Nuclear News Presents:

A Look Back at the Fukushima Daiichi Accident

Tuesday, March 2

Webinar Program

- Report Safety Recommendations
  - Dale Klein, Former Chairman of USNRC
  - Mike Corradini, Emeritus Professor, University of Wisconsin
- Lessons Learned from Forensics
  - Joy Rempe, Principal, Rempe and Assoc. LLC
- Site Cleanup & Decommissioning
  - Lake Barrett, Senior advisor, TEPCO and IRID
- Socio-Economic Aspects
  - Paul Dickman, Senior Policy Fellow, Argonne National Lab

ANS Special Committee on Fukushima

The special committee was formed by ANS in Spring 2011.

The objective was to provide a clear and concise explanation of the events surrounding the accident to the general public as well as the needed actions to better communicate with the public.

http://fukushima.ans.org

Co-Chairs: Dale Klein, Univ. of Texas, Michael Corradini, Univ. of Wisconsin

Paul T. Dickman, Argonne National Laboratory

Jacopo Buongiorno, Massachusetts Institute of Technology

Hisashi Ninokata, Tokyo Institute of Technology

Mike Ryan, M.T. Ryan and Associates LLC

Craig D. Sawyer, Retired Senior Engineer

Amir Shahkarami, Exelon Nuclear

Akira Tokuhiro, University of Idaho

Special Thanks to Laura Scheele, Former ANS Staff (now at INL)

ANS Special Committee on Fukushima

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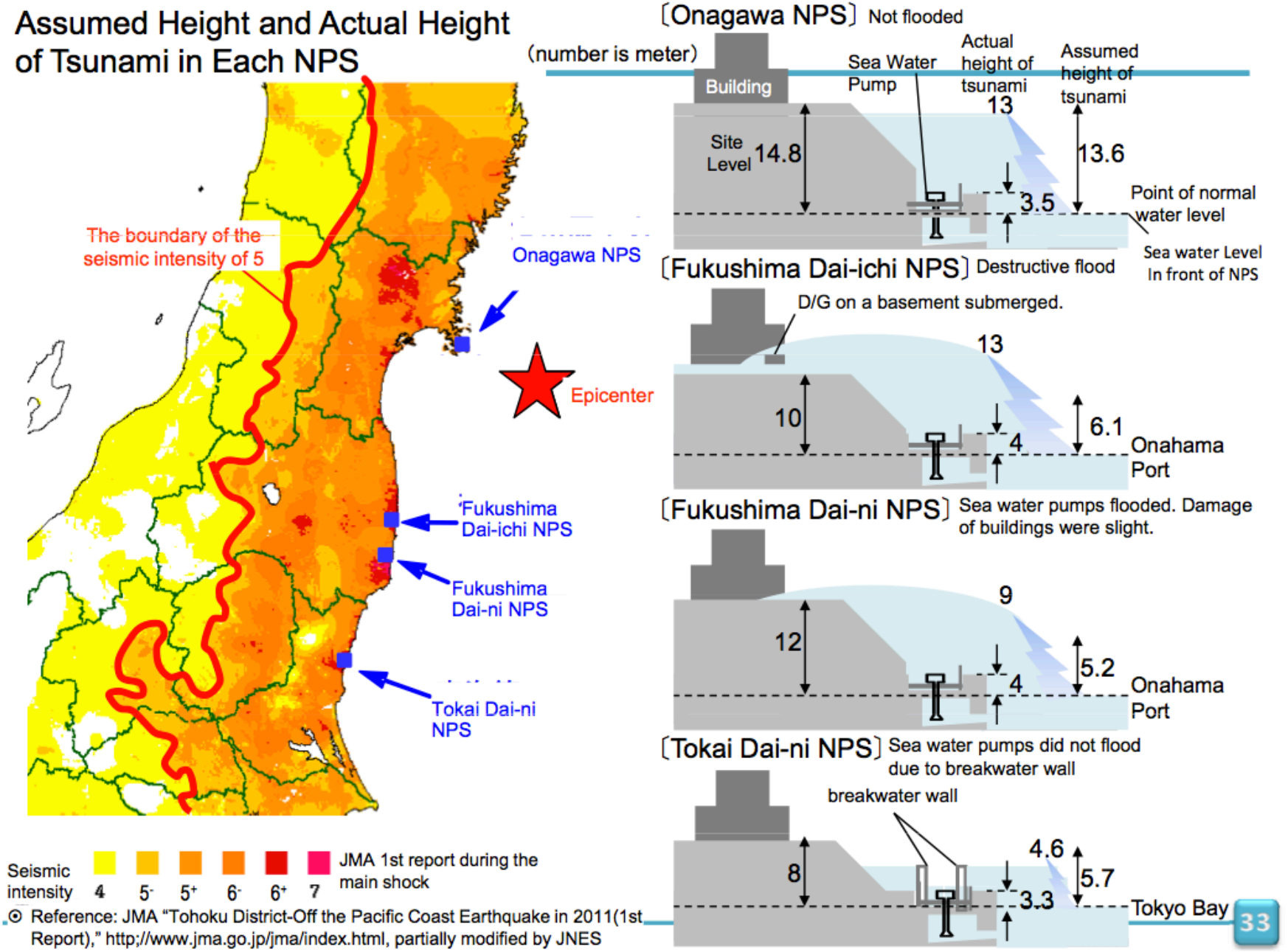
Fukushima-1 Accident Summary

- March 11th earthquake/tsunami struck Fukushima Daiichi, a six-unit BWR nuclear plant site on the NE coast of Japan
- Earthquake/tsunami caused station blackout, disabling safety systems
- Extensive fuel damage occurred in the reactors at Units 1-3
- Containment failure at Units 1-3 resulted in a release of radioactive materials into atmosphere and ocean
- The accident resulted in large environmental impacts
- Nuclear Industry and Regulators have learned lessons from the events and the analysis

Tsunami Effect on Power Plant Sites



Report Safety Recommendations

Report focus on key technical issues as a basis for regulatory actions

- Risk-informed approach to safety; e.g., SFP study, SAWA study
- External Hazards: Confirm plants have consistent and appropriate design bases for natural disasters (reassess on periodic basis)
- Multi-unit risk should be part of plant safety assessments
- Accident diagnostic tool development; BWROG, PWROG efforts
- Plant hardware design modifications; e.g., FLEX approach (use of installed safety systems, on-site operator actions, off-site assist)
  - Protect DC batteries and improve robustness of RCIC & AFW
  - Ability to reroute water sources with robust pump systems
  - Logistically position fuel, generators and pumps to move onto plant site

Report Safety Recommendations

- Develop Severe Accident Guidelines (coordination with Emergency Proc. by BWR & PWR Owner's groups)
- Command & control: Confirm that command/control of an accident resides with plant manager on-site to assure safety during any event
- Emergency Planning: Confirm that current approach to EP is appropriate
- Health Physics assessment need to continue for long-term (e.g., https://www.mdpi.com/1660-4601/15/6/1219)
- Perform Societal Risk comparison for all energy sources.

Interim Lessons from Daiichi Forensics Examinations

Joy Rempe
Rempe and Associates, LLC

Acknowledgement:
This presentation draws upon information from the DOE-sponsored U.S. Forensics Effort, a collaborative U.S. /Japan effort with participation by experts in plant operations and reactor safety. In particular, the author would like to acknowledge the contributions of Shinya Mizokami and Tatsuro Kobayashi, TEPCO Holdings Company; Akira Nakayoshi and Tadahiro Washiya, Japan Atomic Energy Agency; Masaya Yasui, Japan Nuclear Regulatory Authority; Phil Amway, Exelon Corporation and BWR Owners Group (BWROG); Mitch Farmer, Argonne National Laboratory; Bill Williamson, TVA and BWROG; Kevin Robb, Oak Ridge National Laboratory; Jeff Gabor, Jensen Hughes; Wison Luangdilok, Chan Paik, and Marty Plys, Fauske and Associates, LLC; Randy Bunt, Southern Nuclear Company and BWROG; Phil Ellison, GE Hitachi and BWROG; Roy Linthicum, PWR Owners Group (PWROG); Lucas Albright, Nathan Andrews, Randy Gauntt (retired), and David Luxat, Sandia National Laboratories; Michael Corradini, University of Wisconsin-Madison; Karen Kirkland, Texas A&M University, Kelli Voelsing and Matthew Nudi, Electric Power Research Institute; Donald Algama, Hossein Esmaili, Richard Lee (retired) and Don Marksberry, US Nuclear Regulatory Commission; and Damian Peko, US Department of Energy.

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DOE Forensics Effort Coordinated with TEPCO D&D Activities

Objectives:

- Develop consensus US input for *high priority time-sequenced examination tasks and supporting research* that can be completed with minimal disruption of TEPCO Decommissioning and Decontamination (D&D) activities
- Evaluate obtained information to:
  - Gain a better understanding of events that occurred in each unit at Daiichi
  - Gain insights to reduce uncertainties in predicting phenomena and equipment performance during severe accidents
  - Provide insights beneficial to TEPCO Phase 2 Fuel Debris Retrieval Evaluations
  - Confirm/improve guidance for severe accident prevention, mitigation, and emergency planning
  - Periodically update/refine original information requests
- Facilitate implementation of Japan-led international research efforts to support D&D

Motivations:

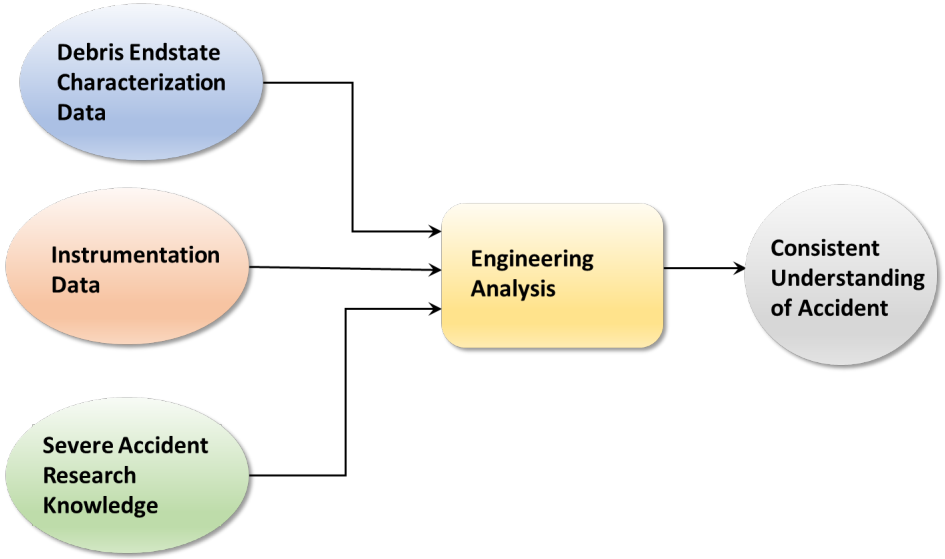
- Provides US access to full-scale, prototypic data from multiple units with distinct accident signatures
- Provides Japan access to US expertise in plant operations, severe accident modeling & testing, and defueling & cleanup

Image Courtesy of ANS

FY2020 report publicly available (https://www.osti.gov/biblio/1602189)

FY2021 report with updated information need requests (March 2021).

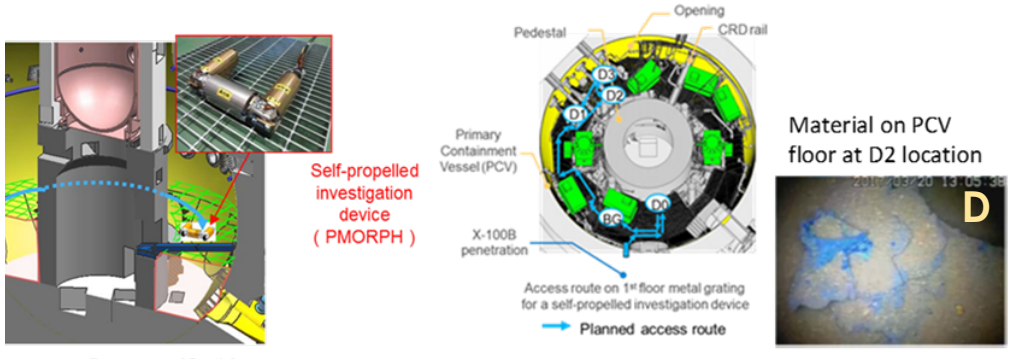
Similar Approach Applied for Post-Accident Investigations



- **Process relies on instrumentation data, post-accident examinations, existing severe accident knowledge, and engineering analyses**
- **Efforts initially focused on stabilizing reactors and associated structures before focusing on cleanup**

- **Key to prioritize activities, emphasizing those that:**
  - **Minimize future radiation releases and site hazards,**
  - **Ensure safe and efficient D&D, and**
  - ***As resources allow*, reduce uncertainties related to accident progression and reactor safety enhancement.**
- **Most high priority information *desired* for reactor safety insights *required* for D&D**

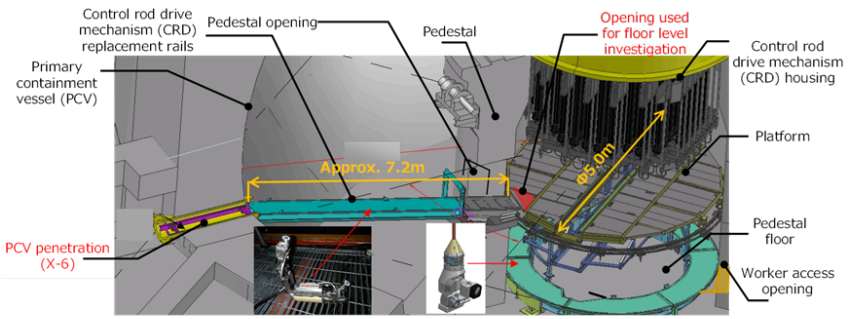
1F1 Information Confirms Adequacy of Revised U.S. Severe Accident Management Strategies

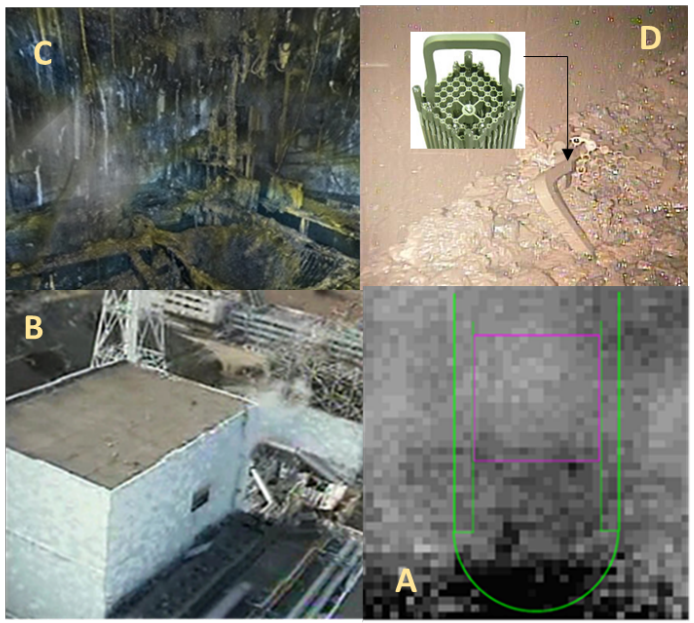


Graphics Courtesy of TEPCO and Fukushima Central Television (FCT)

- BWR/3 rated at 460 MWe in Mark I containment with Isolation Condensers (ICs) for decay heat removal
- Seismic accelerations, tsunami flooding, and station blackout hindered accident mitigation:
  - IC operation
  - Instrumentation availability and calibration
  - Venting
- Plant data, radiation surveys, calculations, and images from muon tomography and robotic inspections indicate:
  - Significant fuel heatup and relocation
  - High temperatures/pressures led to Primary Containment Vessel (PCV) leakage, hydrogen release, and combustion
  - Significant damage to the reactor building and missile shield
  - Reactor Pressure Vessel (RPV) failure and significant relocation to PCV (initial examinations limited to locations external to pedestal)
  - Extent of core concrete interaction uncertain

1F2 Information Confirms Adequacy of Revised U.S. Severe Accident Management Strategies

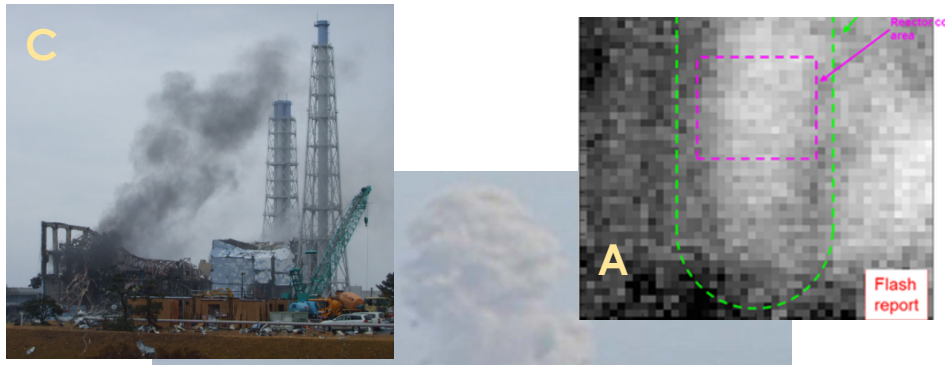


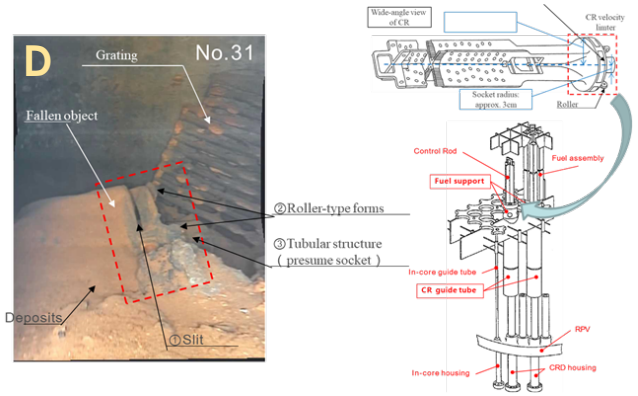


- BWR/4 rated at 784 MWe in Mark I containment with Reactor Core Isolation Cooling (RCIC) system for decay heat removal
- Available information indicates accident progression less advanced:
  - RCIC operation continued for nearly 3 days.
  - H_2 explosion precluded due to “unintentional” early Reactor Building (RB) venting
  - RPV failure with ex-vessel debris holdup on structures
  - Significant relocation and spreading into PCV
  - PCV water level lower than in Unit 1
  - Units 1 and 3 explosions delayed recovery efforts

Graphics Courtesy of TEPCO

1F3 Information Confirms Adequacy of Revised U.S. Severe Accident Management Strategies





Graphics Courtesy of TEPCO, IRID, and FCT

- BWR/4 rated at 784 MWe in Mark I containment with RCIC system.
- Available information indicates accident progression more advanced than in Unit 2:
  - RCIC operation continued for less than 1 day
  - Significant fuel heatup and relocation
  - High temperatures/pressures led to PCV leakage and a multi-stage explosion
  - Venting through Standby Gas Treatment System led to Unit 4 explosion
  - RPV failure with significant relocation and spreading into PCV
  - PCV water level much higher than in Units 1 and 2

Daiichi-Ten Years of Decontamination and Decommissioning

Three Mile Island
1984

American Nuclear Society
Webinar
March 2, 2021
Lake H. Barrett
Lake@Lbarrett.com

Photos Courtesy of TEPCO

Fukushima Daiichi
2015

March *Nuclear News*

ans.org/nn

March 2011 Units 1-4
Major Damage & Contamination

March 2011 Starting Conditions

- **Reactor Buildings Heavy Damage & High Radiation**
- **Melted Cores on Floor With Leaking Primary Containments**
- **Four Steaming Filled Spent Fuel Pools in Damaged Buildings**
- **Highly Contaminated Site**
- **Cs Dust Airborne Releases**
- **Hundreds of Tons per day of Highly Radioactive Water Leaking Into Basements and Pipe Trenches to Sea**

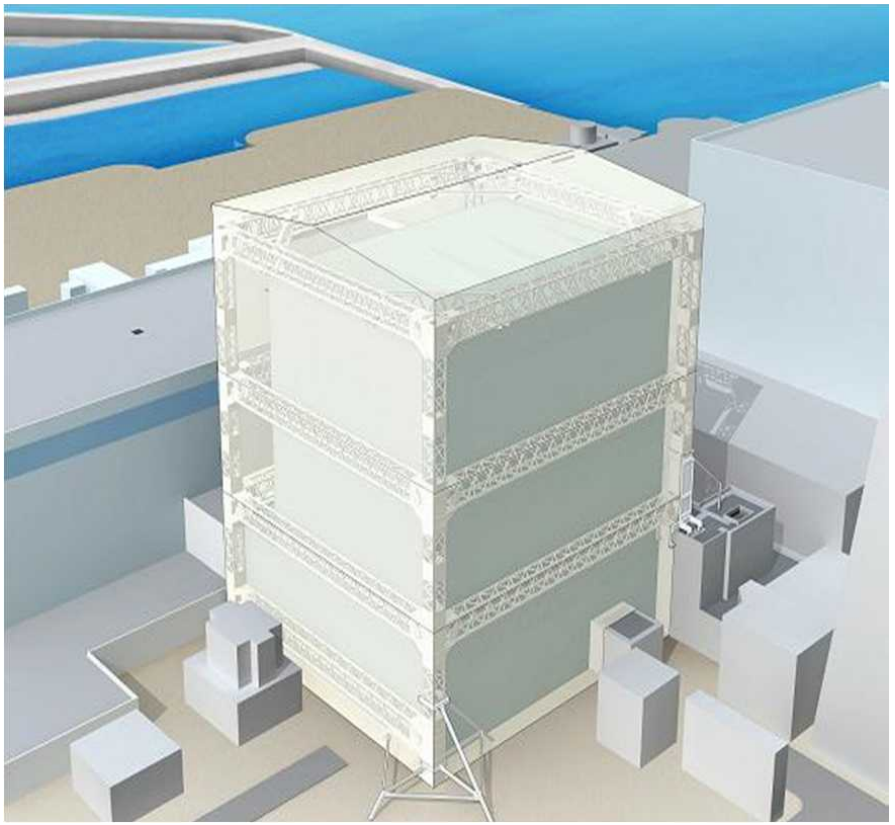
D&D General Approach

- Forward With Risk Informed Risk Reduction
- Worker Safety & Improve Working Conditions
- Stabilize Core Debris
- Control & Minimize Airborne Releases
- Control, Decontaminate, Store, and Eventually Safely Dispose of Radioactive Waters
- Defuel Four Damaged Spent Fuel Pools
- Decontaminate Site and Buildings
- Characterize Internal Core Debris Conditions
- Remove Core Debris
- Safely Process and Store Radioactive Wastes

Airborne Mitigation

Dust Suppression Resin Application

Extensive Soil Paving



Unit 1 Fabric Enclosure
55M High & 47M X 42M

Water Release Mitigation

Contain/Retard Intake Structure Cs/Sr Contamination

Sluice Gate to Minimize Outflow To Ocean

Sealing Underground Trenches

Steel Seawall Construction

Silt Fences, To Adsorb Cs/Sr

Ice wall Construction

Water Retention Tank Farms

Quickly Constructed & Expanded with Welded Tanks

Water Decontamination Systems

Cs & Contaminate Removal Allowed Recycle Cooling

Individual Zeolite Beds

Shielded Skids

Advanced Liquid Processing System:

Removes Most But Tritium

Operational 2013

High Radiation Solid Waste Storage

New Canister Storage Facility

5,000+ Cans March 2021
1-3M high each
Highly Radioactive ~Sv+/Hr.

Processed Salt Water Containing Tritium Is Stored On Site

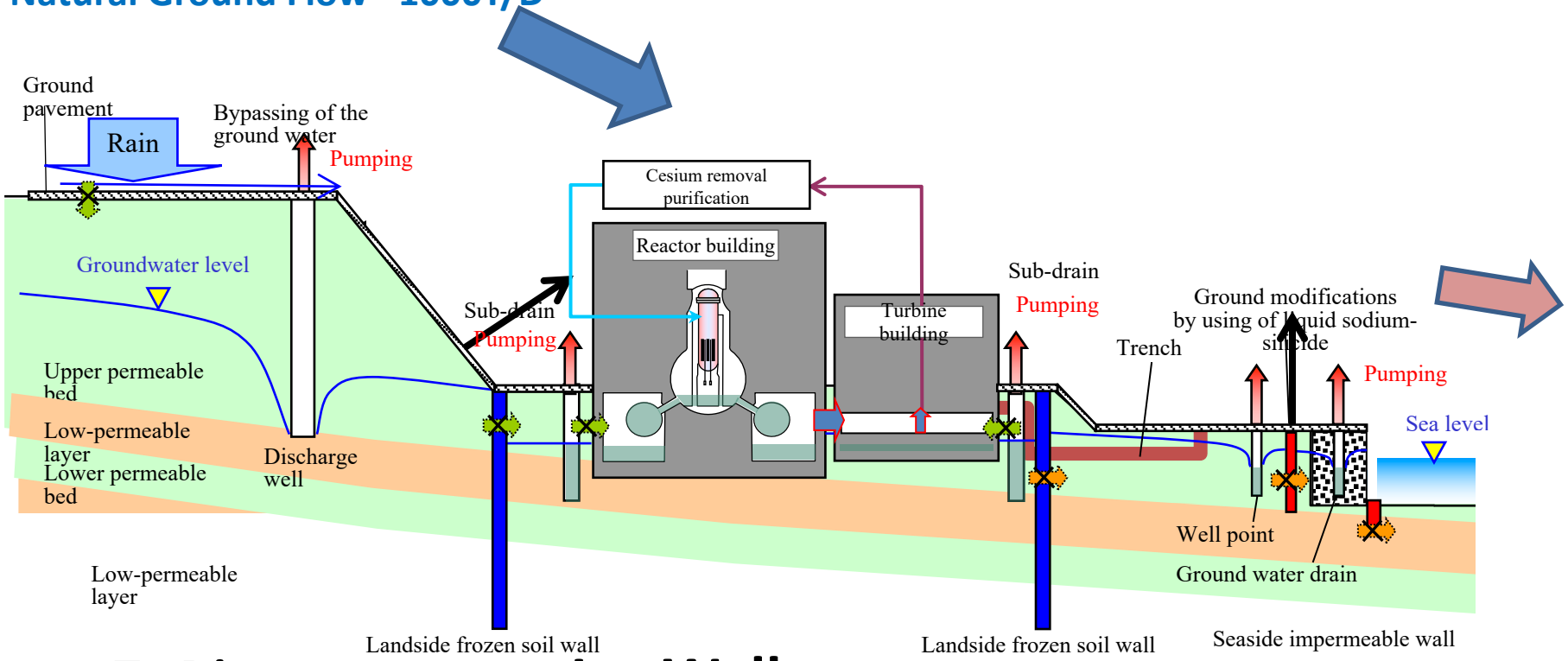
~1,000+ Tanks & ~1 Million Tons

Mitigating Groundwater Paths To Sea

Minor Contamination

Major Public Concern

Natural Ground Flow ~1000T/D



Pump To Divert Upper Ground Water

Ice Wall

To Reduce Building In leakage

Seaside Walls & Ground water Pumping

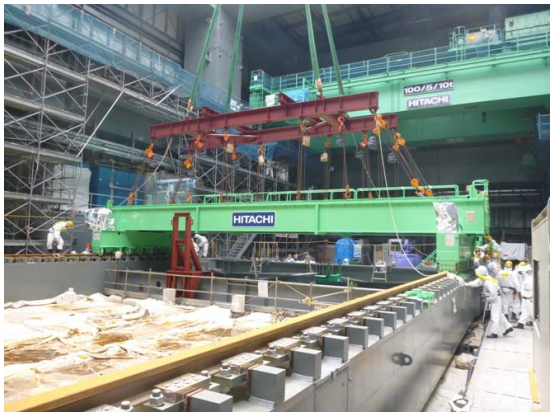
Spent Fuel Pool Defueling- Unit 4

Explosion Caused By Unit 3 H2 Backflow-Not SFP

2011

2013-New Seismic Cantilevered Building

Unit 4 SFP Defueling Success



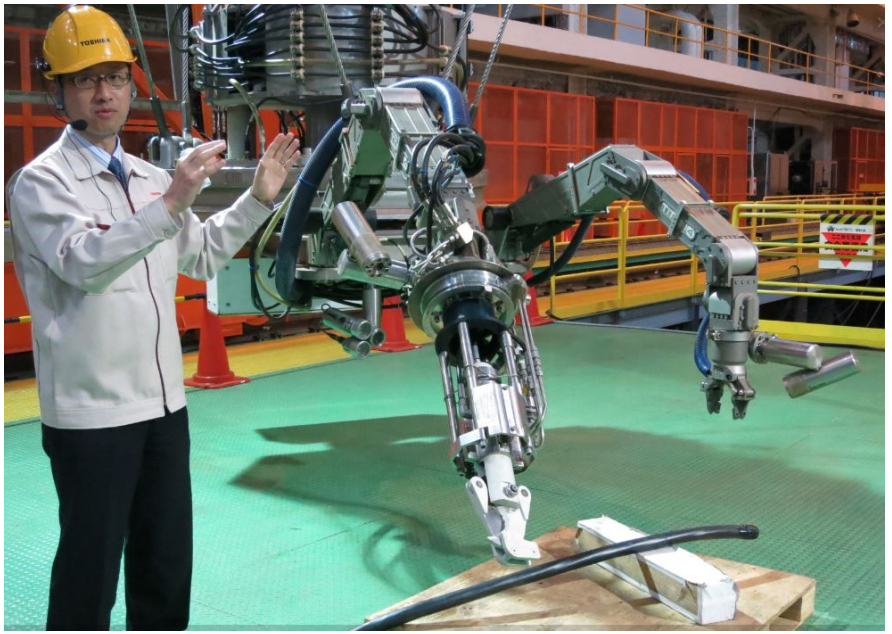
All 1533 Assemblies Safely Removed in 2014

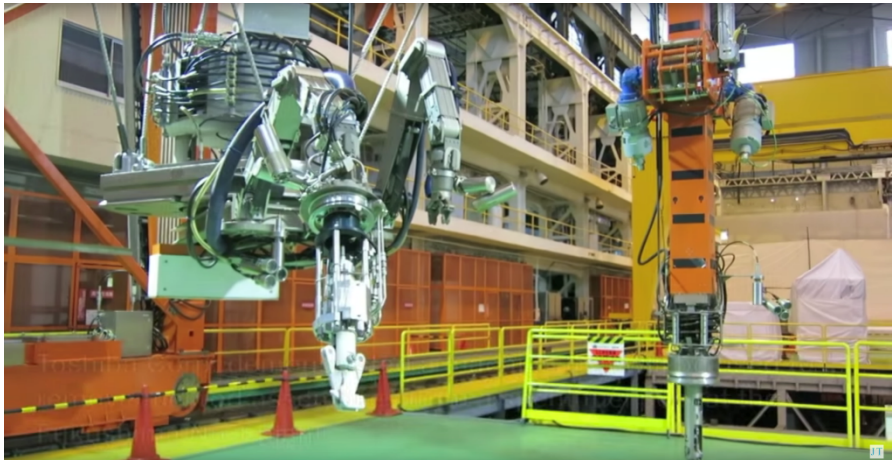
Spent Fuel Pool Defueling-Unit 3

2011-With Steaming Spent Fuel Pool

2018-New Seismic Defueling Building

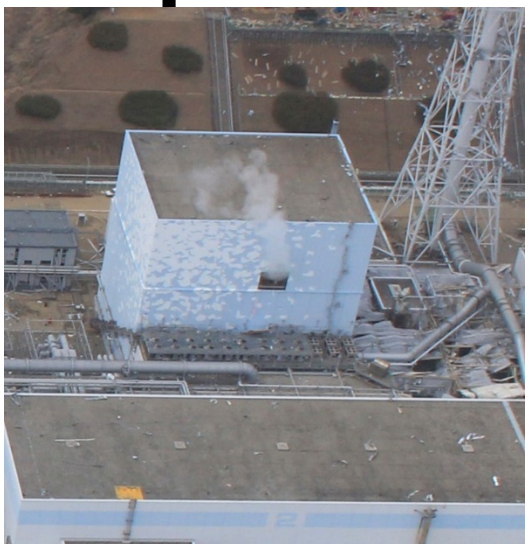
Unit 3 SFP Robotic Defueling: Completed





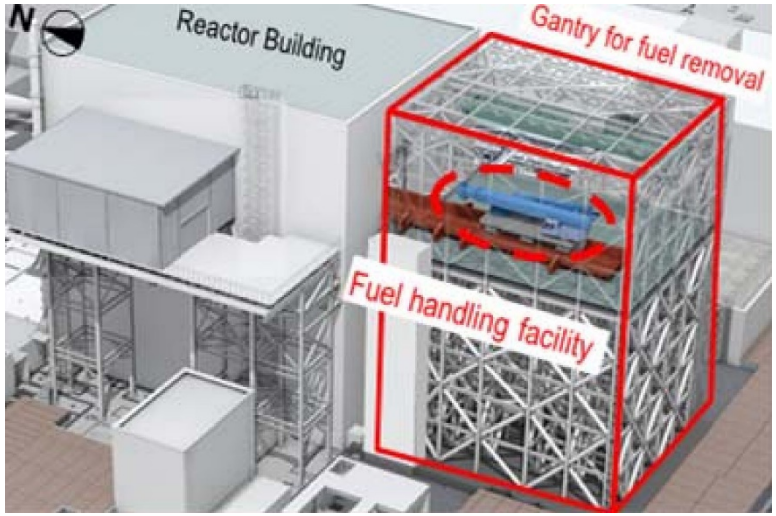
All 566 Fuel Assemblies
Safely Removed
28 February 2021

Spent Fuel Pool Defueling- Unit 2



2011

Defueling Floor Access-2018

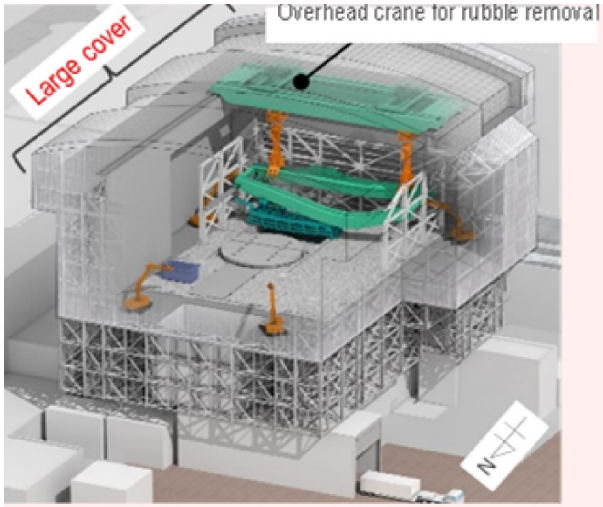


New Defueling Building Plan 2024-26

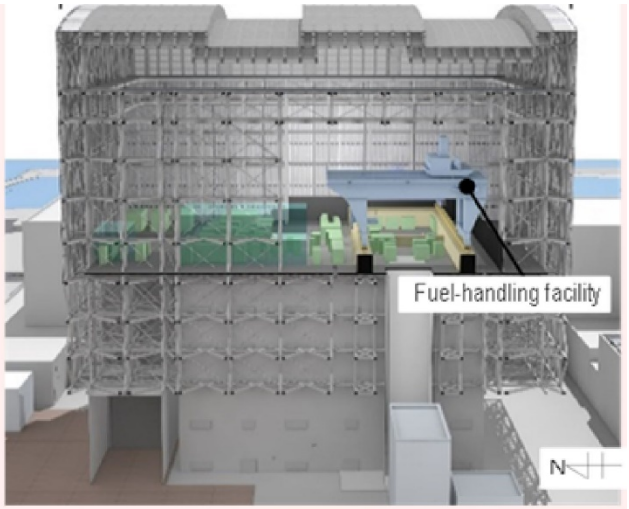
Spent Fuel Pool Defueling- Unit 1

2011

2013-Dust Mitigation Cover



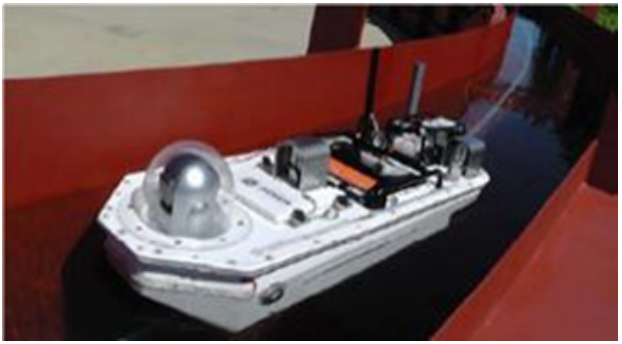
Rubble removal (image)



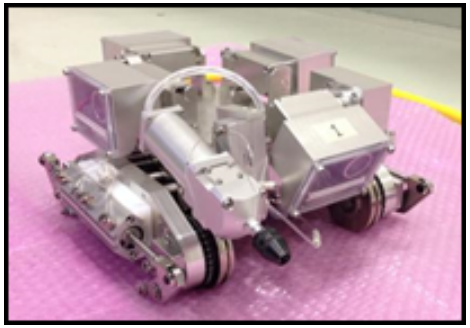
Fuel removal (image)

New Defueling Building Plan for 2027-28

Robotic Internal PCV Investigations



Unit 1 Torus Boat



U2 Torus
Magnetic Crawler

Unit 2 Swimming
Robot

U1 Shape Changing

U2 Scorpion

U3 Sunfish

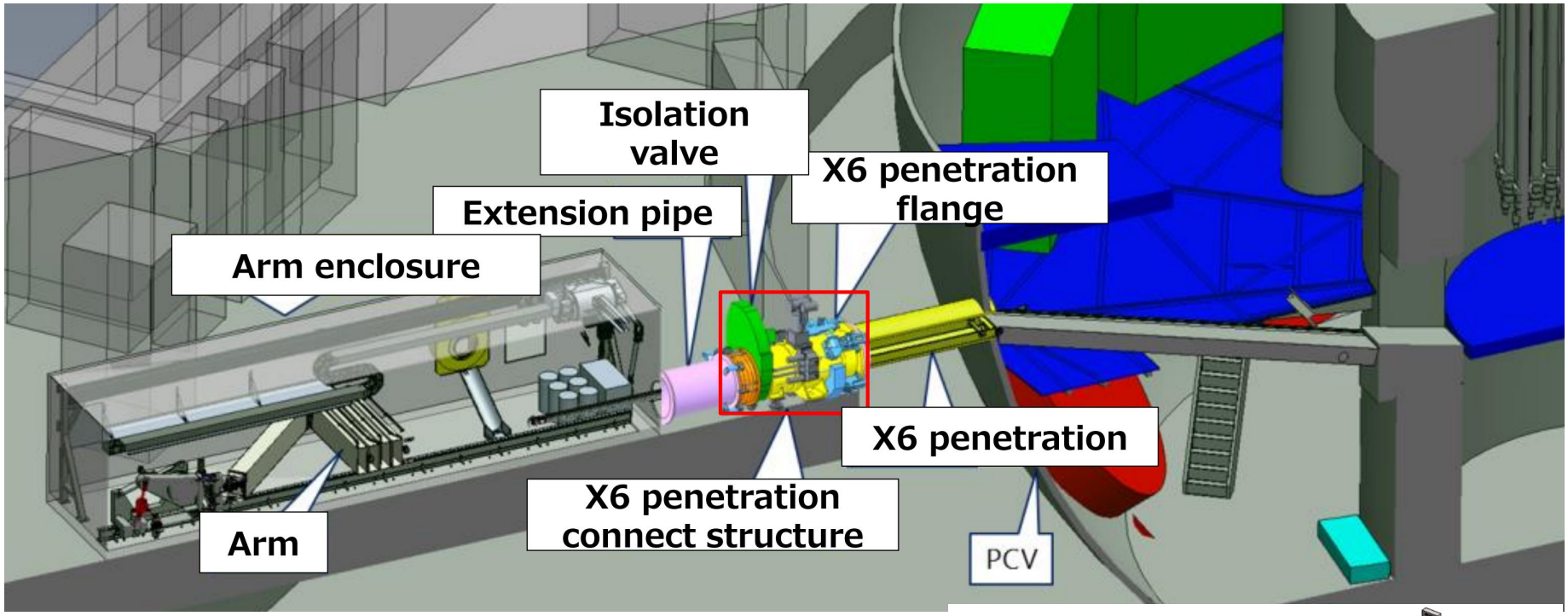
Unit 2 Core Debris Investigations

Fuel Assembly Lifting Handle & Ejected Core Internals

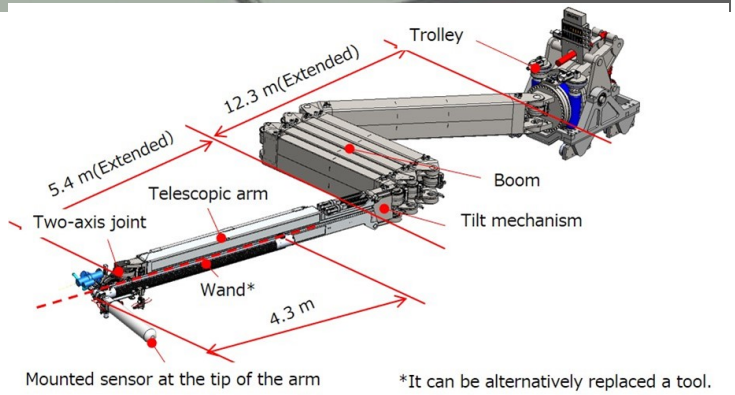
Unit 2- Under Pedestal Core Debris

Under Reactor Vessel: Melted Steel Grating

Unit 2 Core Debris Sample Removal



Planned 2021



22 M Long Remote Arm

Decontamination Robots Supports Defueling Access

Dry Ice Surface Blaster/Vacuum Robot System

Debris Removal Robot

Offsite Decontamination

Mostly Complete

House Roofs

Parking Lots

School Buildings

Children's Playgrounds

Offsite Decontamination Waste Management

Planning For a
~ 20 Million+ M3 Interim Storage Facility

Currently Thousands of Local Storage Sites

Difficult Social Issues

Human Feelings & Reactions

Future Outlook

- **Much Has Been Technically Accomplished & Many Challenges Ahead**
- **Social/Political Considerations Are Significant**
- **USA Successfully Recovered from the Three Mile Island Accident and Learned with Improved Nuclear Safety and Reactor Performance**
- **Japan Has the Capacity to Do So Also**

Fukushima: Social and Economic Impacts and Recovery

American Nuclear Society Webinar

March 2, 2021

Paul Dickman

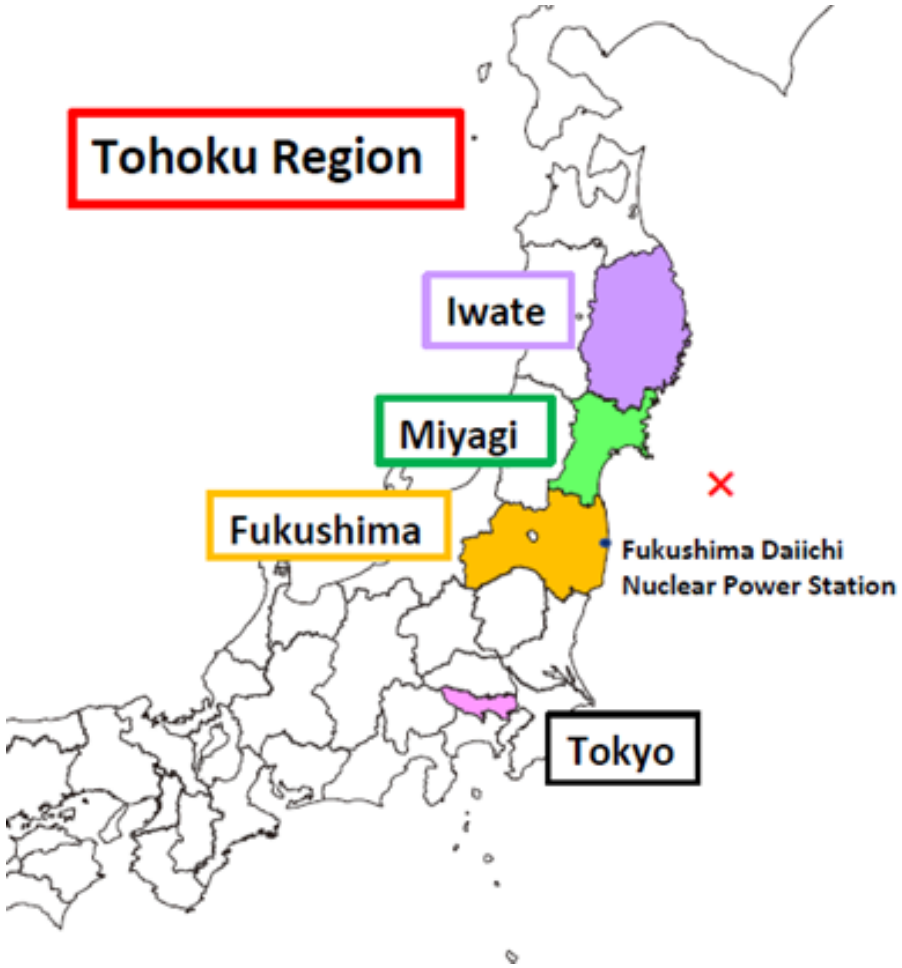
Argonne National Laboratory

Photo credit: Asahi Shimbun and REUTER

Quick Disclaimer

- I serve as an International Special Advisor to the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF), the Japanese Government agency responsible for the decommissioning of the Fukushima Daiichi accident site.
- My views are in support of the American Nuclear Society and may not reflect those of Argonne National Laboratory or the NDF.
- Contact: Paul.Dickman@anl.gov

The Great East Japan Earthquake and Tsunami Forced Massive Regional Evacuation



Human Casualties

- Deceased: 19,729
- Missing: 2,559
- Injured: 6,233

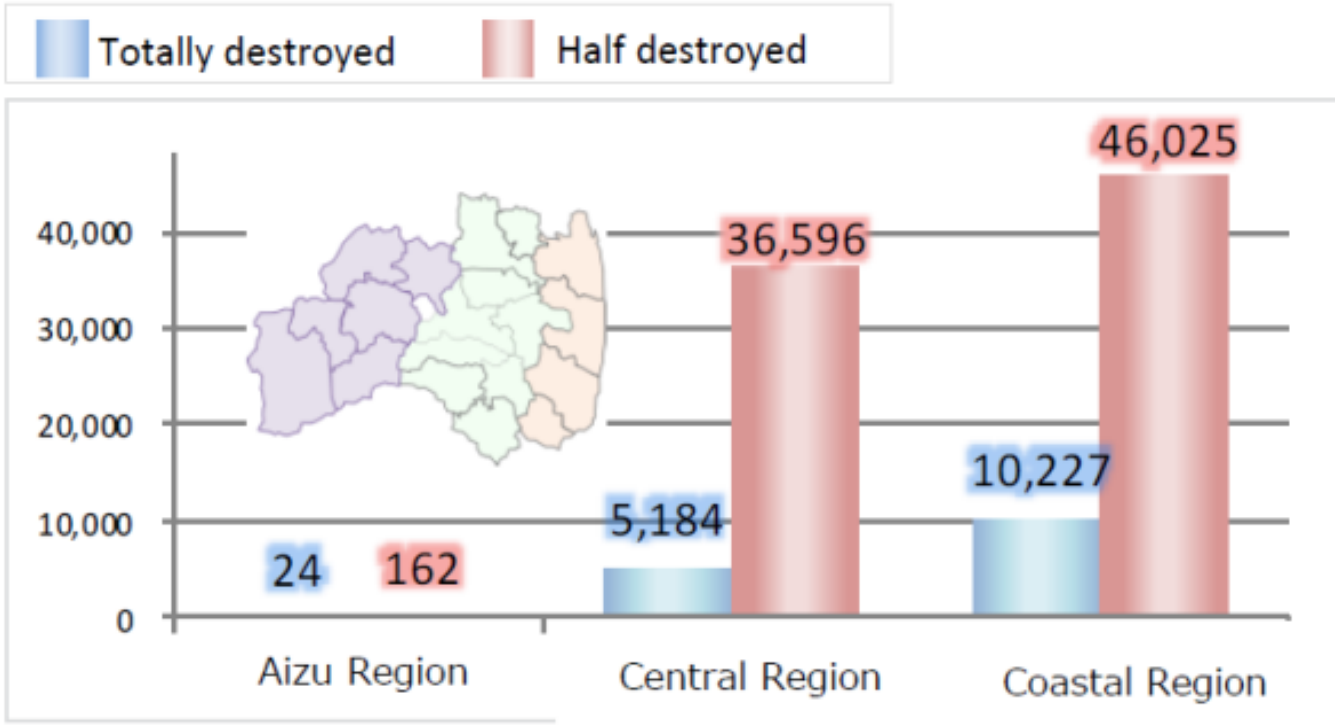
Damaged Buildings

- Completely destroyed: 121,996
- Half destroyed: 282,941
- Partially Destroyed: 748,461

Fukushima Area Devastation: Triple Impact

◆Damage status 【As of 2020.7.6】

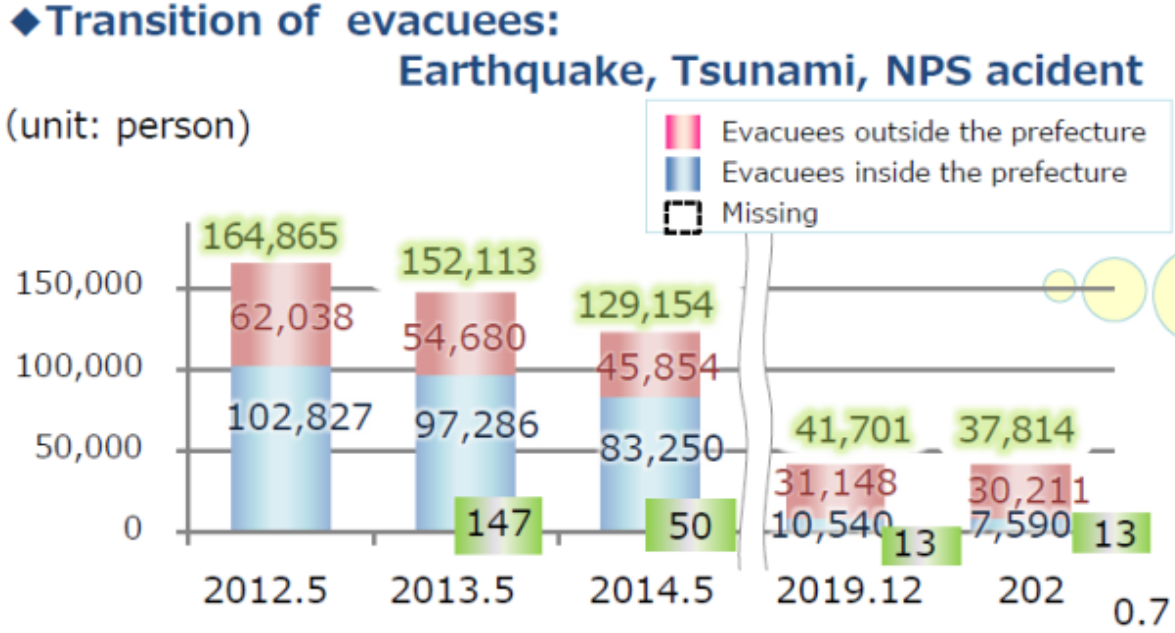
■Totally destroyed: 15,435 houses
■Half destroyed: 82,783 houses

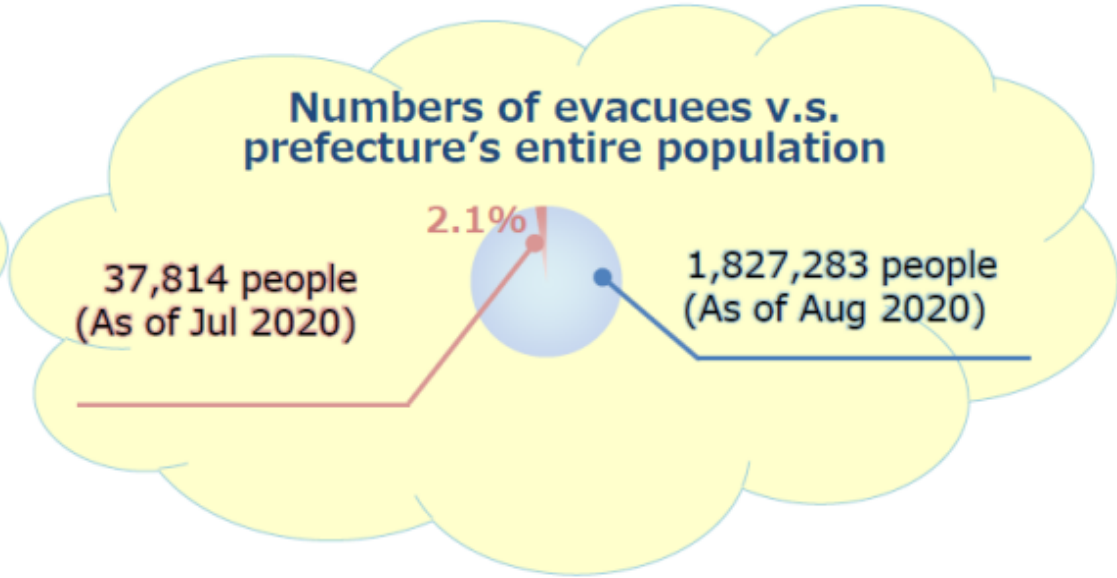


Ten Years Later: Thousands Remain Displaced

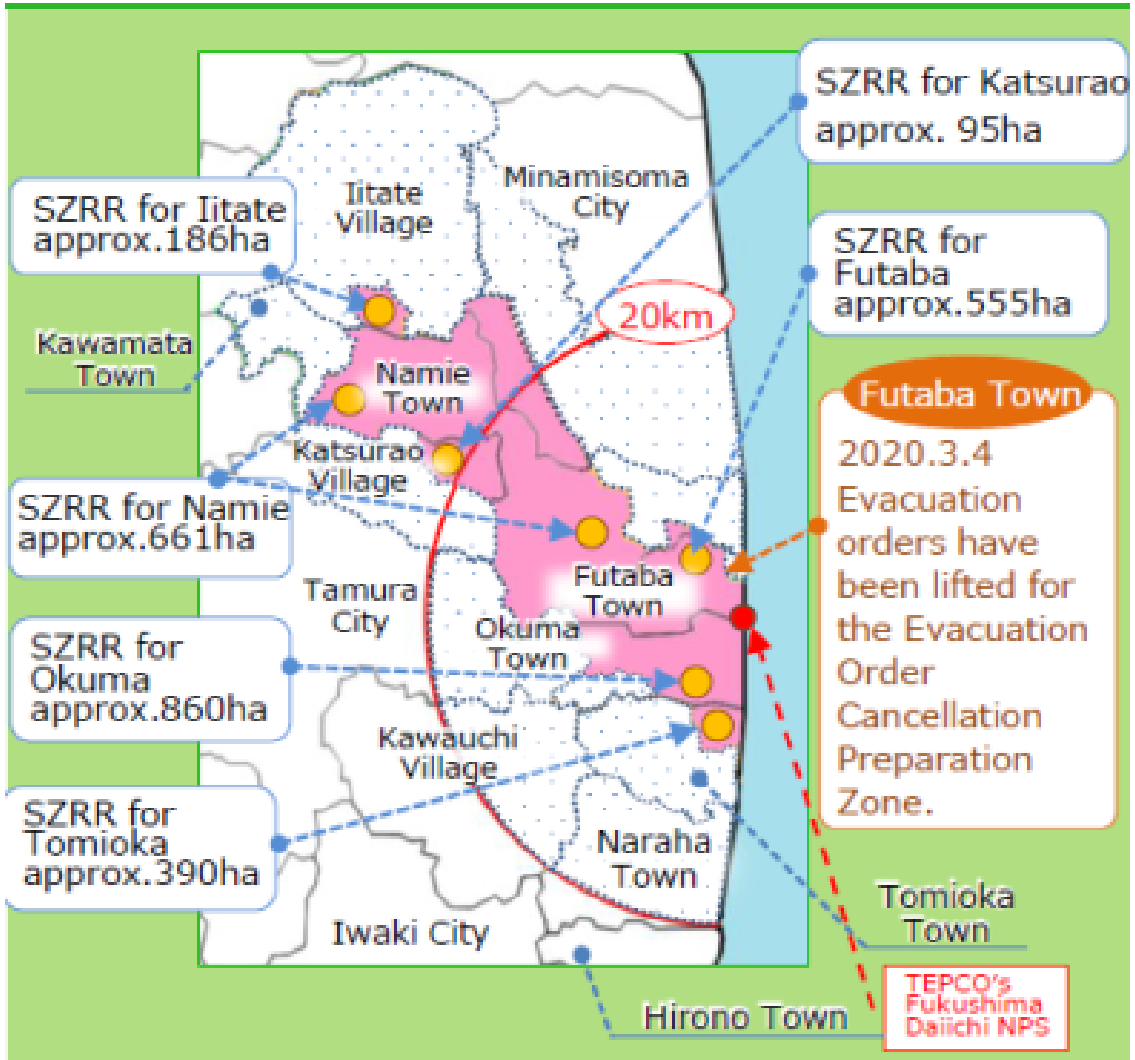
- A total of 164,865 residents of the Fukushima Prefecture were forced into evacuating their homes.
- Approximately 38 thousand are still under evacuation orders but many thousands of evacuees will never return.
- Some townships have less than 35% returnees.

◆**Transition of evacuees:**





“Difficult to Return” Zones Remain Hindrance to Revitalization



Designate Special Zones for Reconstruction and Revitalization

Futaba Town	[Sep 15 2017]
Okuma Town	[Nov 10 2017]
Namie Town	[Dec 22 2017]
Tomioka Town	[Mar 9 2018]
Iitate Village	[Apr 20 2018]
Katsurao Village	[May 11 2018]

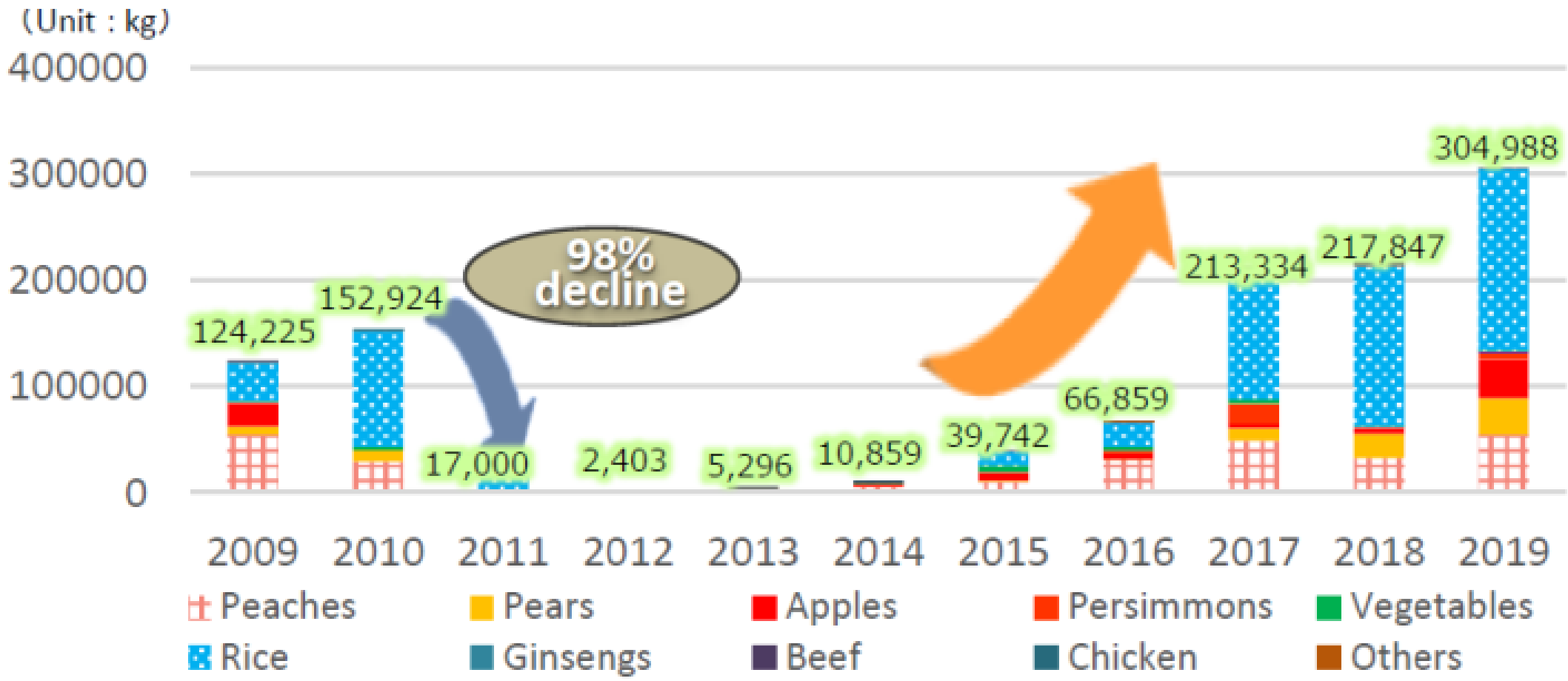
Difficult-to-return zone

- Annual integrated doses are over 50mSv.
- Entry is prohibited with some exceptions.
- Lodging is prohibited.

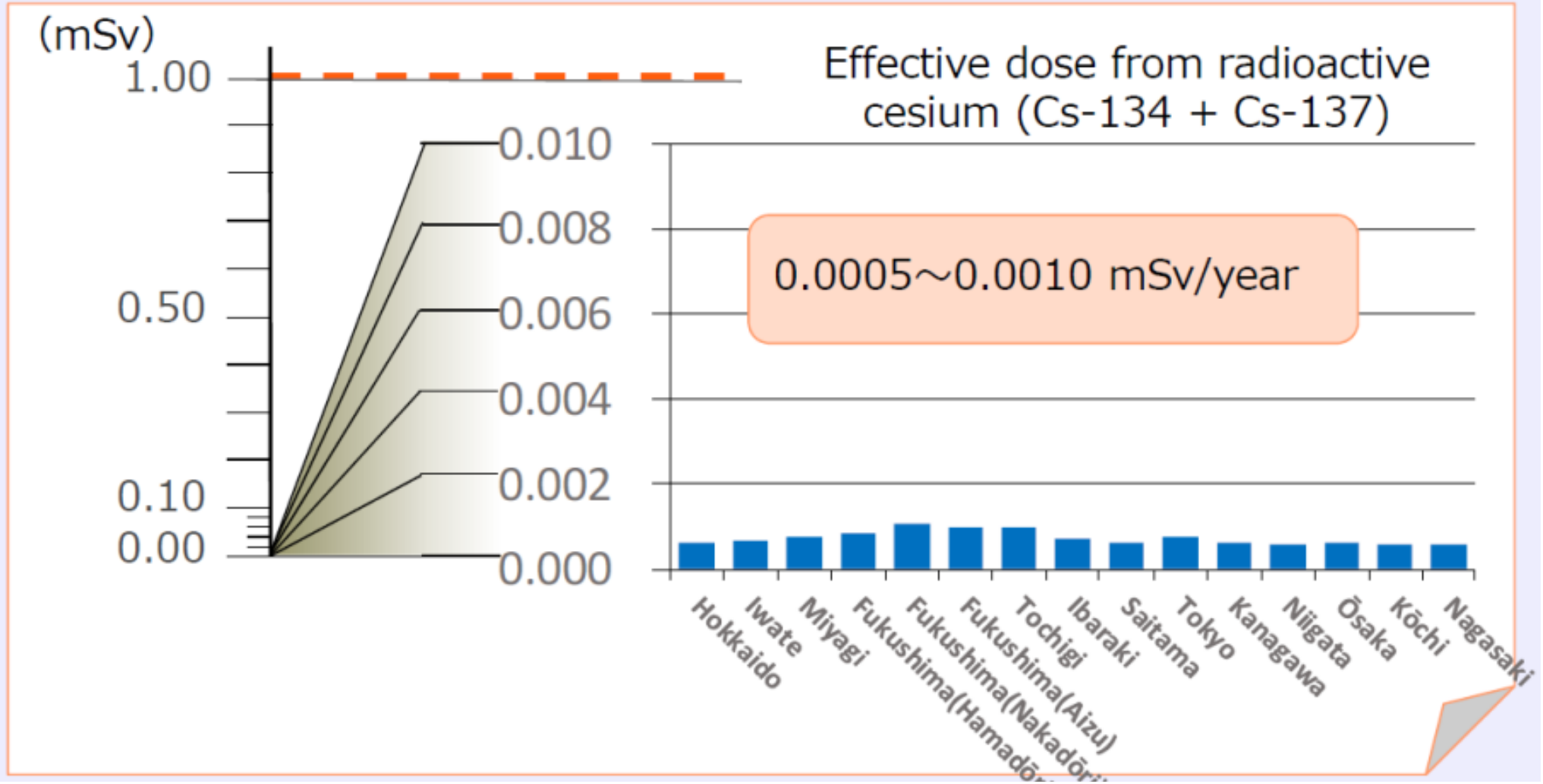
- Areas where evacuation orders have been lifted.

Special Zones for Reconstruction and Revitalization

Food Safety Measures Have Benefited Economic Revival



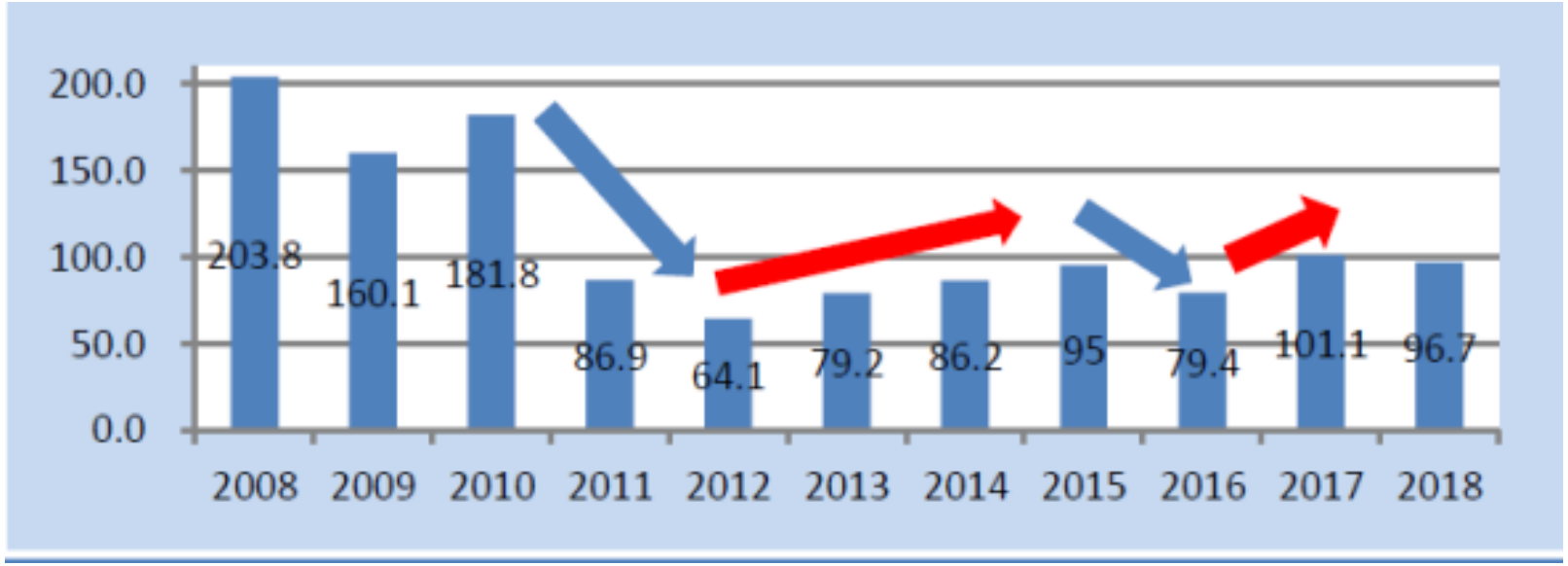
Transparent Monitoring of Radioactive Materials in Foods



Marine Fisheries Remain Severely Impacted

The Fukushima Region was prized across Japan for its high-quality seafood.


Photo by Thom Davies



Treated Water Release: An International Mis-Information Campaign

Fukushima water release could change human DNA, Greenpeace warns

By Amy Woodyatt and Yoko Wakatsuki, CNN

Updated 10:21 AM ET, Sat October 24, 2020

CNN World LIVE TV

GLOBAL TIMES

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World worries about release of Fukushima nuclear water

By Xu Keyue Source: Global Times Published: 2020/10/18 21:33:40

Seoul mulls response to Fukushima water release

2020-10-20 15:32

ENVIRONMENT

Fukushima: How the ocean became a dumping ground for radioactive waste

Taiwan Votes to Maintain Import Ban on Fukushima Food Imports

Information about Current Progress

Fukushima Prefectural Government Web Site

https://www.pref.fukushima.lg.jp/site/portal-english/

Ministry of Economy, Trade, and Industry (METI)

https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/index.html

Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF)

http://www.dd.ndf.go.jp/eindex.html

Ministry of Health, Labor and Welfare

https://www.mhlw.go.jp/english/topics/2011eq/index.html

Tokyo Electric Power Company (TEPCo)

https://www.tepco.co.jp/en/hd/decommission/index-e.html

Summary

- The impact of the Great East Japan Earthquake and Tsunami is generational, recovery will take decades.
- The accident at Fukushima Daiichi NPP overshadows the massive regional destruction.
- Significant progress has been made in regional economic recovery with important exceptions.
- The NDF, METI, and TEPCO are starting to leverage remediation expenditure in supporting economic revitalization.
- Release of treated water from 1F has become a surrogate for international grievances and trade disputes.

The Great East Japan Earthquake and Nuclear Disaster Memorial Museum –Futaba Town

Summer Olympics- ~~2020~~ 2021

- 2020 Summer Olympics will begin on Friday, July 23, 2021 and ends on Sunday, August 8, 2021

- Japan has made major effort to highlight food and products from Fukushima area as part of Olympics venue and training.

- In Fukushima, the J-Village National Training Center served as central command post for 1F accident. It is again the Olympic training center for soccer.

TOKYO 2020