

US - Japan Cooperative Research Results Benefitting Operating Nuclear Power Plant Safety

Sixth Symposium on US-Japan Nuclear Energy Research Cooperation

Washington, DC

February 24, 2023

Presented by: Joy Rempe

Contributors: Joy Rempe, Rempe and Associates, LLC; Mitch Farmer, Argonne National Laboratory; Damian Peko, US Department of Energy; and Donald Marksberry, US Nuclear Regulatory Commission

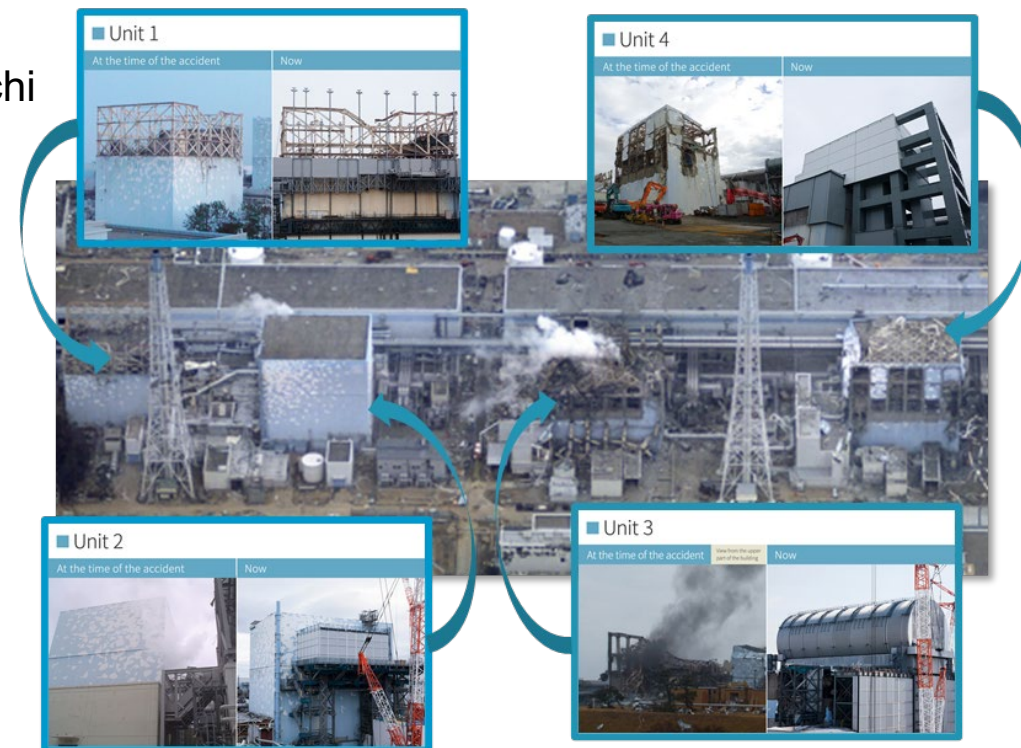
DOE-led Forensics Effort Offers US Perspective to Fukushima Daiichi D&D Activities

Objectives:

- Develop consensus US input to Japan for **high priority time-sequenced examinations and related evaluations** that can be completed with minimal disruption of 1F 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 1F fuel debris retrieval evaluations
 - Confirm/improve guidance for severe accident prevention, mitigation, and emergency planning
 - Periodically review status/refine information requests
- Facilitate implementation of Japan-led international research efforts to support D&D

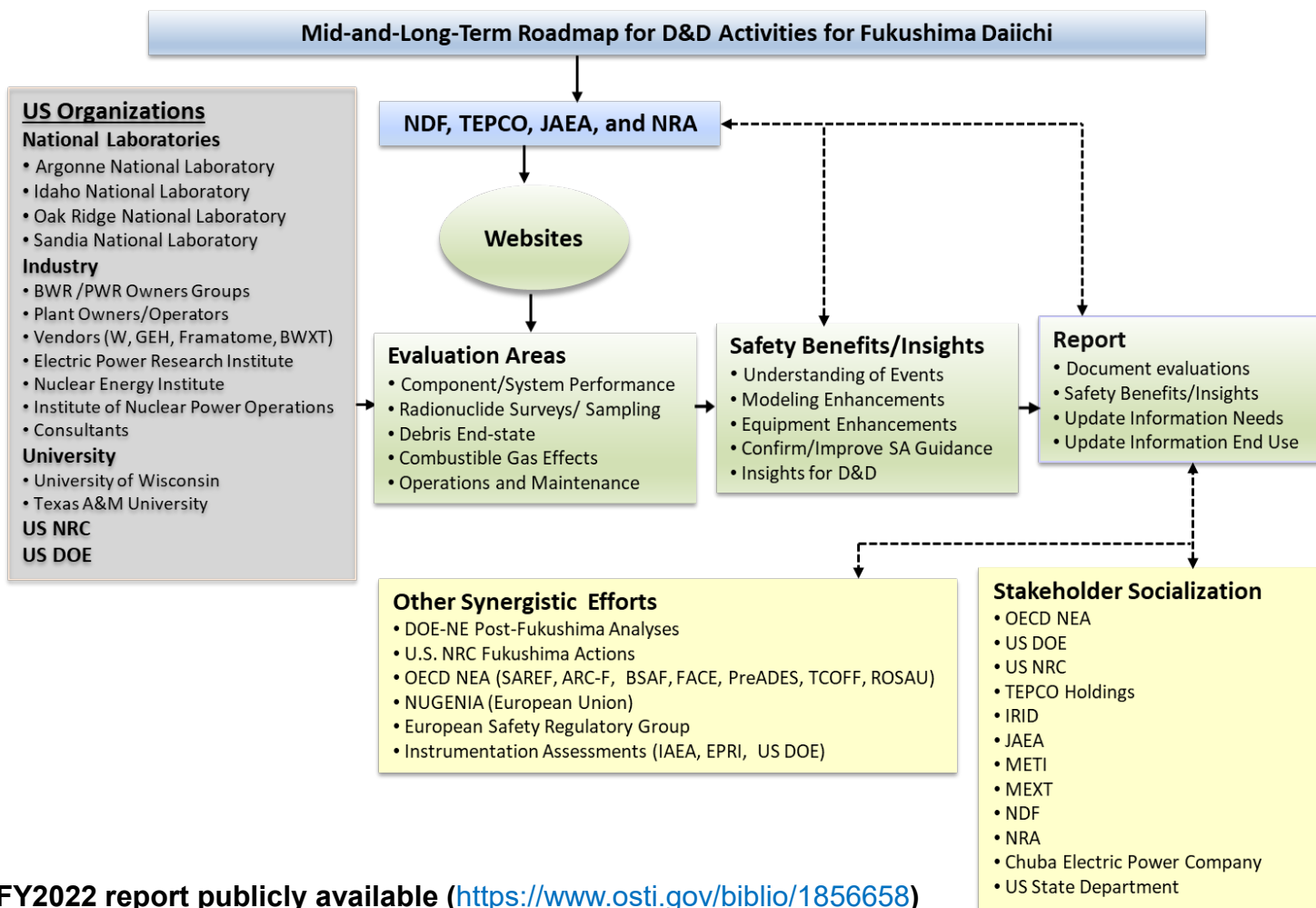
Motivations:

- 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



Graphics courtesy of TEPCO (March 2011, larger center image and left side of smaller images) and (December 2022, right side of smaller images)

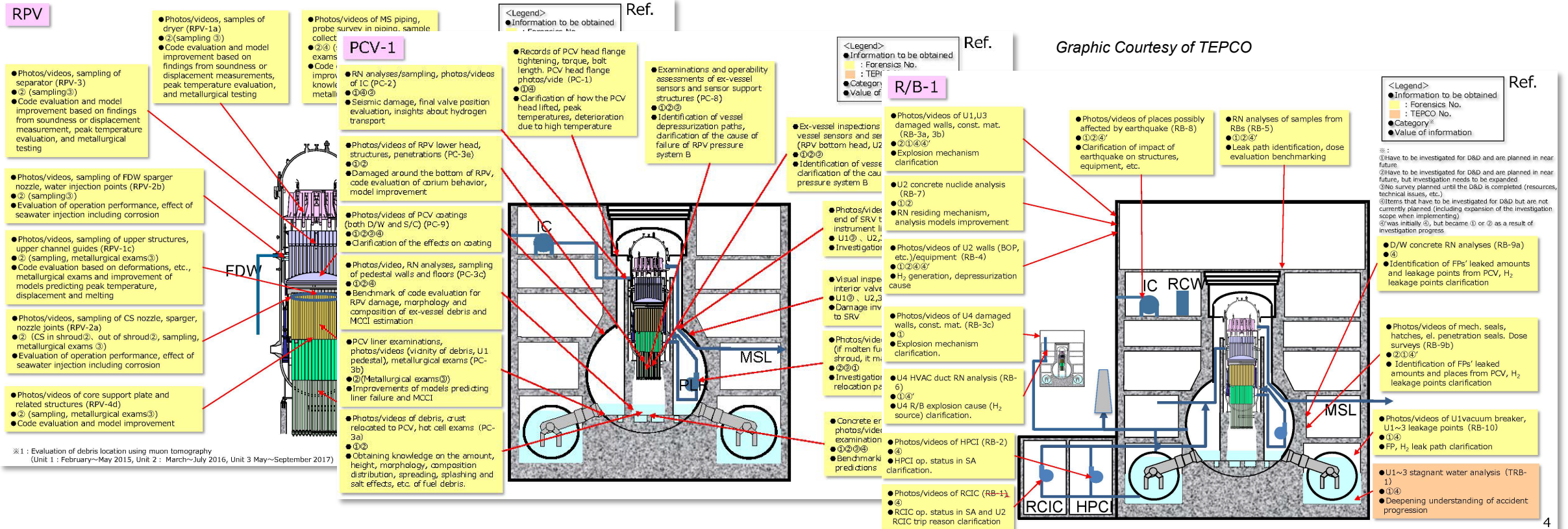
Efforts leverage US Experience to Gain Fukushima Lessons for Enhanced Reactor Safety



Graphics courtesy of ANS and ANL

US Forensics Effort Organized to Facilitate Completing Objectives

TEPCO Mid-and-Long Term Accident Investigation Plan includes Remaining US Information Requests



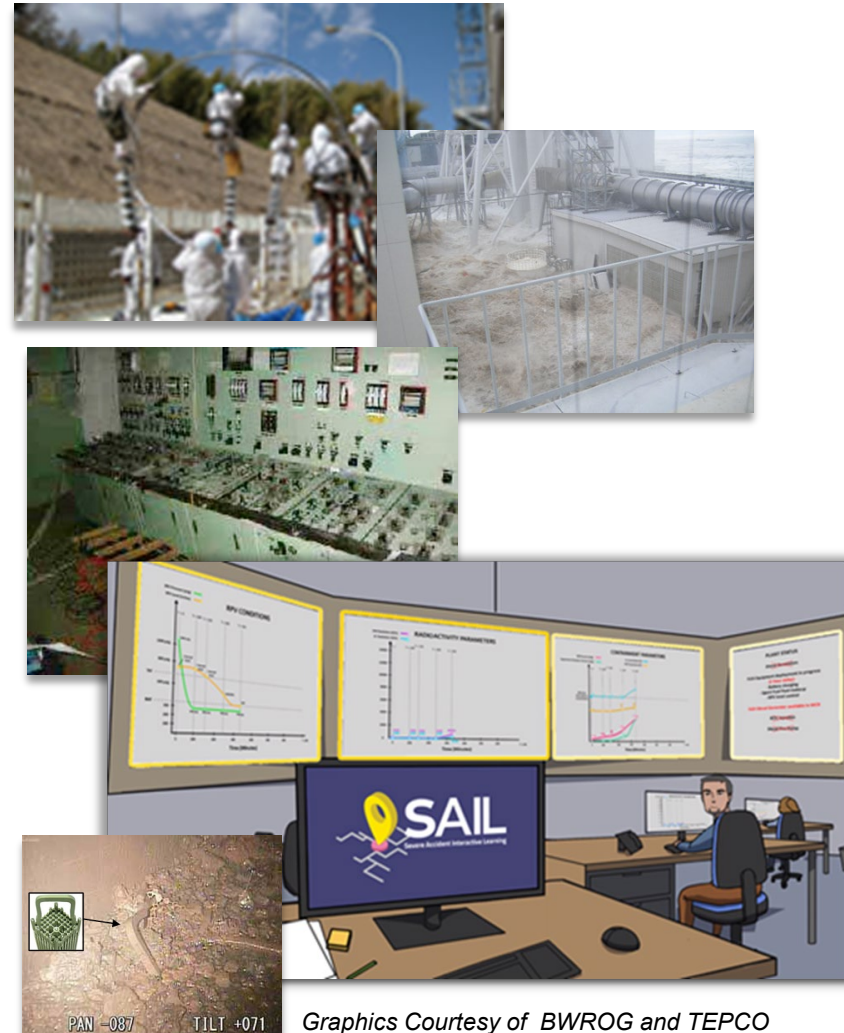
In addition to facilitating safe D&D, examination information provides important safety insights for operating and advanced reactors (LWR and non-LWR)

Actions to Address 1F Lessons Learned

US Actions to Prevent and/or Mitigate Beyond Design Basis Events (BDBEs)

- US Industry Diverse and Flexible Coping Strategies (FLEX) Program
 - Plant sites maintain additional equipment for water injection, power restoration, and debris removal
 - Similar equipment at two national response centers
- Improved spent fuel pool (SFP) water level instrumentation and strategies to address challenges to SFP cooling
- Hardened containment wetwell vent (BWR Mark I and II containments)
- Alternate venting and water addition strategies (based on insights from instrumentation evaluations, experimental testing, code simulations, and examinations)
- Revised procedures and guidance and updated training

Images, such as the fuel assembly handle observed in 1F2 PCV examinations, provide critical insights regarding RPV failure in new BWROG computer-based Severe Accident Interactive Learning (SAIL) training and guidance.



Actions to Address 1F Lessons Learned (continued)



US/Japan Terry™ Turbine Performance Insights, Testing, and Implementation

- Terry™ Turbine Expanded Operating Band Project expanded / defined Terry™ turbine systems (i.e., RCIC/TDAFW) operating limitations
 - Concluded 1F2 and 1F3 RCIC operation (based on available plant data and bilateral Terry™ turbine testing at TAMU and model development /assessment by SNL) repeatable
 - Provided information for RCIC system Terry™ turbine and HPCI system performance models
- Implementation
 - Obtained data used to revise BWR emergency operating procedures (EOPs) and to support basis of relaxing the low pressure start up test for Terry™ turbines (BWROG topical report)
 - Post-Fukushima EOP changes to Level 8 trips important in maintaining RCIC and HPCI system performance and in reducing SRV cycling during Duane Arnold Energy Center severe, long-lived windstorm (derecho) event
 - Revised procedures and proficiency important to restoring systems during a LOOP
 - Plant transient response was as expected and agreed with simulator training for LOOP response



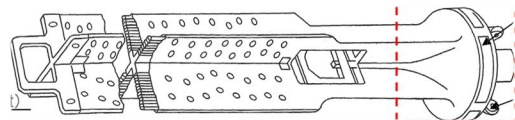
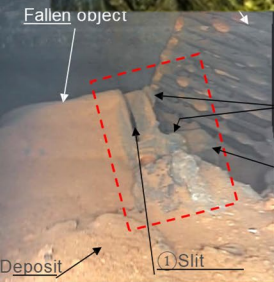
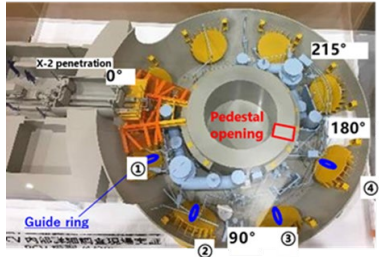
Graphics Courtesy of TAMU and BWROG

US Actions to Address 1F Lessons Learned (continued)

Updated US / Japan Systems Analysis Code Models

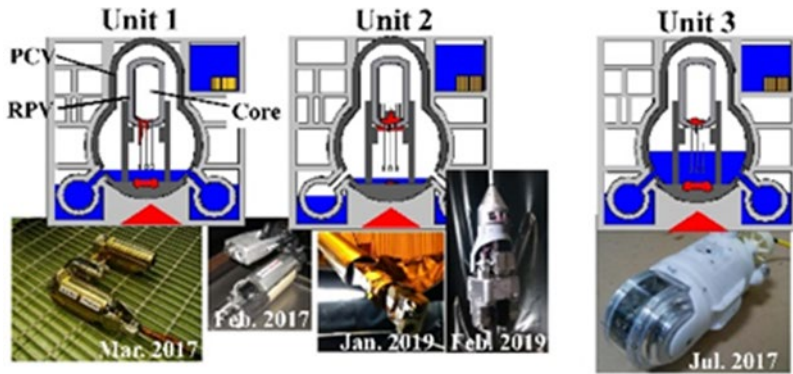
- Improved detail in BWR primary system thermal hydraulic models
- New containment fluid stratification model to allow simulation of suppression pool phenomena inferred from 1F3 PCV pressure data
- RCIC system Terry™ Turbine and HPCI system performance models
- Ex-vessel relocation and debris coolability modeling improvements to reflect images of holdup and observed relocation of debris and relocated components
- New corium spreading and molten core concrete interaction erosion models inferred from images obtained during 1F examinations [OECD ROSAU testing underway at ANL to provide additional insights]

Graphics Courtesy of TEPCO



Improved models used to facilitate D&D and optimize BWROG updated guidance efforts

New 1F D&D Technologies offer Additional Benefits to Operating and New Reactors



■ New technologies facilitate 1F D&D

- Muon tomography
- Special-purpose robots, drones, and Unmanned Aerial Vehicles (UAVs)
- Portable gamma-ray imaging camera
- Infrared thermography
- Real-time monitoring with 2D or 3D visualization of radiation levels and temperatures
- Plastic scintillation fiber monitors

■ These technologies also offer the potential to reduce personnel exposure and costs during routine plant operations and maintenance activities

Closing Remarks

- Continued safe and economic performance essential aspect for public acceptance of operating and new nuclear reactors
- Insights, which continue to be obtained from 1F D&D efforts, offer international community opportunities to enhance global nuclear safety and economics
- DOE-sponsored Forensic Effort has provided input to facilitate future D&D activities, to better understand the accident progressions, and to reduce uncertainties in simulating severe accidents



Graphics Courtesy of TEPCO and OECD



- The nuclear enterprise has used insights gained from the Forensics Effort to update guidance and training for severe accident prevention, mitigation, and emergency planning
- More reactor technology-neutral safety lessons and new D&D technologies for improved maintenance, applicable to operating plants and new reactor designs, expected

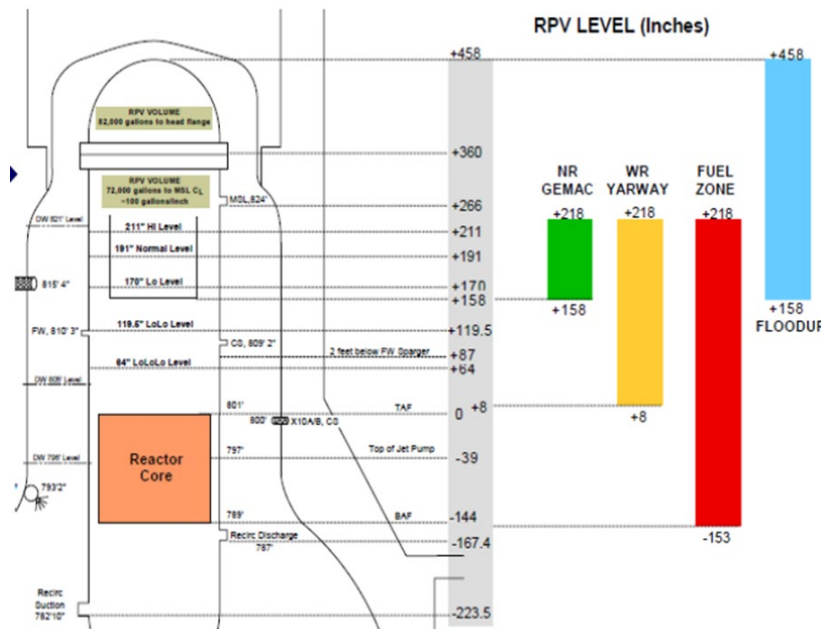
Acronyms and Abbreviations

ARC-F	Analysis of Information from Reactor Buildings and Containment Vessels in Fukushima Daiichi Nuclear Power Station	OECD	Organization for Economic Cooperation and Development
ANL	Argonne National Laboratory	OECD NEA	OECD Nuclear Energy Agency
BDBE	Beyond Design Basis Event	PCV	Primary Containment Vessel
BSAF	Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant	PreADES	Preparatory Studies for Fuel Debris Analysis
BWR	Boiling Water Reactor	PWR	Pressurized Water Reactor
BWROG	BWR Owners Group	PWROG	PWR Owners Group
BWXT	BWX-Technologies	R/B	Reactor Building
D&D	Decontamination and Decommissioning	RCIC	Reactor Core Isolation Cooling
EOP	Emergency Operating Procedure	ROSAU	Reduction of Severe Accident Uncertainties
EPRI	Electric Power Research Institute (US)	RPV	Reactor Pressure Vessel
FACE	Fukushima Daiichi NPS Accident Information Collection and Evaluation	SA	Severe Accident
FLEX	Diverse and Flexible Coping Strategies	SAIL	Severe Accident Interactive Learning
GEH	GE-Hitachi Nuclear Energy Americas LLC	SFP	Spent Fuel Pool
HPCI	High Pressure Coolant Injection	SRV	Safety Relief Valve
IAEA	International Atomic Energy Agency	TAMU	Texas A&M University
IRID	International Research Institute for Nuclear Decommissioning (Japan)	TCOFF	Thermodynamic Characterization of Fuel Debris and Fission Products Based on Scenario Analysis of Severe Accident Progression at Fukushima-Daiichi Nuclear Power Station
JAEA	Japan Atomic Energy Agency (Japan)	TDAFW	Turbine Driven Auxiliary FeedWater
LOOP	Loss of Offsite Power	TEPCO	Tokyo Electric Power Company Holdings Company
LWR	Light Water Reactor	UAV	Unmanned Aerial Vehicles
METI	Ministry of Economy, Trade and Industry (Japan)	US	United States
MEXT	Ministry of Education, Culture, Sports, Science and Technology	W	Westinghouse
NDF	Nuclear Damage Compensation and Decommissioning Facilitation Corporation	1F1, 1F2	Fukushima Daiichi Units 1, 2, 3, 4, 5, and 6
NRA	Nuclear Regulatory Authority (Japan)	1F3, 1F4,	
NRC	Nuclear Regulatory Commission (US)	1F5, and 1F6	
NUGENIA	Nuclear Generation II & III Alliance (European Union)	2D	Two dimensional
		3D	Three dimensional

Implemented Actions Enhanced Recovery during 2020 DAEC LOOP (continued)

Response to LOOP Event

- Derecho approached DAEC with peak windspeeds between 100 and 130 mph; Loss of Offsite Power (LOOP) at 12:49 on August 10, 2020.
 - A generator load reject occurred, tripping the turbine and causing reactor scram
 - 'A' and 'B' emergency diesel generators automatically started; supplying power to safety related busses
 - Recirculation pumps tripped (LOOP prevented restart)
 - RPV water level initially lowered rapidly to Level 2 due to loss of feedwater.
 - RCIC and HPCI systems automatically initiated and restored RPV water level until Level 8 reached, causing both systems to trip.
- Operators placed both systems in manual control and intentionally increased water levels to promote natural circulation cooling.
 - Using revised guidance, operators quickly established pressure control using main steam line drains and RCIC.
 - Revised Level 8 trip values allowed operators to maintain RCIC and HPCI system operation and reduce SRV cycling
- Shutdown cooling started at 22:30 on August 10, 2020; cold shutdown established at 02:30 on August 11, 2020.



Graphic Courtesy of BWROG