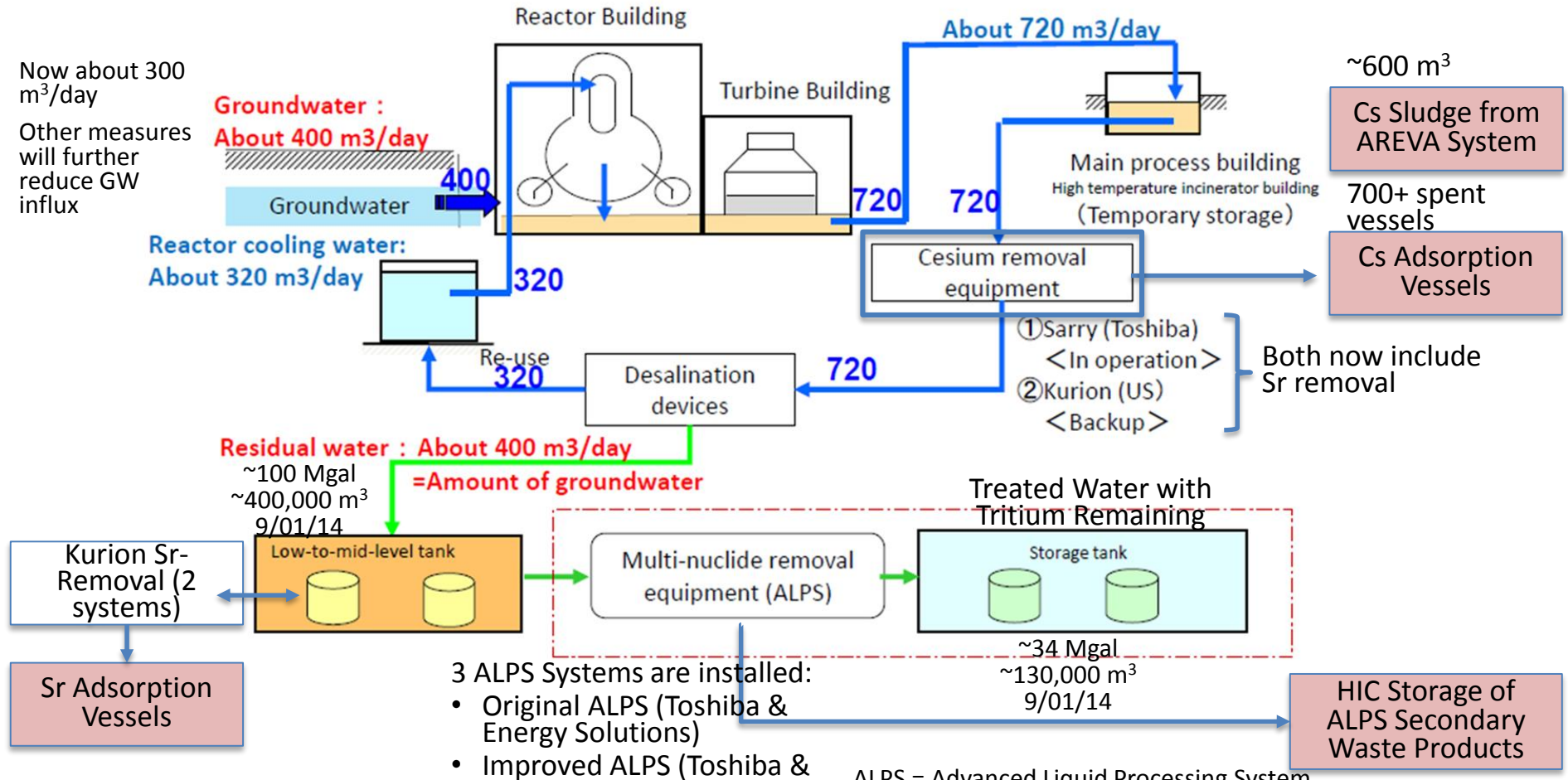
	Hanford Tank Waste	Fukushima
Total Cs-137	39 MCi	19 MCi (Melted fuel and contaminated water)
Concentration	236 µCi/mL (LAWPS Conceptual Design Specification)	135 µCi/mL (initial) 0.54 µCi/mL (recent)
Chemistry	Highly alkaline (high pH) with high sodium concentration	Initially, highly saline (from seawater used to cool reactors) but now resembles local groundwater
		Removed = 7.0 MCi (through August 2014)

Fukushima Water Treatment System



ALPS = Advanced Liquid Processing System
SARRY = Simplified active water retrieval and recovery system
HIC = High-Integrity Container
Sr = Strontium

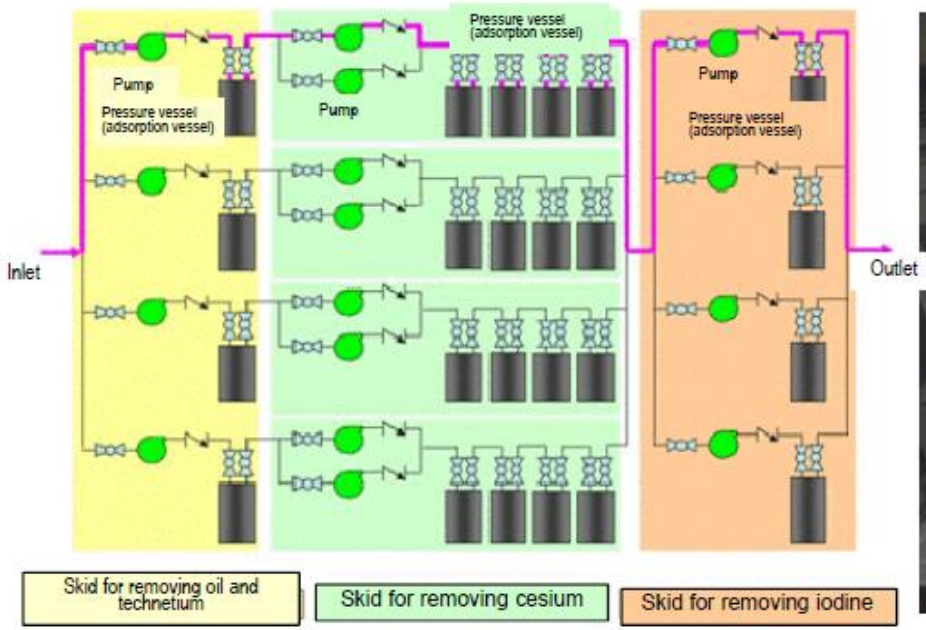
Three primary cesium removal technologies have been used at Fukushima

1. Areva
   - Coagulation/sedimentation process
   - Generated very large volume of difficult to manage waste sludge (~600 m^3) stored in tanks (ferrocyanide and other issues)
   - Discontinued operation after about 3 months (June-August 2011)
2. Kurion
   - Zeolite-based system; herschelite-based media (chabazite – naturally-occurring mineral) (KUR-H™ later replaced with KUR-EH™)
   - Spent adsorbent columns replaced then removed to storage
   - Shielding provided by carbon steel outer container
   - Strontium removal recently added (KUR-TSG™)
   - Operated June 2011 to present
3. SARRY: Hitachi with Shaw Environmental and AVANTech
   - Zeolite-based system; crystalline silico-titanate (CST) man-made media;
   - Spent adsorbent columns replaced then removed to storage
   - Shielding from double-layered carbon steel container with lead shot in annulus
   - Passive cooling integrated into container design
   - Strontium removal recently added
   - Operated August 2011 to present

Sources: IRID, TEPCO, Kurion, AVANTech

Cesium adsorption device (Kurion)

Outline of cesium adsorption apparatus (KURION)



Appearance of cesium adsorption apparatus

- Dimensions: 1.4 m (dia) x 2.4 m (h)
- Weight: Approx. 15 tons
- Zeolite-filled stainless steel vessel with carbon steel container as shield
- Surface dose rate = 400 mrem/h (Vessel replaced at this dose)

- Up to ~20k – 30k curies cesium per vessel
- Decontamination Factor (DF) = 10^5 – 10^6
- Processing capacity: up to 1,200 m^3/day (with 4 systems)
- ~600 spent vessels in storage (4.6 MCi as of August 2014 [JAEA])

Source: IRID

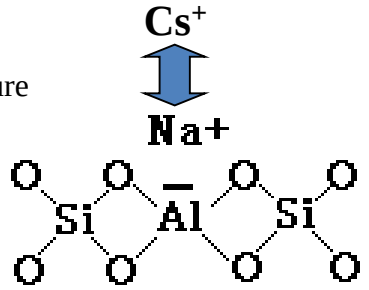
Method of decontamination employed by cesium adsorption tower (Kurion)

- Decontamination by adsorption tower
  - Accumulated water is passed through the adsorption tower that has been charged with an adsorbent and the radioactive materials and contaminated materials are removed.
  - Zeolite is used as the adsorbent because its basic design enables it to remove oil, technetium (Tc), cesium (Cs) and iodine (I). (Sr removal has recently been added.)
    - By leveraging the ion exchange effect of zeolite, radioactive materials, such as cesium, are adsorbed and the water is purified.
    - Zeolite is the broad name for aluminosilicates with relatively large spaces in their crystalline construction. They are inorganic and have superior radiation-resistant properties.
    - Zeolite was also used at Three Mile Island in the US to treat contaminated water.

Zeolite example

Chabazite is a naturally-occurring zeolite that Kurion has modified for cesium removal at Fukushima.

Positive ions within the structure are replaced by Cs



Source: TEPCO

2nd Cesium adsorption device -- Simplified Active Water Retrieval and Recovery System (SARRY)

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Source: TEPCO

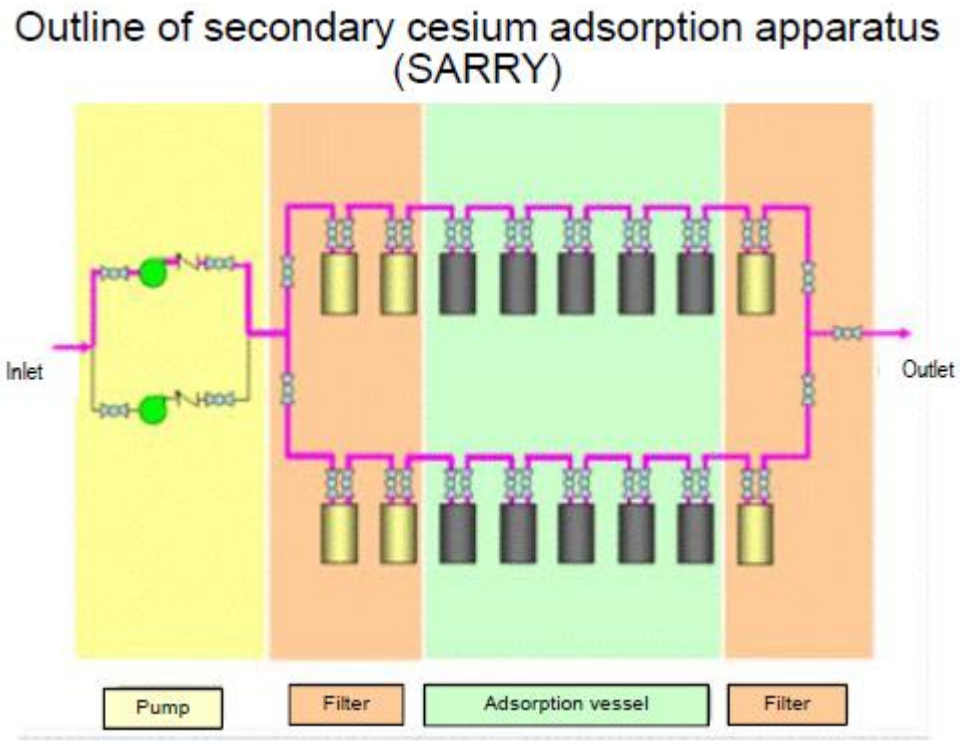
- Contaminated water is fed through a special material (zeolite) that selectively adsorbs radioactive materials.
- Spent vessels are periodically replaced.
- The SARRY system is a cooperative effort by Hitachi, Shaw Environmental, and AVANTech.

SARRY (2nd) Cesium adsorption device

- Up to ~200k Ci cesium per vessel
- DF = 10^6
- Surface dose rate = 400 mrem/h
- Passive cooling system built into container design
- Processing capacity: 1,000 – 1,200 m^3/day (with two systems)
- ~120 spent vessels in storage; ~2.4 MCi (August 2014, JAEA)
- Cylinder: Weight: Approx. 24 tons, Outer diameter: 1.4m, Height: Approx. 3.6m

Outer appearance of 2nd Cesium adsorption device – (SARRY)

2nd Cesium adsorption device
(vessel loading)



Source: TEPCO & IRID

Cesium adsorption tower temporary storage facility

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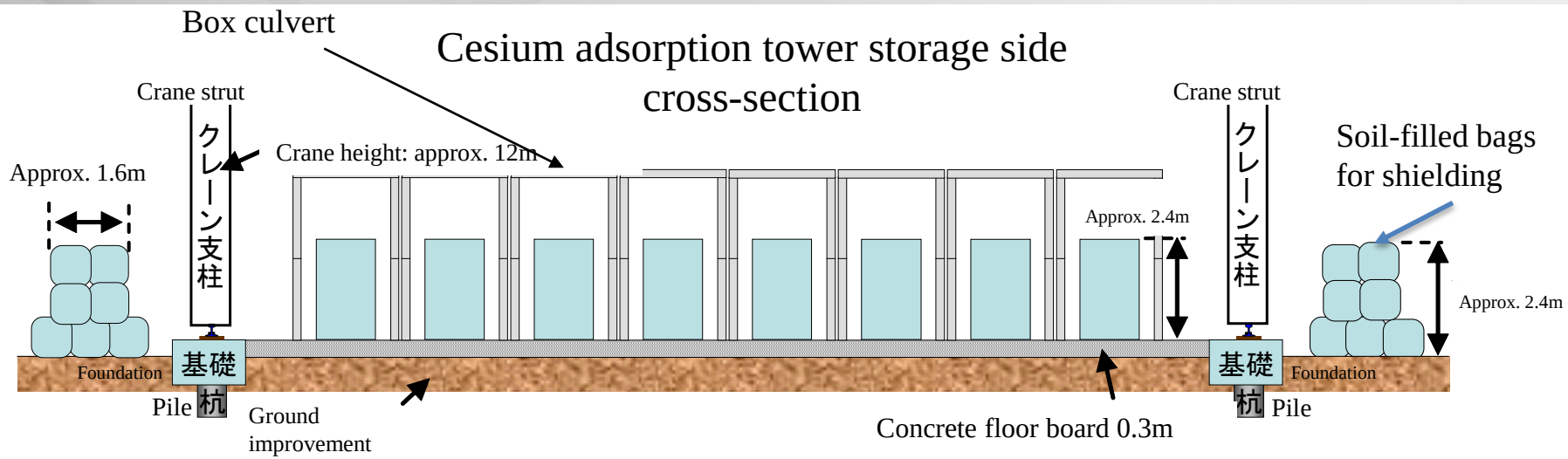
Source: TEPCO

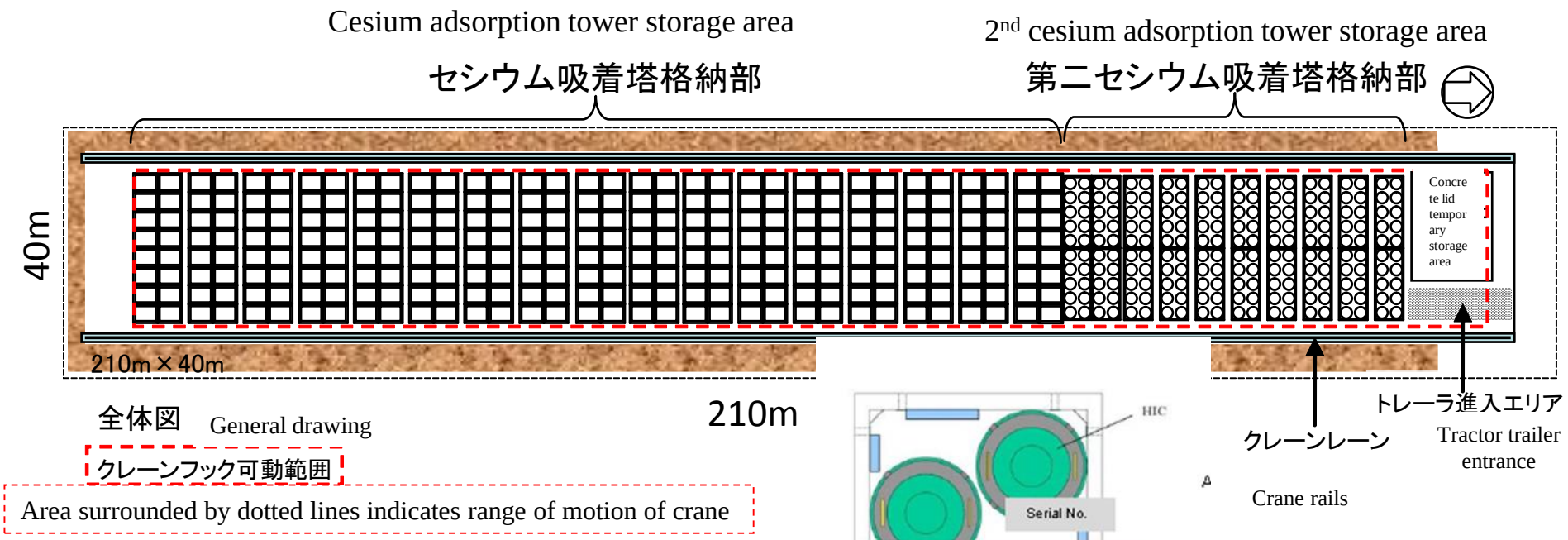
Kurion cesium adsorption towers: 594, SARRY cesium adsorption towers: 122 (as of March 27, 2015)

Cesium adsorption tower temporary storage facility



Source: TEPCO

Cesium adsorption tower temporary storage facility



Two spent adsorbent vessels stored in each concrete box (HICs shown)

Source: TEPCO

Research into long-term storage and disposition of Fukushima waste

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(Source: International Research Institute for Reactor Decommissioning (IRID), July 18, 2014)

Characterization
- Analysis on concentrations of radioactive nuclide
- Physical properties and chemical composition

Long term storage
- Assessment of safety on long term storage
  - Safety of hydrogen gas
  - Corrosion of container
  - Stability of waste

Conditioning (processing for disposal package)
- Technical research on conditioning
- Basic test for technical assessment
  - Vitrification
  - Geopolymer solidification

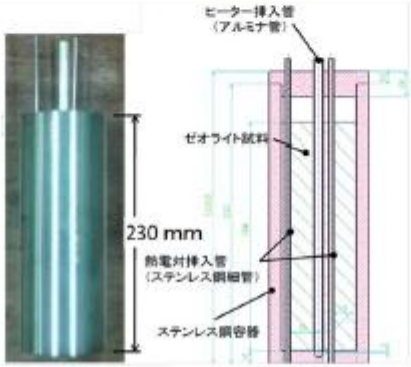
Disposal
- Investigating disposal concept
- Disposal safety assessment
  - Domestic and international research on disposal concept and safety assessment techniques, and their applicability

Analysis on radioactive nuclide in waste

JAEA staff collecting rubble near 4th reactor

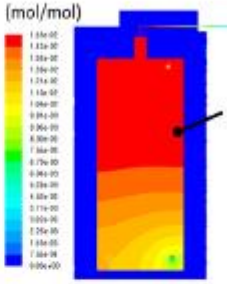
Analytical work on ^{3}H, ^{14}C

Measurement of thermal conductivity of waste



Measurement of effective thermal conductivity of zeolite layer

Hydrogen generation from the waste



$[H_2] \leq 1.51\%$ (less than explosive limit)

Calculated result on hydrogen concentration

Basic test for technical assessment on conditioning

Vitrification

Geopolymer solidification

Japan Atomic Energy Agency (JAEA) Research on Storage and Disposition of Spent Cs Vessels

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- Heat load distribution (maximum temperature ~500º F)
- Hydrogen generation and diffusion (vessels are vented; hydrogen concentration < 1.8%)
- Options for long-term storage and disposition including vitrification testing of zeolite media

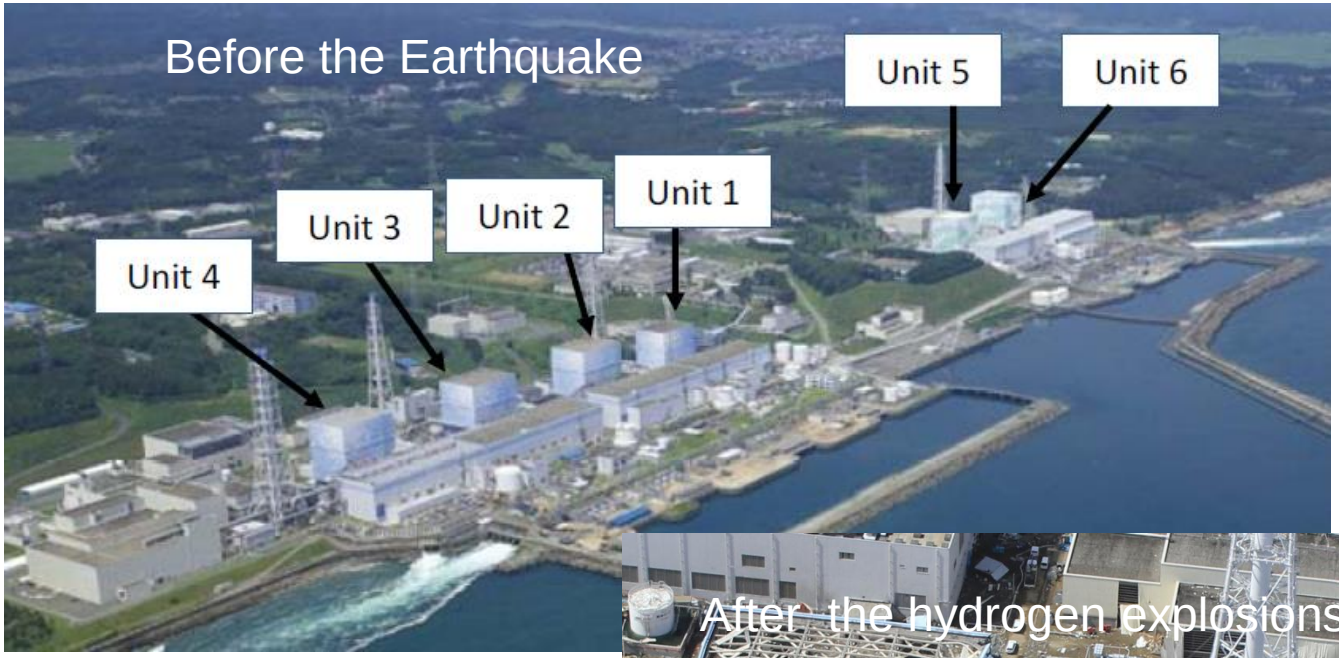
Closing

- Fukushima will continue to remove cesium, strontium and other radionuclides from reactor cooling water
- Cesium and strontium removal and storage operations are working well with very high reliability
- Key storage issues have been addressed with support from the Japan Atomic Energy Agency (JAEA)
  - Dose, shielding, safe storage system
  - Heat generation and stability of media
  - Hydrogen generation, etc.
- Options for long-term disposition including vitrification media are being evaluated

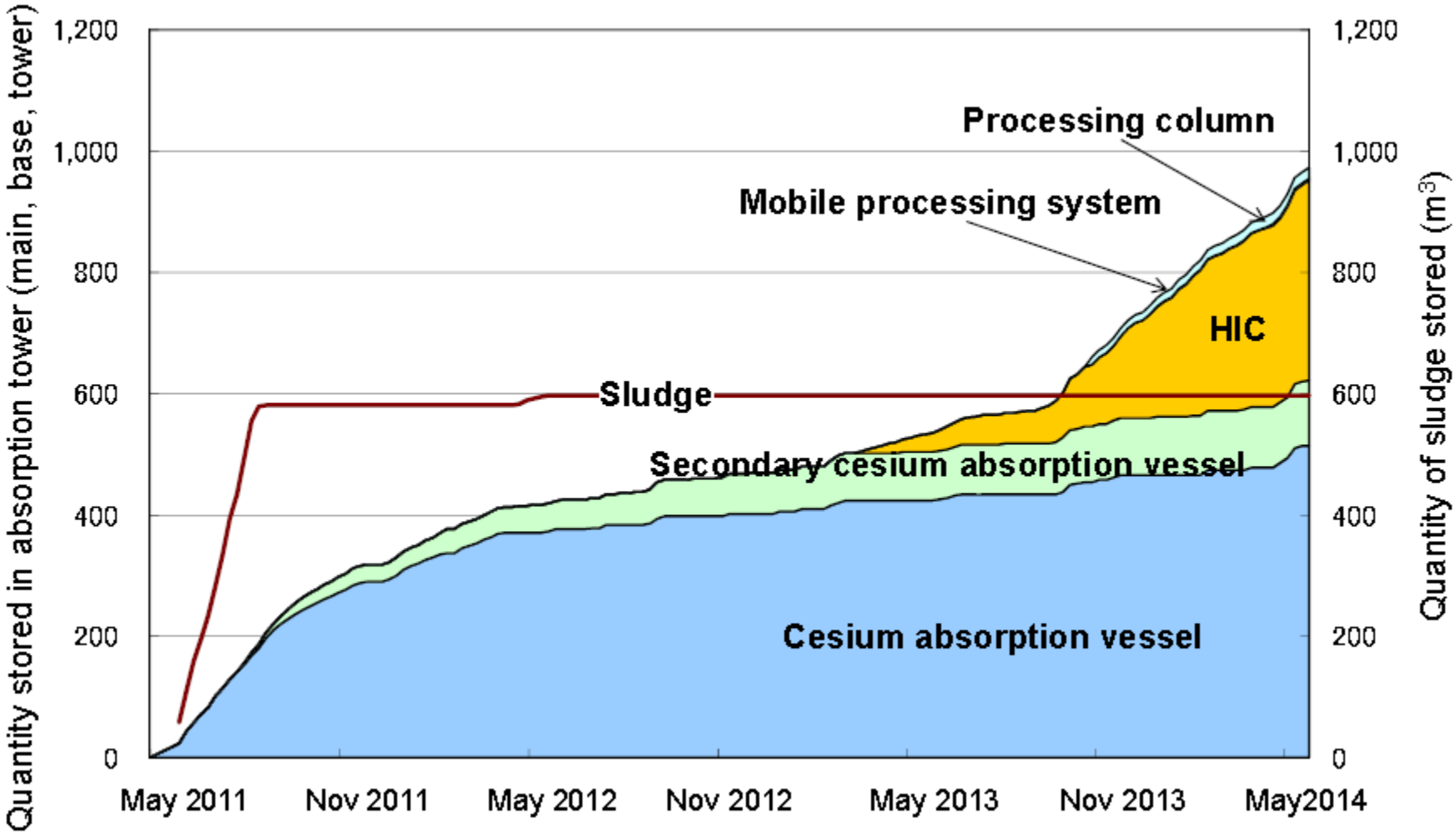
Backup Slides

Background – March 11, 2011 Earthquake and Tsunami

Accident at Fukushima



Quantity of secondary wastes in storage at Fukushima Daiichi



Source: IRID