RPV Support Skirt Anchor Bolt Fracture Event at Kuosheng Unit 1

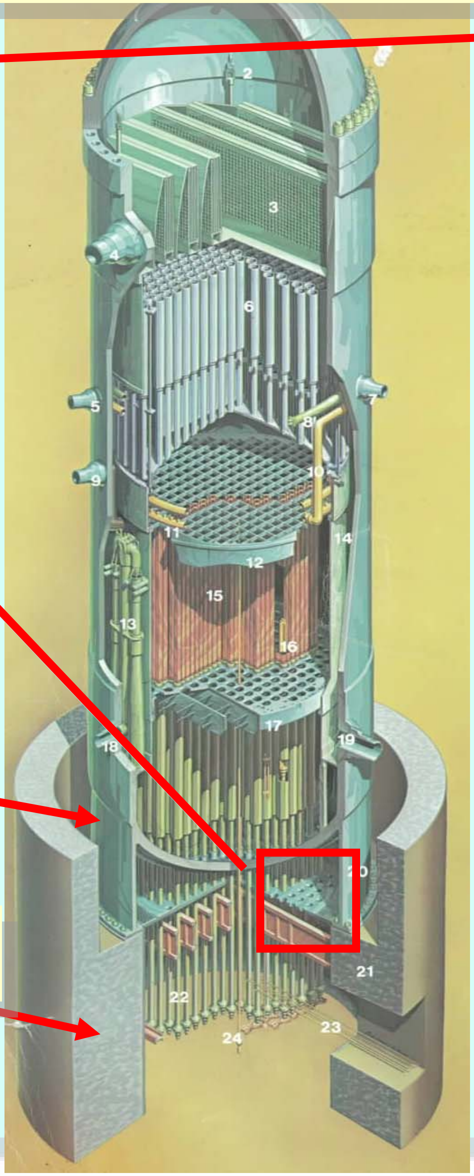
Taiwan Power Company

2012/6/20

Outline

1. Background
2. Root Cause Analysis
3. Corrective Actions
4. Vibration Monitoring Program
5. Follow-up Inspection Program
6. Conclusions

RPV Support Skirt Anchor Bolts



Skirt

Skirt

Pedestal

Inner Bolts (60)

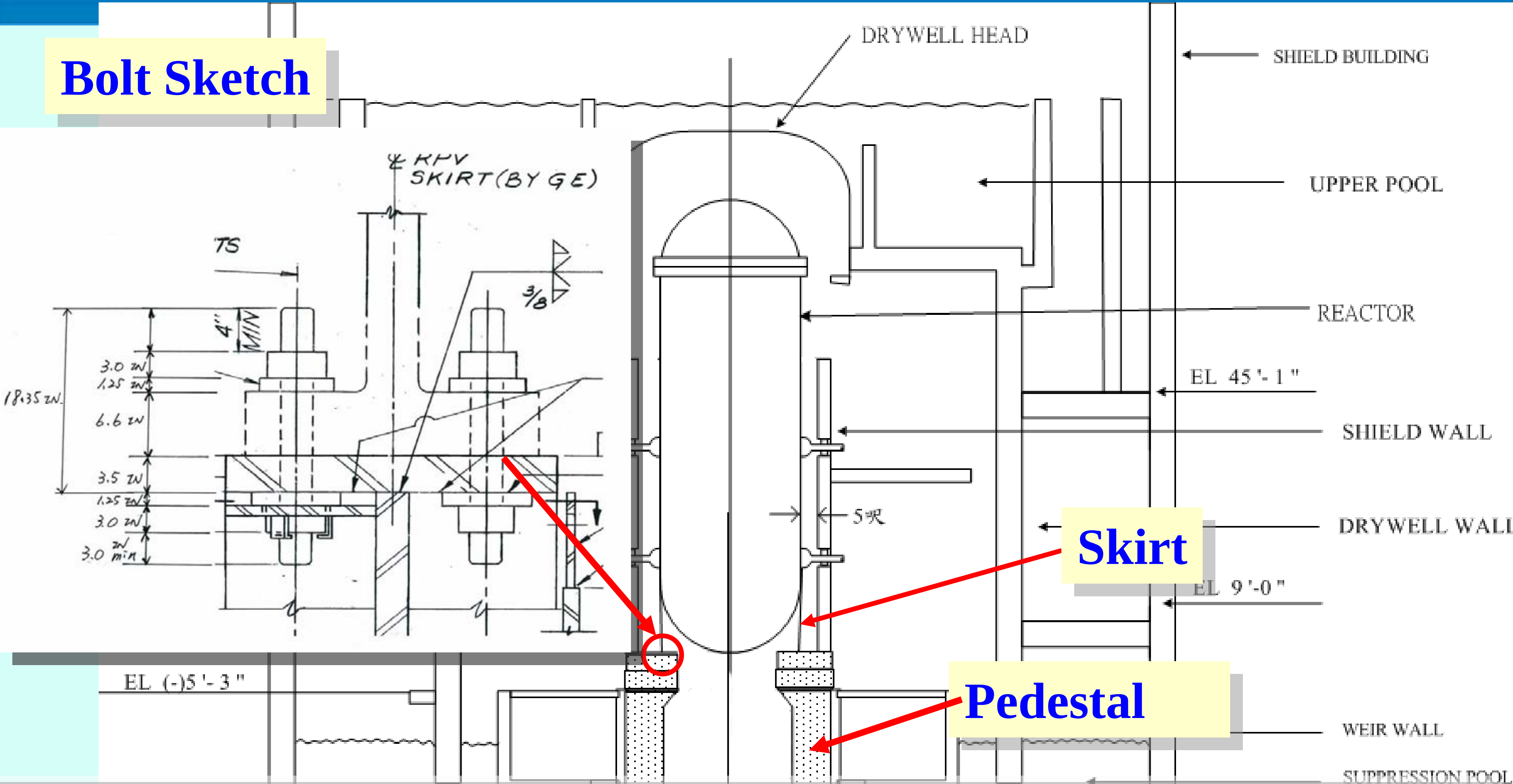
Outer Bolts(60)

ASTM A-540 Gr. B23 Class 1 ,
φ ：3 inch (7.6 cm)
L：26 inch (66 cm)

Background

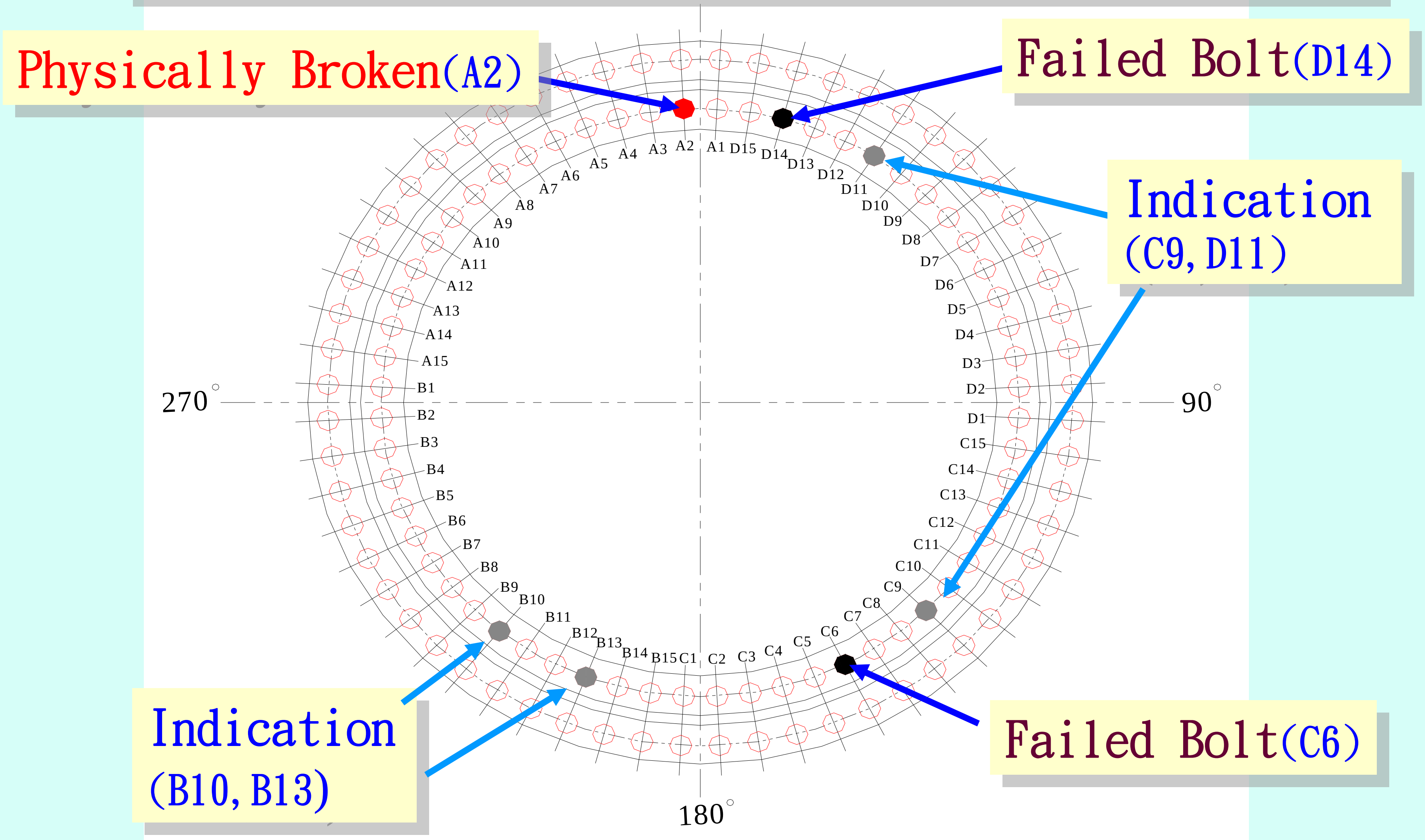
- **During Kuosheng Unit 1 EOC-22 refueling outage in 2012, RPV inner skirt bolt A2 was found to be physically broken.**
- **Following UT on the remaining RPV skirt bolts, additional two failures were found on inner skirt bolts C6 & D14, and indications were found on four inner skirt bolts B10, B13, C9, & D11.**
- **The UT results of the remaining 113 anchor bolts are all “Accept”.**

Bolt Sketch



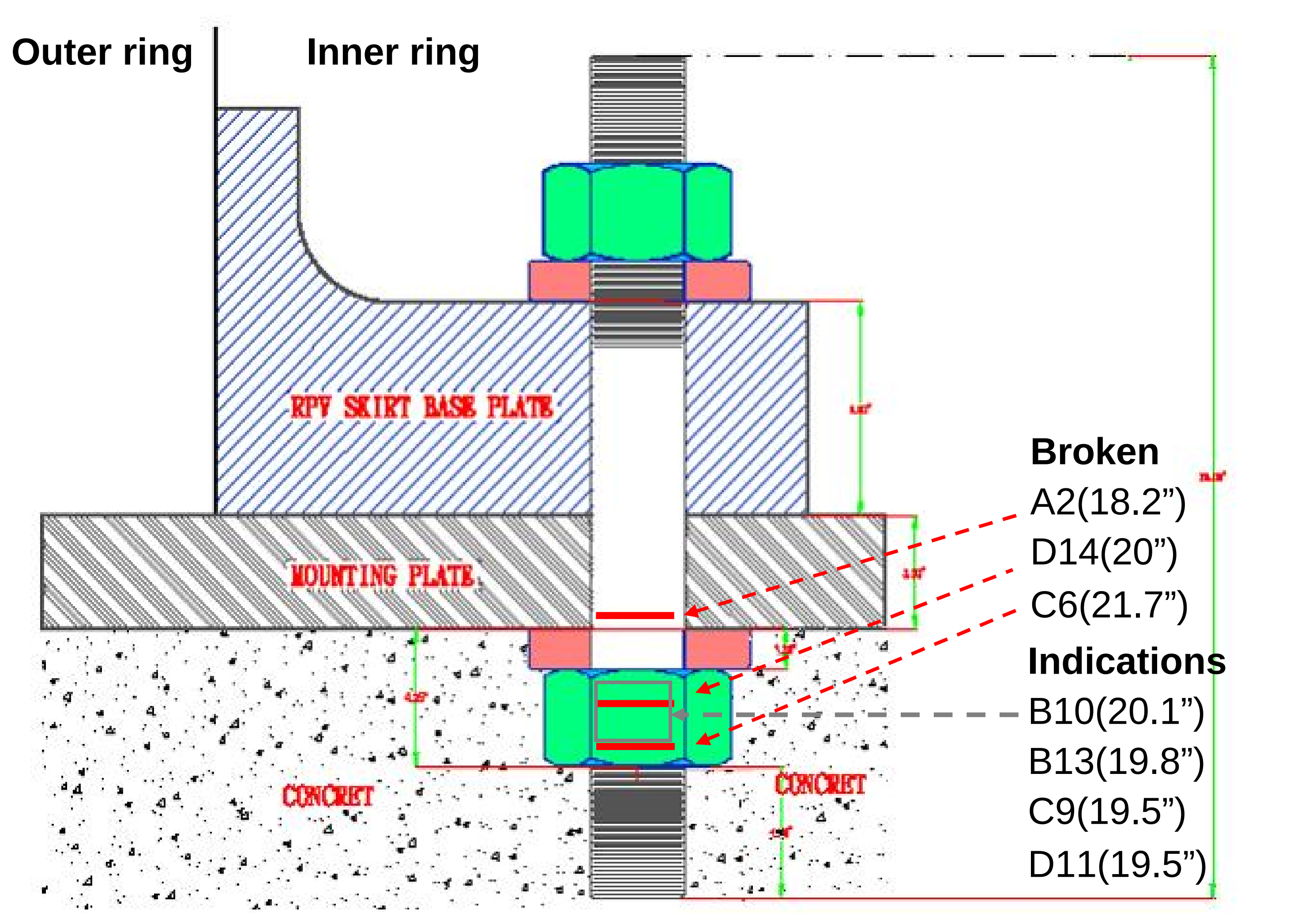
1. **The function of the anchor bolts is to prevent sliding between pedestal mounting plate and RPV support skirt flange.**
2. **The weight of the reactor and the internal components rely on reinforced concrete pedestal.**

RPV Support Skirt Anchor Bolts



PLAN VIEW FROM ABOVE

Fracture/Indication Locations Sketch



Broken Bolts

A2

C6

fracture surface

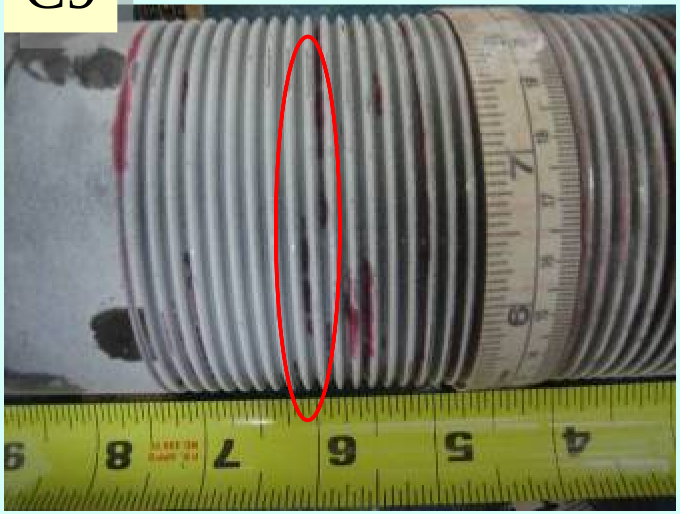
D14

fracture surface

Bolts with indication

D11

C9



B10

B13

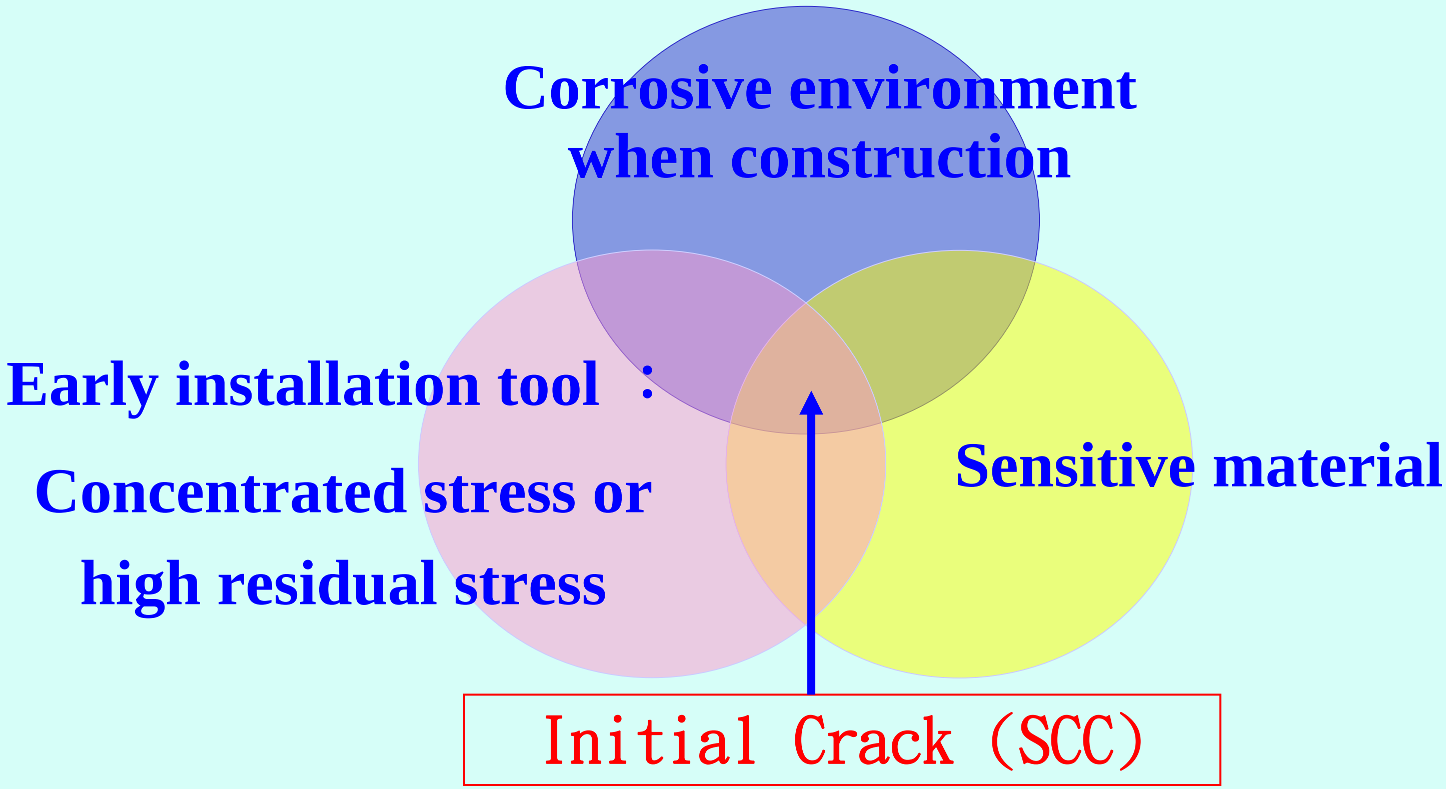
Root Cause Analysis

- **Broken bolts have been sent to the hot cell for material and chemical analysis.**
- **Sensitive material, concentrated stress or high residual stress due to early improper installation tool and corrosive environment when construction were the conditions for stress corrosion cracking (SCC) to occur, and resulted in the different length of intergranular cracks.**

Root Cause Analysis

The root cause of crack to initialize：

Stress Corrosion Cracking (SCC).



Root Cause Analysis

- **Under normal operating load, the corrosive environment no more exist, the stress intensity factor (△K) of tiny crack is still below the threshold (△Kth), and it will not grow.**

- **Long crack will release most of the preload, so the bolts will not fracture instantaneously. The crack will grow slowly, and long before the fracture.**

Root Cause Analysis

Corrosive environment when construction

+

Early improper installation tool ： Concentrated stress or residual stress

+

Sensitive material

→ SCC → The different length of intergranular cracks

Normal operating load

- Long crack will release most of the preload, so the bolts will not fracture instantaneously. The crack will grow slowly, and long before the fracture.
- The stress intensity factor (△K) of tiny crack is still below the threshold (△Kth), and it will not grow.

Root Cause Analysis

- **By the fracture surface of the thickness of the corrosion products, it's proved that the crack has grown for a long period of time, and will not instantaneously fracture.**
- **The initial crack growth mechanisms disappeared after construction was completed and the environment was improved.**

Corrective Actions

- **Preparation of a JCO for 1 cycle of operation with 7 failed bolts was successful with no safety concerns or operational problems.**
- **For conservative considerations, TPC replaced all the 7 damaged bolts.**

Corrective Actions

Replacement Process

1. **Removed the closure plate and concrete surrounding the bottom of the studs.**

Corrective Actions

Replacement Process

2. **Cut the damaged studs and nuts.**

Corrective Actions

Replacement Process

Prior to installation Mockup

3. Installation

Installation and Preload

Corrective Actions

Replacement Process

3. Installation

Elongation Check

New studs after installation

Corrective Actions

Replacement Process

4. 24 hours after completion of installation, re-check preload status.

Corrective Actions

Replacement Process

5. Recovery

Recovery of the closure plate

Recovery of the surrounding concrete

Corrective Actions

- **Preload checks for the remaining 113 bolts have been executed by GE-H to ensure it's in intact condition (560kips，510kips+10% Margin).**
- **After preload checks, UT examination has been performed on all 120 bolts to verify their integrity.**

Vibration Monitoring Program

- A set of continuous monitoring mechanisms has been established at Kuosheng Unit 1 for early detection of possible vibration of the reactor pressure vessel/pedestal.

- A seismometer “0SG-XE-135 ”, mounted on an instrument platform, as per original plant design, at the reactor vessel anchoring elevation outside the biological shield wall, will remain in place for measuring the reactor vessel/pedestal seismic response.

Vibration Monitoring Program

- In addition, 8 “piezoelectric accelerometers” of recent design are installed at similar elevations outside the biological shield wall to augment the function of the original seismometer.

- TPC also have established a special procedure to monitor and record the vibration of the reactor pressure vessel/pedestal.

Follow-up Inspection Program

- **A rigorous inspection program on the anchor bolts has been set up for each of the two Kuosheng units.**

- **All 120 anchor bolts for each Kuosheng unit will be thoroughly inspected by UT examination during each of its subsequent refueling outages. (in lieu of the prevailing regulatory requirement that visual inspection be conducted on the anchor bolts once every 10 years.)**

Conclusions

- **After replacement, the RPV skirt-to-pedestal connection has been restored back to the original.**
- **The root cause of fracture has been confirmed to be stress corrosion cracking (SCC).**
- **The initial crack growth mechanisms no more exited after the corrosive environment was improved.**

Conclusions

- **According to the fracture mechanics analysis and the fatigue analysis implemented by TPC, the anchor bolts would not fracture immediately and fatigue failure will not happen within 1 fuel cycle.**
- **120 anchor bolts have been performed UT examination to confirm its integrity.**
- **Preload on all anchor bolts have been checked and the results meet the design requirements.**
- **The online vibration monitoring program and the follow-up inspection program will ensure the security of the anchor bolts.**

Thank you.