Energy, Air, Water, & Earth
Fukushima & Three Mile Island: Accident, Recovery & Challenges

Foundation For Nuclear Studies

Congressional Briefing Update

July 29, 2011

Lake H. Barrett

Lake@Lbarrett.com

Disclaimer: Fukushima Information is preliminary especially regarding interpretation of events; opinions expressed are mine and mine alone.

Evolutionary Background

- **Mankind**
  - **Huts to Modern Cities**
- **Energy**
  - **Simple Fire to Fossil Electricity to Nuclear Electricity**
- **Energy Density**
  - **Diffuse/Intermittent to Concentrated/Continuous**

Constant Evolutionary Societal Benefit/Risk Tradeoffs

- **No Energy Source is Free From Risk or Cost**

Oil Rig Fire

Gas Pipeline Explosion

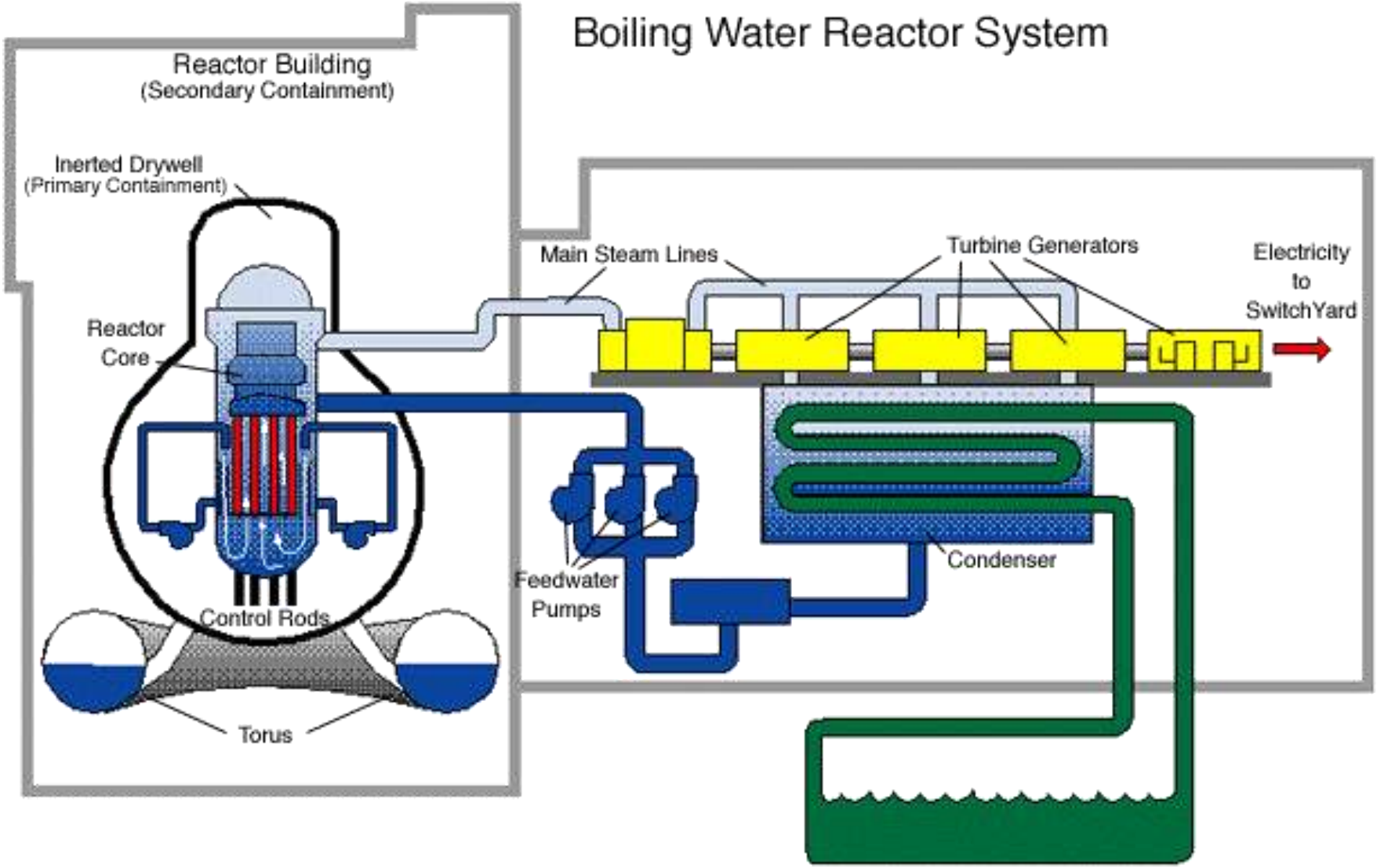
Wind Mill Collapse

Coal Mine Accident

Coal Ash Dam Break

Solar Panel Roof Falls

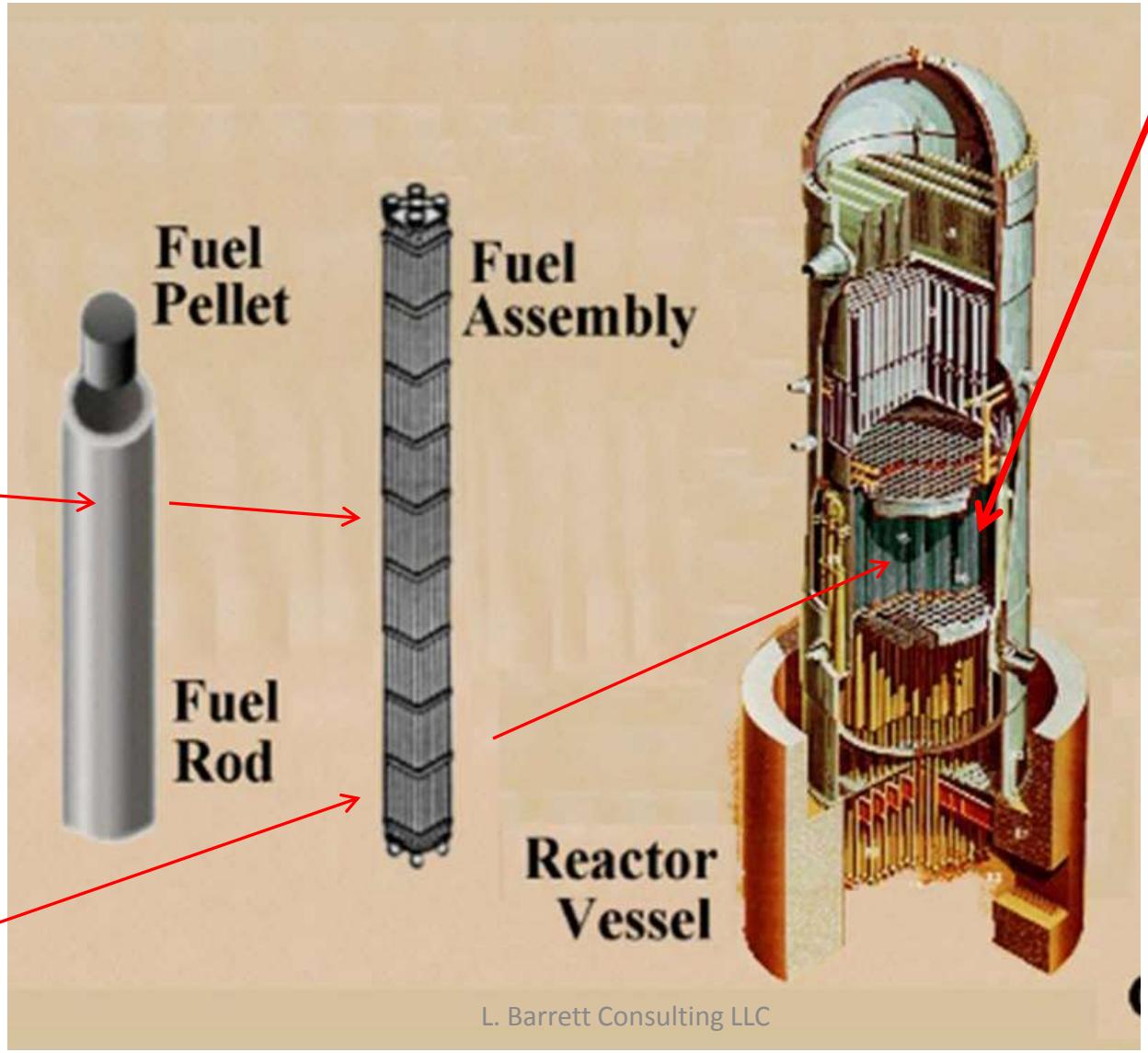
Nuclear Power Plant



Nuclear Fuel Barriers & Heat Output

~33,000 12' Long Fuel Rods

538 Assemblies With 62 rods



Fukushima 2-4 Core Produces ~2400MWT

At Full Power can Melt a Ton of Steel in ~1 second

Decay Heat Drops Quickly @ Scram

1Min	3.0%
~30 sec to melt 1 ton	
1hr	1.3%
8 Hr	0.7%
~2 min to melt 1 ton	
1 Day	0.5%
1 Week	0.3%
1Month	0.2%
~7 min to melt 1 ton	
6 Months	0.1%

Three Mile Island Units 1 &2

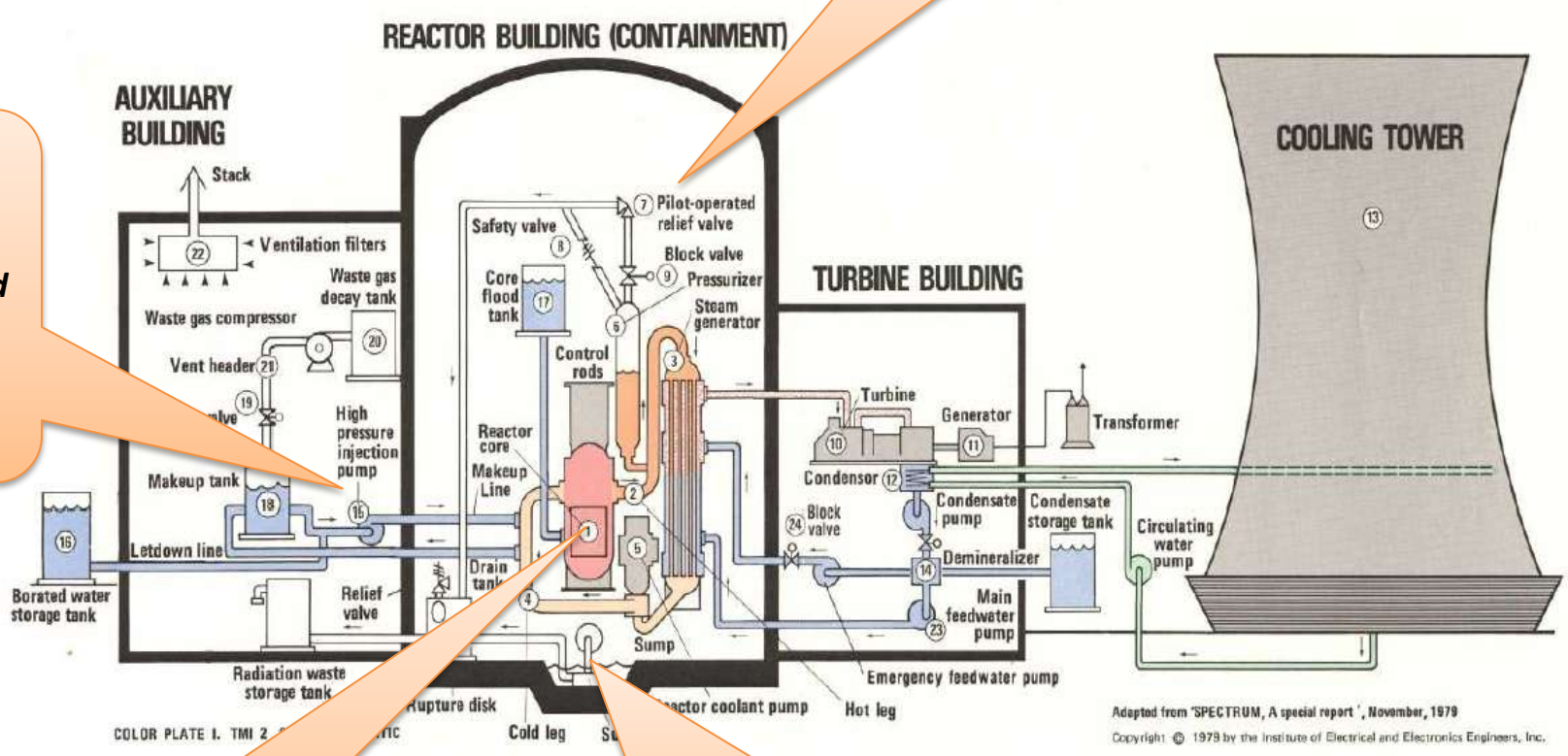
March 28, 1979

Three Mile Island Unit-2 Accident

March 28, 1979

Relief Valve fails to close

Operators Believe Reactor Overfilled and Turn Off Injection Pumps

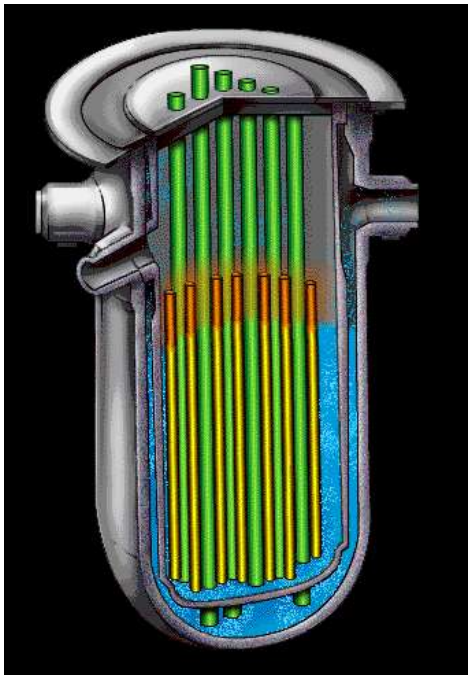


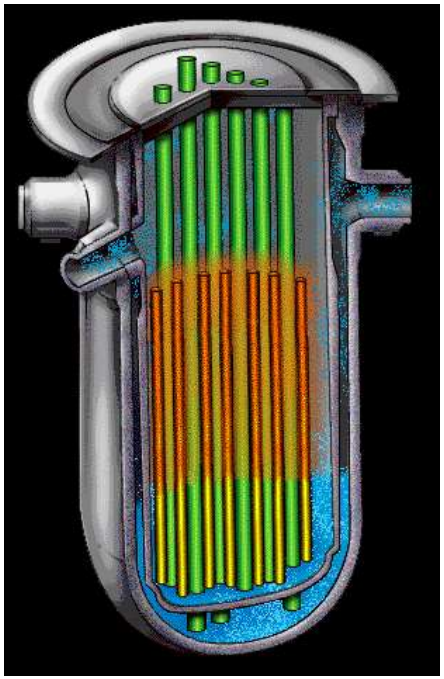
COLOR PLATE I. TMI 2

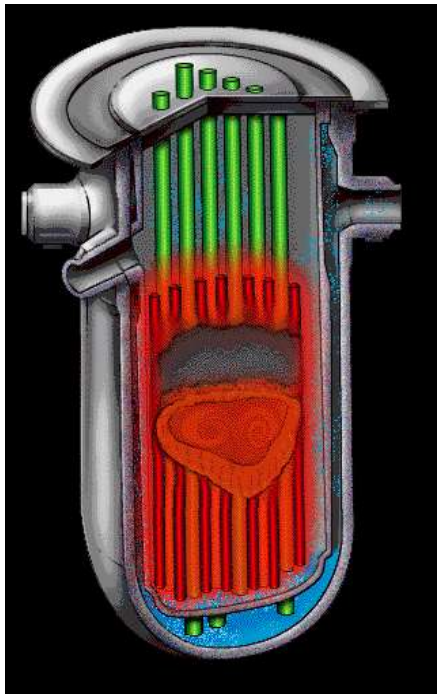
Core is uncovered Fuel overheats/fails/~50% Melt

650,000 gallons of highly radioactive water collects

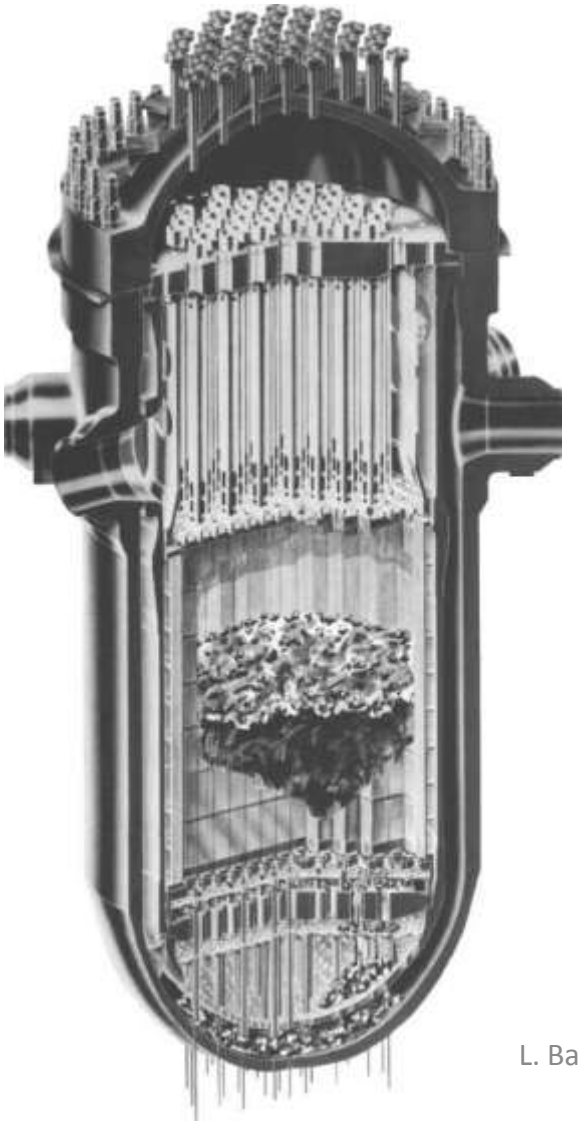
TMI Core Damage Sequence







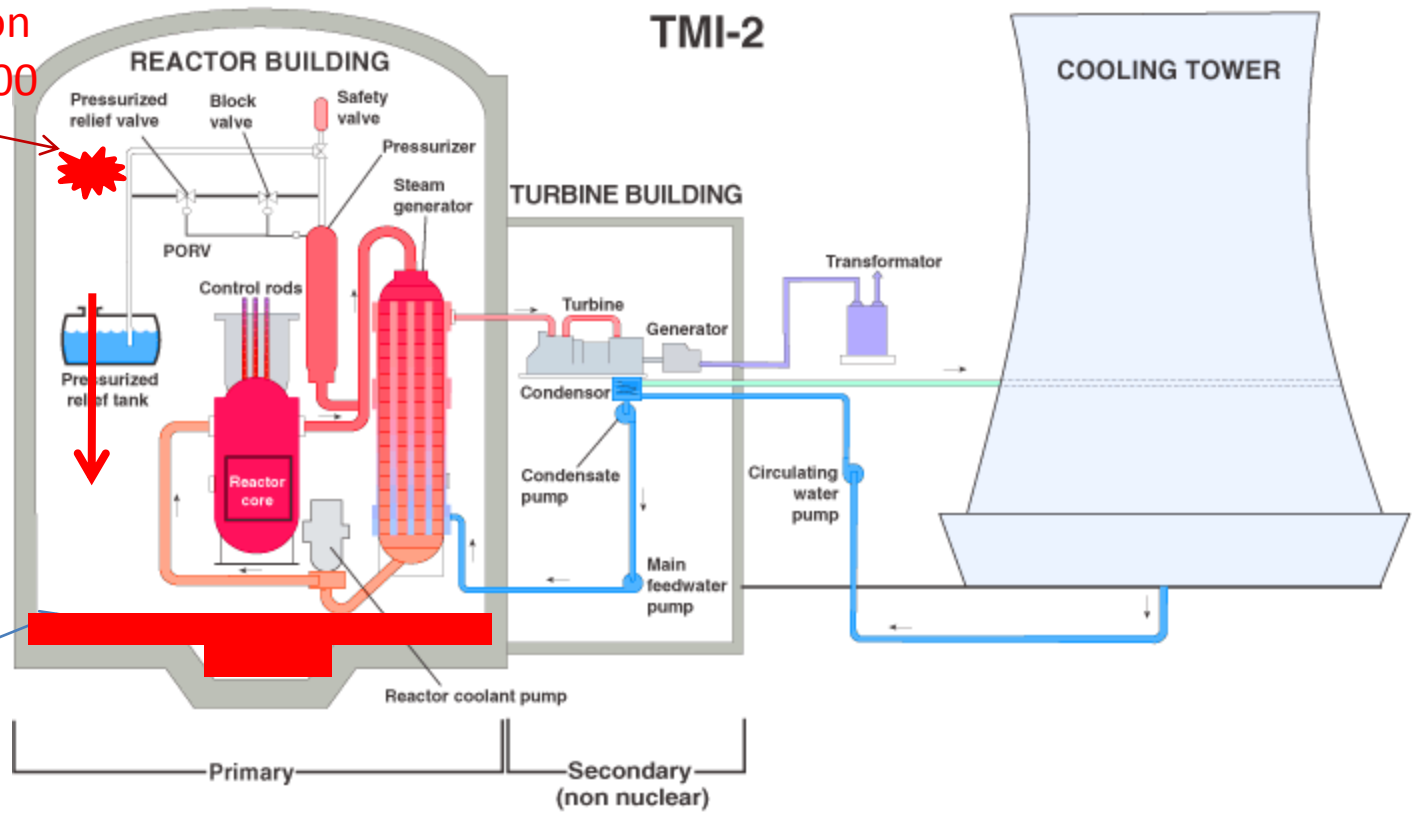
TMI Core Configuration
~Evening 3/28/1979



Damaged Fuel Rods

Three Mile Island
March 28, 1979

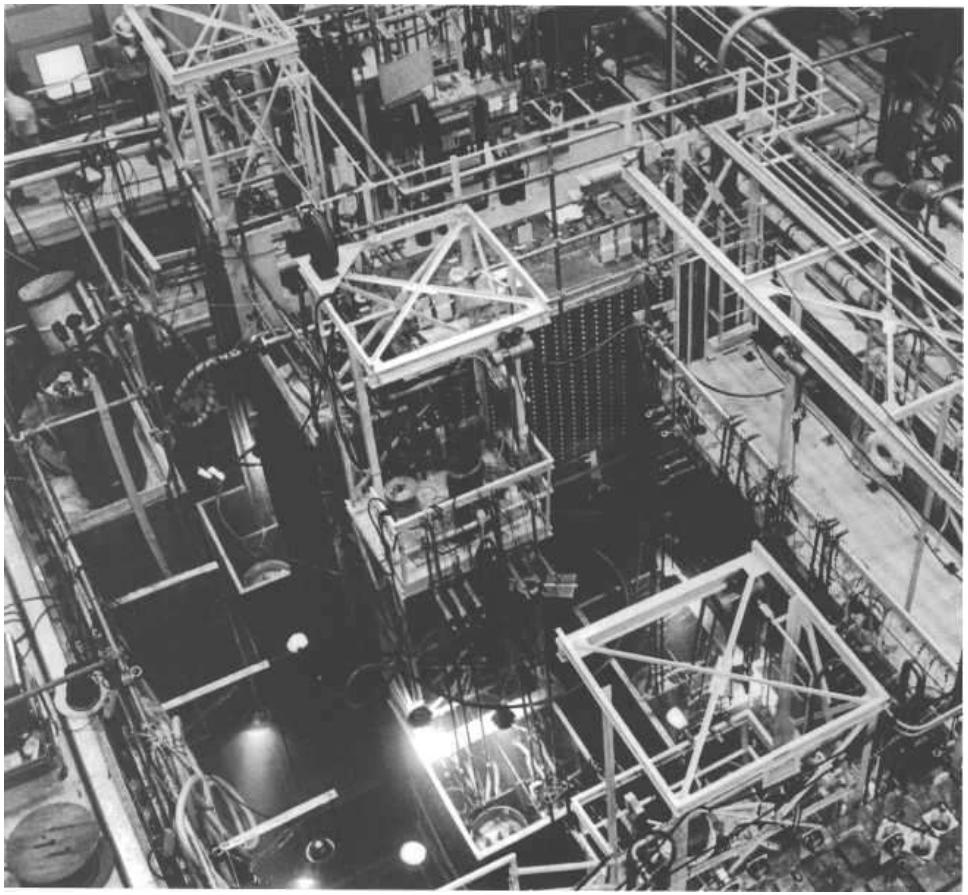
Hydrogen
Deflagration
28psig 13:00



~3M deep
water
1000R/hr
@ 2 yr

Recovery Cleanup Actions

Building Remediation to Gain Core Access (Barrett Entry)



Phased Unique Air and Water Cleanup Systems Created Based on Best Available Technology

TMI Damaged Core Removal

~1985-1990

Three Mile Island History

- Reactor Scram: 04:00 3/28/79
- Core melt and relocation: ~ 05:00 – 07:30 3/28/79
- Hydrogen Deflagration: 13:00 3/28/79
- Recirculation Cooling: Late 3/28/79
- Phased Water Processing: 1979-1993:Removed ~1.2MCi Cs137
- Containment Venting 43KCi Kr-85: July 1980
- Containment Entry: July 1980
- Reactor Head removed and core melt found: July 1984
- Start Defuel: October 1985
- Shipping Spent Fuel: 1988-1990
- Finish Defuel: Jan 1990
- Evaporate ~2.8M gallons Processed Water: 1991-93
- Cost: ~$1 Billion

Fukushima Daiichi Nuclear Power Station

Event Initiation

March 11, 2011

•About 14:46, a 9.0 magnitude earthquake struck (Plant design basis earthquake: 8.2)- Plant safety systems reportedly function satisfactorily.

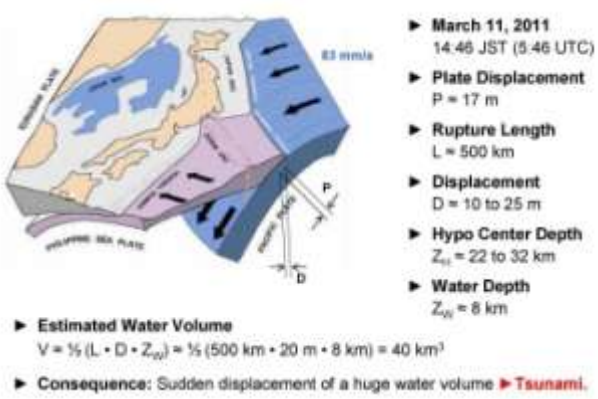
•Units 1,2 & 3 Scram & Unit 4 has 100 day old core offloaded into Unit 4 Spent Fuel Pool

•~ 15:45, a tsunami 14 meters high inundated the site, whose design basis was 5.7 meters – the reactors and backup diesel power sit roughly 10 to 13 meters above sea level

•The impacts up and down the northeast coast resulted in tragic loss of 20,000+ lives, damage, and destruction of infrastructure.

By Janet Loehrke, USA TODAY

Subduction Fault



No Reported Seismic Safety Damage

Despite Huge Earthquake, Seismic Loads Close to Design
Some Non Safety System Damage

Recorded Intensity of Ground Motion and Basic Earthquake Ground Motion

		Observed Maximum Response Acceleration * (Gal)			Max Response Acceleration against Basic Earthquake Ground Motion (Gal), Ss		
		Horizontal (N-S)	Horizontal (E-W)	Vertical	Horizontal (N-S)	Horizontal (E-W)	Vertical
Fukushima Daiichi	Unit 1	460	447	258	487	489	412
	Unit 2	348	550	302	441	438	420
	Unit 3	322	507	231	449	441	429
	Unit 4	281	319	200	447	445	422
	Unit 5	311	548	256	452	452	427
	Unit 6	298	444	244	445	448	415
Fukushima Daini	Unit 1	254	230	305	434	434	512
	Unit 2	243	196	232	428	429	504
	Unit 3	277	216	208	428	430	504
	Unit 4	210	205	288	415	415	504

* At the lowest basement of reactor building

12

Tsunami Waves

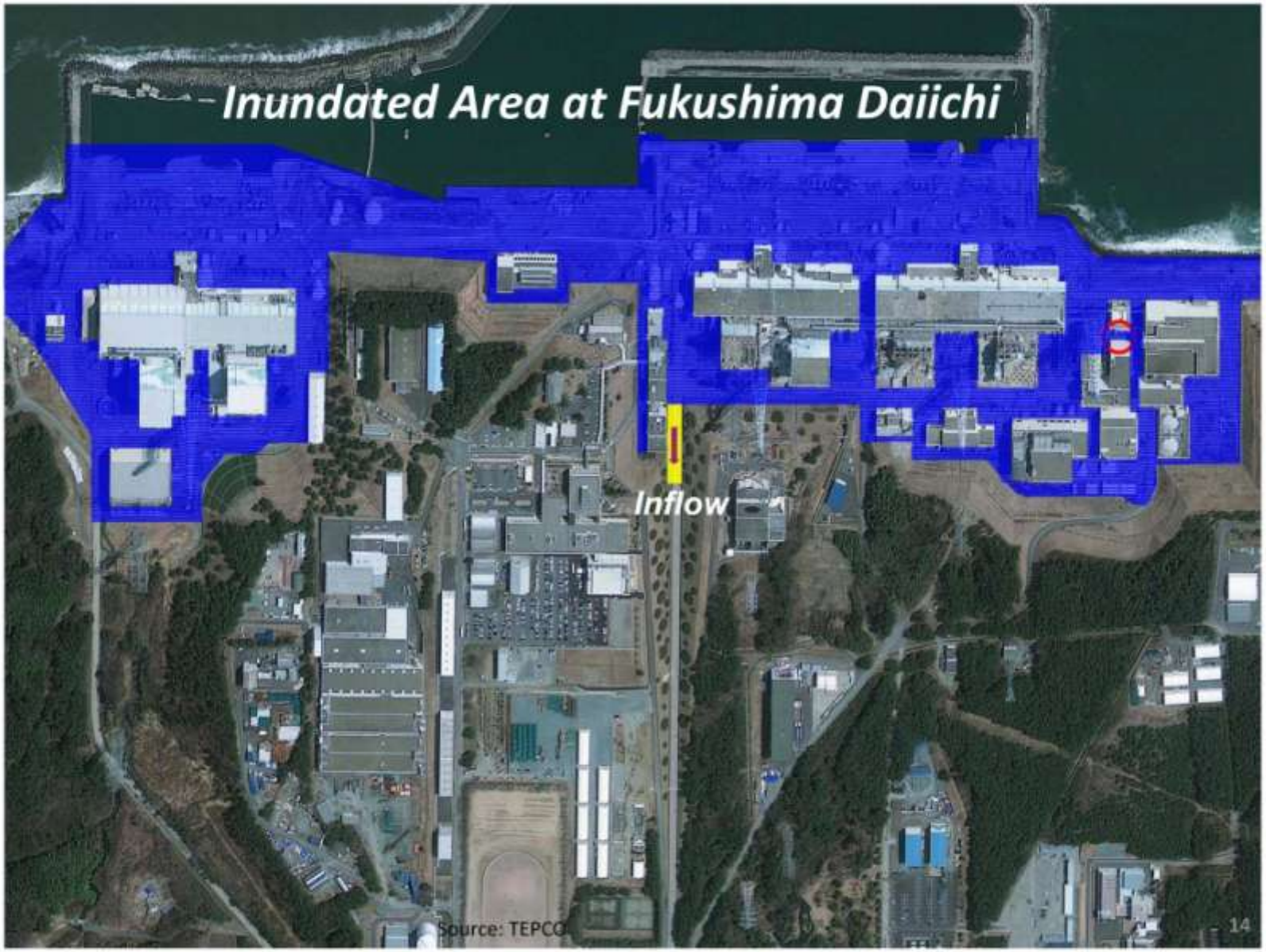
Incoming Wave Behind Reactor Building
15:42

Wave Behind Reactor Building 15:43:26

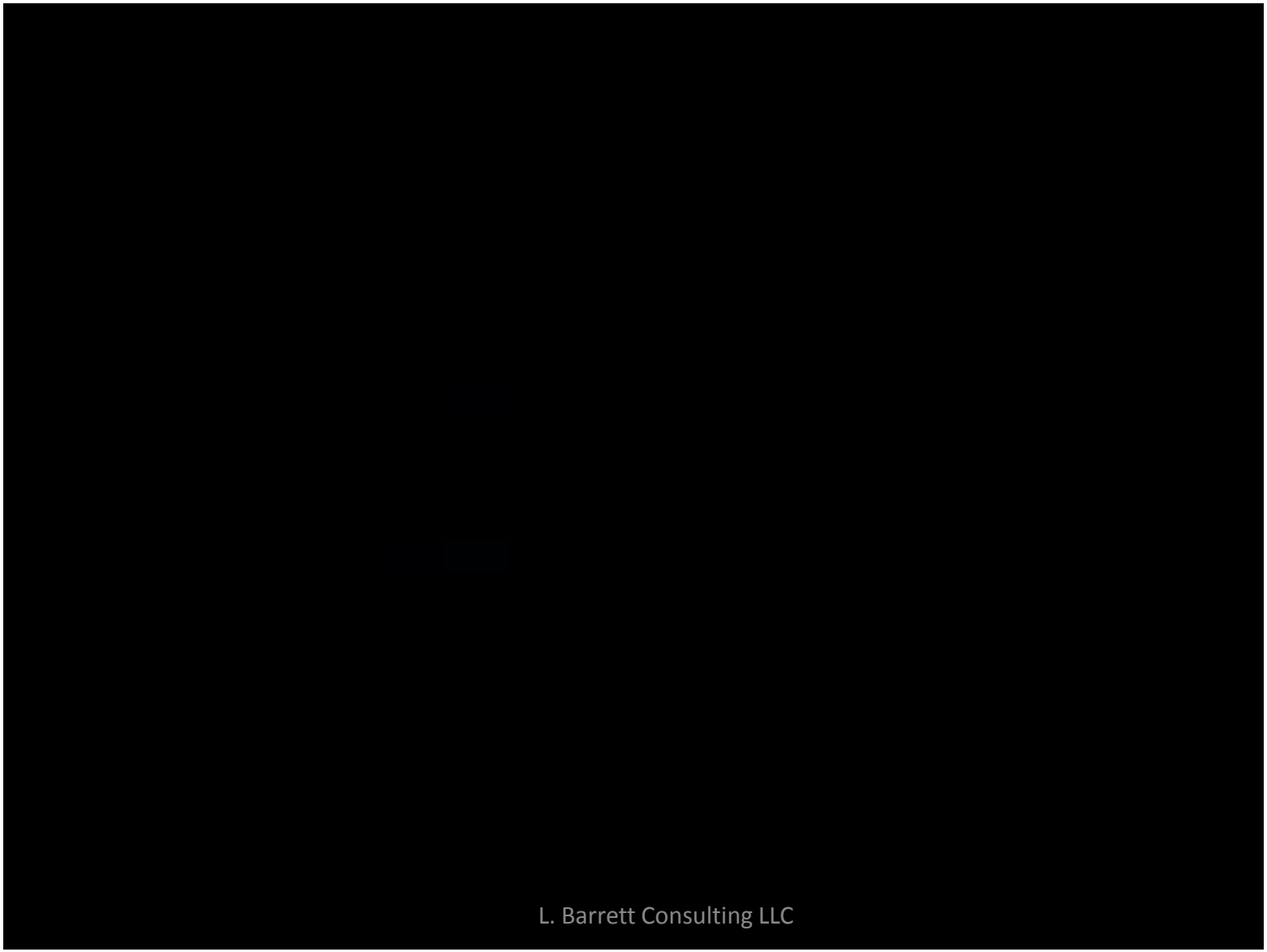
Wave Behind Reactor Building 15:43:54

Wave Behind Reactor Building 15:44:58

Wave Behind Reactor Building 15:47

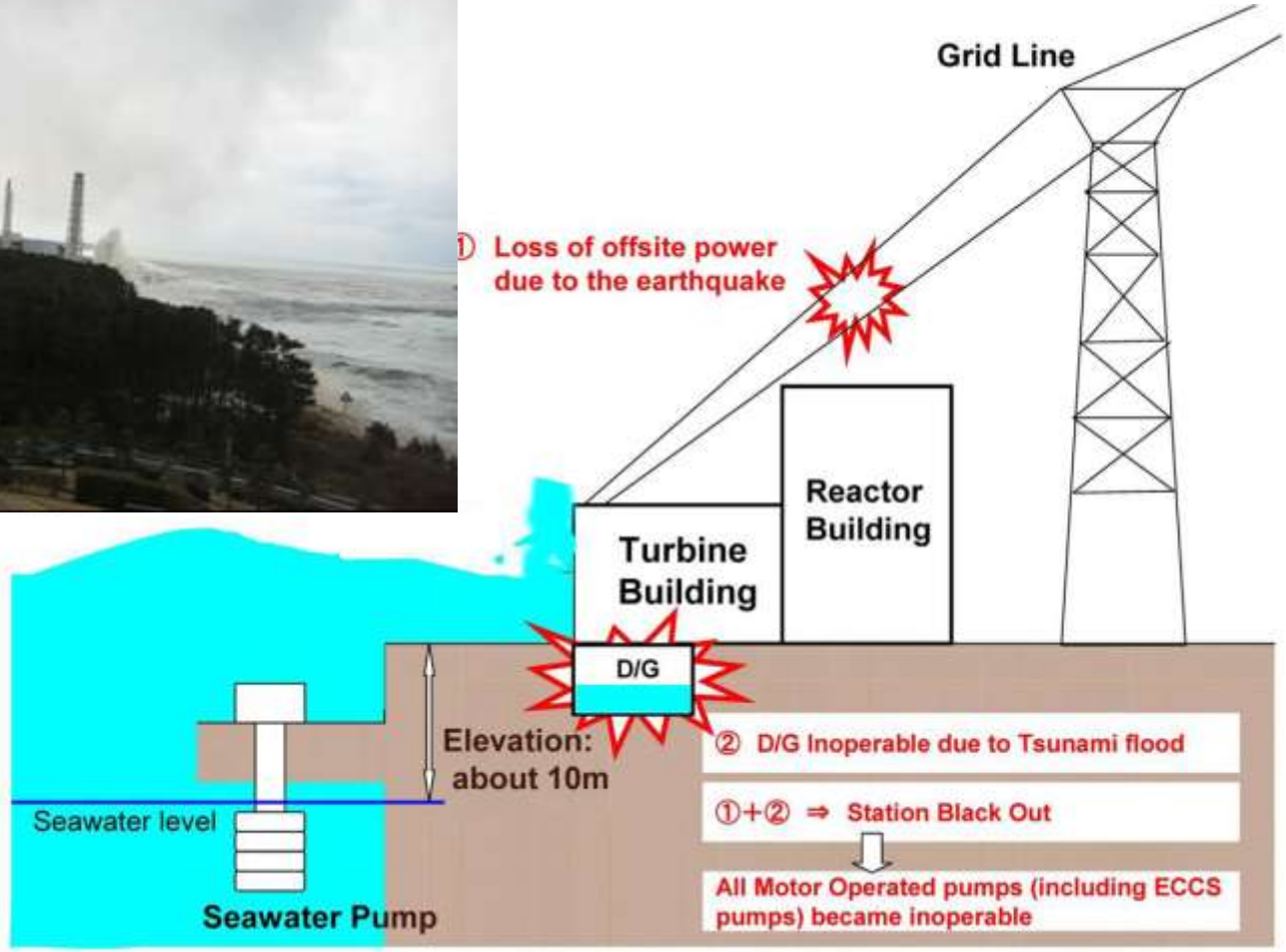

Inundated Area at Fukushima Daiichi
Inflow
Source: TEPCO
14

Wave Hitting Turbine Building



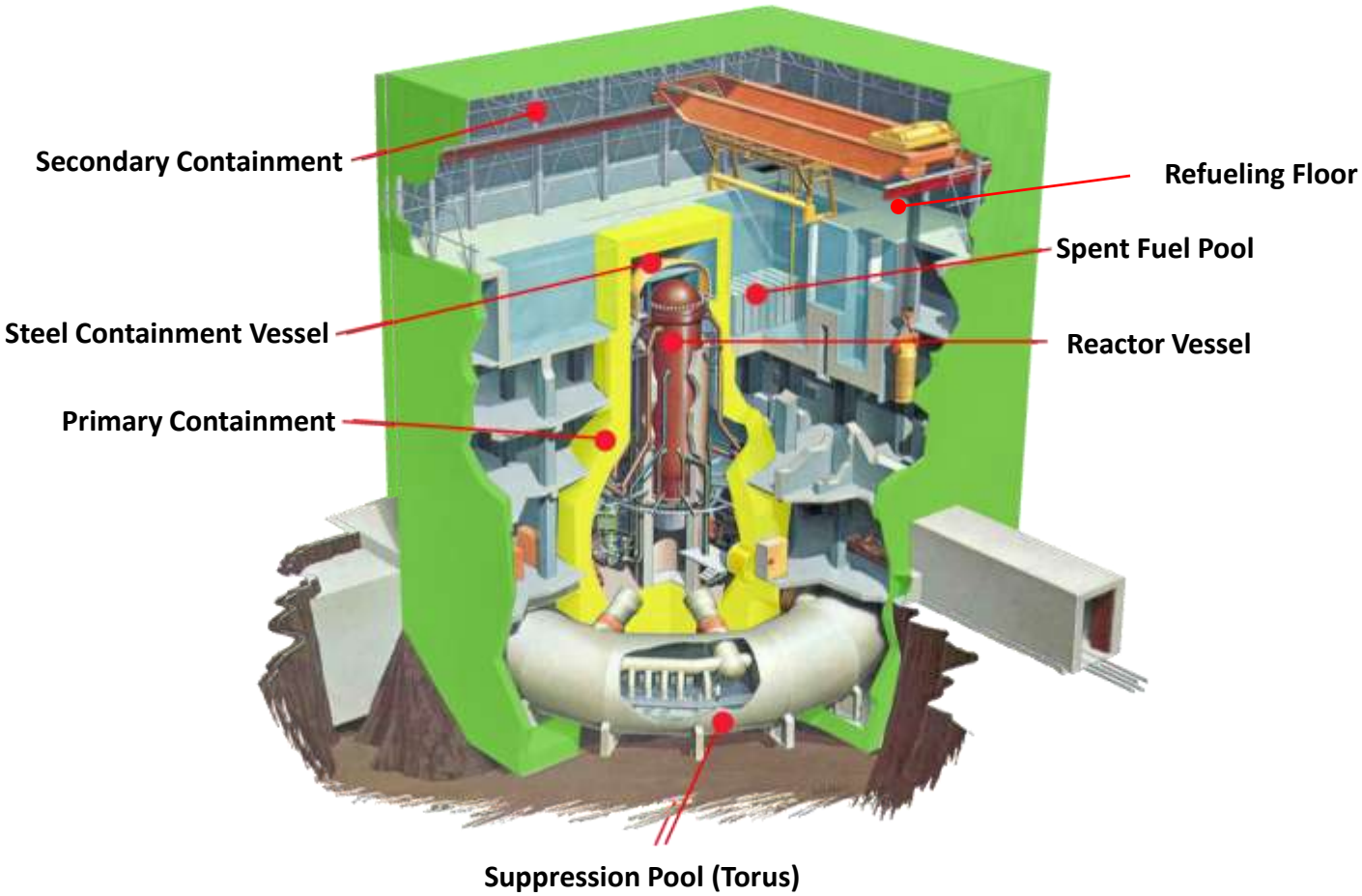
Tsunami Size: Main Safety Factor

3/11 15:45



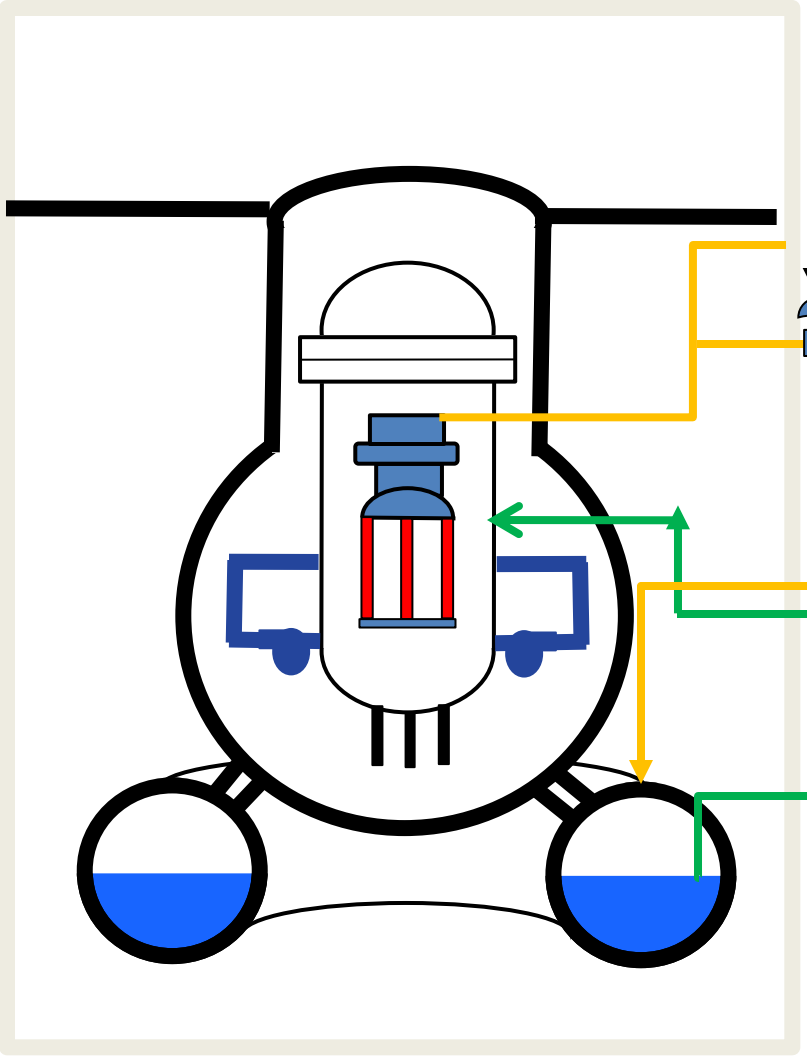
GE Mark I Reactor Building

Boiling Water Reactor Design
At Fukushima Daiichi



Browns Ferry Primary Containment

Battery Power Control of Steam-Driven Reactor Core Isolation Cooling System In Units 2 &3 (Unit 1 Had Isolation Condenser which Operators Stopped)



3/11 15:45 JST

CST?

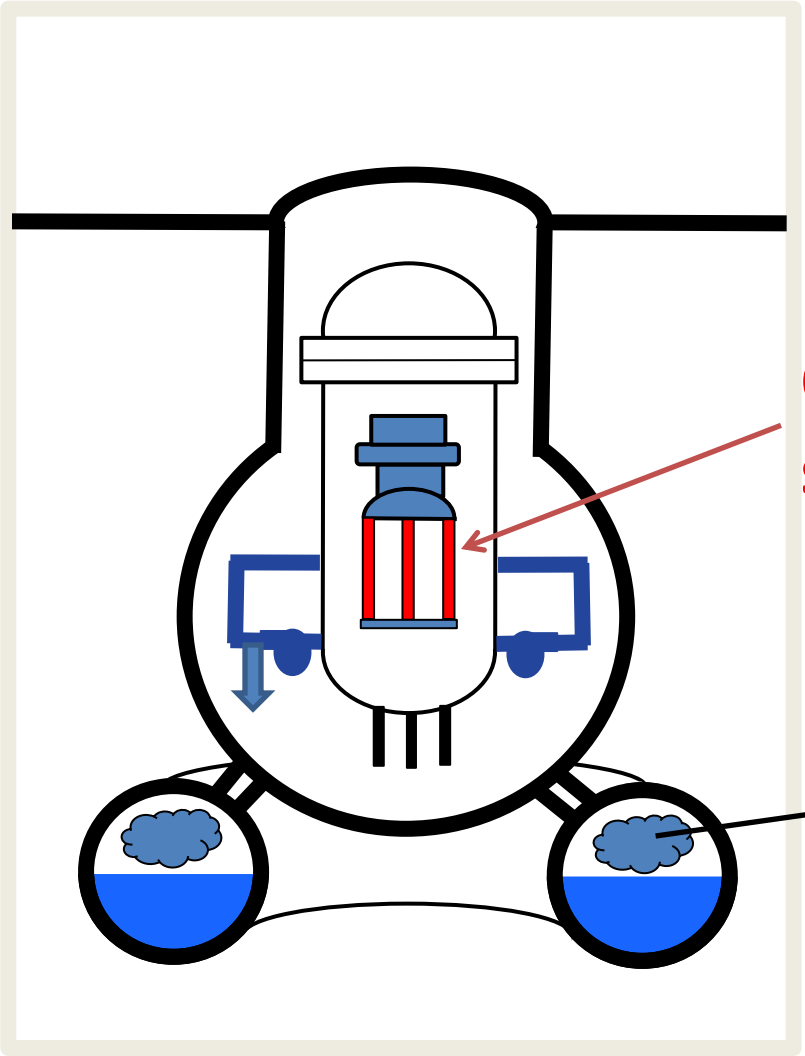
3/11 15:45 to ~ 3/11 24:00 JST

Actions to Extend DC Power For Control

Scavenged Truck Batteries To Maintain Reactor Instrumentation

Control Room Operator During Black Out

Battery Power Exhausted

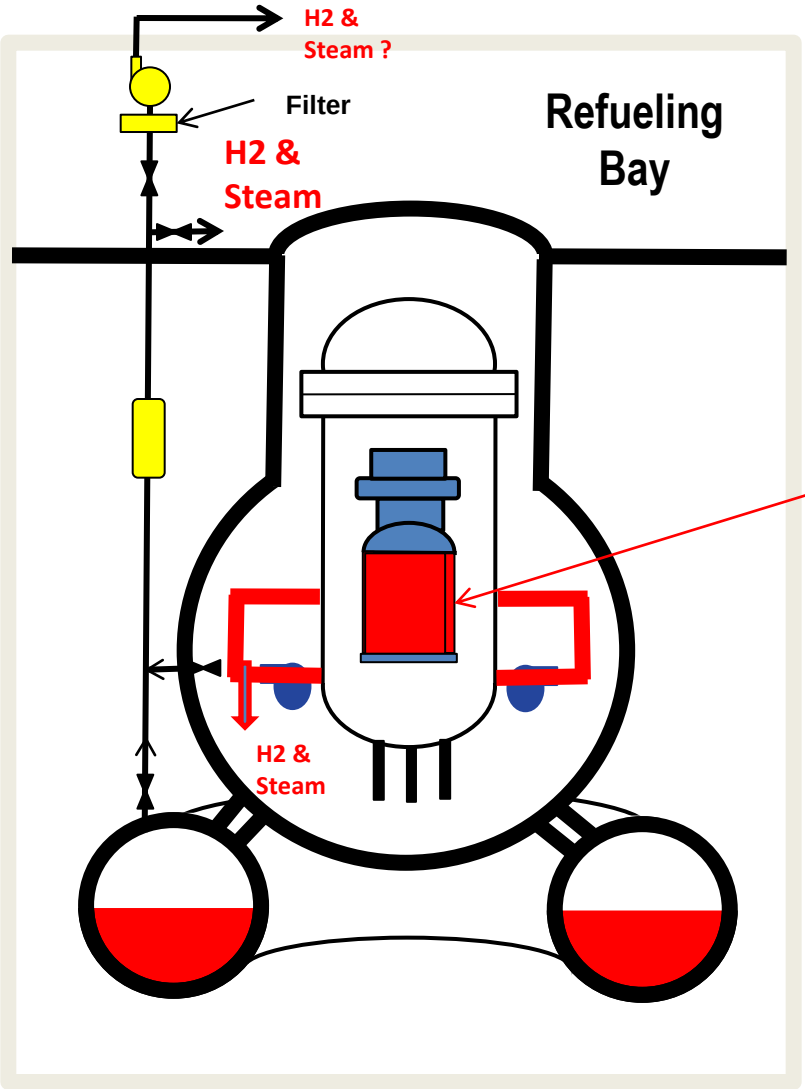


Core Uncovers and starts to overheat

Suppression pool (wet well) becomes saturated

3/12 ~02:00 JST

Venting Primary Containment



Core Overheated

Primary Containment Pressure~ 90psia @02:00 3/12

Uncertain Command & Control Actions & Unit 1 Vent Valve Operability

3/12 ~05:30 U1
3/13 ~ 00:00 U2
3/13 ~ 08:40 U3

0

Unit 1 Reactor Building Explosion

3/12 15:31

Unit 3 Reactor Building Explosion

3/14 11:15

Unit 1 Reactor Building

Unit 3 Reactor Building

Before

Reuters

After

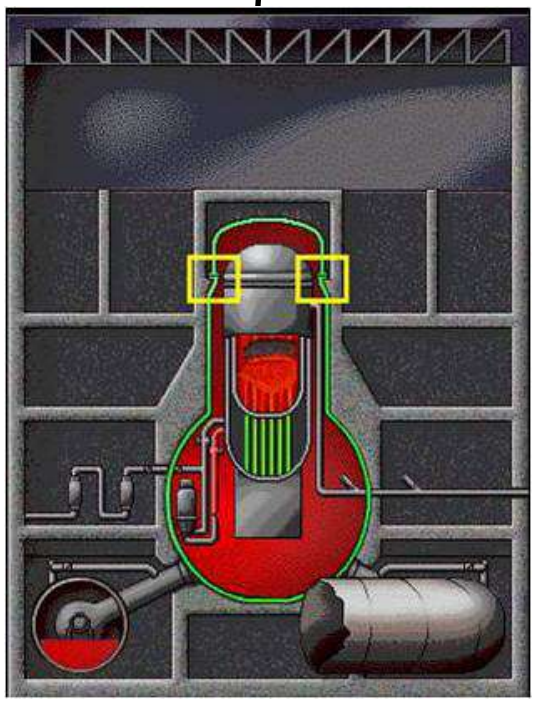
TEPCO

Fukushima: Reactor Vessel-Primary-Secondary Containment Sequence

Primary Coolant System

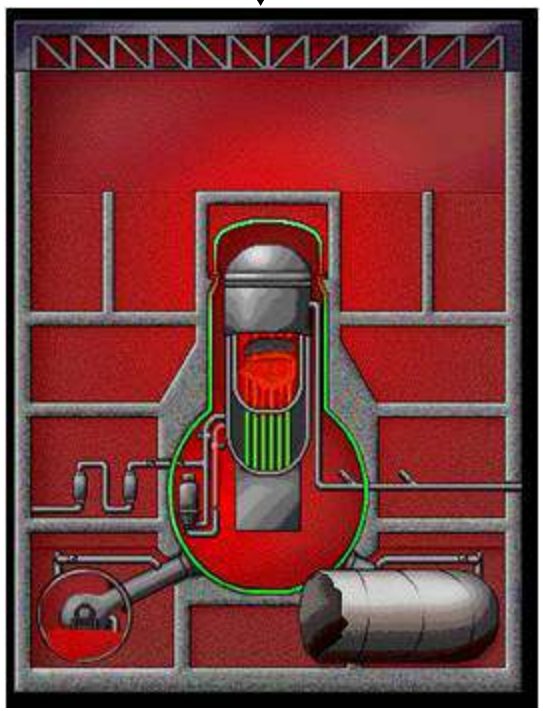
Core Over Heats
-Clad Burst ~900C
-Clad Oxidize ~1200C
-H2 Release
-Partial Melt~1800C-2700C
-Primary Coolant System Overpressure

Primary Containment



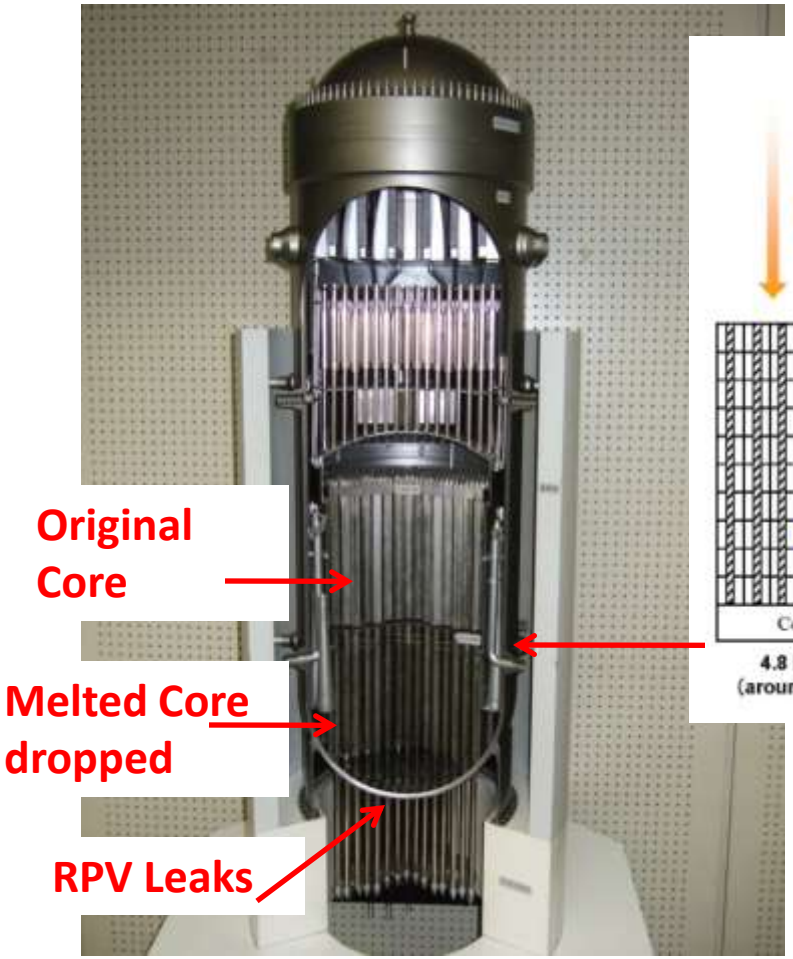
Vent from Primary Coolant Sys to Primary Containment- H2, Steam, & Fission Products (Xe, Kr, I, Cs etc)

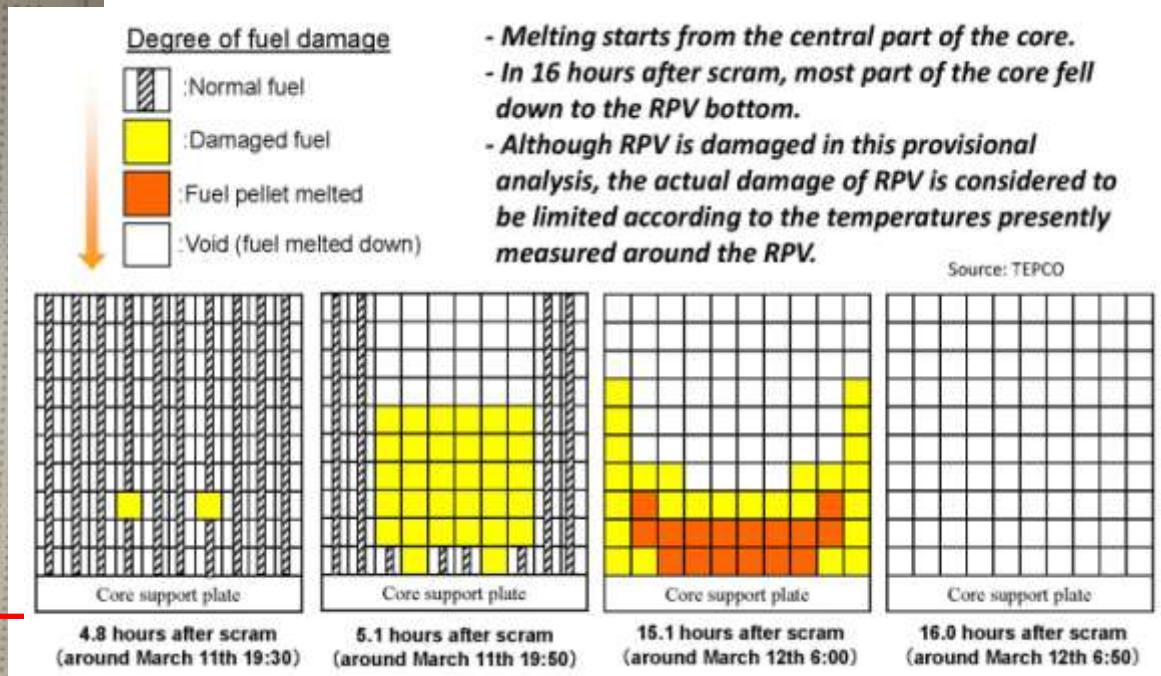
Secondary Containment



No Primary Containment Cooling therefore Primary Containment Overpressure- Vent to Secondary Containment

Cores Melted, Slumped Into Lower Head & Likely Failed Some CRD Penetrations





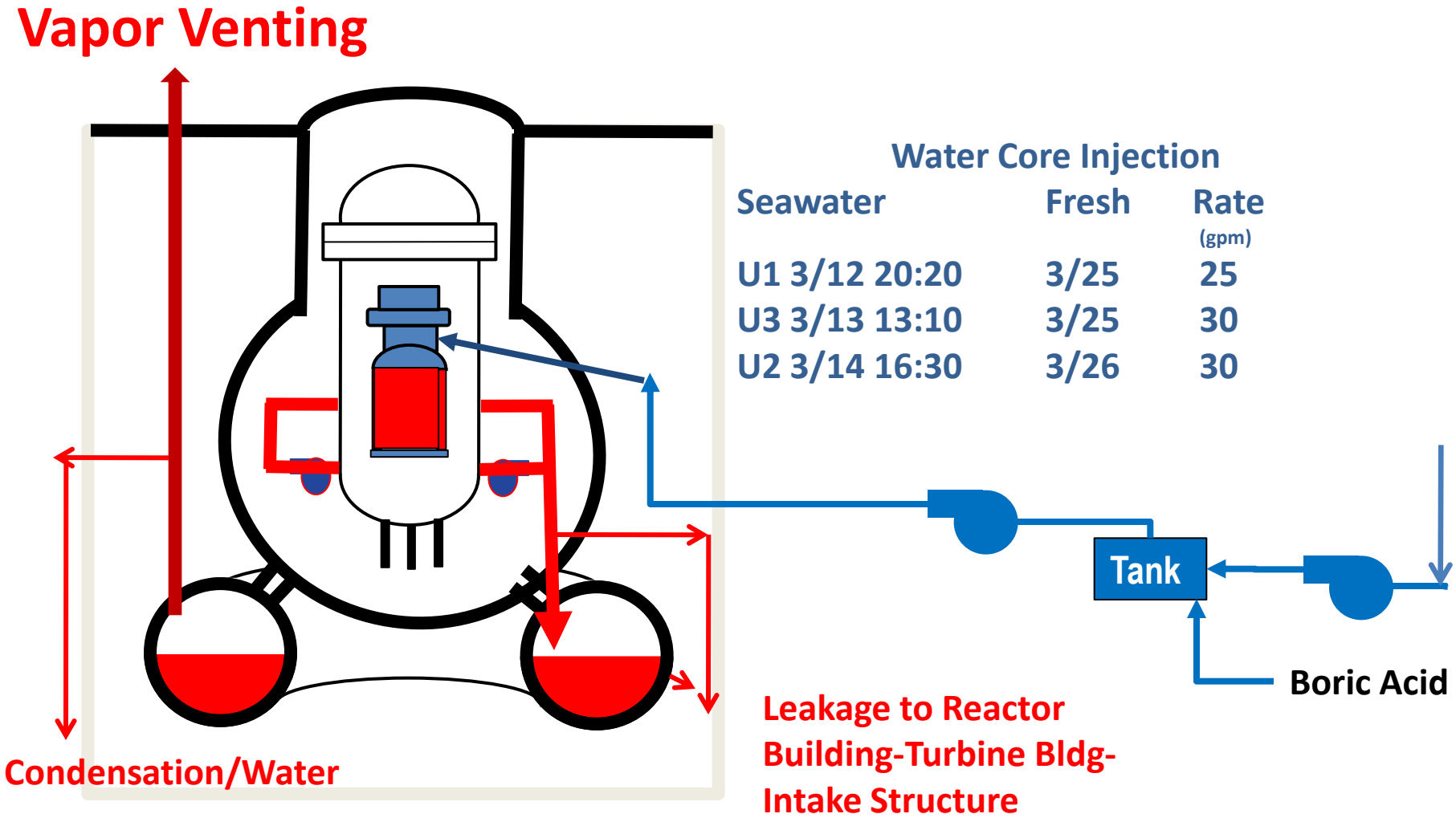
Unit 1 Melt: 3/11~19:00
Unit 2 Melt: 3/14 ~20:00
Unit 3 Melt: 3/13 ~09:00

Core Cooling Established With Fire Truck Sea Water Injection

Bleed & Feed Core Cooling Established

Seawater Injection Started Using Fire Engine Pump

Shift to Fresh Water Injection: To Dissolve Possible Salt Cakes



Water Core Injection

Seawater	Fresh	Rate (gpm)
U1 3/12 20:20	3/25	25
U3 3/13 13:10	3/25	30
U2 3/14 16:30	3/26	30

Immediately After Unit 3 Explosion

3/14/11 ~10:00AM JST

Post Unit 3 & Pre Unit 4 Explosion(s)

Spent Fuel Pool in Reactor Building

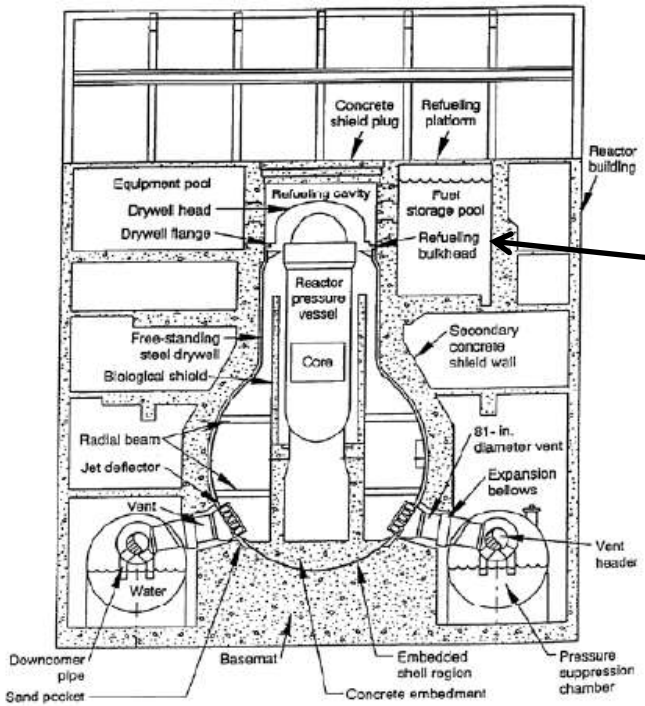
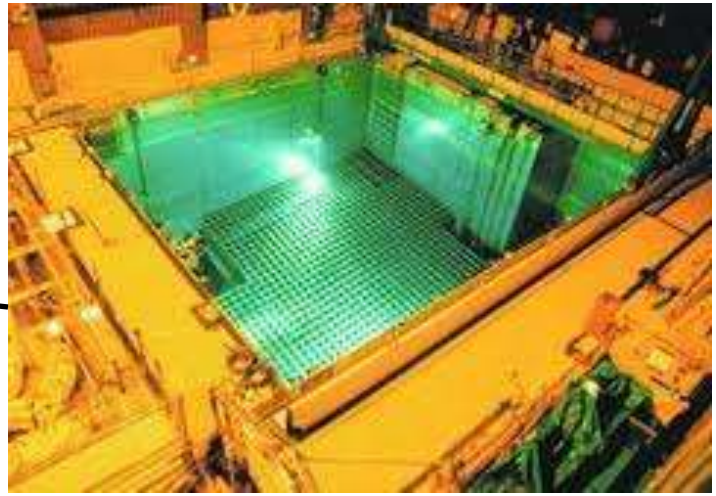
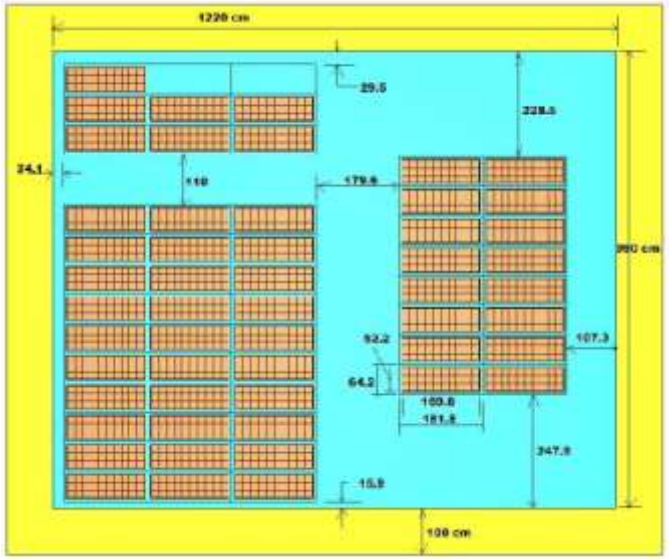


Figure 20. Mark I General Electric,GE BWR Containment.



Unit 4 Pool



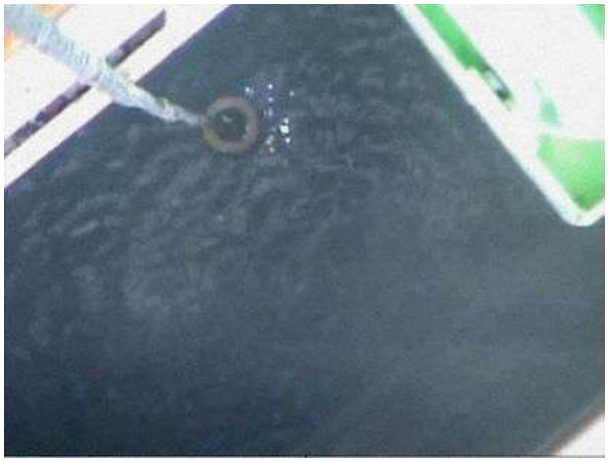
~350,000 Gal
U4:1331 Assemblies SF ~100 day old
U3:514 Assy SF~ 200 Days old
U2: 587 Assy SF ~120 Days Old

Unit 4 Reactor Building

Reuters

TEPCO

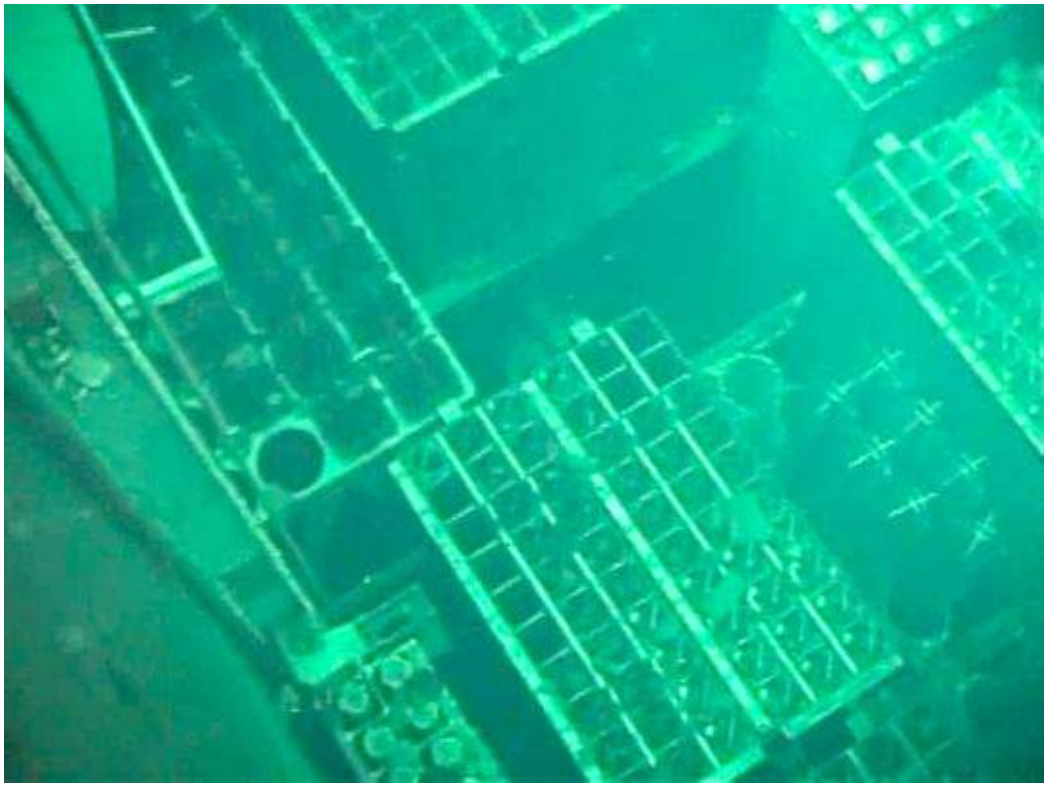
Unit 4 Spent Fuel Pool Water Sampling



Boom Inserting Probe ~11-04-11

400ml Sample Probe ~11-04-11

Unit 4 Spent Fuel Pool



Sampling Indicates Little Fuel Damage

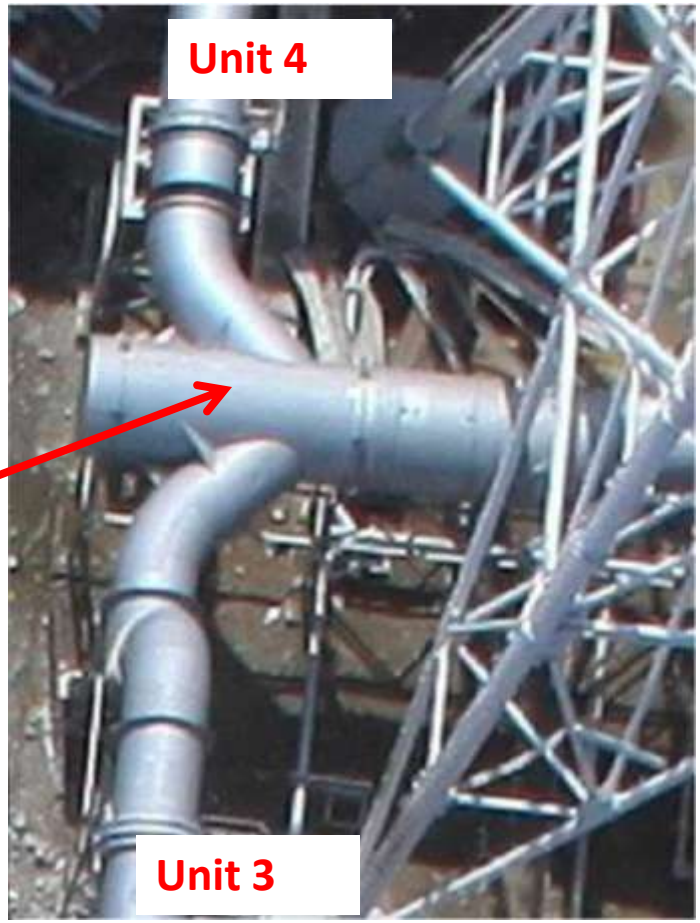
- **Low Cesium Levels in 90Bq/ml**
- **Water Level Lowered For Seismic Safety**

Units 2 & 3 Pools Have Damaged Fuel

-Cesium 137 Levels in 150,000 Bq/ml
-Low Iodine, indicative of older stored fuel
-High Ph ~11.3
-Al Rack Corrosion
-Adding Boric Acid

Building Debris In Unit 3 Pool ~25R/Hr at U3 Refueling Floor

Unknown Unit 4 Explosion Source



Best Theory is Unit 3 H2 Entered Unit via Joint Stack Piping

Fukushima Stabilizing

- Just Established Recirculation Core Cooling
  - Damaged Pressure Vessel(s) & Containments
- Mitigate Airborne Releases
- Mitigate Water Releases
- Gain Building Access to Start Recovery Activities
- Maintain Personnel Safety: High Rad Areas
- Reduce and Mitigate Evacuation Zone Impacts

Units 1-6 After U4 Spent Fuel Pool Explosion

Units 1-4 After U4 Spent Fuel Pool Explosion
3/16

Units 3, 2, & 1 Looking Down

Units 4 & 3 Looking Down

Unit 4 Fuel Pool-Side

福島第一原子力発電所 4号機(3/16 PM撮影)

Unit 3 & Unit 4

Unit 3 Spent Fuel Pool
3/16

福島第一原子力発電所 3号機(3/16 PM撮影)

Water Spray to Unit 3 Pool Area

Unit 4 Reactor Building
Water Injection Boom To Spent Fuel Pool