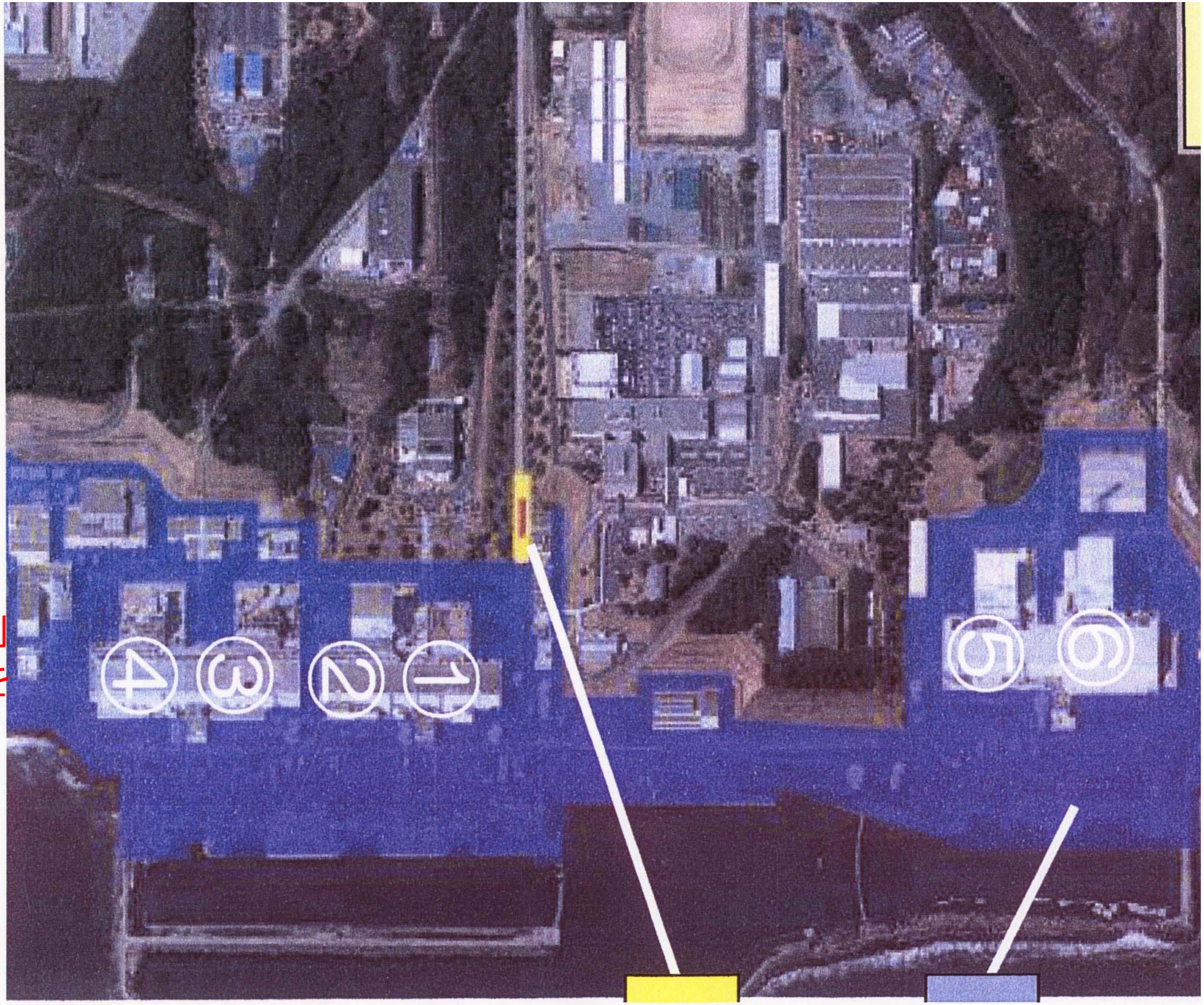
Reactor core meltdown and radioactivity release during the Fukushima Daiichi accident

12/06/27 Ebisawa T

1. Introduction
2. Structure of “Mark Ⅰ” Boiling Water Reactor
3. Available Core Cooling Systems
   in the Fukushima Accident after SBO
4. How the Reactor Cores Now ?

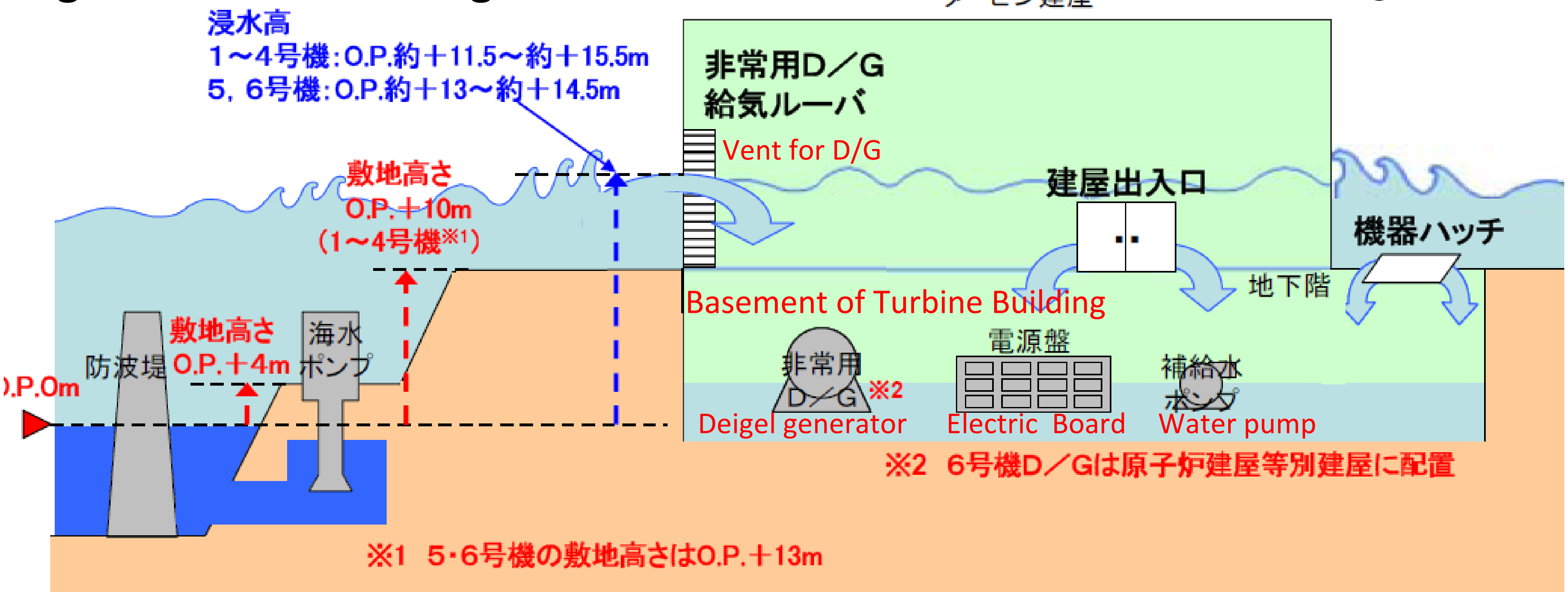
25m掘削
原子炉を
設置



浸水経路になったと考えられる。　　　　　　　　　　　　　　　　　　　【添付７－１】

　なお、建屋内部の水配管等からの溢水で重要機器が損傷しないように必要な箇所には溢水対策を講じており、隣接するエリアからの浸水防止のため堰や水密扉の設置などを行っている。しかし、今般のようにルーバなど上部から浸水し、その浸水箇所の水密性が高い場合（非常用Ｄ／Ｇ室など）、浸水が滞留するケースも見られた。

Fig. 1 Turbine Building Attacked Tsunami



（２）津波による設備被害

　１４時４６分に地震が発生し、その地震動の到達によって各プラントでは地震動を検

2 Structure of MARK Ⅰ BWR

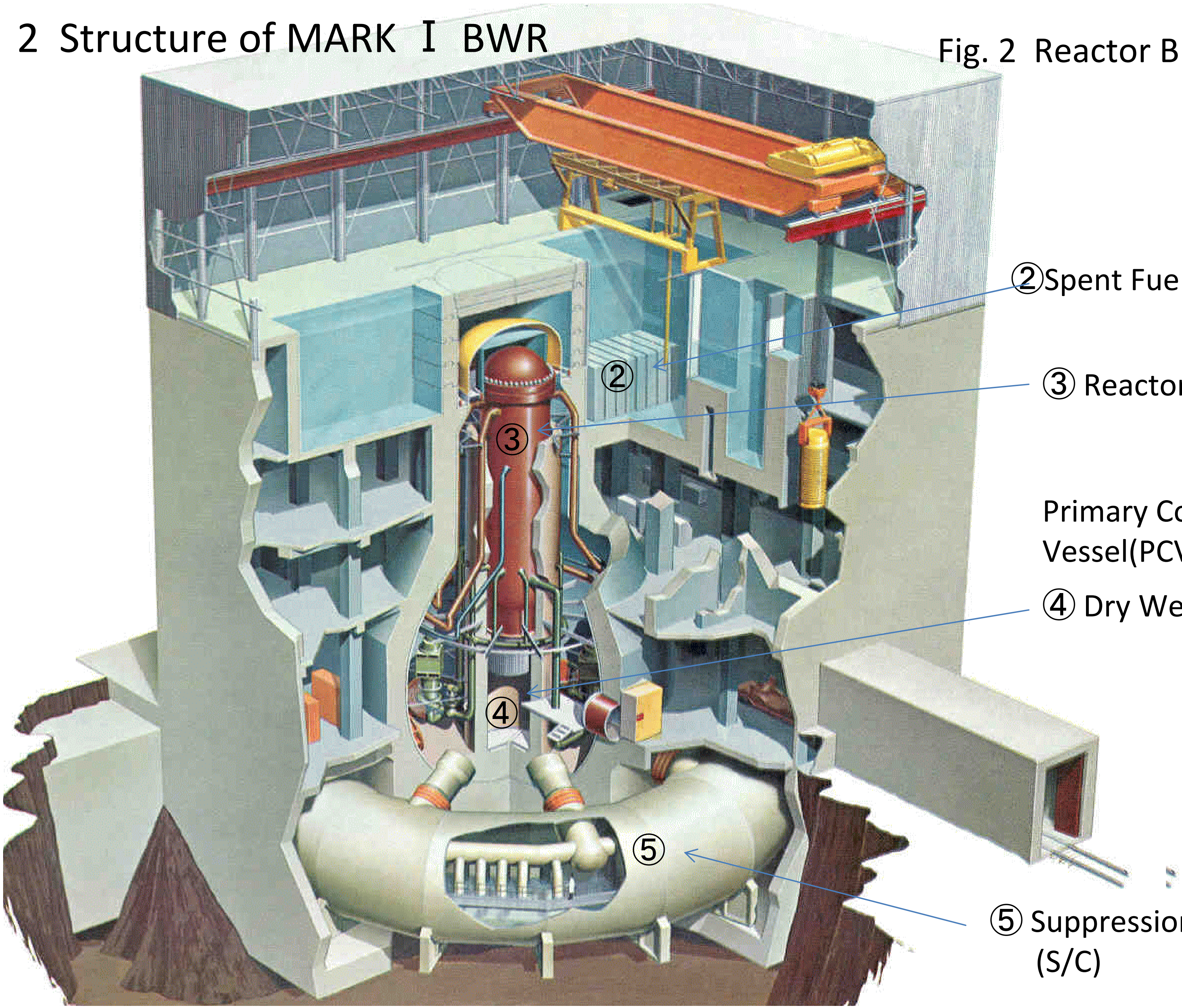
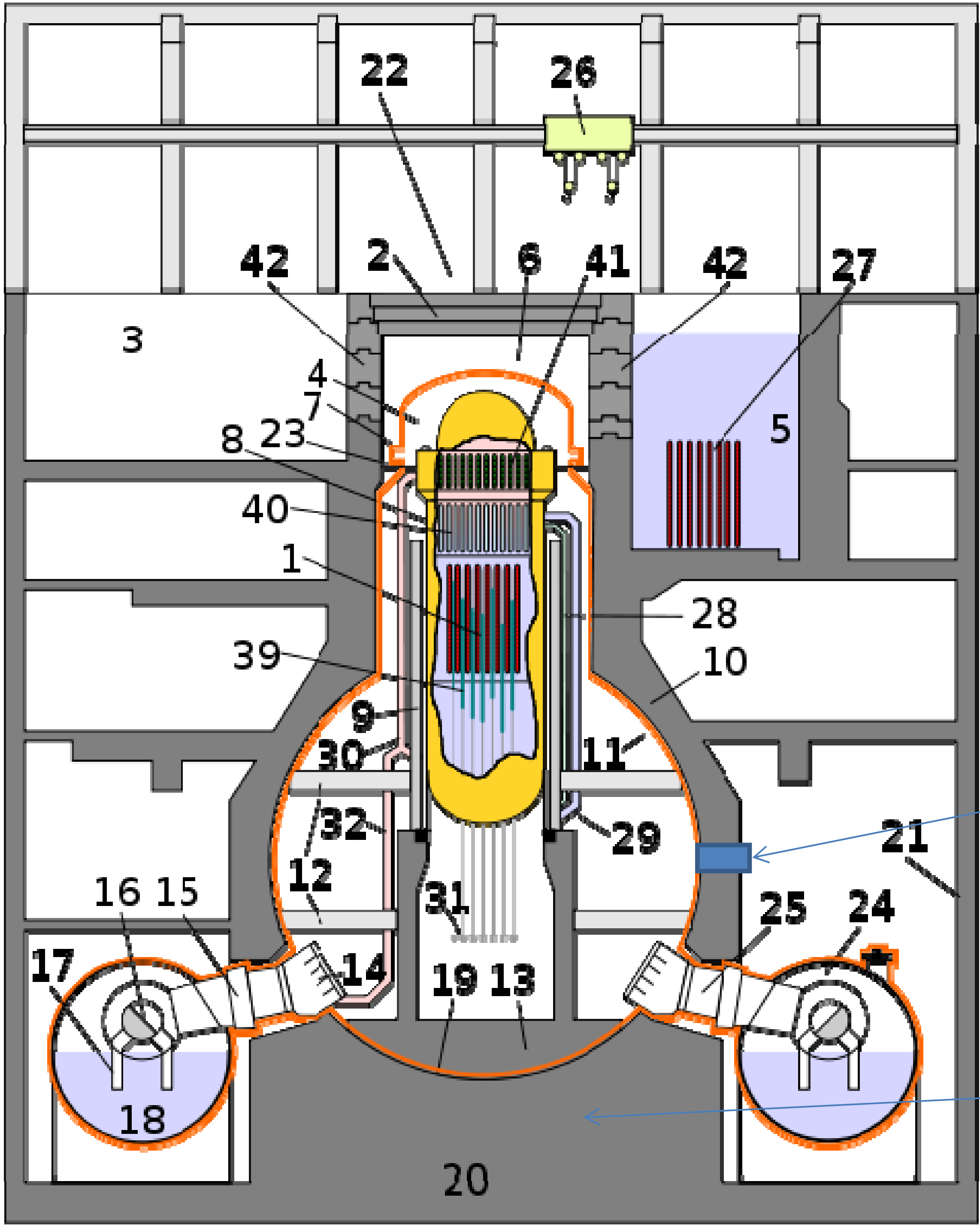


Fig. 2 Reactor Building

Fig. 3 Structure of Reactor Syster

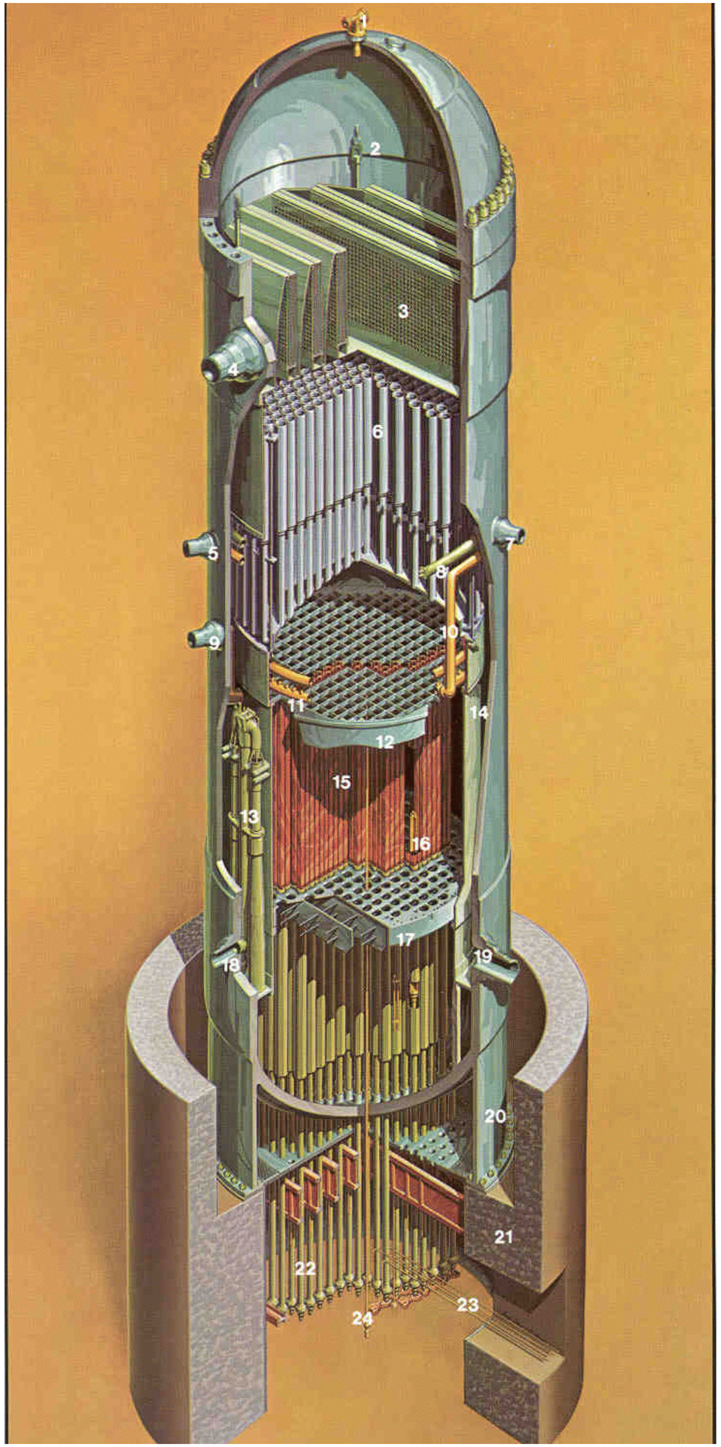


1 Core
5 Fuel storage pool
8 Reactor pressure vessel
9 Biological shield
10 Concrete shield
11 Free standing steel dry well
13 Concrete embedment
27 Spent Fuel
30 Steam pipe
31 Control rods
32 Blow down line

PCV Radiation Monitor

When the radio activities in the core flow into PCV, the monitor detects the radiations.

Basement concrete of about 7 meters thickness



BWR/6

REACTOR ASSEMBLY

1. VENT AND HEAD SPRAY
2. STEAM DRYER LIFTING LUG
3. STEAM DRYER ASSEMBLY
4. STEAM OUTLET
5. CORE SPRAY INLET
6. STEAM SEPARATOR ASSEMBLY
7. FEEDWATER INLET
8. FEEDWATER SPARGER
9. LOW PRESSURE COOLANT INJECTION INLET
10. CORE SPRAY LINE
11. CORE SPRAY SPARGER
12. TOP GUIDE
13. JET PUMP ASSEMBLY
14. CORE SHROUD
15. FUEL ASSEMBLIES
16. CONTROL BLADE
17. CORE PLATE
18. JET PUMP / RECIRCULATION WATER INLET
19. RECIRCULATION WATER OUTLET
20. VESSEL SUPPORT SKIRT
21. SHIELD WALL
22. CONTROL ROD DRIVES
23. CONTROL ROD DRIVE HYDRAULIC LINES
24. IN-CORE FLUX MONITOR

GENERAL ELECTRIC

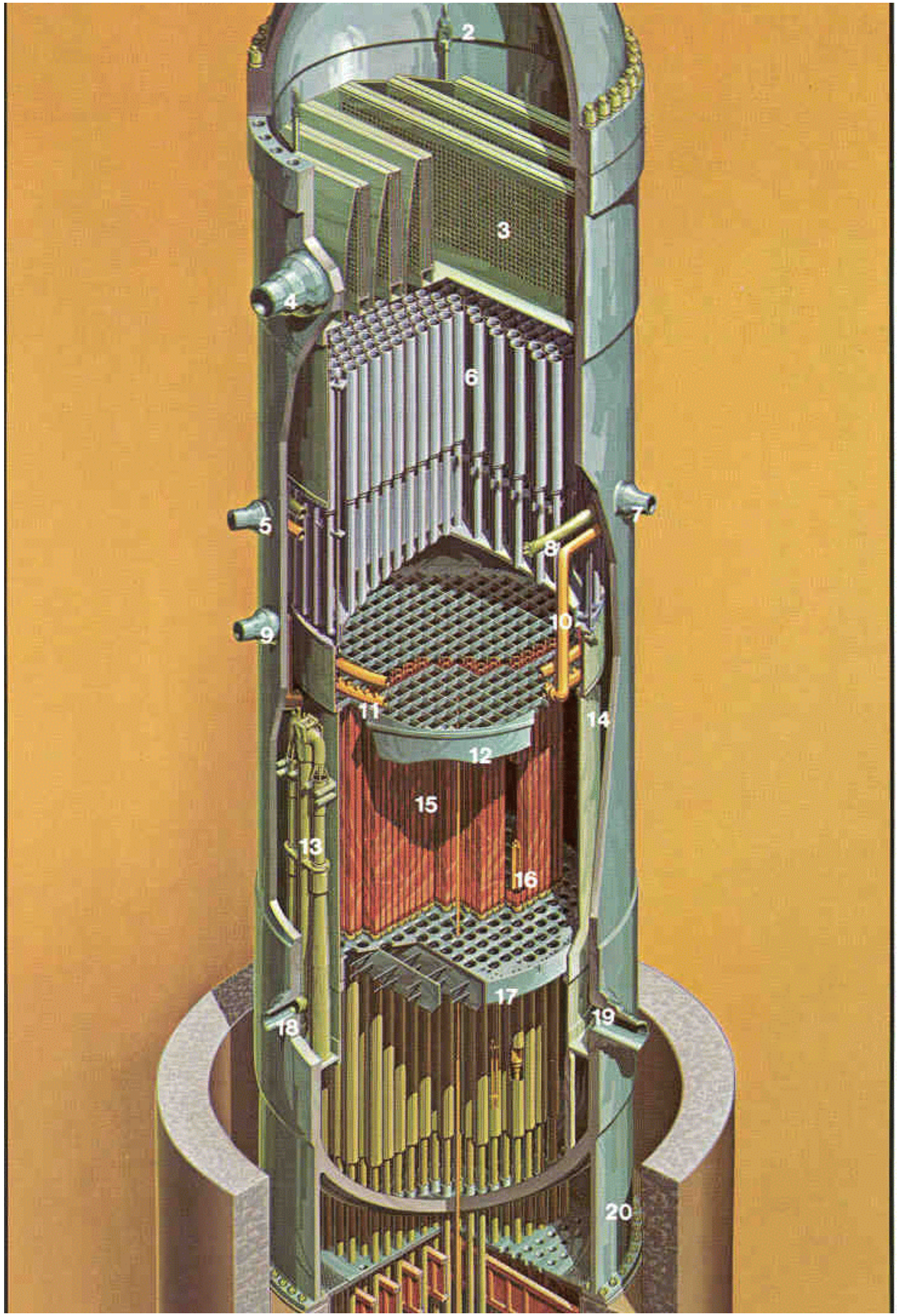


Fig. 4 BWR Reactor

1. VENT AND HEAD SPRAY
2. STEAM DRYER LIFTING LUG
3. STEAM DRYER ASSEMBLY
4. STEAM OUTLET
5. CORE SPRAY INLET
6. STEAM SEPARATOR ASSEMBLY
7. FEEDWATER INLET
8. FEEDWATER SPARGER
9. LOW PRESSURE COOLANT INJECTION INLET
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19. RECIRCULATION WATER OUTLET
20. VESSEL SUPPORT SKIRT
21. SHIELD WALL
22. CONTROL ROD DRIVES

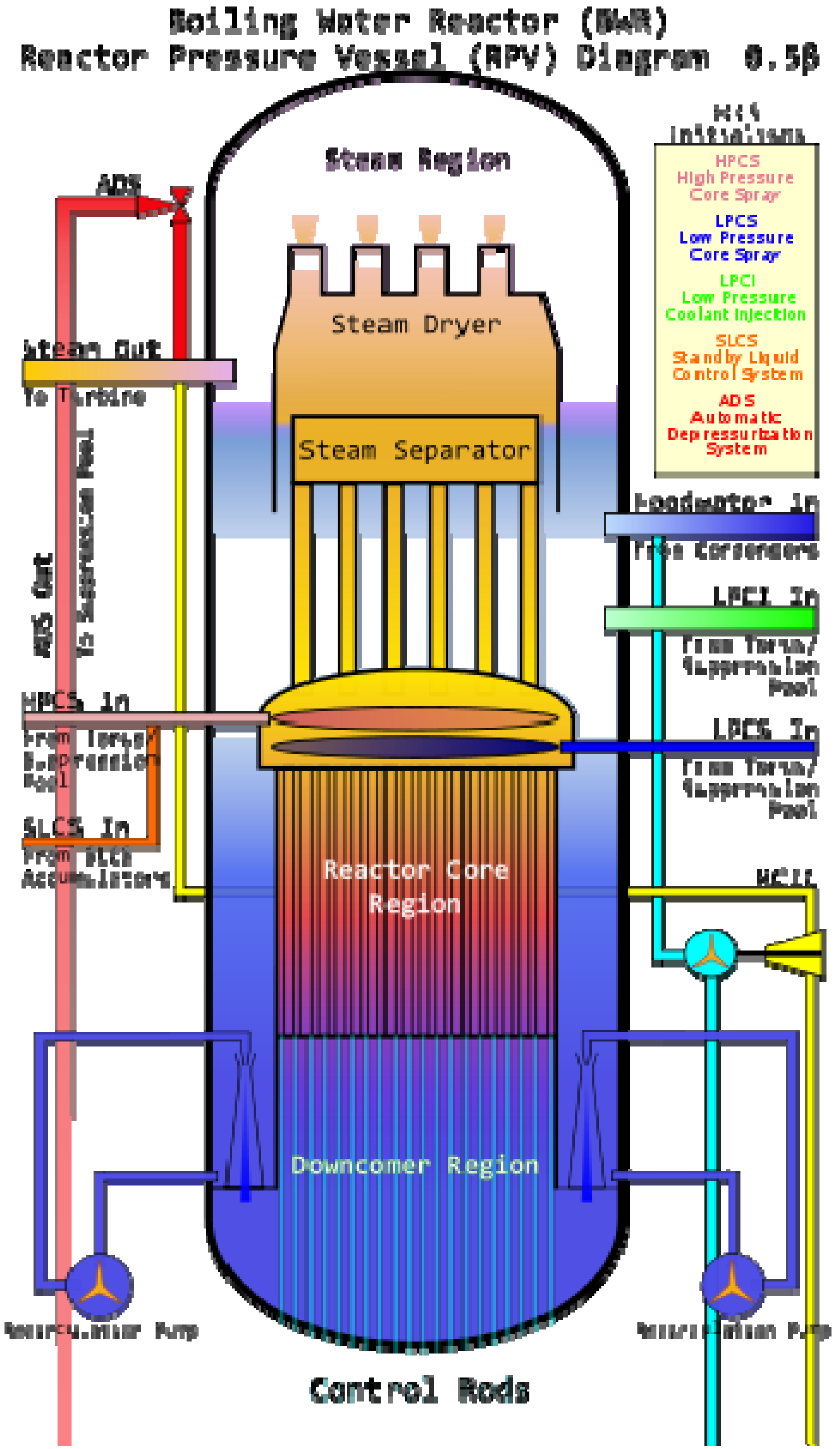


Fig. 5 BWR Cooling System

3. Available Core Cooling Systems in the Fukushima Accident after SBO

3-1 The 1 st Reactor has two Isolation Condensers (IC)

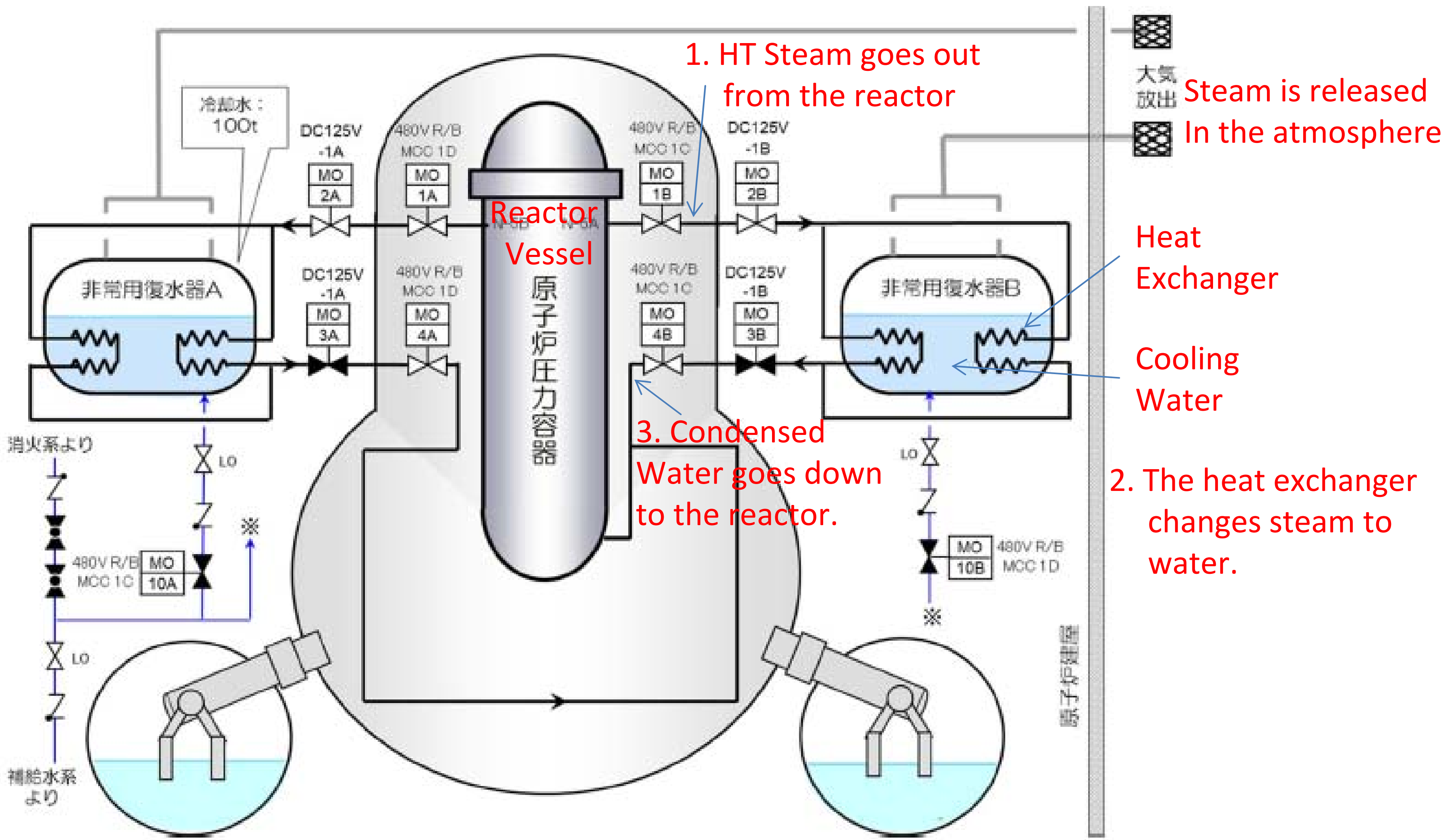
3-2 The 2 nd and 3 rd Reactor have A Reactor Core Isolation Cooling (RCIC) System.

3-3 Fire Engines were used to cool the Molten Cores.

Fig. 5 Isolation Condenser(IC)

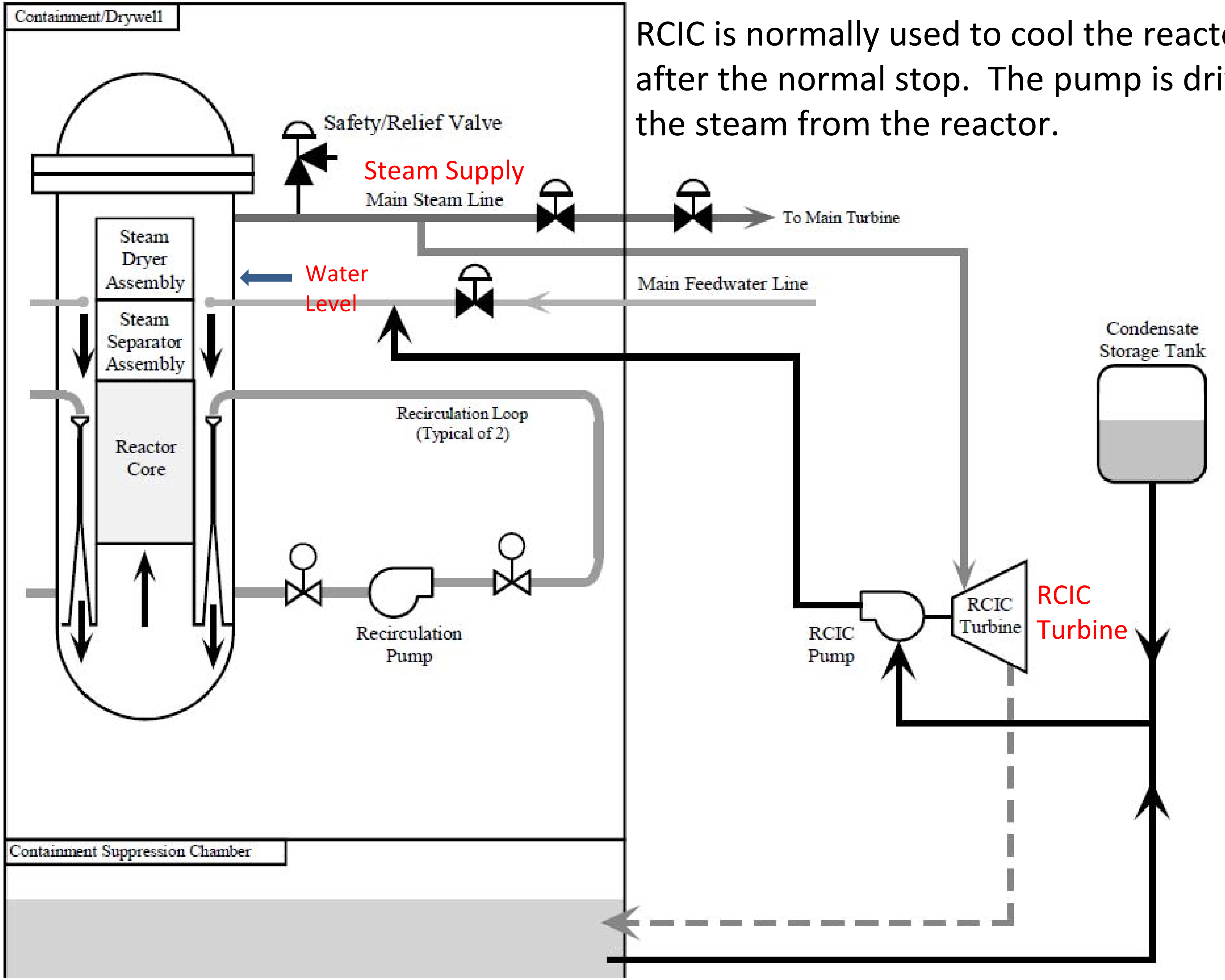
非常用復水器（IC）

資料Ⅱ－17



東京電力作成

Fig 6 Reactor Core Isolation System (RCIC)



RCIC is normally used to cool the reactor core after the normal stop. The pump is driven by the steam from the reactor.

Fig. 7 The Cooling of the molten Core using the Fire Engine

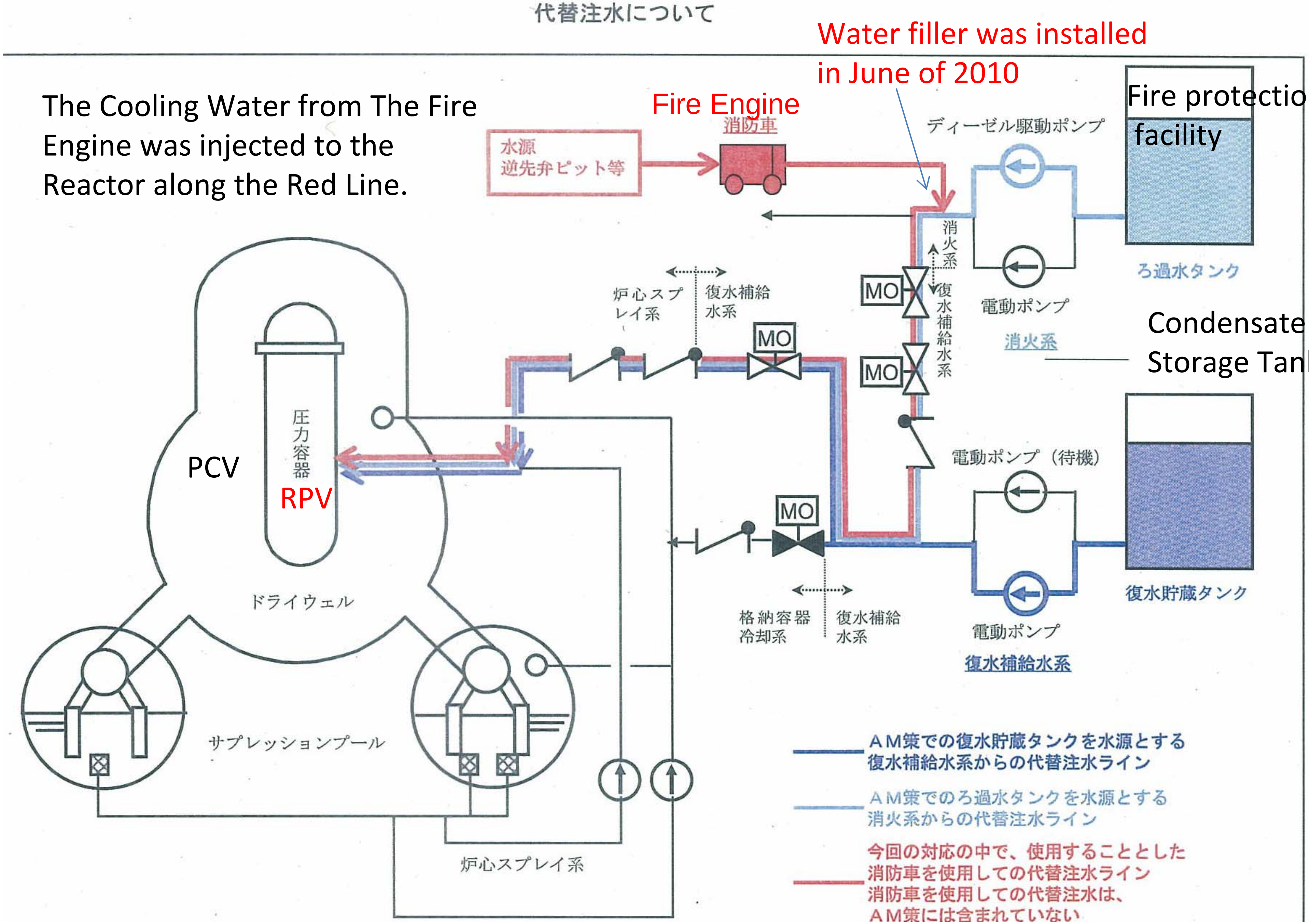


Fig. 8 Simulation results by TEPCO on the PCV pressure.

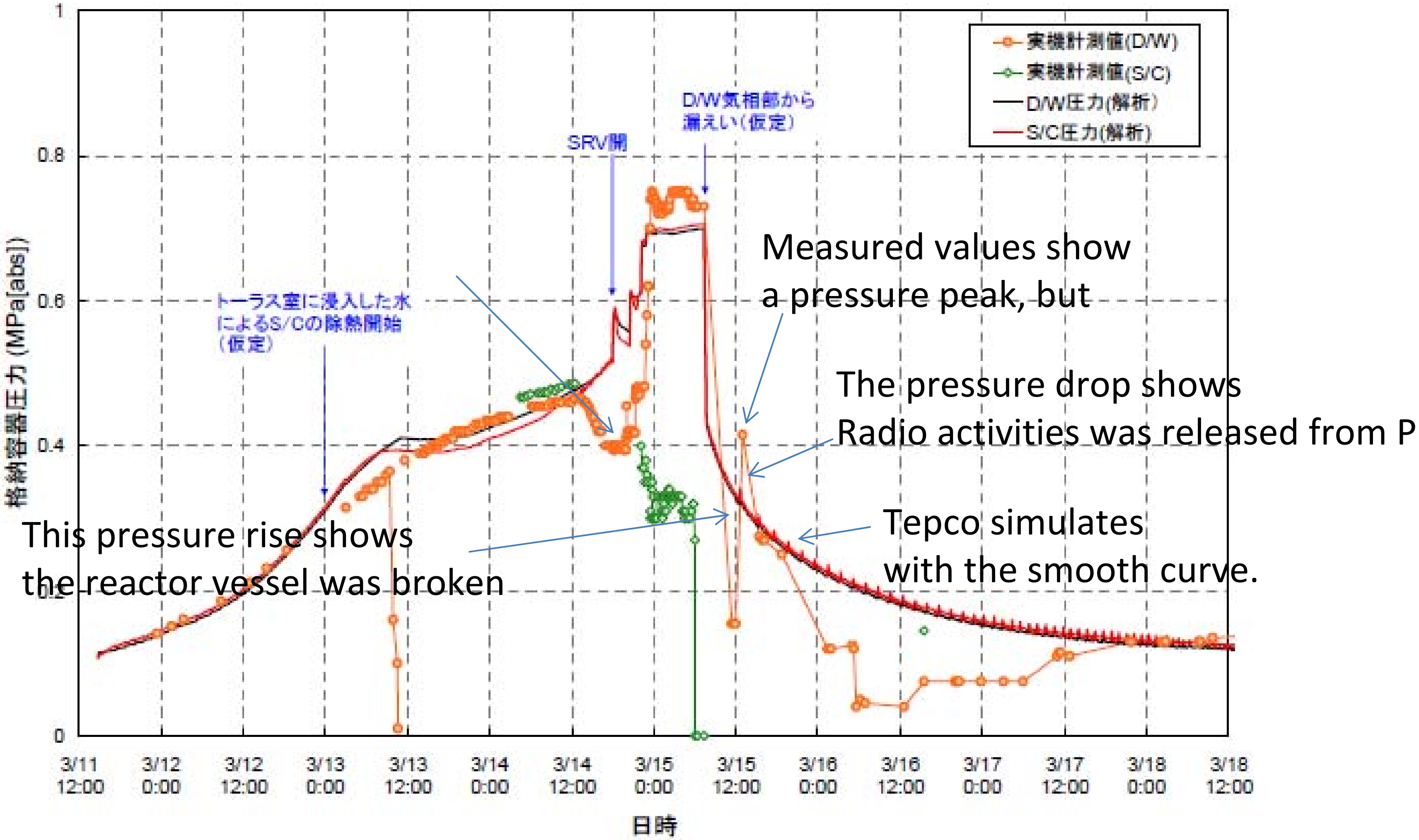
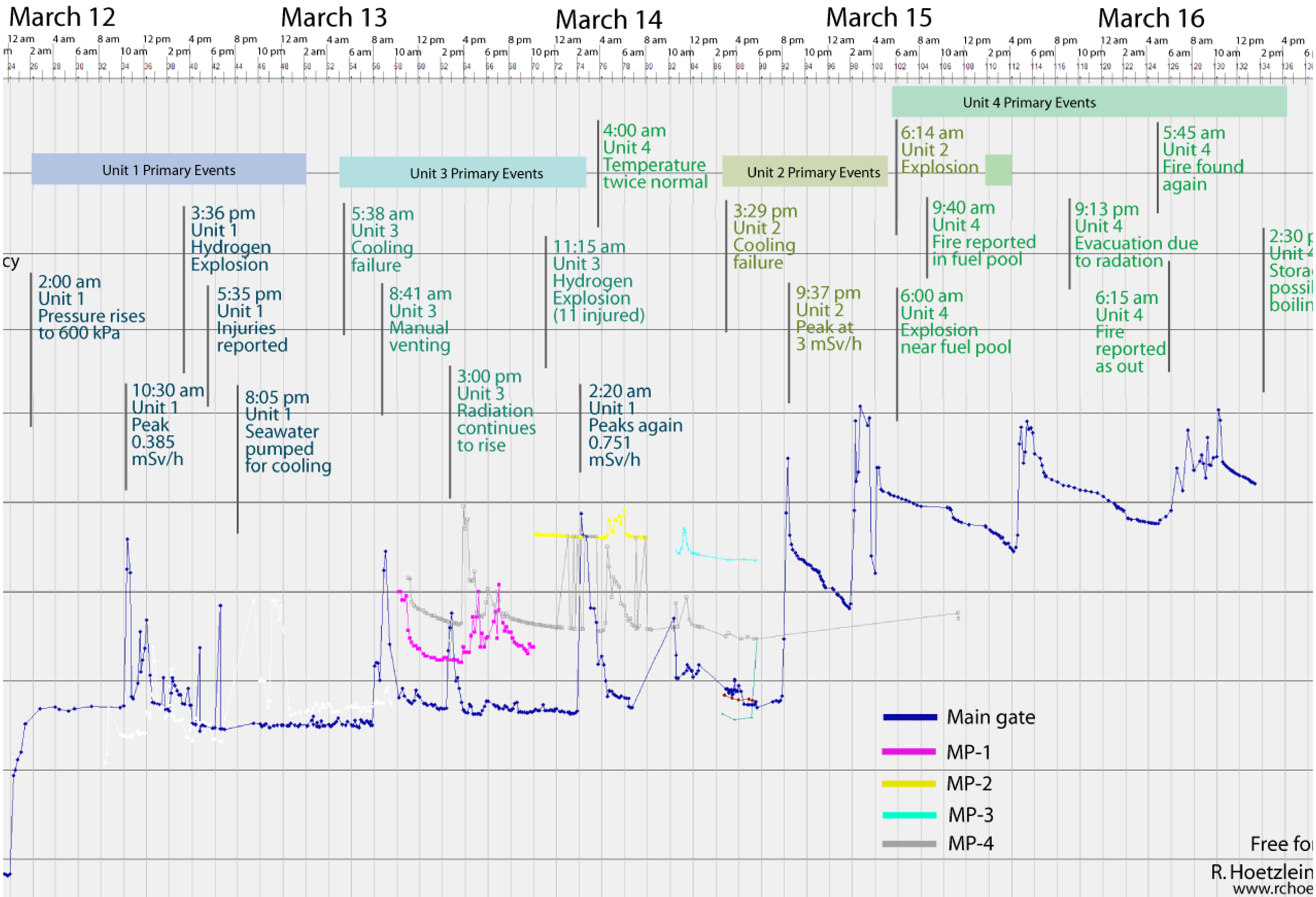


図 3-3　2 号機 格納容器圧力変化



otes: [1] Nuclear event levels are triggered by particular events regardless of radiation doseage. Partially melted rods at Fukushima warrants Level 5. Levels 1, 2 and 3 have specific radiation dosage limits. Source: International Atomic Energy Agency (IAEA), Nuclear Incident Event Scale (INES)

[2] Chernobyl Source: B. Medvedev, JPRS Report on Soviet Union Economic Affairs Chernobyl Notebook, 1989.

[3] Fukushima events from numerous sources. Listed on wikipedia page for Fukushima I Nuclear Accident. Measurement data: TEPCO, Mar. 16th

The accident sequence of the 1st Reactor

In the 1st Reactor, any cooling system did not operate after SBO, so that the event sequences were very simple. IC were not available by the valve problems .

1)11/03/11/14:46 : Earth Quake occurred : Reactor scrummed
2) 11/15:35 : Power station was attacked by Tsunami
3) 11/15:42 : Station Black Out (SBO)
4) 11/18:30 : Reactor water level went down to TAF(Top of Active Fuel)
5) 11/20:30 : Core melting started
6) 11/23:00 : Core collapsed
7) 12/01:00 : Pressure of PVC rose to 0.52 Mpa gauge
8) 12/02:45 : The pressures of the Reactor and PCV became the same
9) Reactor penetration failure occurred until this time.
10) 12/04:00 : Molten core fell down on the concrete floor of PCV
11) 12/05:40 : A fire engine supplied cooling water to the reactor vessel
12) 12/14:30 : PCV(S/C) Vent
13) 12/15:36 : Hydrogen explosion

The accident sequence of The 2nd Reactor

1)11/03/11/14:46 : Earth Quake occurred : Reactor scrummed
2) 11/15:35 : Tsunami occurred
3) 11/15:39 : RCIC (Reactor Core Isolation Cooling system)operated
4) 14/10:00 :RCIC lost the cooling capability
5) 14/16:20 :Water level went down to TAF(Top of Active Fuel)
6) 14/18:20 :Water level went down to BAF(Base of Active Fuel)
7) 14/21:00 :The pressure of Reactor and PCV become same value
8) 14/23:35ー15/7:25 : High pressure of 0.65(Mpa g) kept
9) 15/07:25ー11:25 : Pressure changed quickly : PCV broken
10) 15/11:25ー13:00 :Much steam was generated in the reactor
11) 15/13:30 :Reactor vessel broken in the base
12) 15/15:25 : Peak value of PCV radiation monitor
13) This show that much X-133 were released
14)

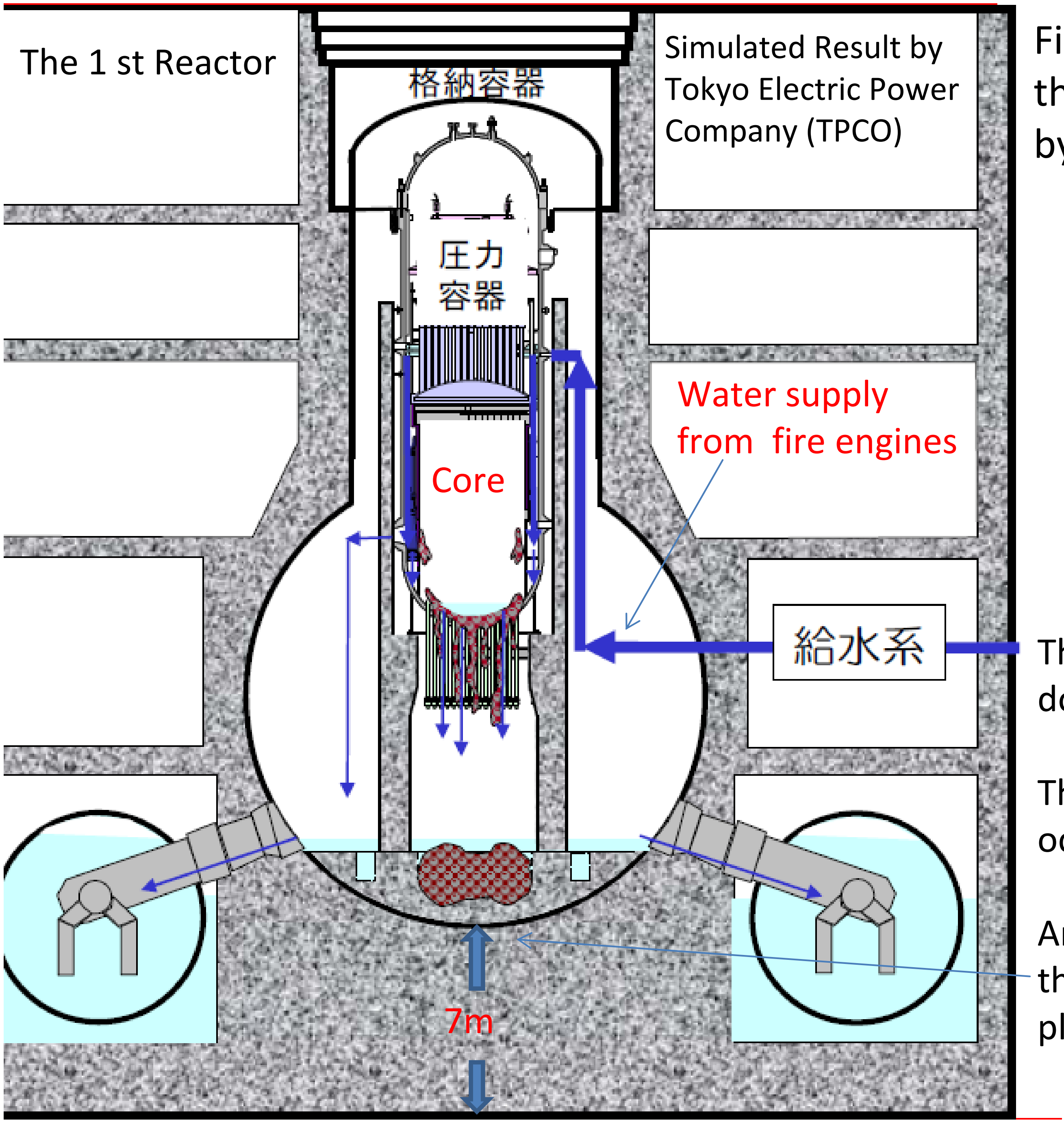


Fig.8 Present status of the 1 st reactor molten core by simulations of (TPCO).

The core of the 1st Reactor fell down on the floor of the PCV.

The core concrete reaction was occurred after the falling down.

Anyone doesn't know the molten core broke the base plate of the PCV or not.

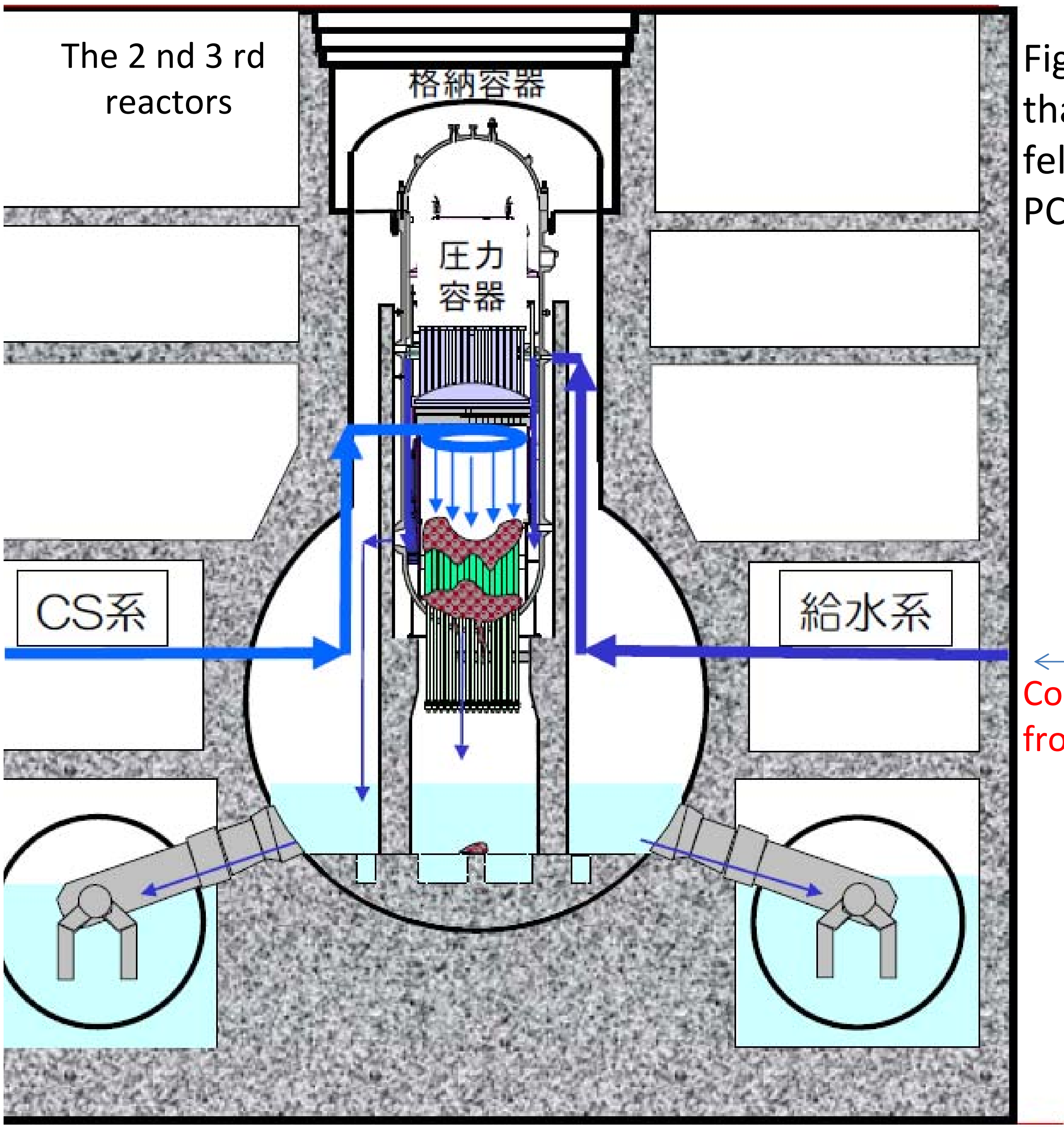
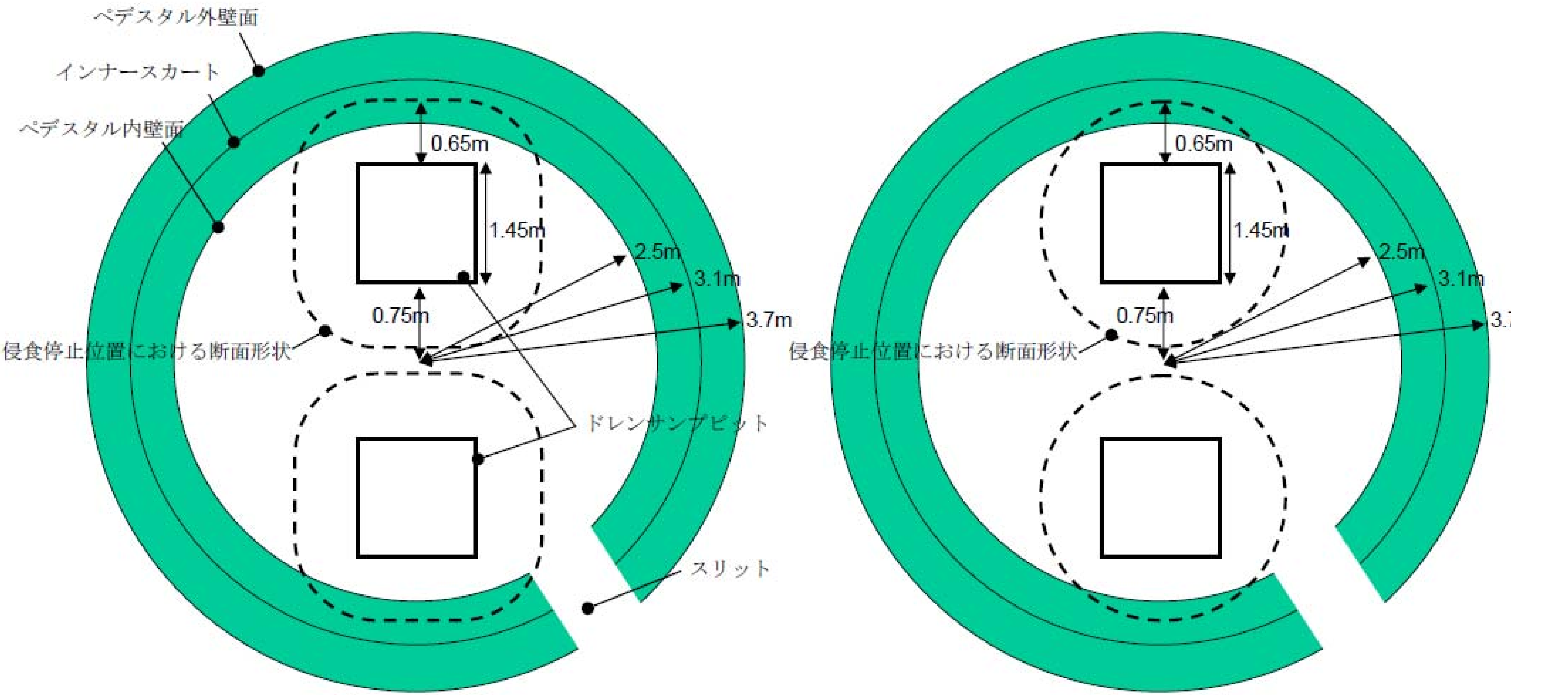


Fig. 9 TEPCO estimates that 60 % of the molten core fell down on the base of PCV in the maximum.

Cooling water supply from fire engines

2. 解析結果　1号機

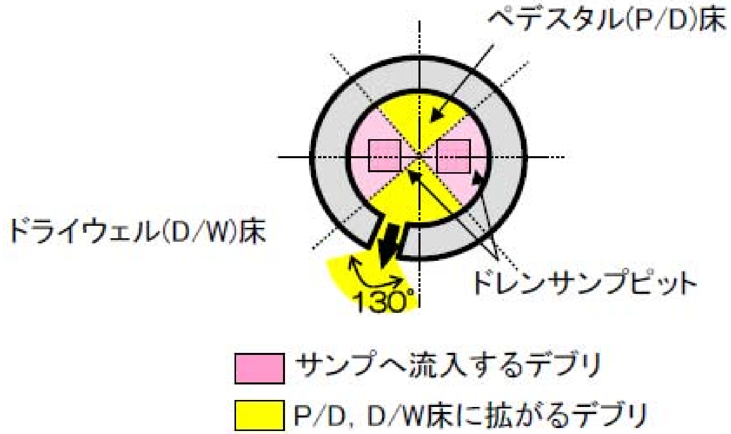


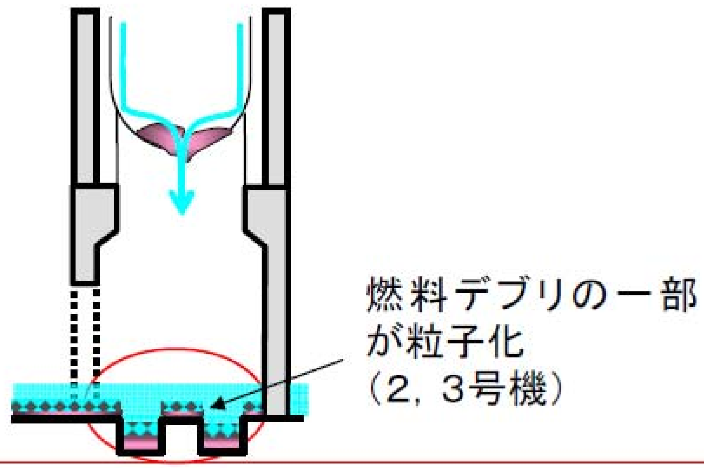
- ドレンサンプピット壁面の侵食が進行するにつれ、侵食面は円形に近づくと推定される。
- このため、実際の侵食停止位置における断面形状は左図と右図の間にあると推定される。

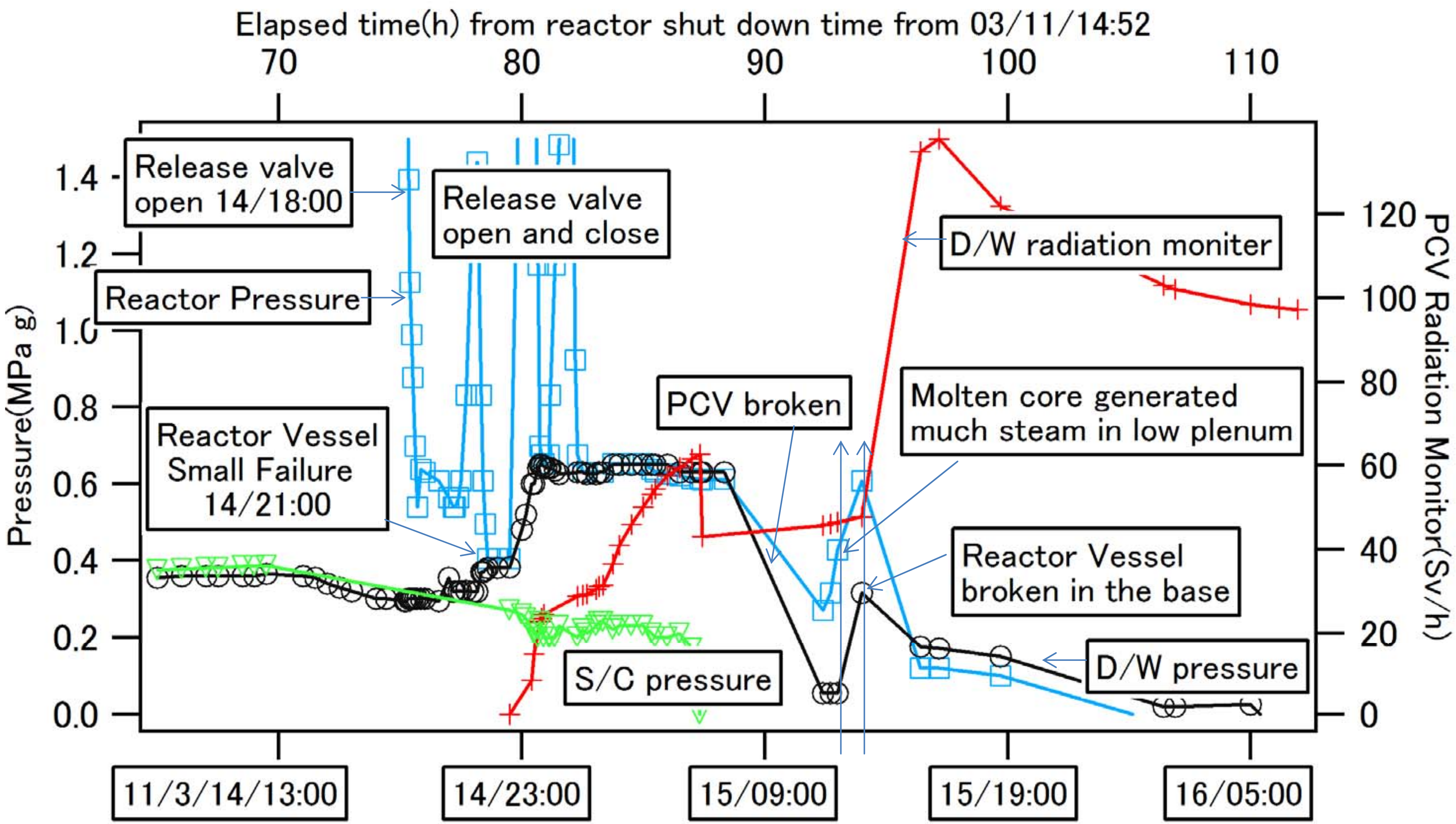
2. 解析条件②

●解析条件

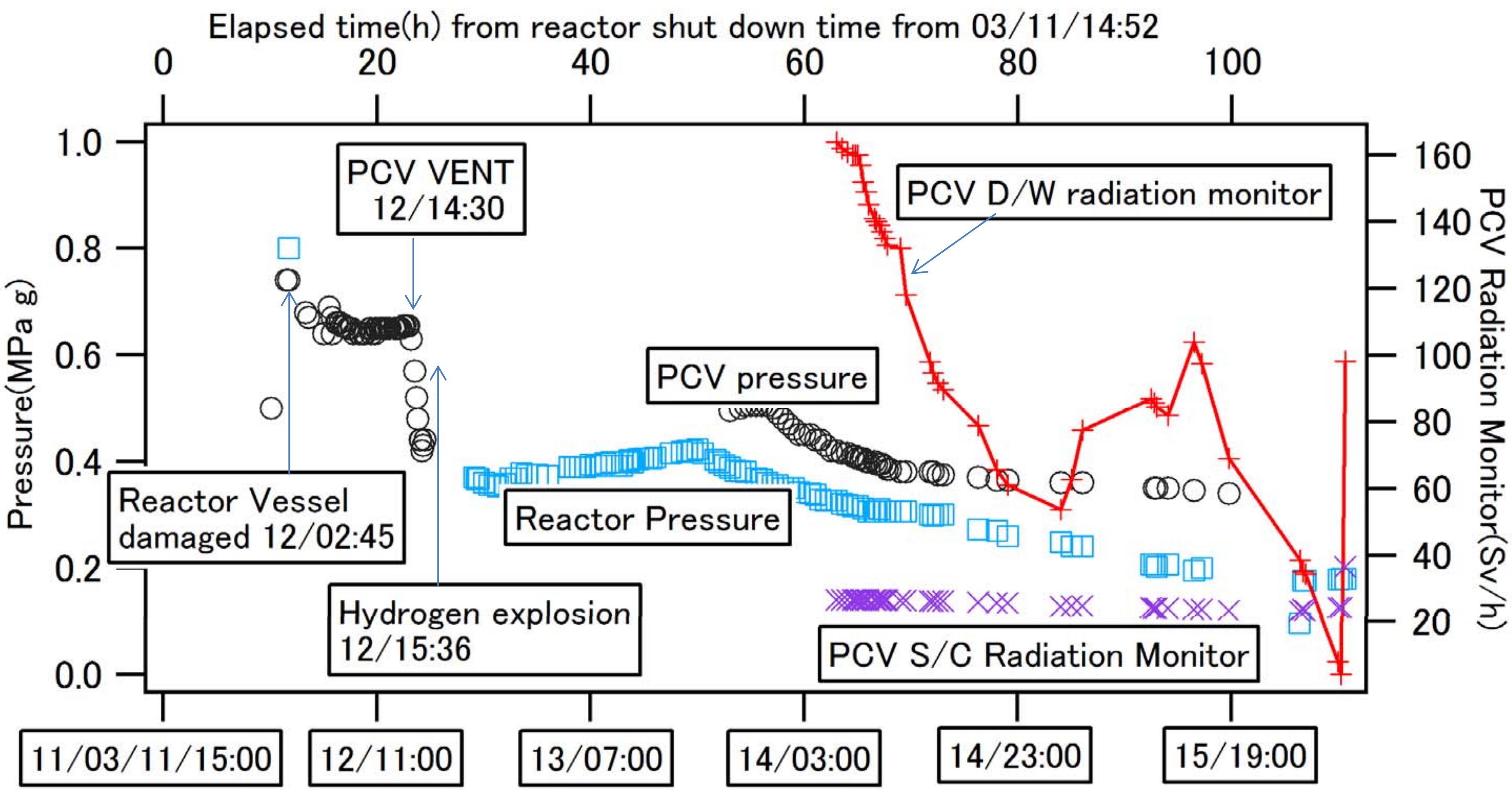
- ➢ 落下炉心割合はMAAP解析から得られた最大の値を保守的に仮定（1号機:100%、2号機:57%、3号機:63%）
- ➢ 崩壊熱ソースはORIGEN2を使用。揮発性FPの放出による崩壊熱の減損（20%）を仮定
- ➢ 燃料デブリ落下時点までにPLRメカシールからのリーク水がペデスタル部に十分溜まっていた場合（2，3号機）は燃料デブリが一部粒子化すると仮定
  ※粒子化しなかった燃料デブリによる侵食を評価
- ➢ 燃料デブリはペデスタル床からスリットを通ってドライウェル床まで流出。ペデスタル内にある2つ（機器／床）のドレンサンプへも燃料デブリが堆積すると仮定



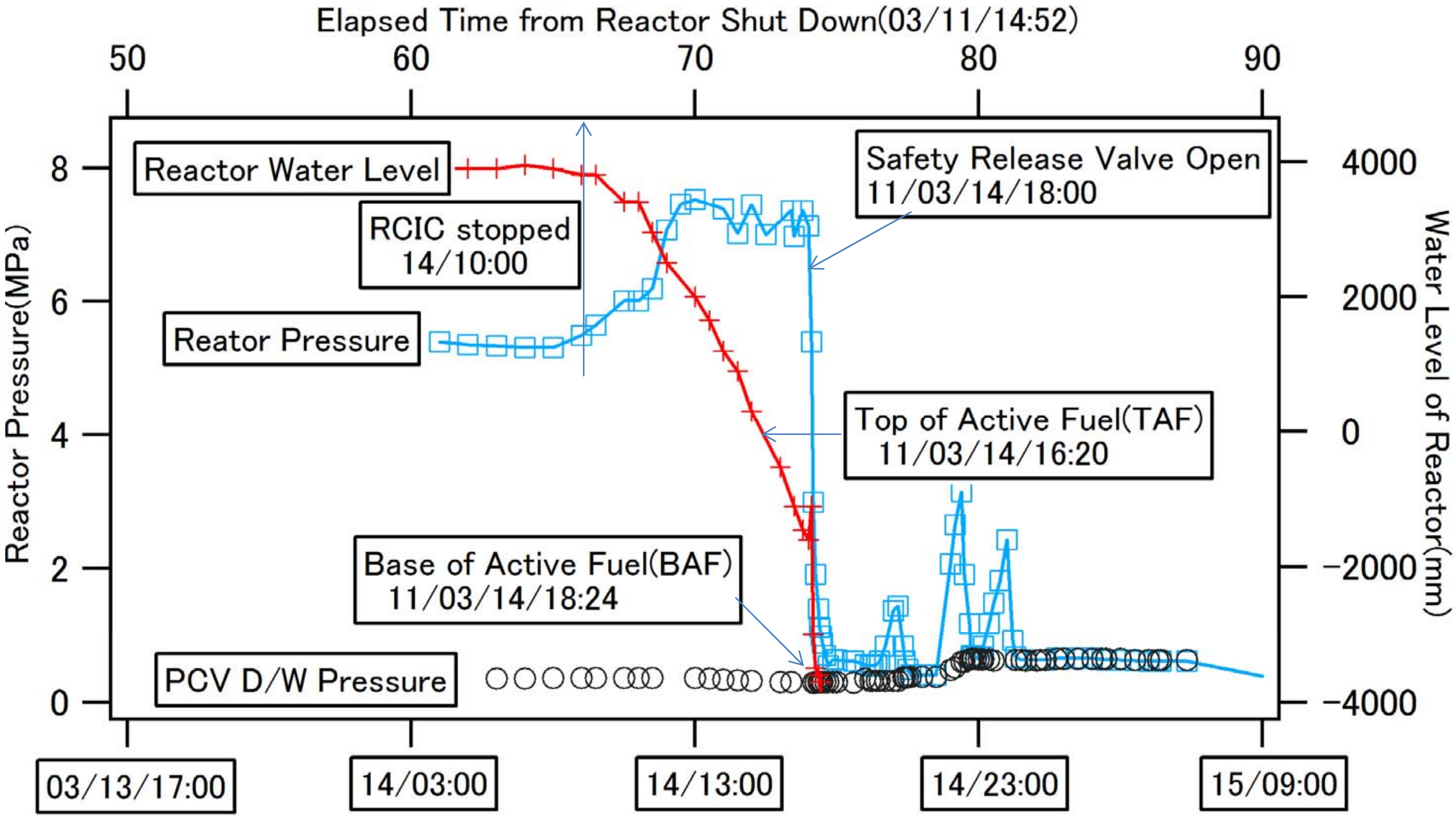




Elapsed time(h) from reactor shut down time from 03/11/14:52
70
80
90
100
110
Pressure(MPa g)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
PCV Radiation Monitor(Sv/h)
120
100
80
60
40
20
0
Release valve open 14/18:00
Release valve open and close
Reactor Pressure
D/W radiation moniter
PCV broken
Molten core generated much steam in low plenum
Reactor Vessel Small Failure 14/21:00
Reactor Vessel broken in the base
S/C pressure
D/W pressure
11/3/14/13:00
14/23:00
15/09:00
15/19:00
16/05:00



Elapsed time(h) from reactor shut down time from 03/11/14:52
0
20
40
60
80
100
1.0
0.8
0.6
0.4
0.2
0.0
Pressure(MPa g)
160
140
120
100
80
60
40
20
PCV Radiation Monitor(Sv/h)
PCV VENT
12/14:30
PCV D/W radiation monitor
PCV pressure
Reactor Vessel
damaged 12/02:45
Reactor Pressure
Hydrogen explosion
12/15:36
PCV S/C Radiation Monitor
11/03/11/15:00
12/11:00
13/07:00
14/03:00
14/23:00
15/19:00



Elapsed Time from Reactor Shut Down(03/11/14:52)
50
60
70
80
90
Reactor Pressure(MPa)
8
6
4
2
0
Water Level of Reactor(mm)
4000
2000
0
−2000
−4000
Reactor Water Level
RCIC stopped
14/10:00
Reator Pressure
Safety Release Valve Open
11/03/14/18:00
Top of Active Fuel(TAF)
11/03/14/16:20
Base of Active Fuel(BAF)
11/03/14/18:24
PCV D/W Pressure
03/13/17:00
14/03:00
14/13:00
14/23:00
15/09:00