Institute of Nuclear Energy Research

# The integration of 3D engineering simulation and virtual technology to the planning of TRR decommission

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International Workshop on Application of Advanced Plant Information Systems for Nuclear Decommissioning and Life-cycle Management

# Outline

1. Introduction
2. Topic
   - TRR 3D simulation
   - TRR 3D application and VR training platform
   - DSP 3D vision and information management platform
3. Conclusion

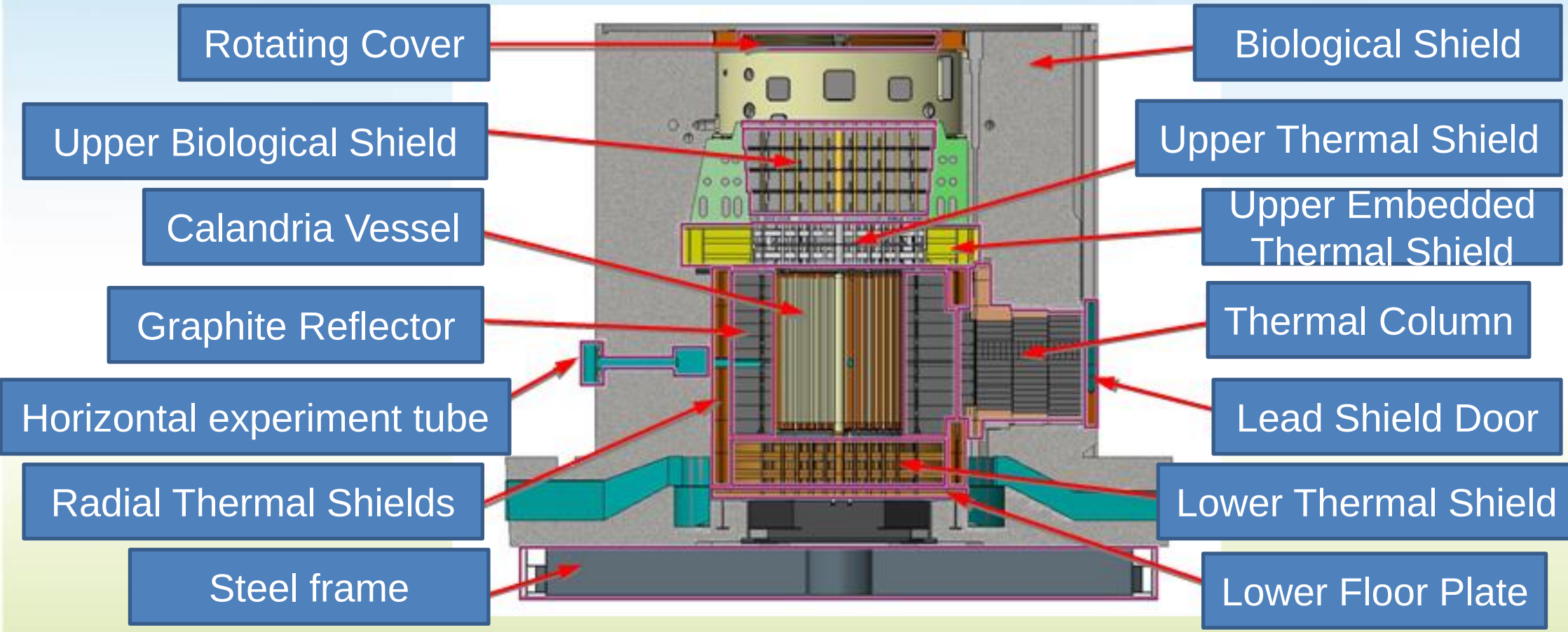
# Introduction of Taiwan Research Reactor

| | |
|---|---|
| **Type:** | **NRX like (CANDU forerunner)** |
| **Purpose :** | **1. Fundamental Research**<br>**2. Isotope Production**<br>**3. Irradiation Experiment** |
| **First Critical :** | **January/03/1973** |
| **Rated Thermal Power :** | **40 MW** |
| **Max. Thermal Neutron Flux :** | **6 x $10^{13}$ n.$cm^{-2}$.$sec^{-1}$** |
| **Fuel :** | **Natural Uranium Metal Rod (Aluminum Cladding)** |
| **Moderator :** | **Heavy Water** |
| **Coolant :** | **Light Water** |
| **Reflector :** | **Graphite** |
| **Power Control :** | **Heavy Water Level** |
| **Beam Port :** | **4 x 12” Dia. Hole**<br>**4 x 6” Dia. Hole**<br>**1 x 4”x 6” Through Tube** |
| **Core Size :** | **Cylindrical, 352 cm height, 269 cm O.D.** |

- TRR was shut down in 1988 with the intent to replace the reactor with a light water moderated, open pool reactor (TRR II Project, then terminated).

- Systems including heavy water system, cooling system, neutron experiment facilities etc. have been dismantled.
- The reactor vessel has been one piece removed and placed under safe storage in 2002.
- **Decommission permit granted in 2004.**
- **Reactor vessel dismantling permit applied in 2018.**

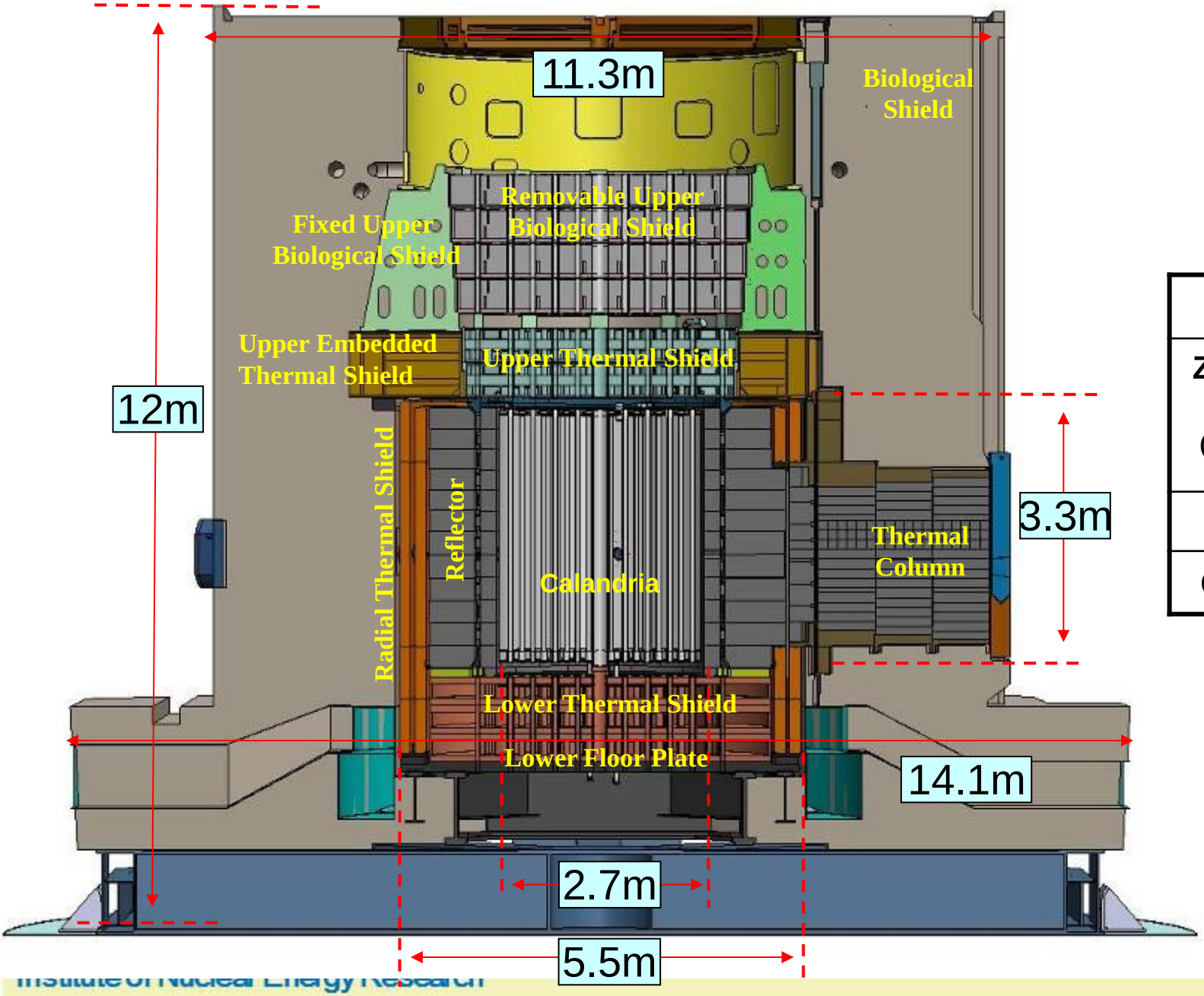
# Internal Components of TRR




TRR furnace body profile and component description

# Status of TRR Reactor Vessel

## Dimensions, components, material, weight



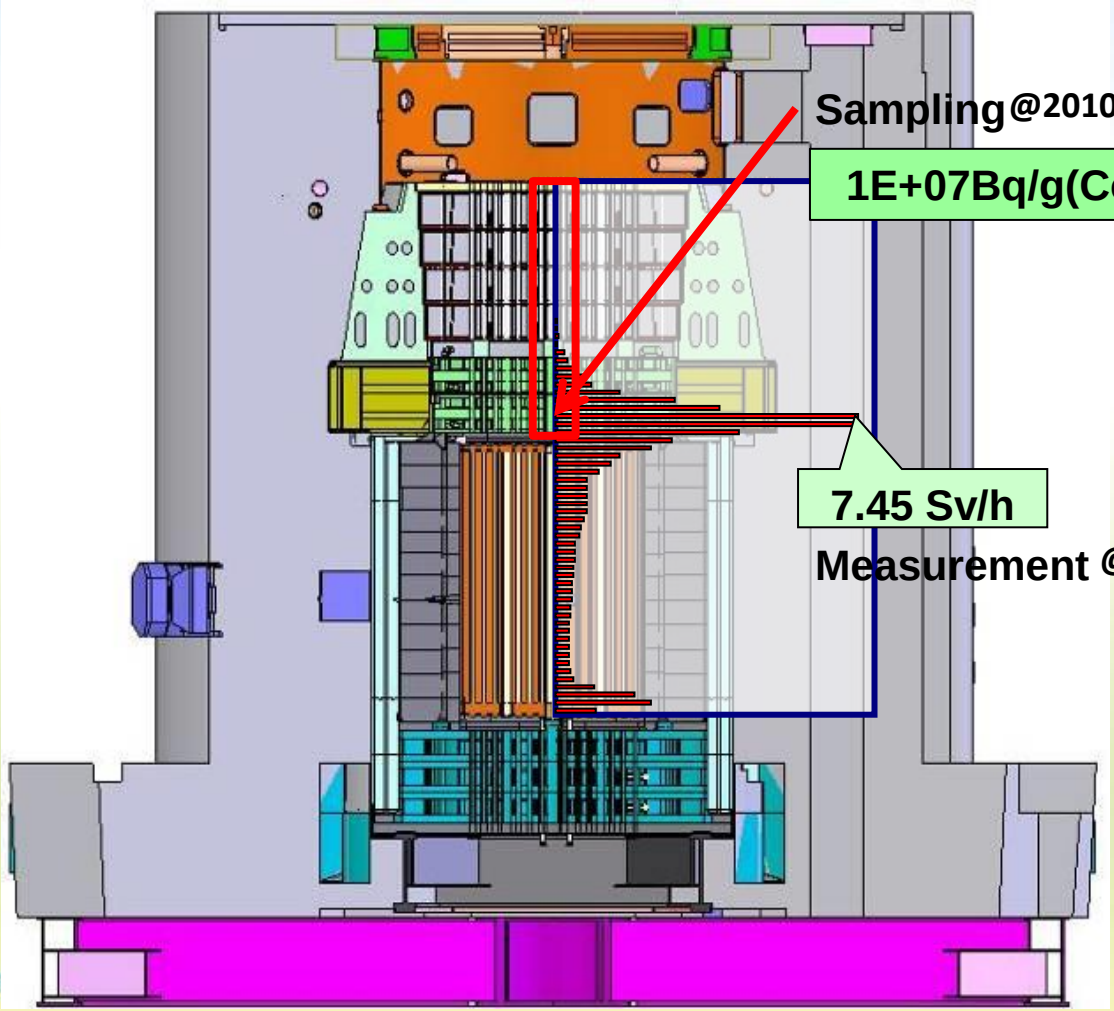

**Total weight: ~2,700 MT**

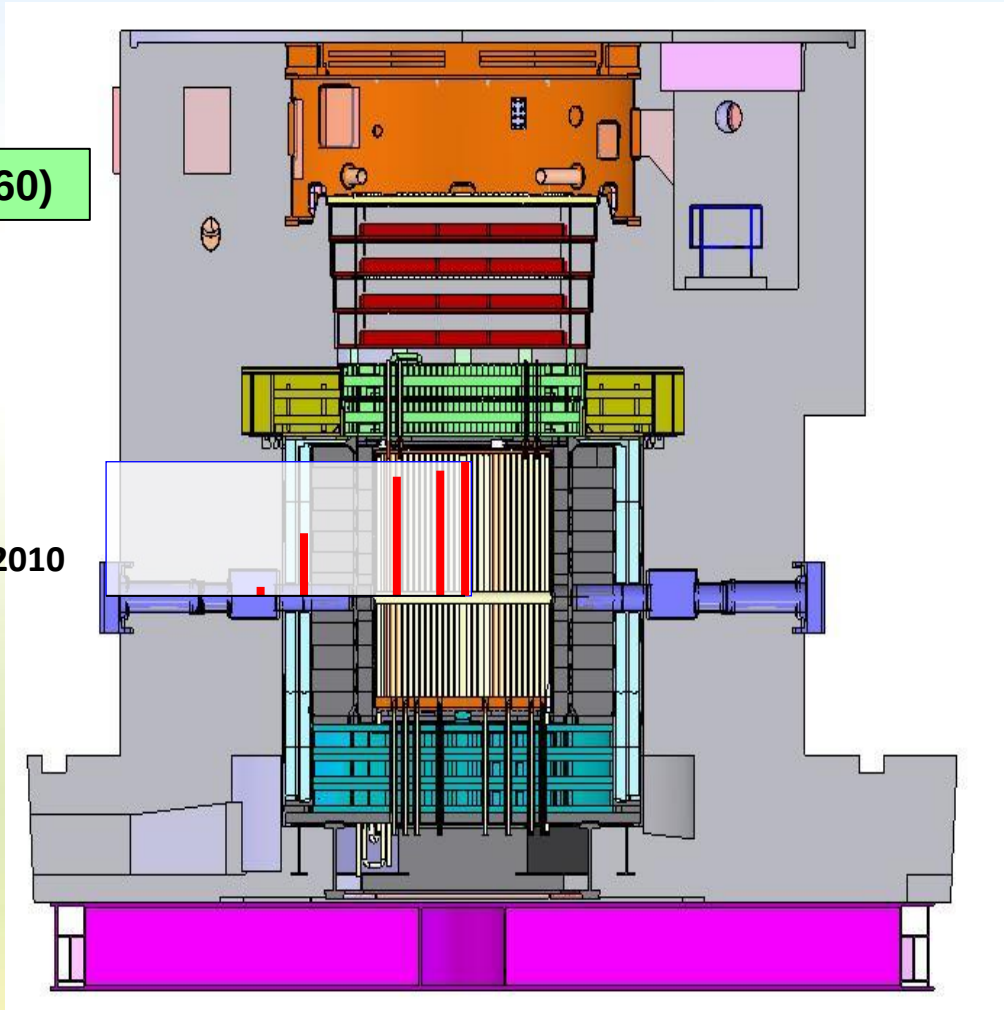
| | | |
|---|---|---|
| Steel | 518 MT | 19.2% |
| Zirconium Alloy (ASTM Grade RA-1) | 3.7 MT | 0.1% |
| Graphite | 77 MT | 2.9% |
| Concrete | 2000 MT | 74.1% |

| | |
|---|---|
| Supporting Structure | 80 MT |

# Status of TRR Reactor Vessel

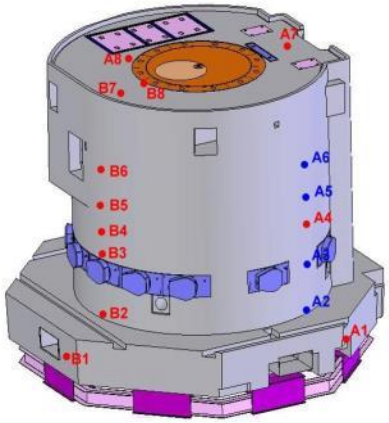
- Measurement along vertical central pipe and horizontal experiment pipes
- Sampling at reachable vertical central pipe
- Estimate waste classification, type A, B, C + Graphite(GTCC ?), planning :
  - ✓ Analysis for hard to detect nuclide in 2019
  - ✓ Analysis during dismantling process for verification



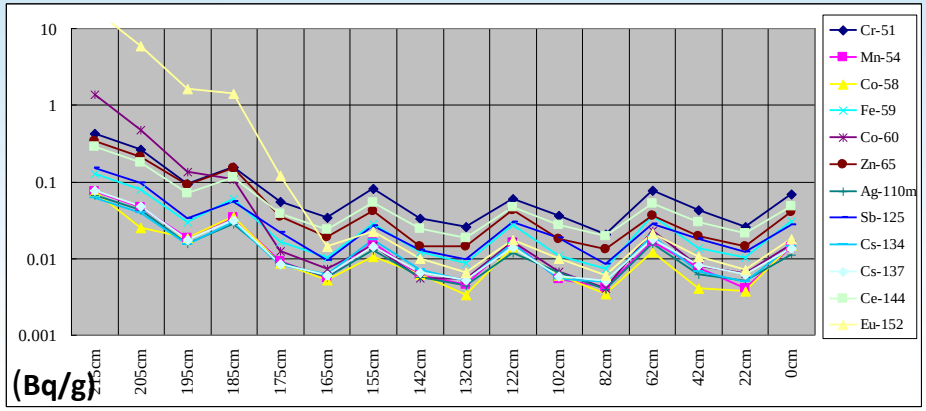
# Status of TRR Reactor Vessel

■ **Bio-shield from 17 sampling drill, 601 MT** **activated concrete**

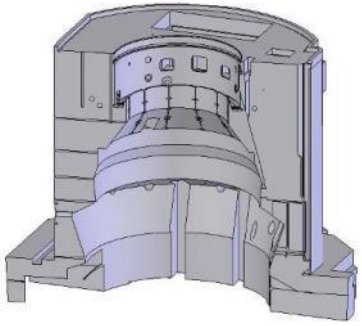



Sampling plan

Sampling

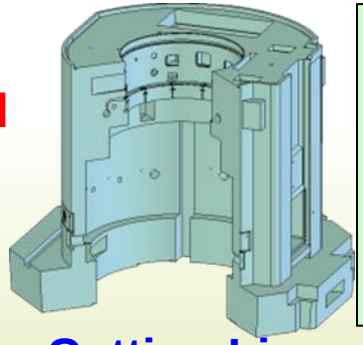



Sampling results



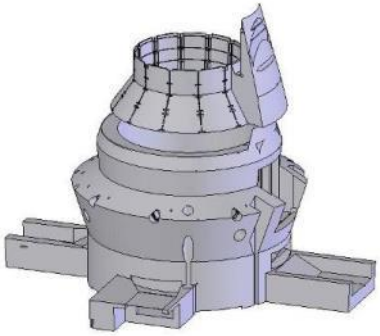
Activated Curve

Activated Depth +10% =Cutting Curve

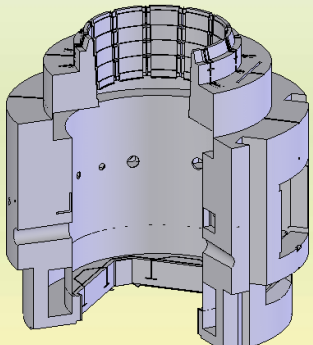


Cutting Line

Compliant with clearance
1369 MT
68.5% (Bioshield)
50.7% (TRR Vessel)



Envelope Straight Line

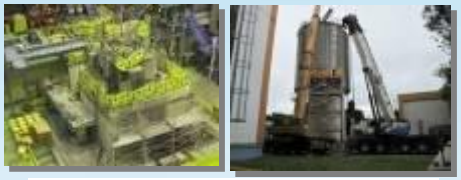


Radioactive waste
601 MT
31.2% (Bioshield)
30.1% (TRR Vessel)

# D&D of TRR (overview)

② Spent Fuel Dry Storage Pit : Cleaning preparation

Reactor vessel: Dismantling permit applying



Facility Dismantling — Material Clearance

**Released :**
- ✓ Concrete 2000 mt
- ✓ Metal scraps 130 mt

① Spent Fuel Pool Cleaning

- Spent fuel
- Fuel debris
- Resin
- Pool water
- Structural

Reactor Hall Reuse

③ Reactor Safe-Storage — Planning — Permit — Mock-up — Dismantling

remote handling, underwater cutting, radioactive protection, waste management,

# Overview of TRR Decommissioning

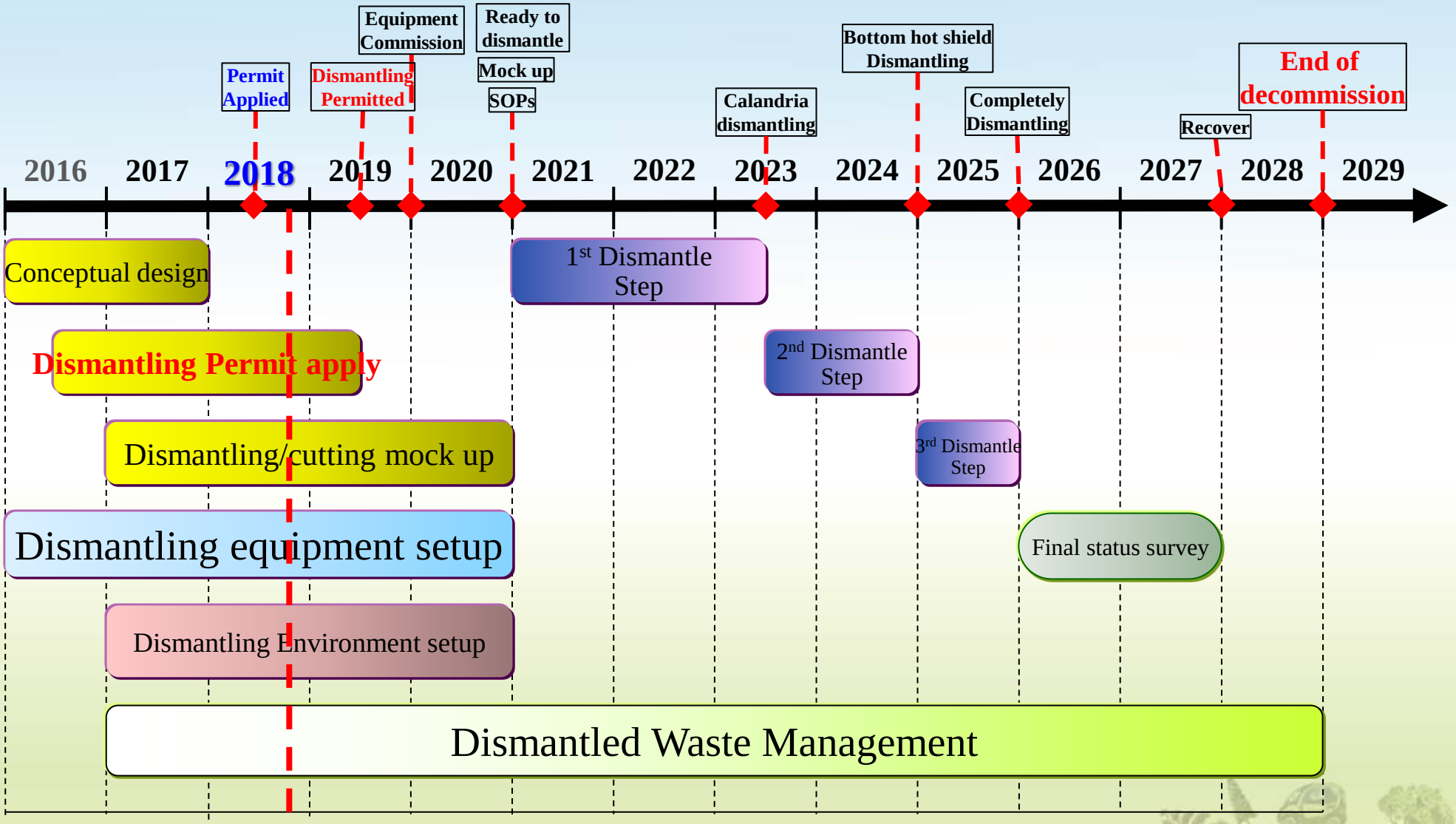
**"Enforcement Rules for the Implementation of Nuclear Reactor Facilities Regulation Act"**
**Article 16**

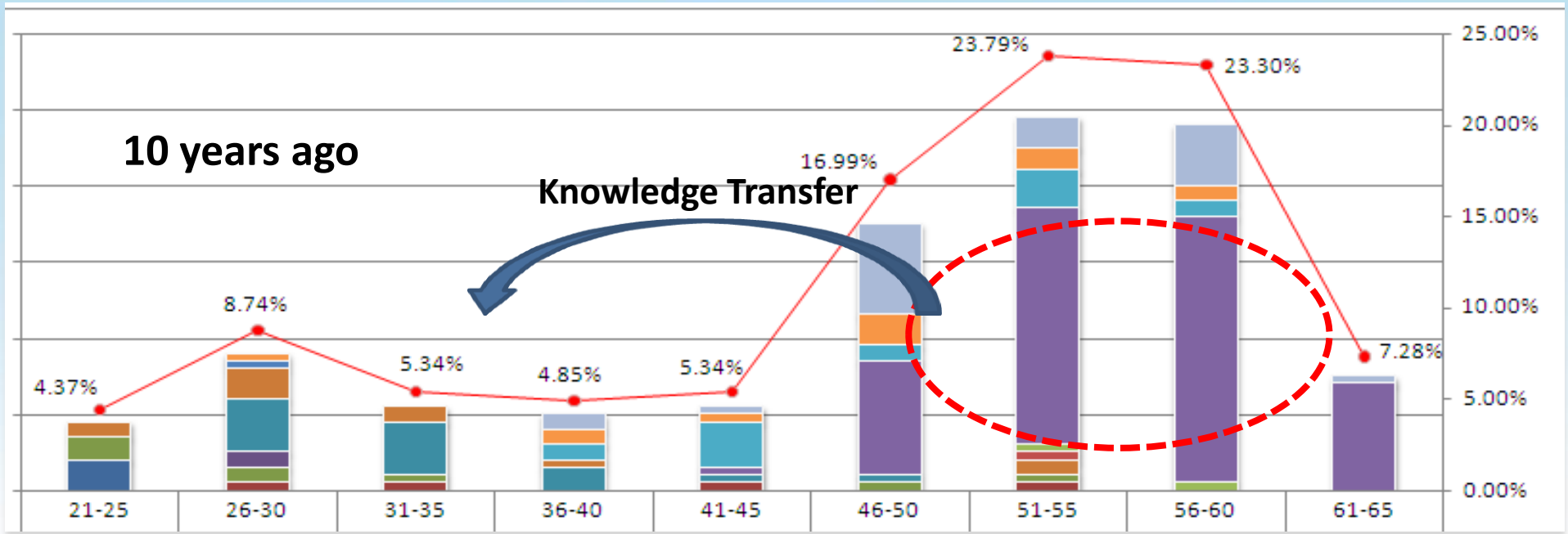
The decommissioning of nuclear reactor facility shall be completed within **twenty- five (25)** years upon obtaining the permit for decommissioning granted by the competent authorities.

| | Year | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase I | Wet Storage tank | | | | | | | | | | | | | | | | | |
| | Cooling tower | | | | | | | | | | | | | | | | | |
| SFP | Miscellaneous wastes | | | | | | | | | | | | | | | | | |
| | Spent fuel | | | | | | | | | | | | | | | | | |
| | Spent IER | | | | | | | | | | | | Required further stabilization | | | | | |
| | Fuel debris | | | | | | | | | | | | | | | | | |
| | Water | | | | | | | | | | | | | | | | | |
| | Structure | | | | | | | | | | | | | | | | | |

| Phase II | Year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DSP | Characterization | | | | | | | | | | | | | | | | |
| | Cabins and ventilation system | | | | | | | | | | | | | | | | |
| | Cleaning permit applying | | | | | | | | | | | | | | | | |
| | Pits removal | | | | | | | | | | | | | | | | |
| | Waste management | | | | | | | | | | | | | | | | |
| | Warehous reuse | | | | | | | | | | | | | | | | |
| TRR | SafeStore and monitoring | | | | | | | | | | | | | | | | |
| | Dismantling plan and tool design | | | | | | | | | | | | | | | | |
| | Dismantling permit applying | | | | | | | | | | | | | | | | |
| | Equipment and tools build up | | | | | | | | | | | | | | | | |
| | Dismantling | | | | | | | | | | | | | | | | |
| | Waste Management | | | | | | | | | | | | | | | | |
| | Final status survey | | | | | | | | | | | | | | | | |

# Dismantling Schedule



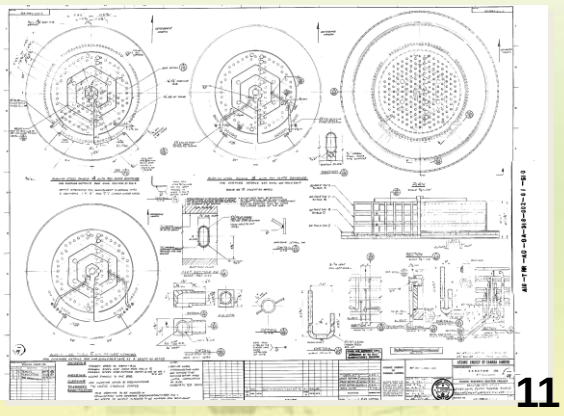


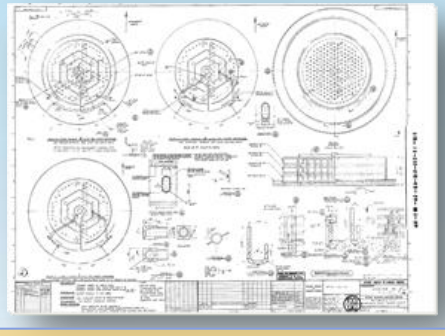

**Long decommissioning time, knowledge gap, such as TRR dismantling**





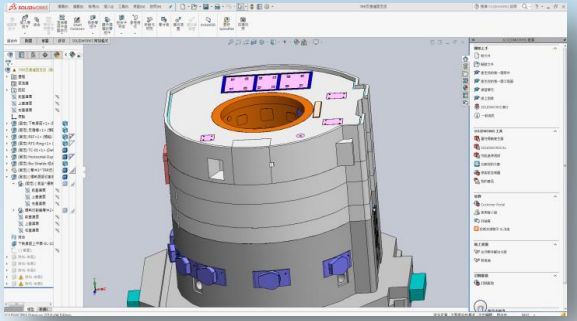




Equipment parts drawing

Study paper drawings by human



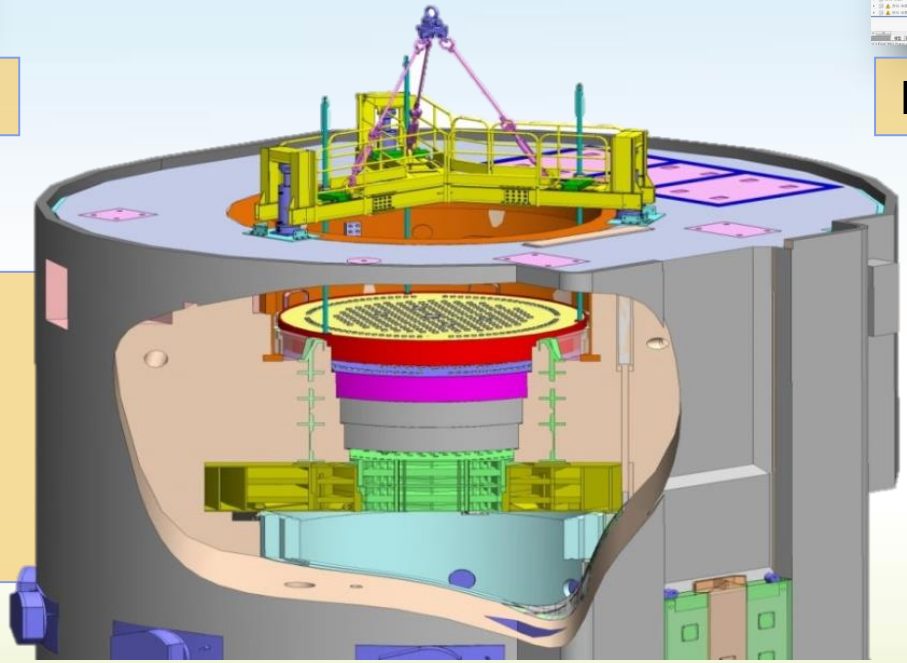
Build model(Solidworks)

Model check (Output by software)

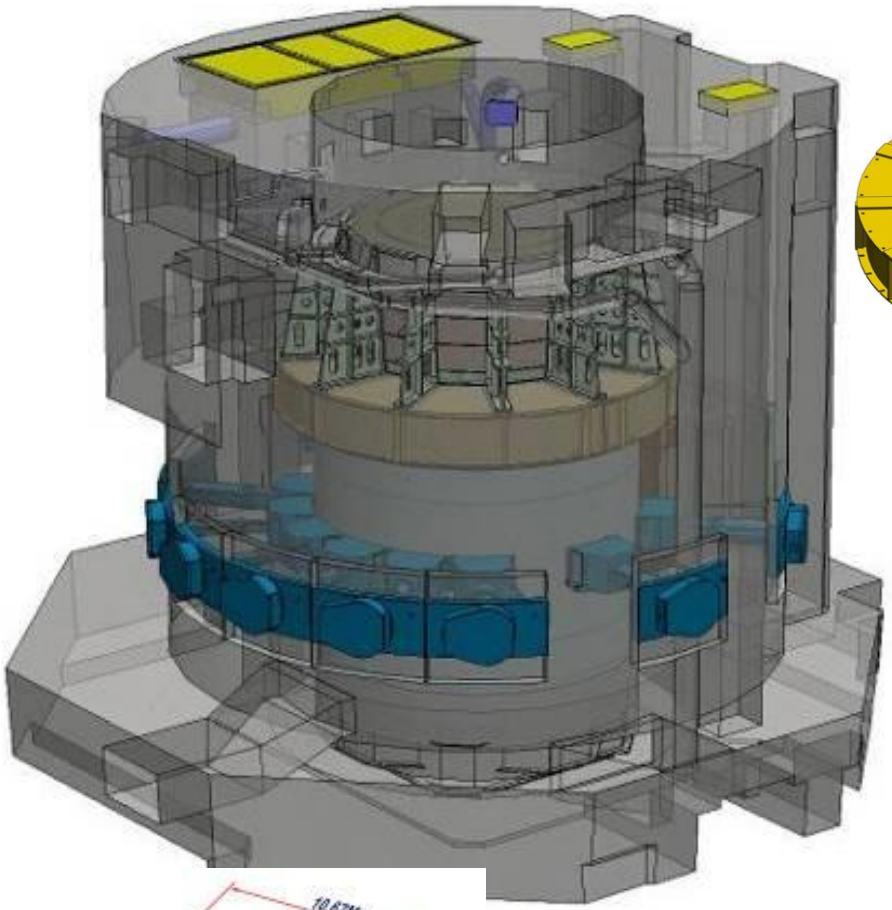
Model correctness verification (Check equipment parts drawing)

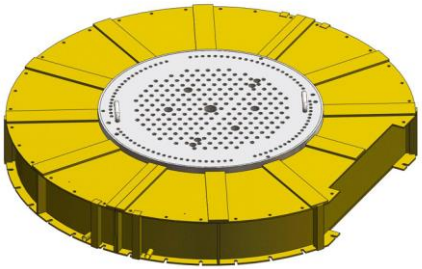
Output model engineering information (size, material, weight...)

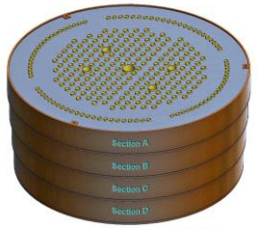
1.Engineering information establishment
2.TRR waste assessment
3.TRR cutting and packaging simulation

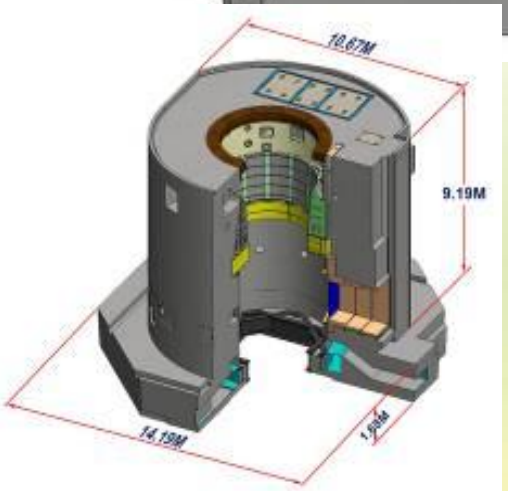


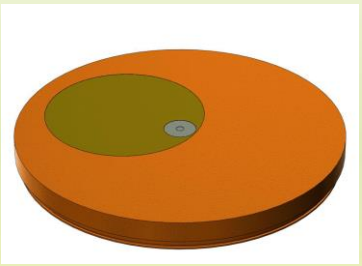
# Dismantling of TRR Vessel

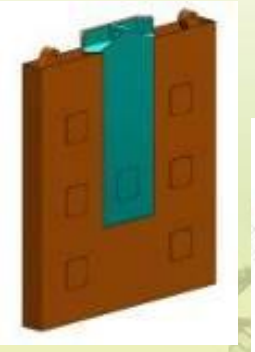




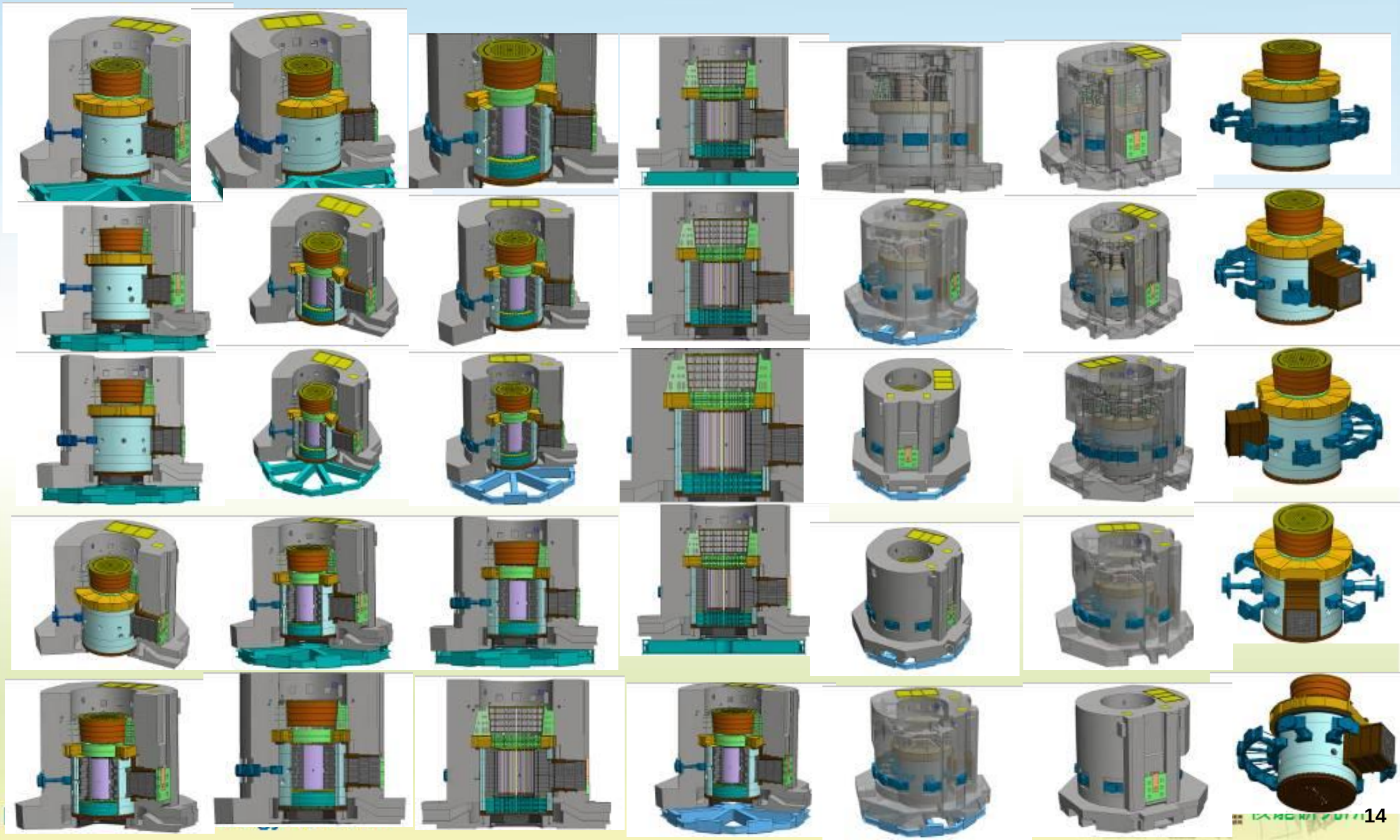


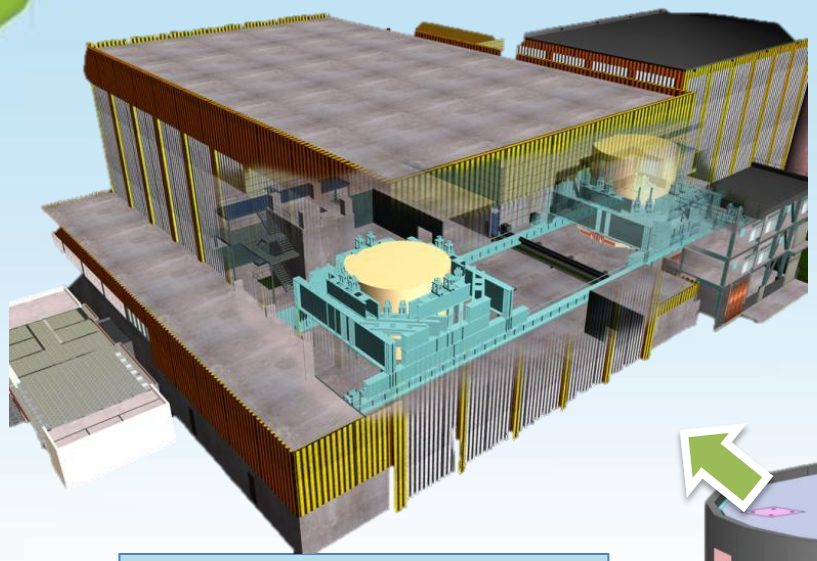


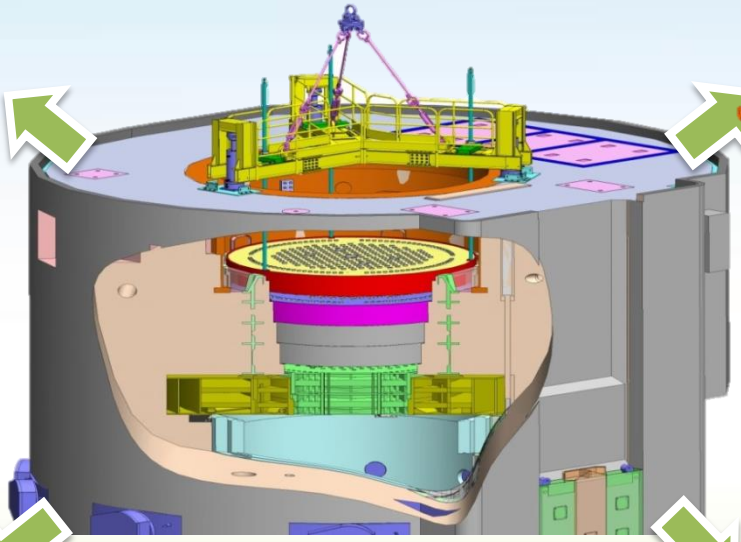


# Dismantling of TRR Vessel

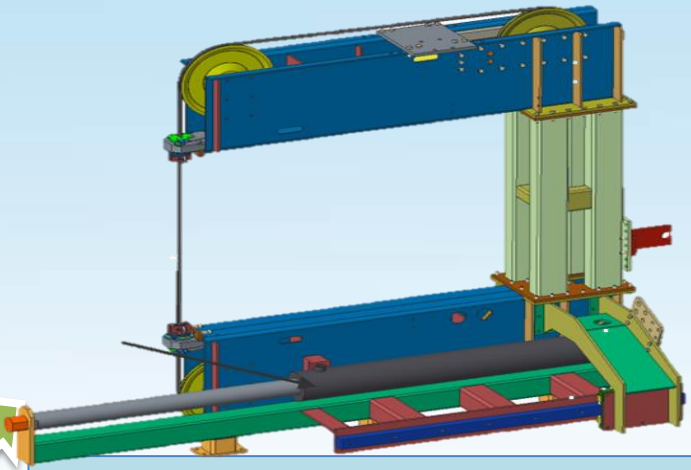




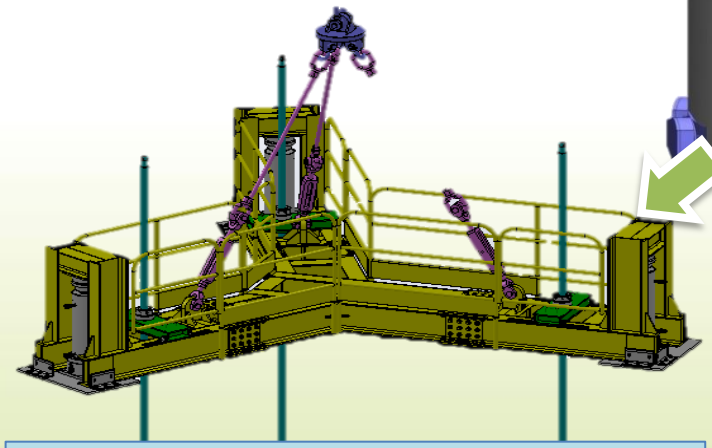
Shift TRR



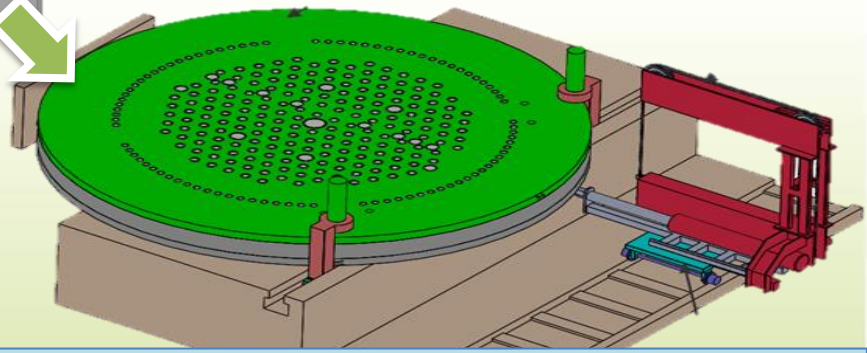
TRR 3D Model



Cutting equipment development



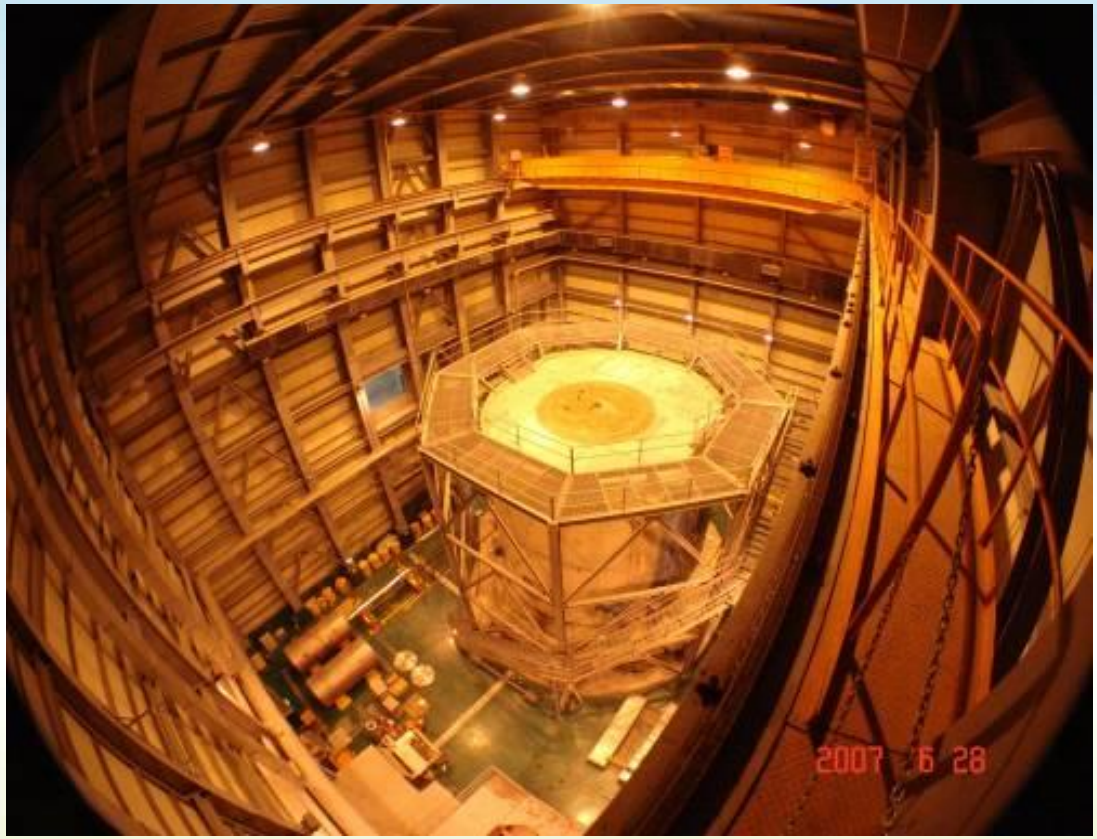
Lifting equipment development

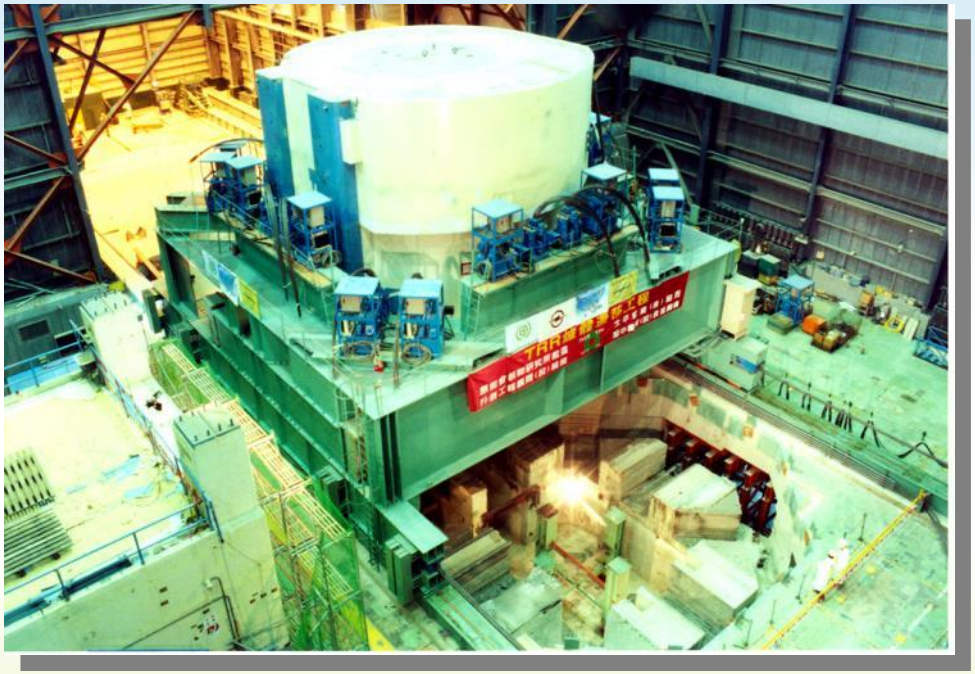


Cutting method simulation

# Dismantling of TRR Vessel

## Layout of the TRR dismantling room

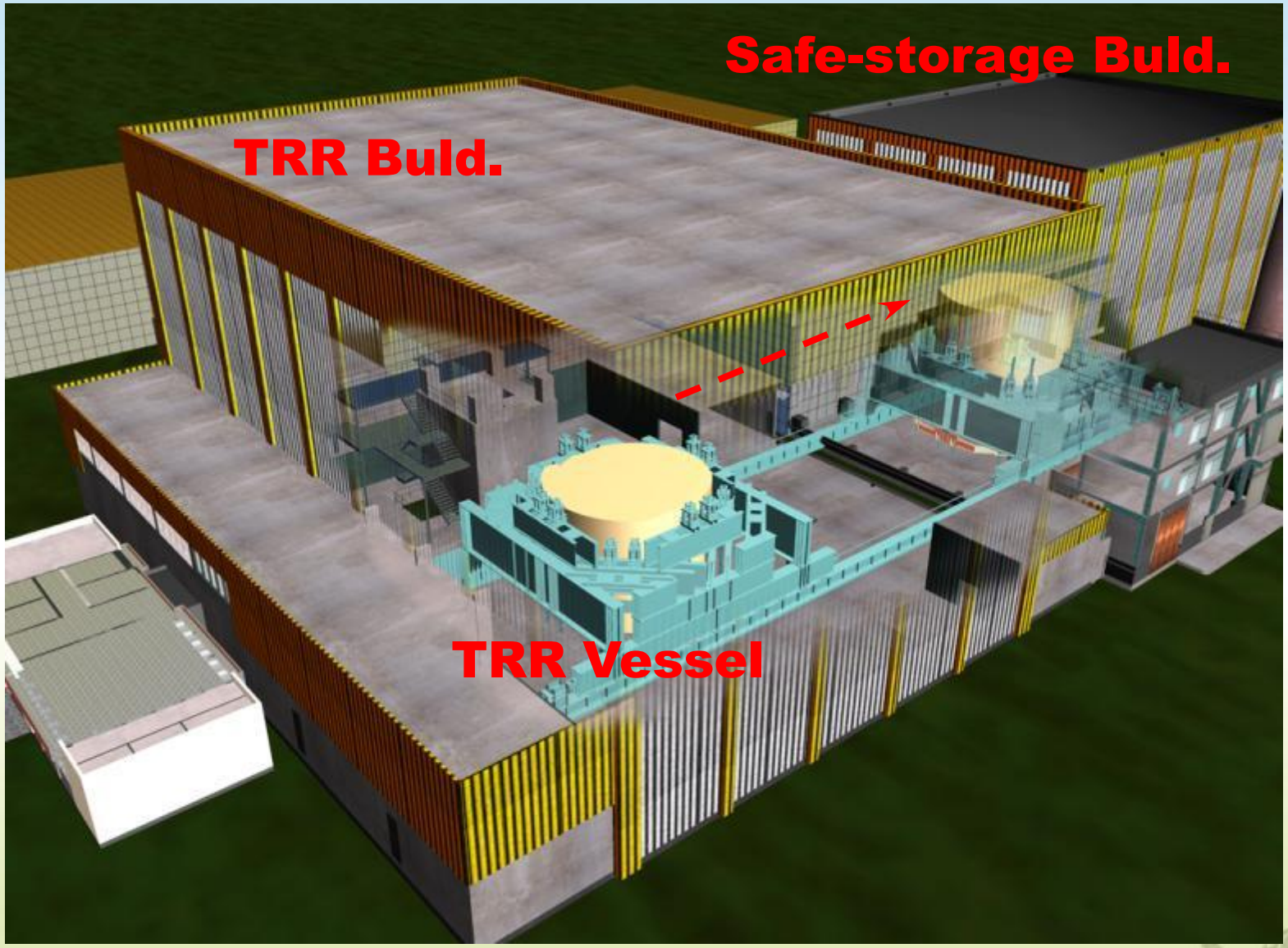


**Limitation:**

1. The **space** (high and area) of the dismantling room are very limited.
2. The **safety and Structural stability** of the reactor vessel during dismantling are the major concern.

# One piece removal of TRR vessel

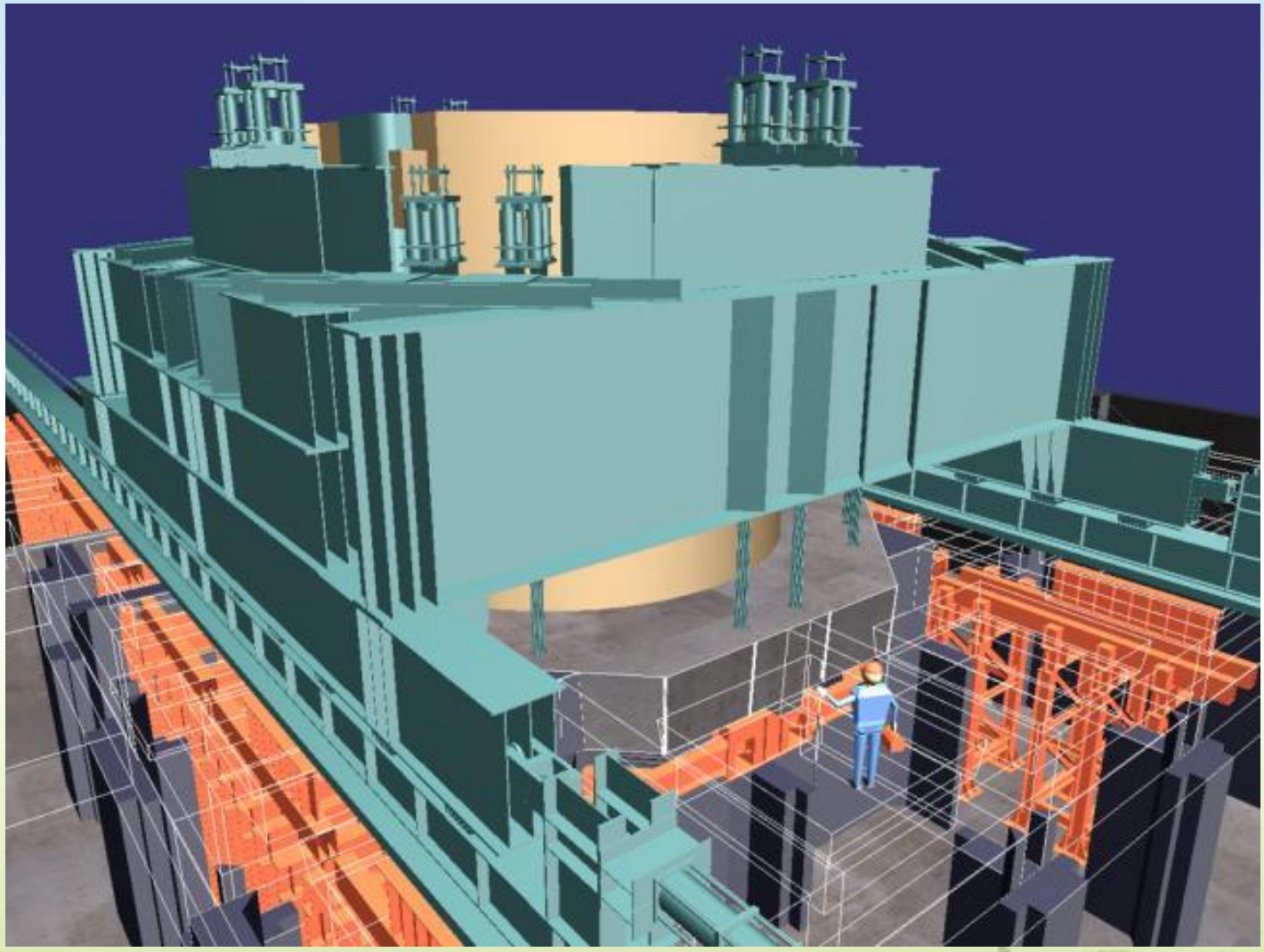


# One piece removal step of TRR vessel

## TRR Vessel

**Rail & Lifting Frame:**

**Install rail and lifting frame with 16 lifting jacks and 4 pulling jacks systems.**



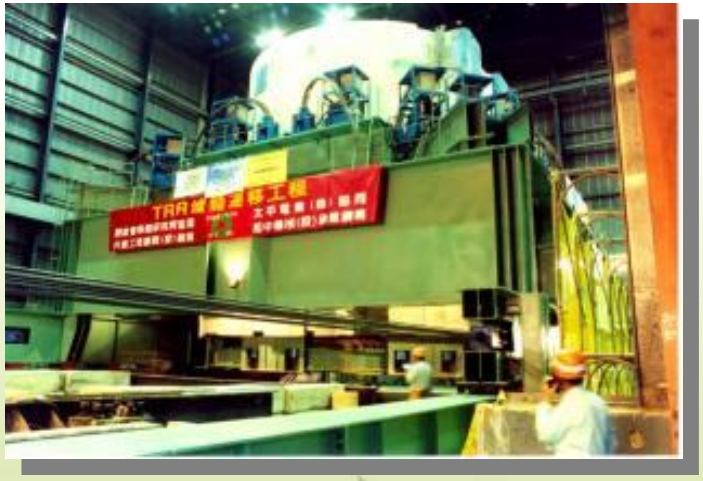
# One piece removal step of TRR vessel

Remove original vessel support

Floor column support below transfer rout

Transfer roller and guide roller

Bottom Support



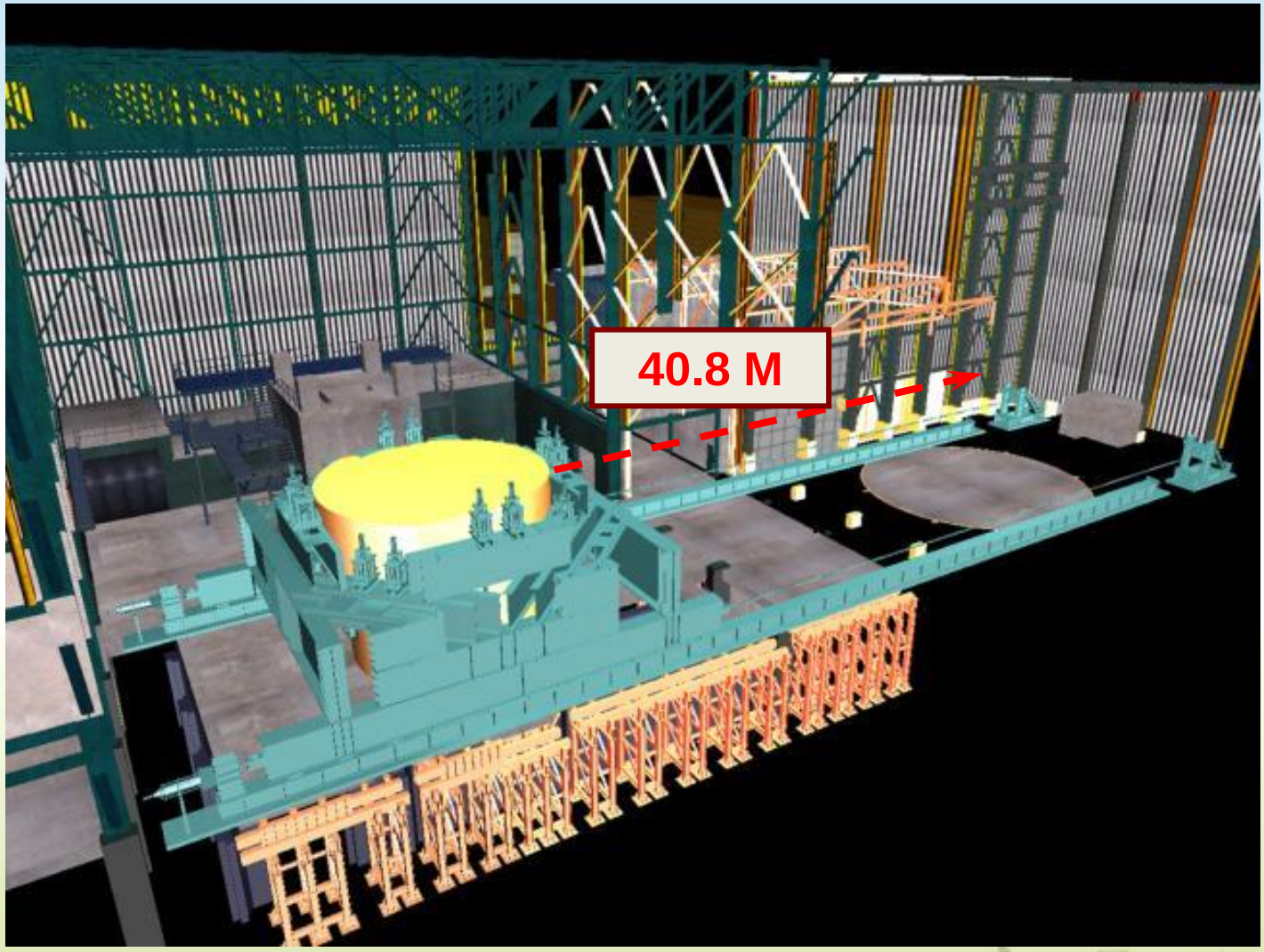
Vessel & Lifting Frame

# One piece removal step of TRR vessel

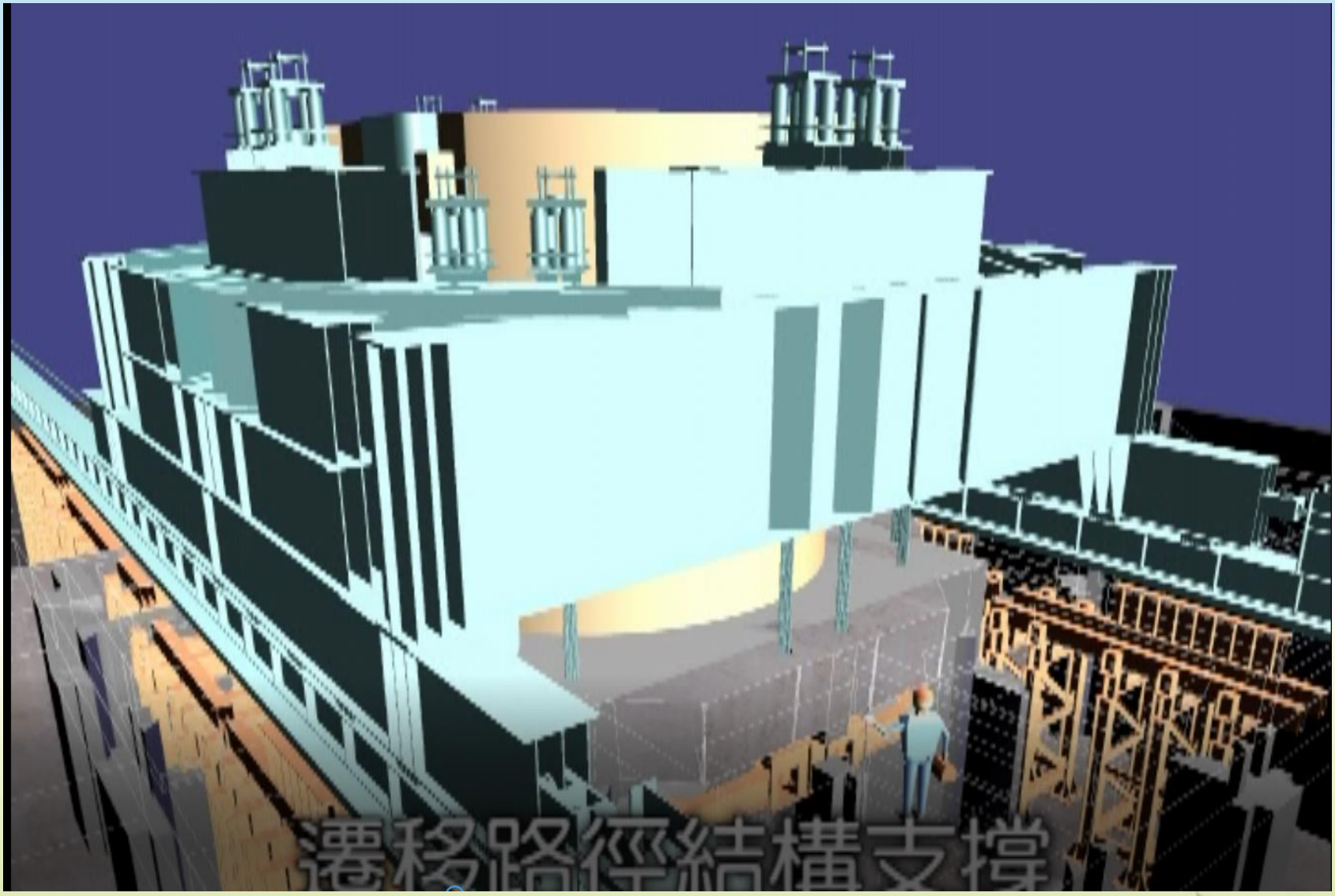
## TRR Vessel

### Lift & Transfer:

Vessel block was lifted to **4m** high above the floor and move **40.8 M** to the storage building.

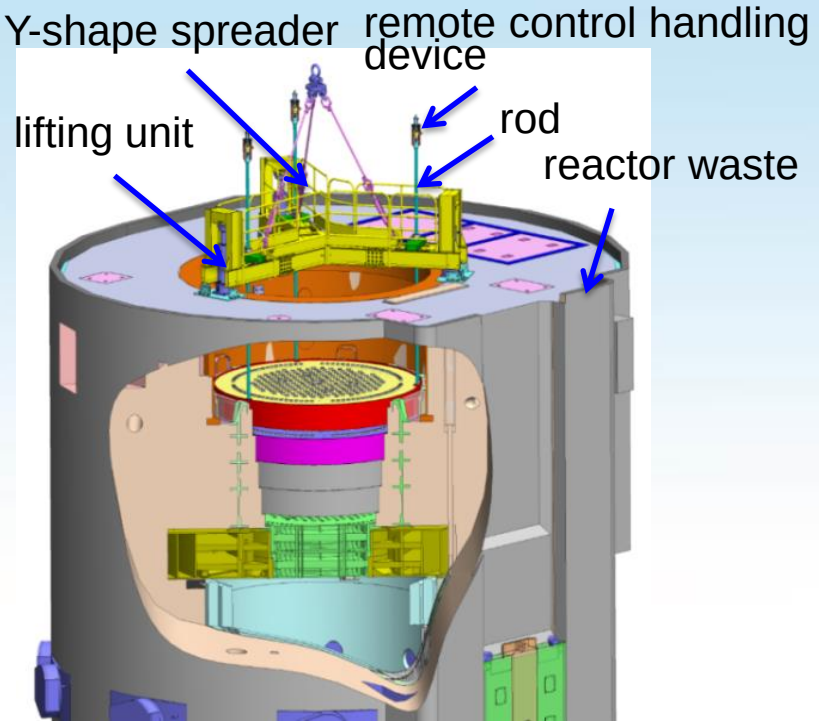


# DEMO

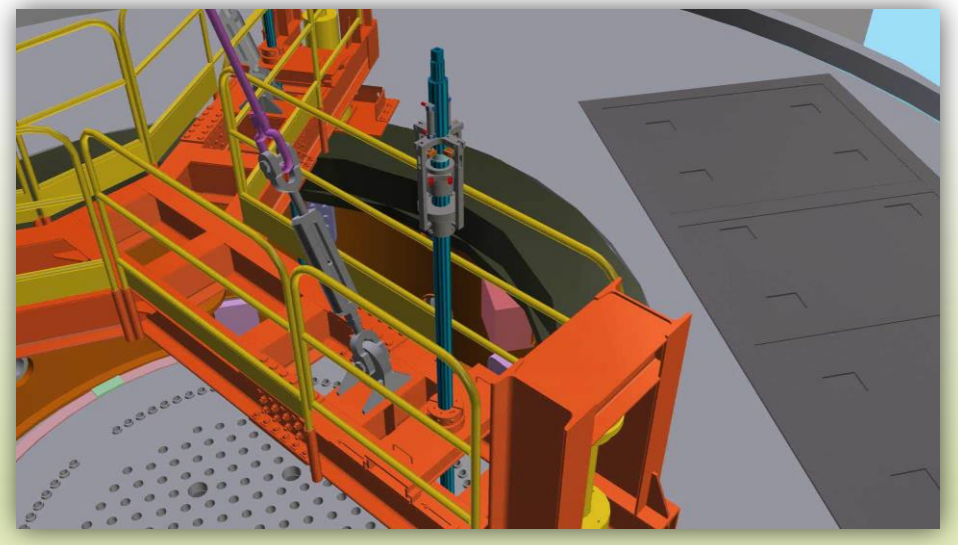


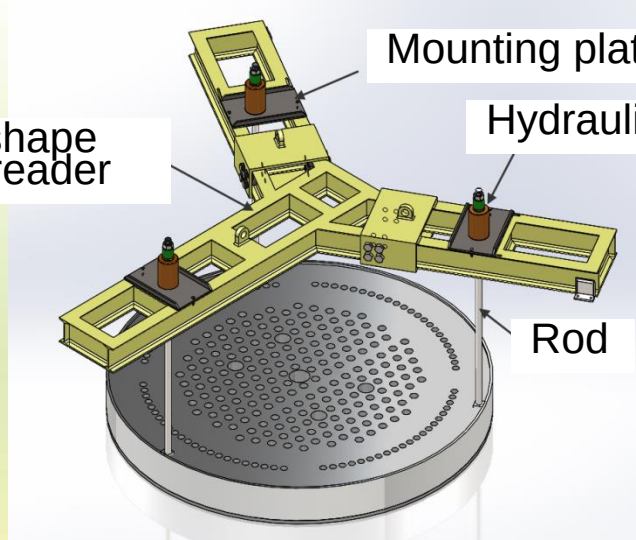
# Lifting equipment development

- Y-shape spreader
  - Hydraulic jack
  - Rod
  - Mounting plate
  - guide plate



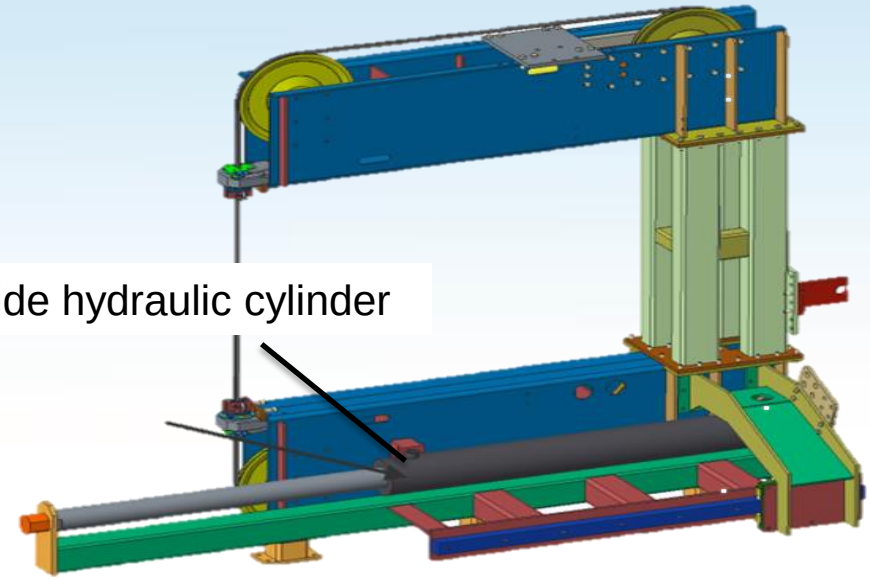
3D model of Y-shape spreader

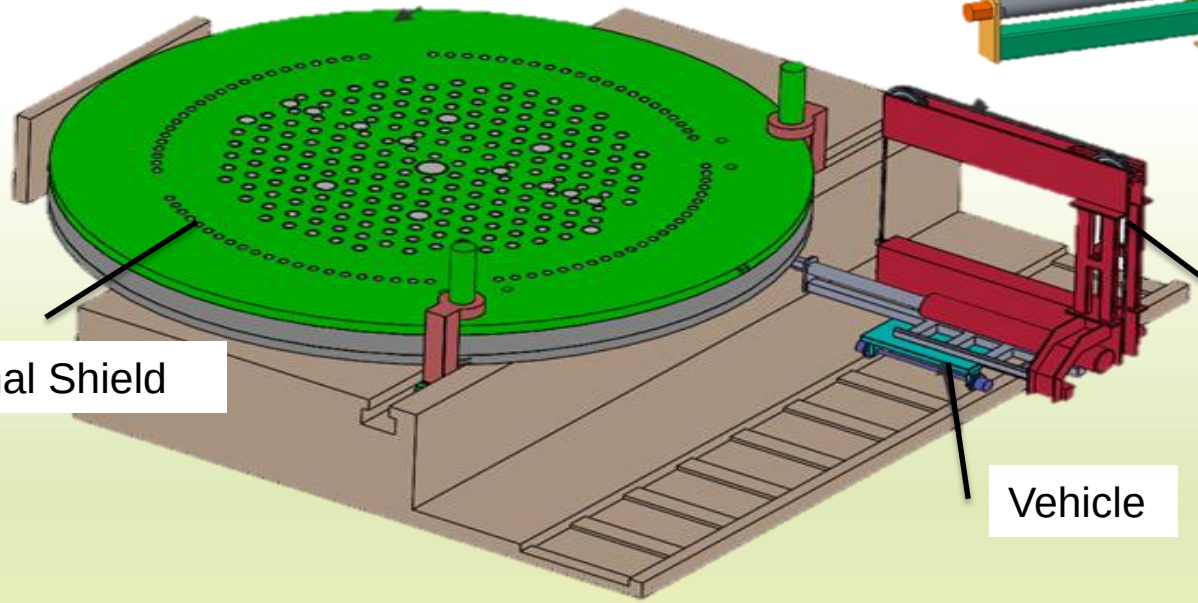




# Cutting equipment design

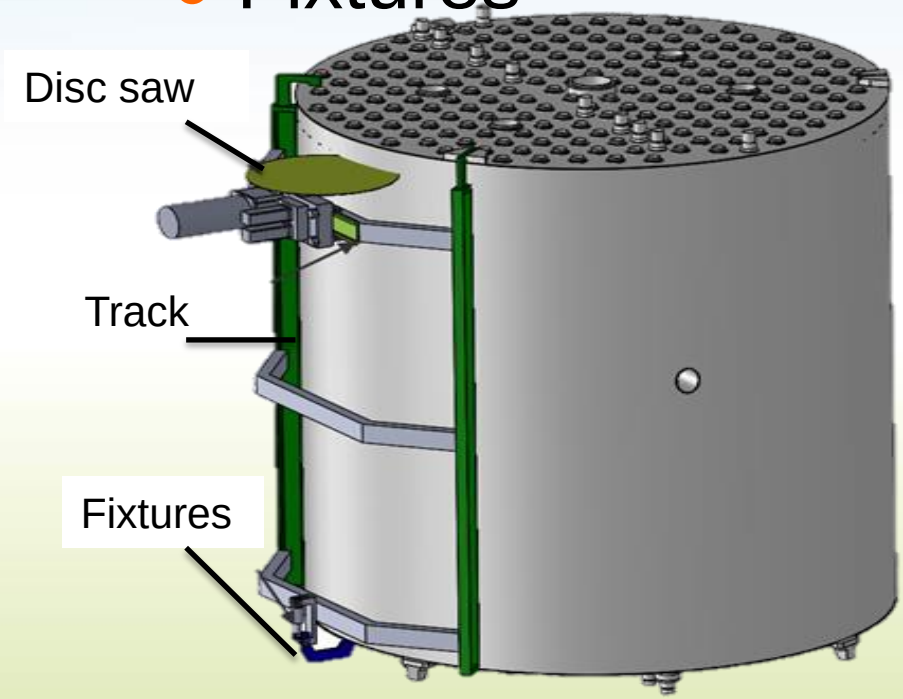
- Underwater band saw cutting equipment
  - Foundation
  - Vehicle and track
  - Band saw
  - Side hydraulic cylinder

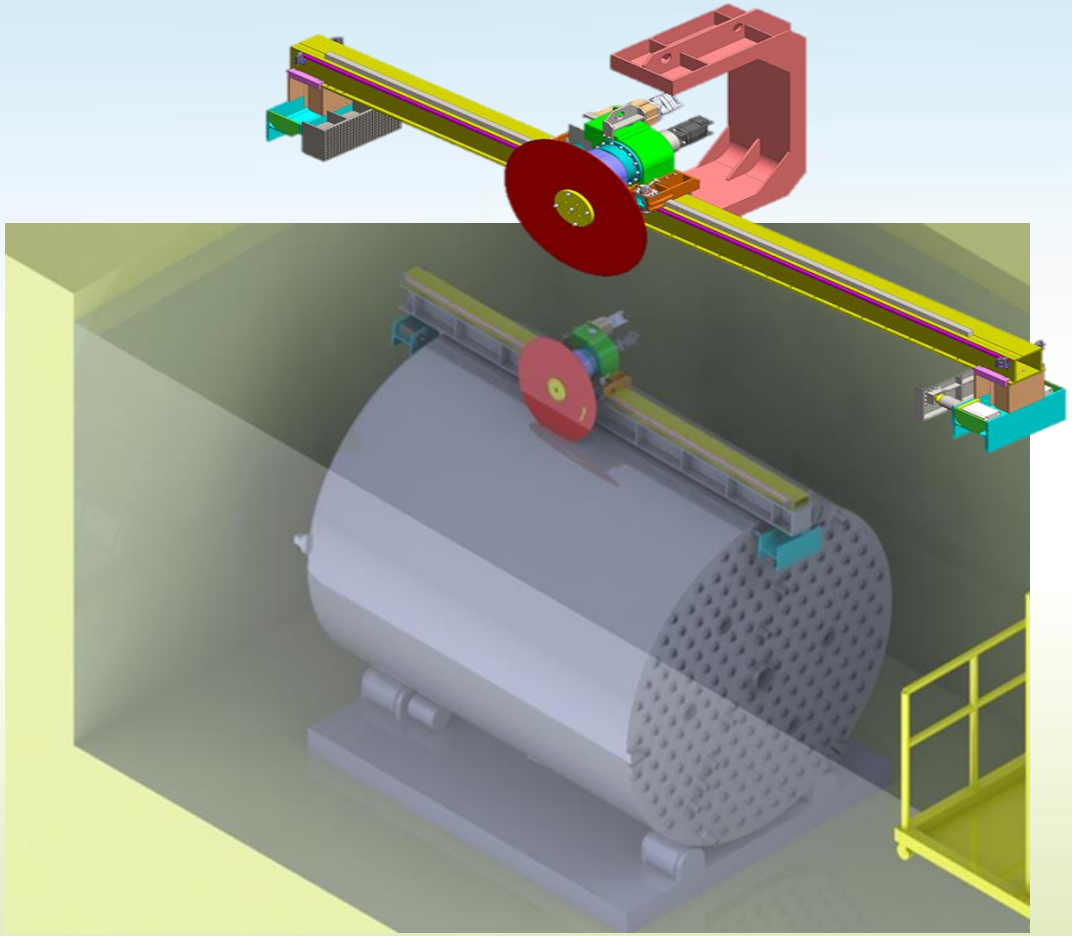


# Cutting equipment design

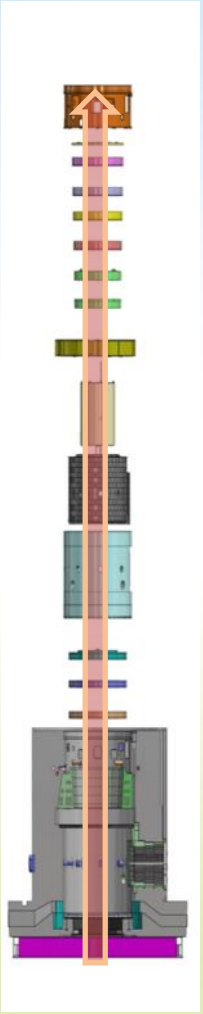
- Underwater disc saw cutting equipment
  - Track
  - Disc saw
  - Fixtures

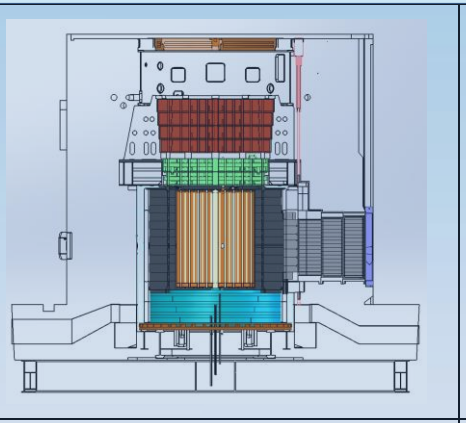


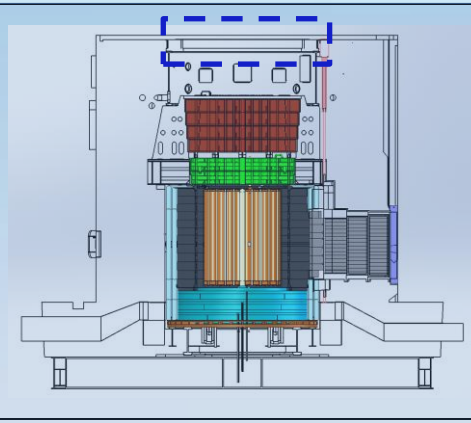
# Dismantling Procedure

- From top to bottom, form inside to outside, reserve direction as installation
- Because of lifting height limitation and geometry limitation, bio-shield cutting divides into 3 steps.

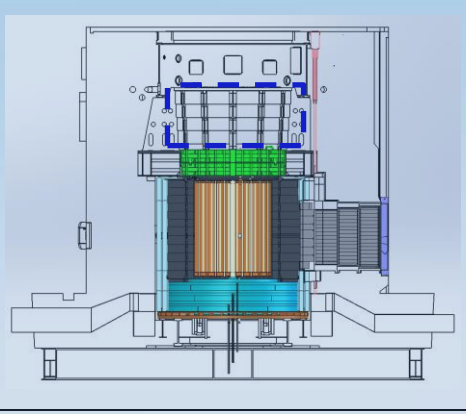




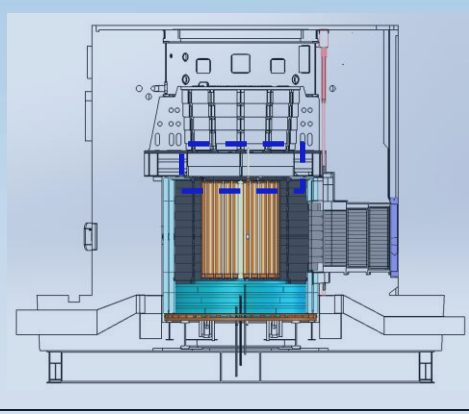
(0) TRR



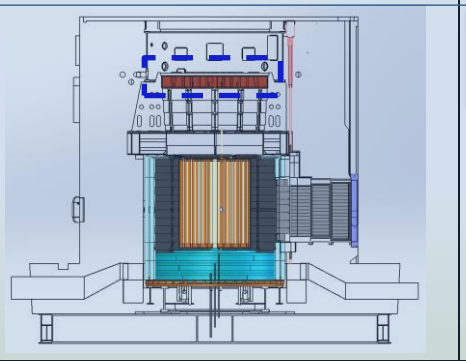
(1) Rotate cover open



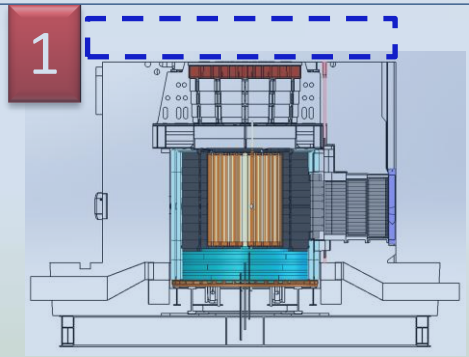
(2) Upper bio-shield plates removal



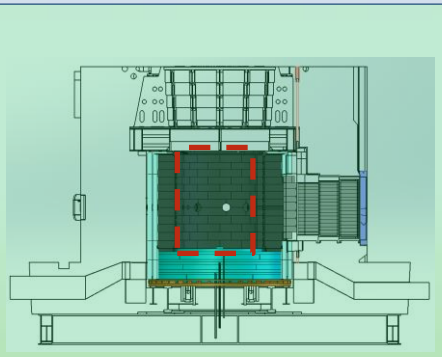
(3) Upper thermal-shield plates removal



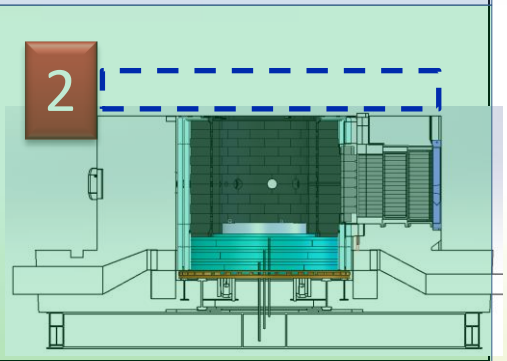
(4) 1st bio-shield plate cover again



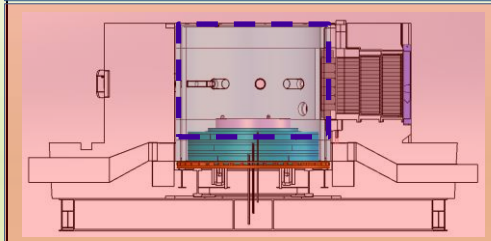

(5) 1st layer Biological shield dismantle



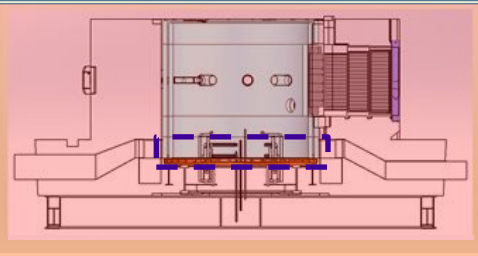
(6) Calandria removal



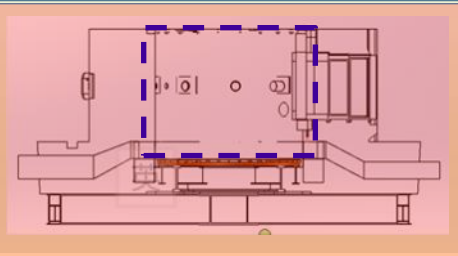

(7) 2nd layer biological shield dismantle



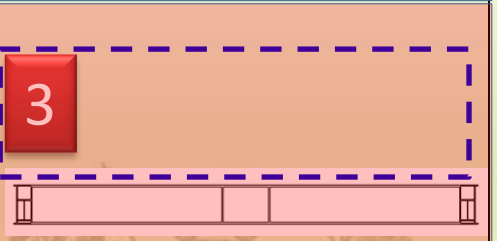
(8) Graphite reflector removal



(9) Lower thermal shield plates removal

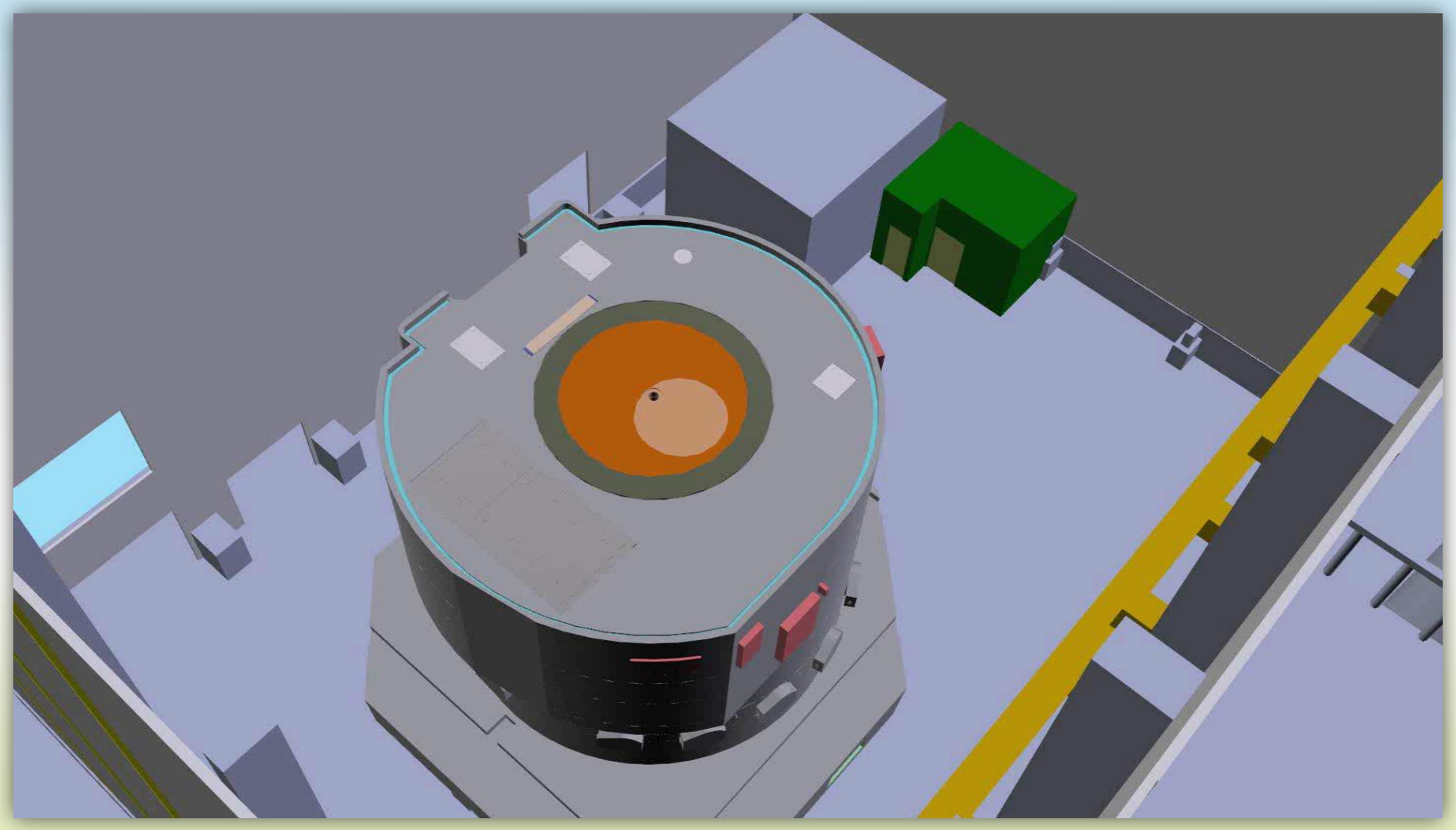


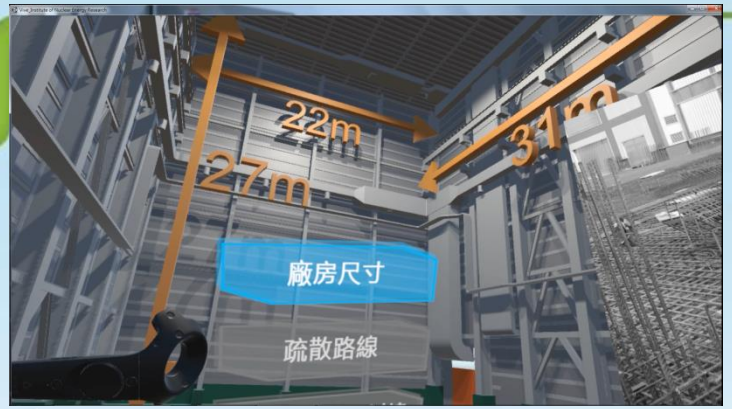
(10) Radial thermal shield removal

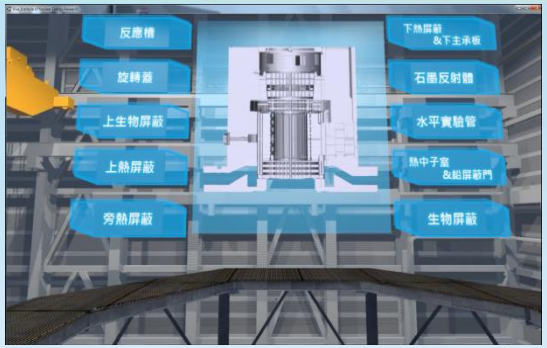



(11) 3rd layer biological shield dismantle

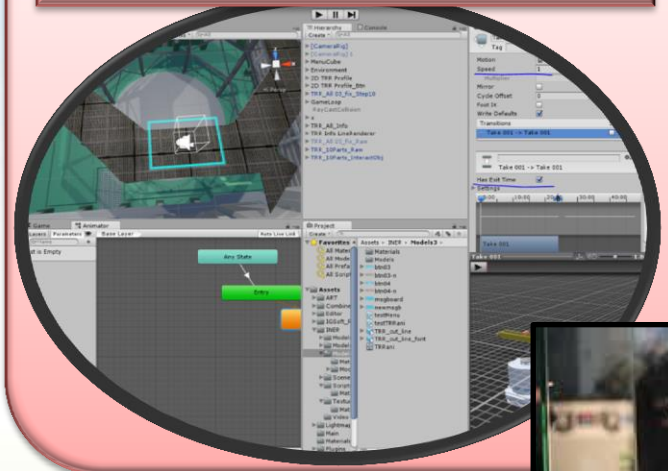
# DEMO



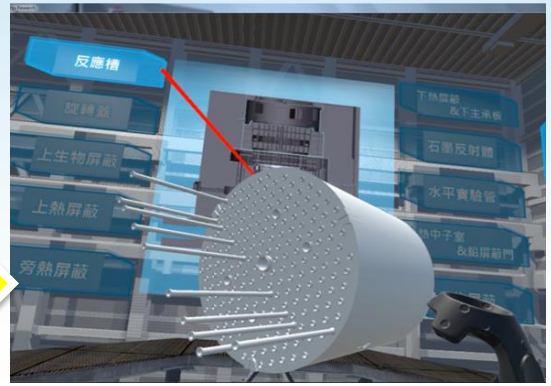


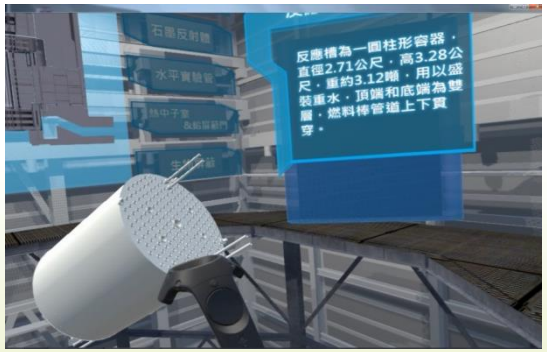




## 3D PlatForm

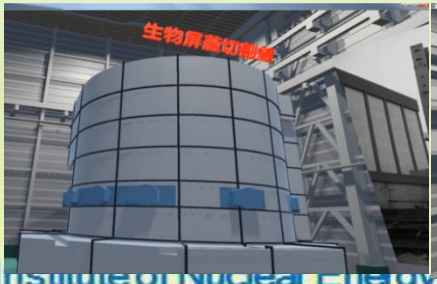


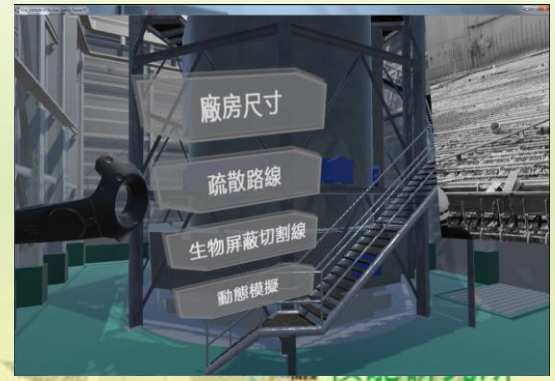
## 3D Model




## VR



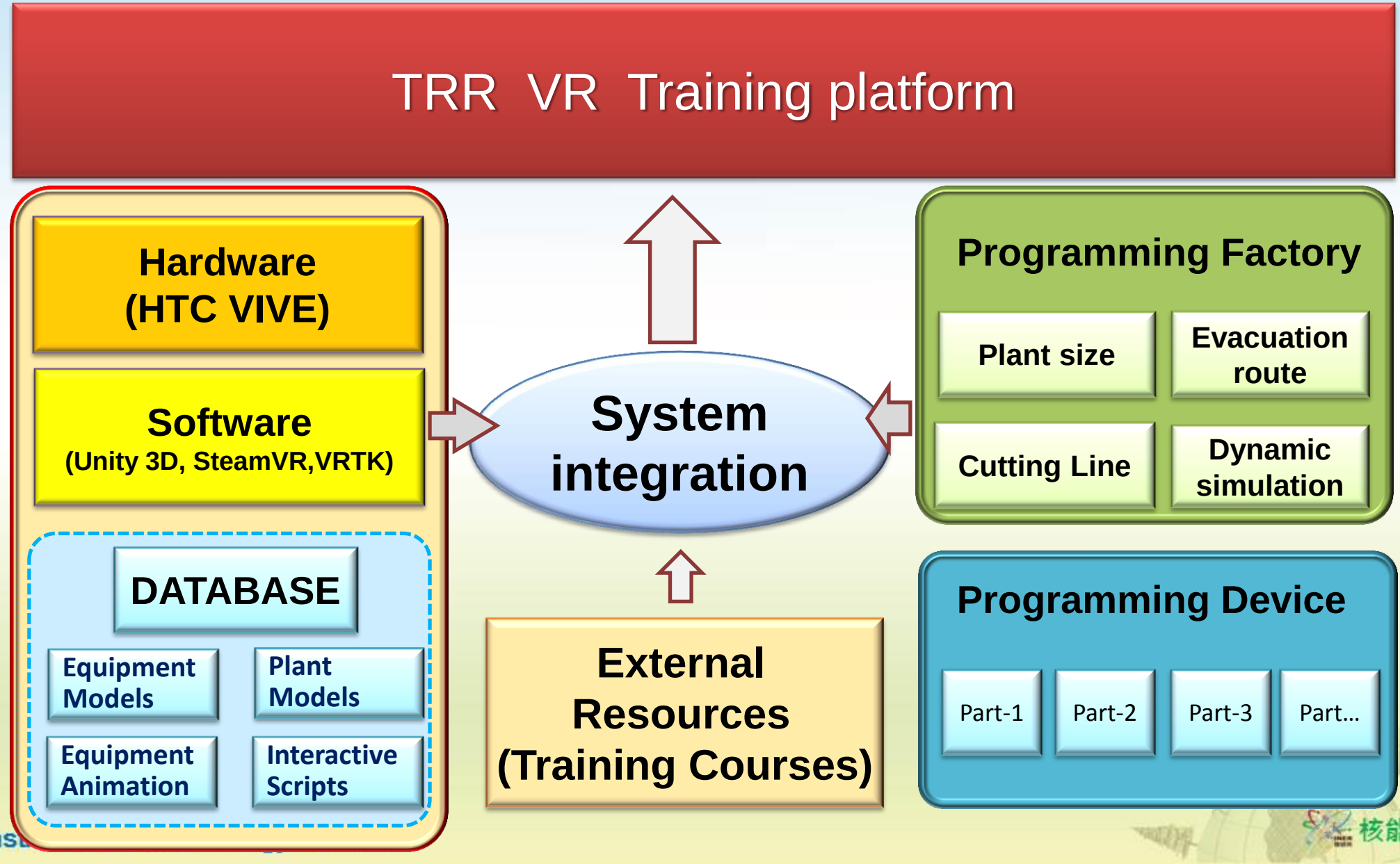
# TRR Virtual Reality Training platform

- SolidWorks
- 3DMax
- Unity 3D
- HTC Vive



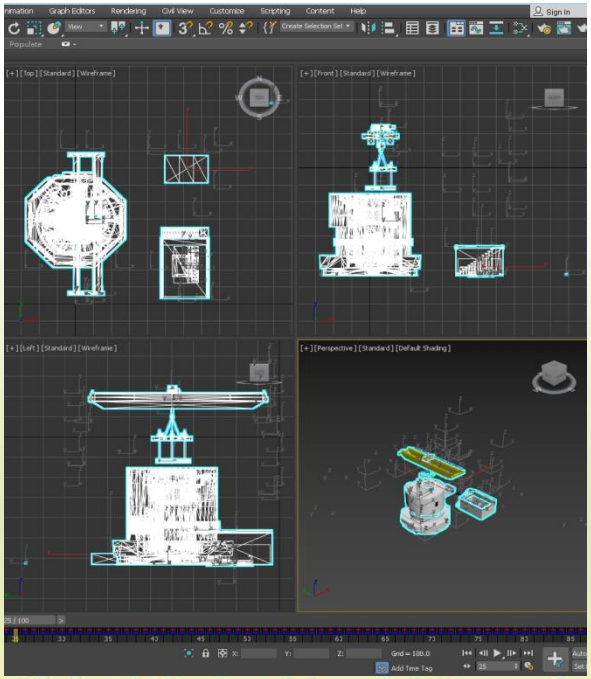

# TRR Virtual Reality Training platform

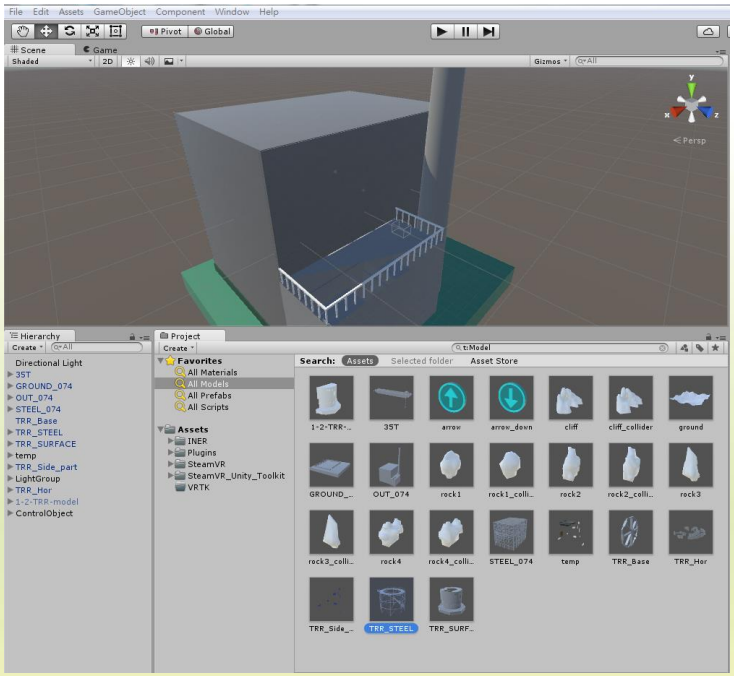
## System design architecture



# TRR Virtual Reality Training platform

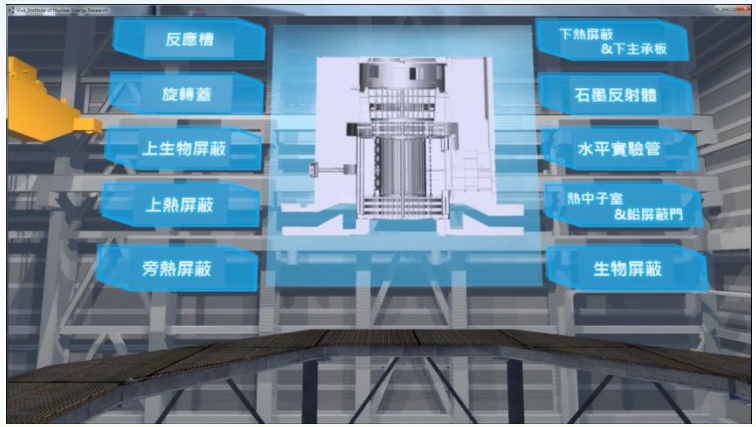
- Environment Display
  - Interaction
  - Immersion
  - imagination

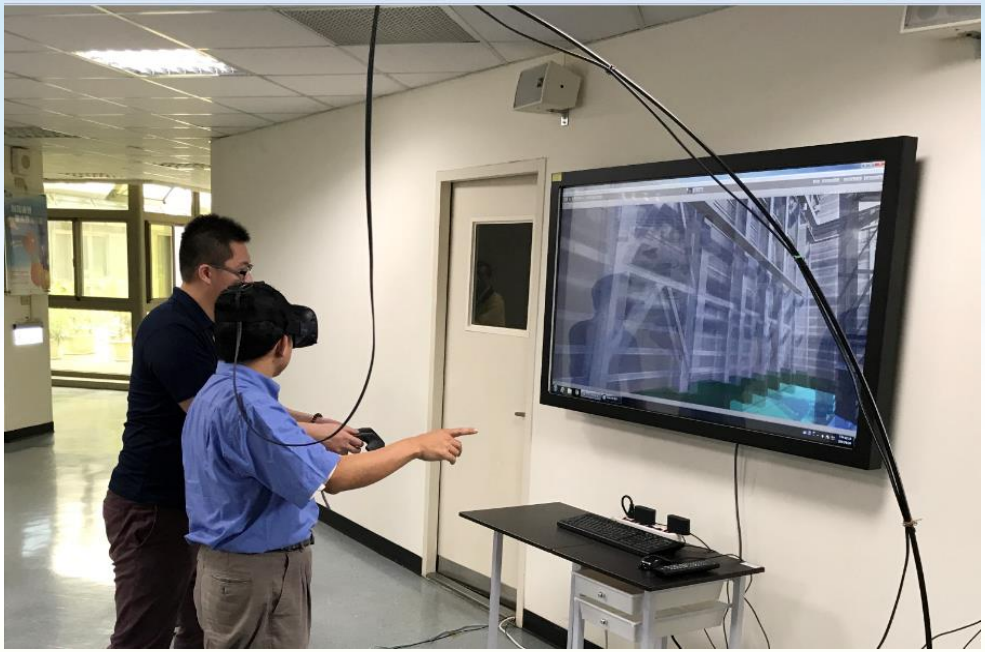



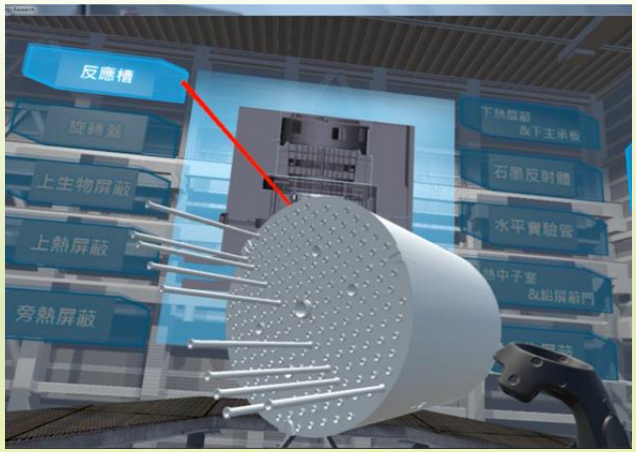


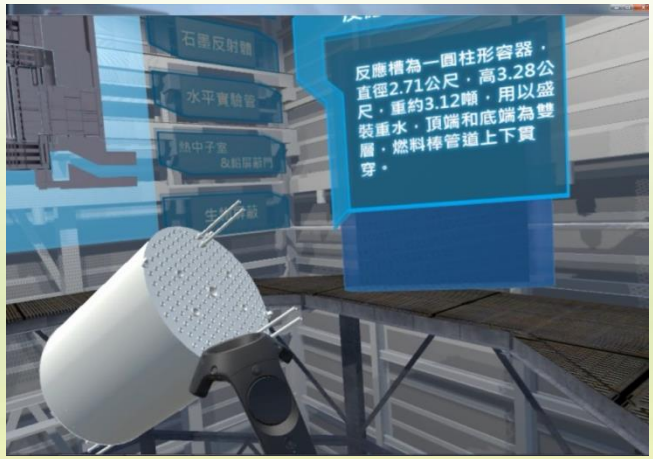
# TRR Virtual Reality Training platform

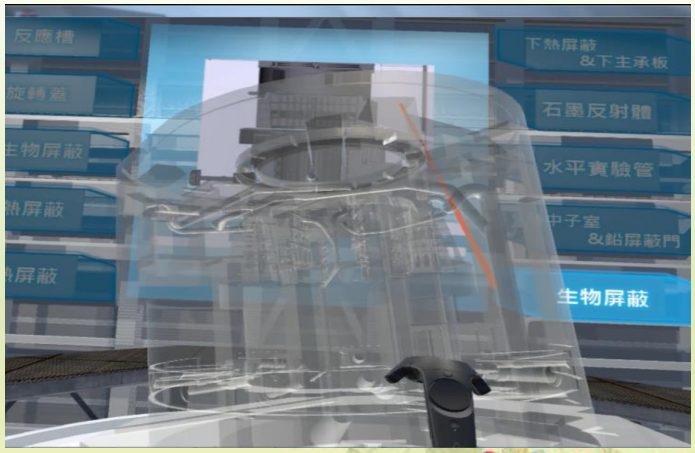
- Staff training &Component display
  - Interaction
  - Immersive environment



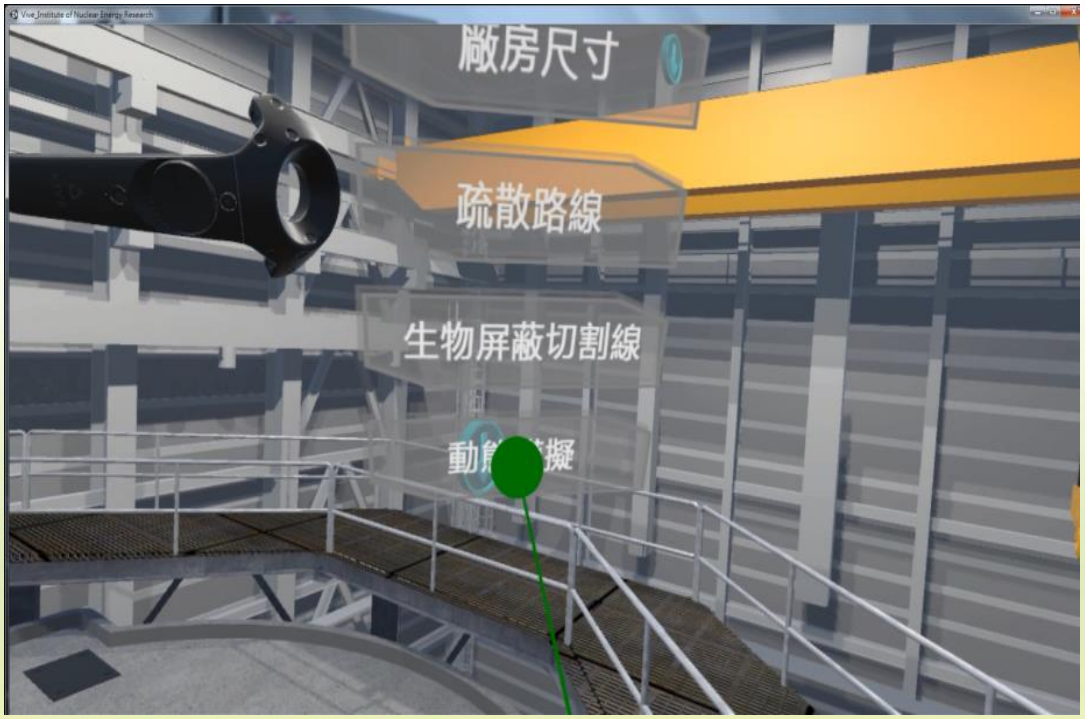


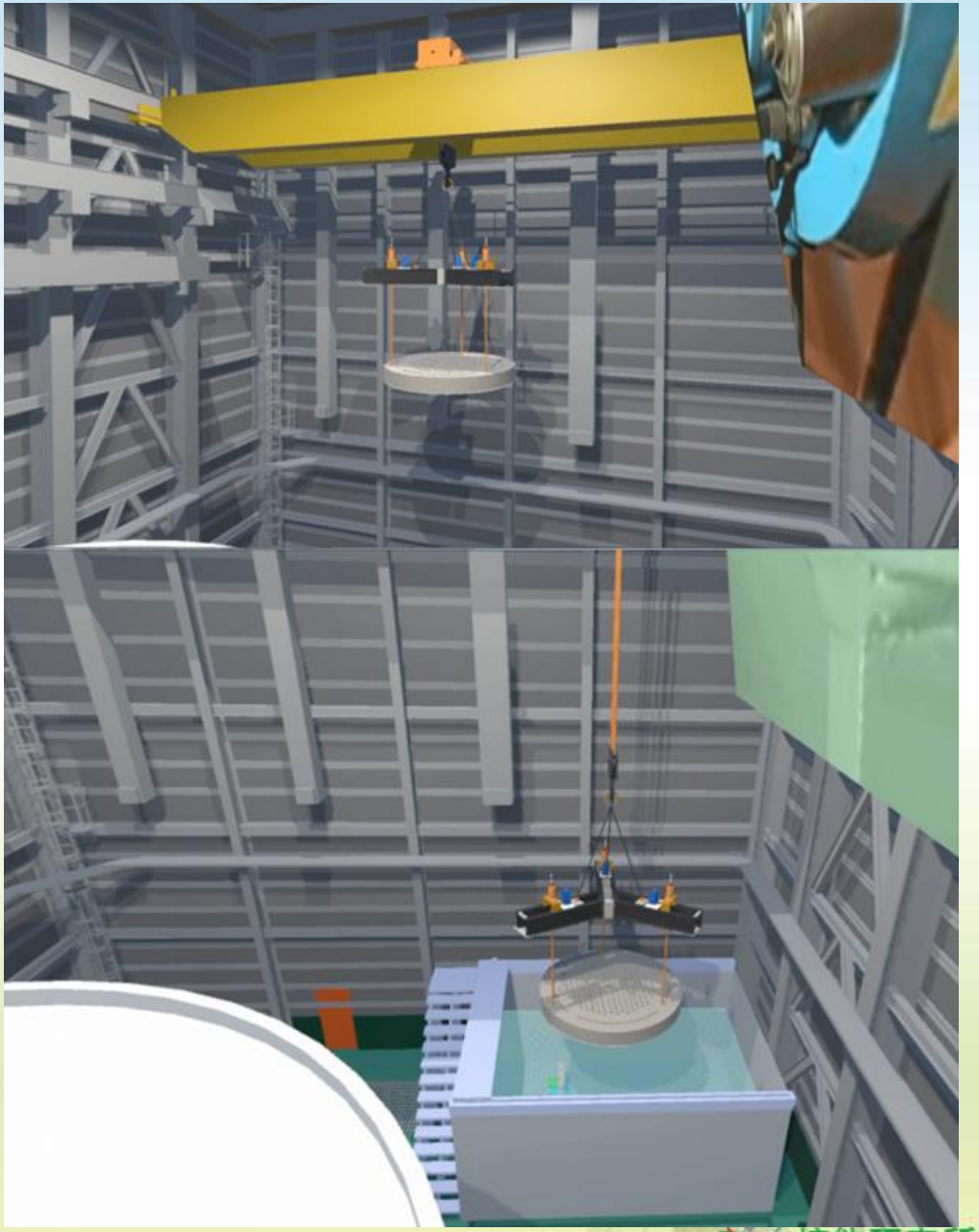



# TRR Virtual Reality Training platform

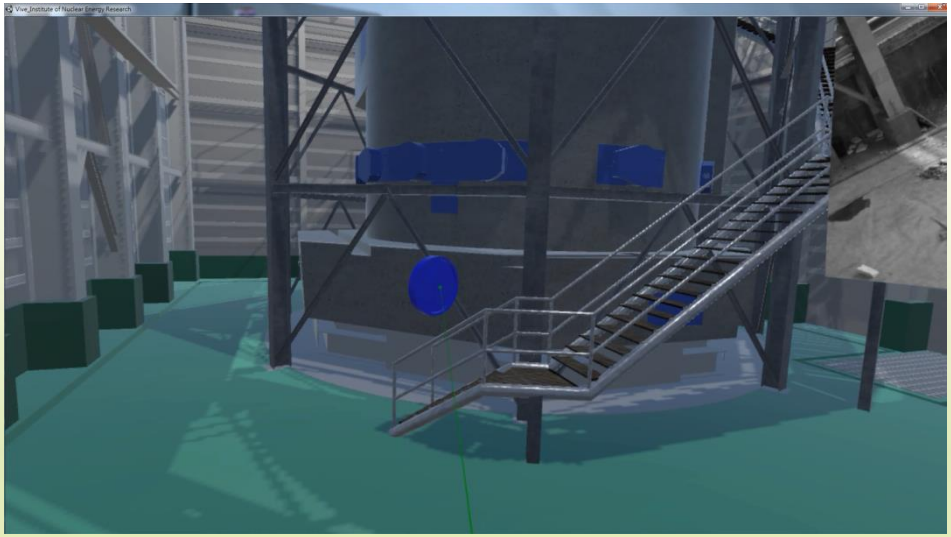
- Display Disassembly & Hanging simulation
  - Component lifting process.
  - Planning of the construction steps.

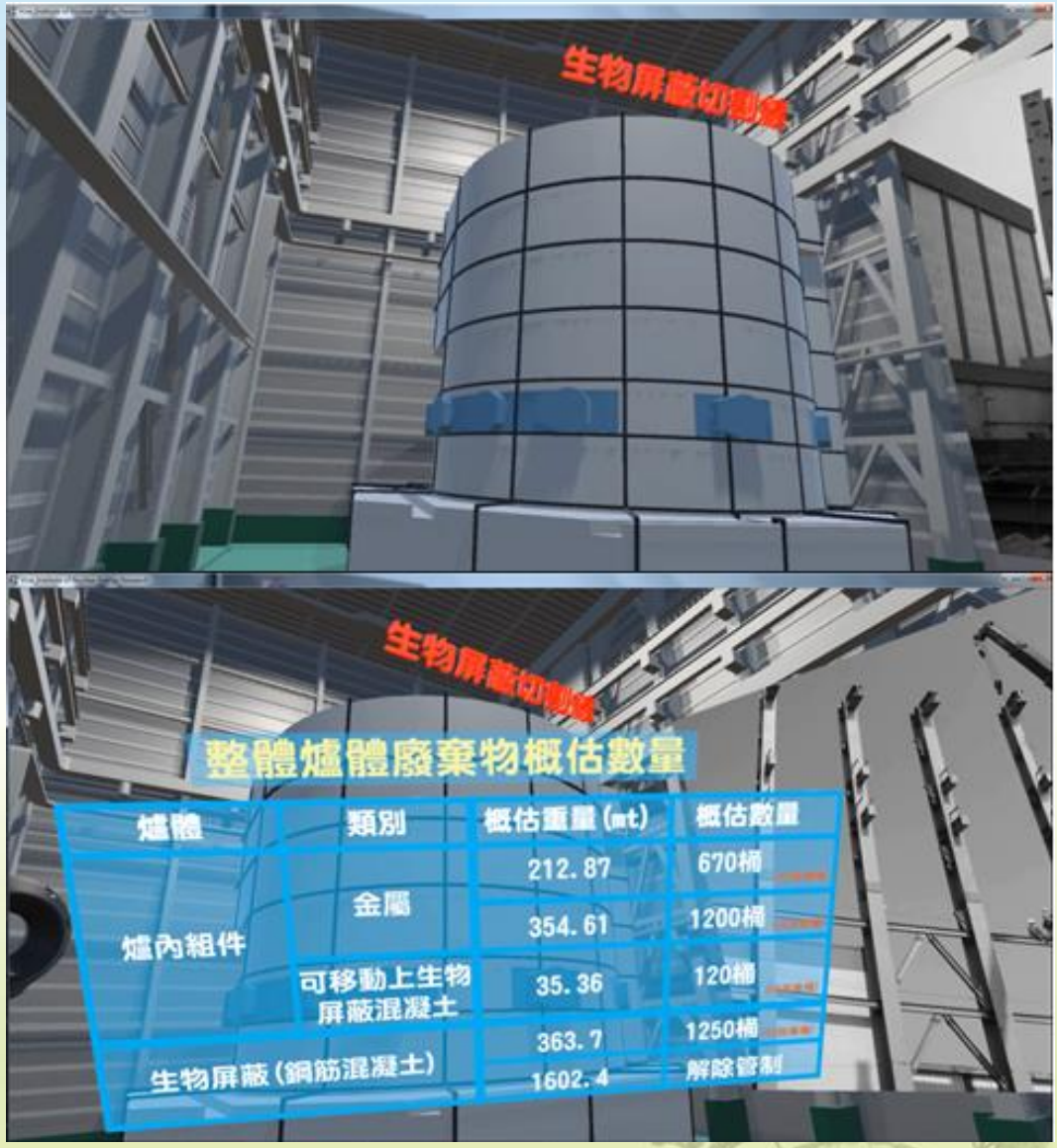


# TRR Virtual Reality Training platform

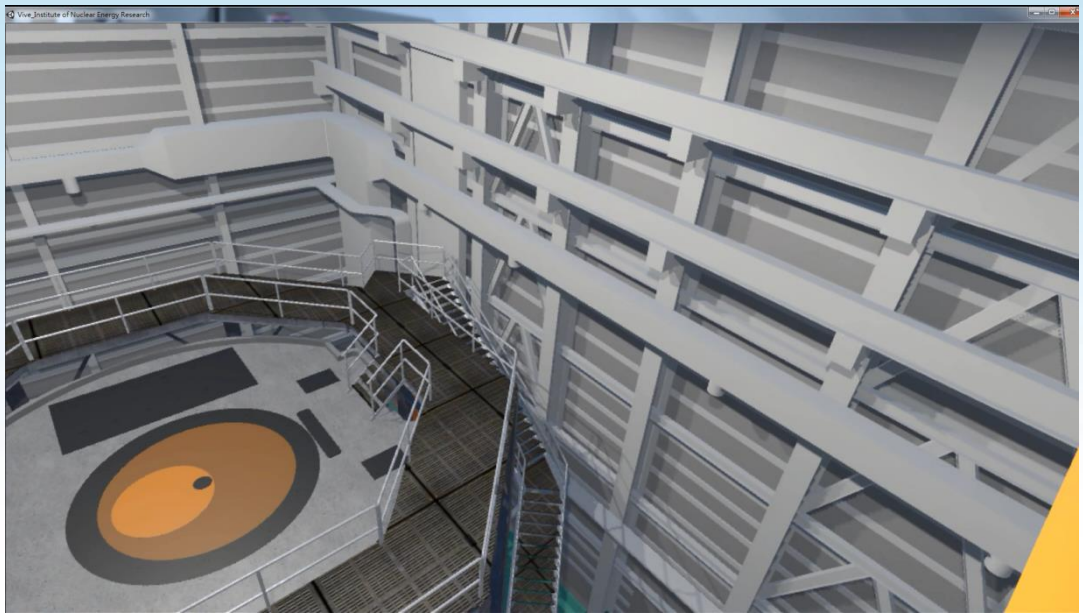
- **Cutting line & Waste management**
  - Space
  - Moving plan

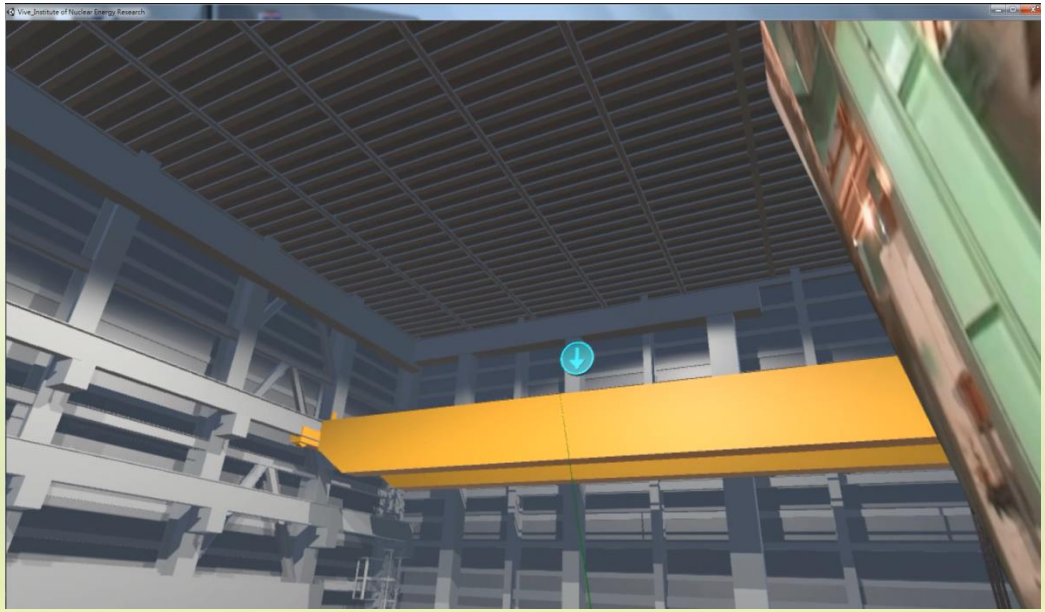


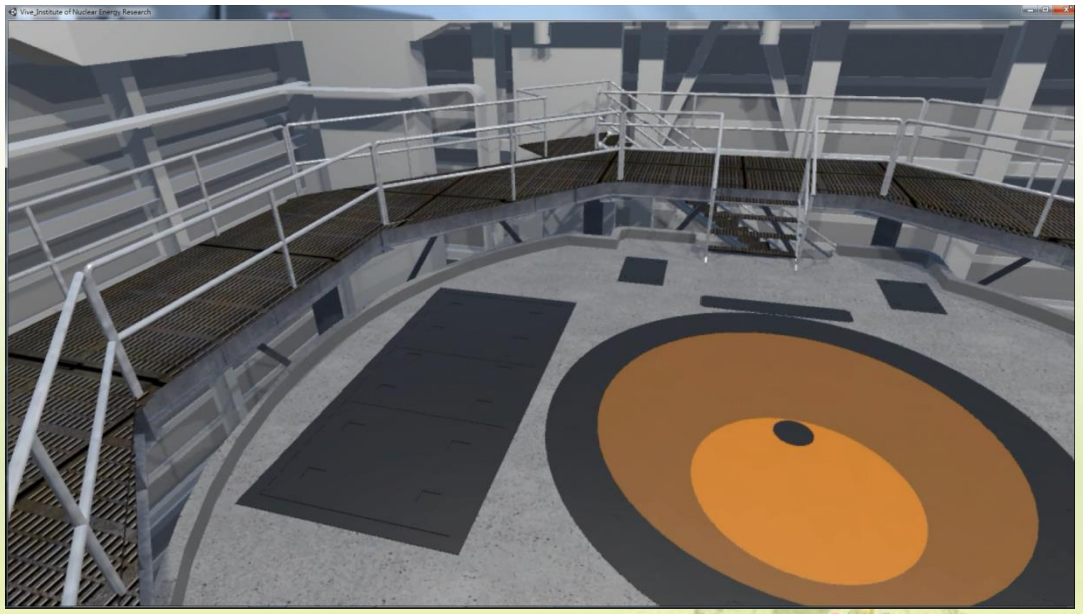


# TRR Virtual Reality Training platform

- **Situation simulation**
  - Work safety
  - ALARA(Save money)



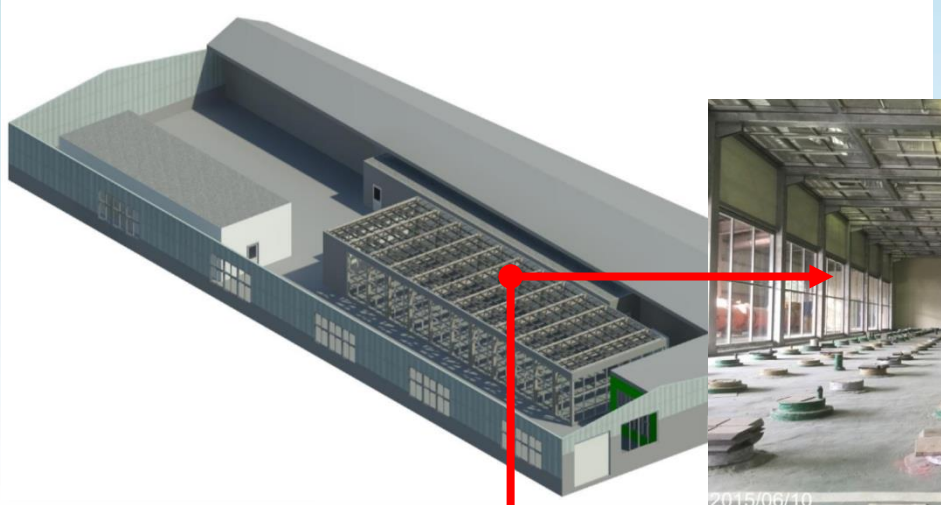


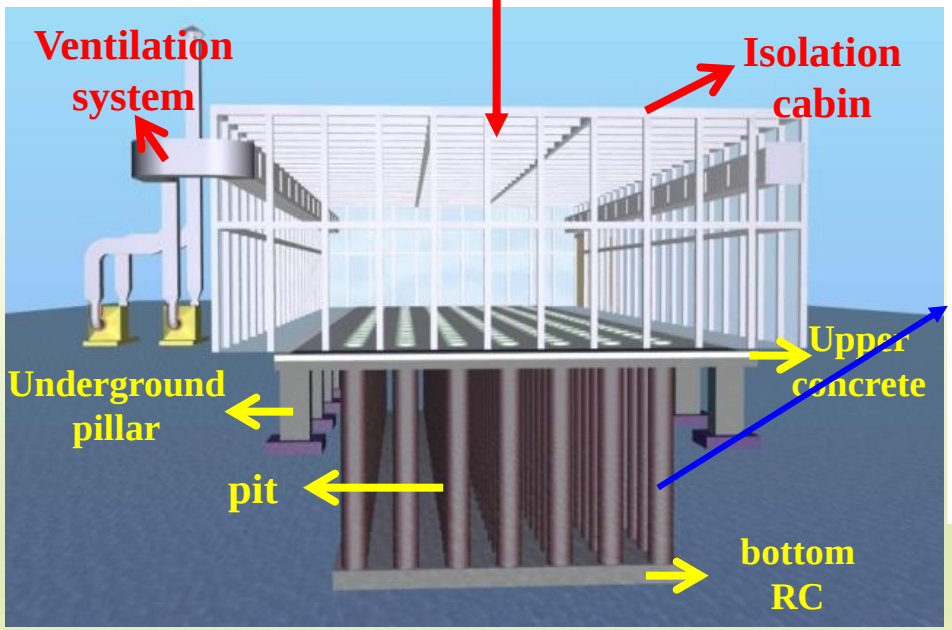


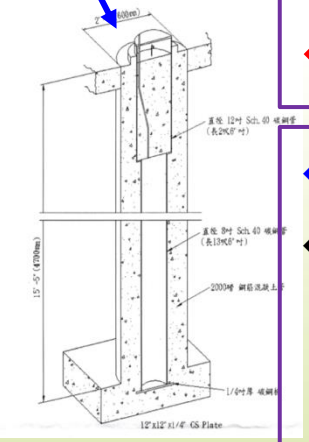
# TRR VR Training platform Demo

# Cleaning of Spent Fuel Dry Storage Pit

## Status and Confinement



- 175 pits were installed underground (1976)
- Cleanup boundary:

  31.2m (length) × 9.2m (width) × 5m (depth)

- **Inside column** is carbon steel (232 kg) composited by upper part (Φ304.8 mm × h825 mm) and lower part (Φ203.2 mm × h4100 mm).
- **Outside shell** is reinforced concrete.
- **Length: 5 m → (limited by cabin)**
- **Weight: 3800 kg → (No crane)**

- **69 pits never used**
- **Sorting by radiation dose rate:**

  High: 10 mSv/h ≦ **16 pits** ≦ **153 mSv/h**

  Middle: 400 μSv/h ≦ **14 pits** ＜10 mSv/h

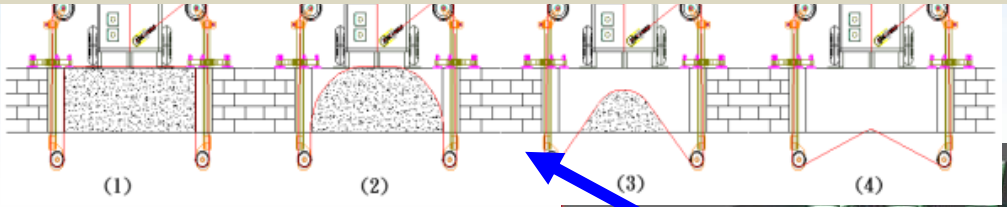
  Low: **76 pits** ＜400 μSv/h

# Cleaning of Spent Fuel Dry Storage Pit

## Cleaning Engineering Detail Design

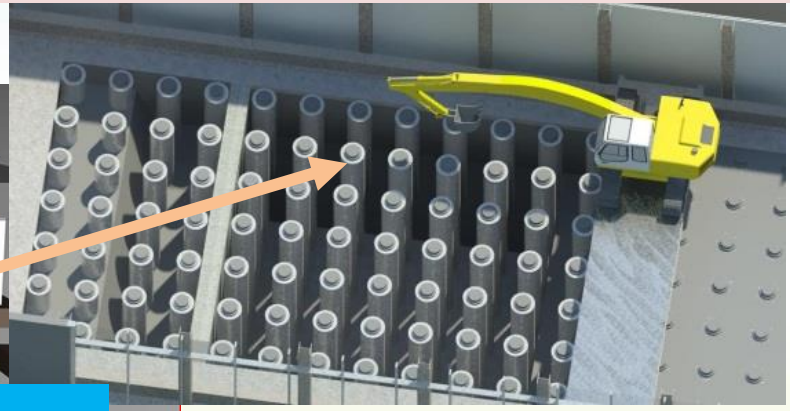
### I. Upper concrete cutting (wire saw)

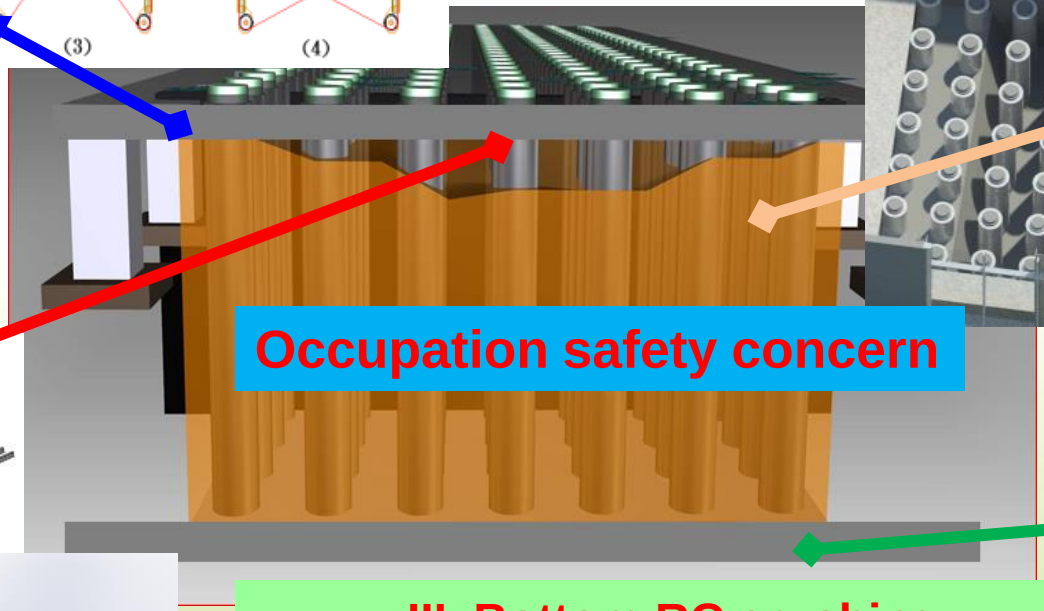
- Airborne (dust) prevention and HEPA protection
- Less coolant (water) using
- Precisely cutting prevent pits from damage




### II. Soil excavation

- Electric power driving (not diesel engine) →VAC protection
- **Remote** control excavator (no driver) →Occupation safety concern
- Moving boundary limitation

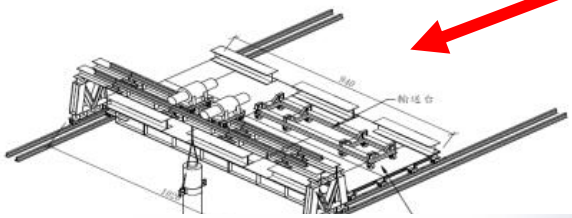


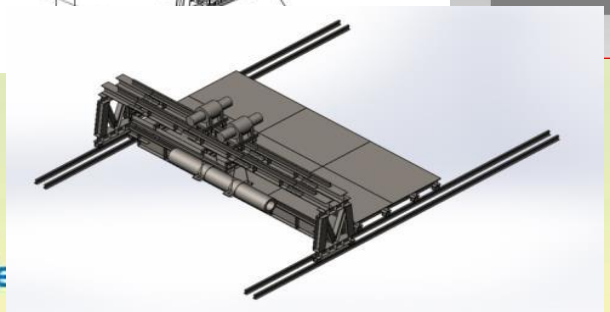


**Occupation safety concern**

### IV. Pit removal

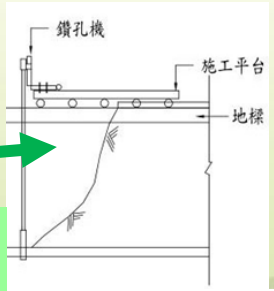
- **Remote** handling
- Stable operation

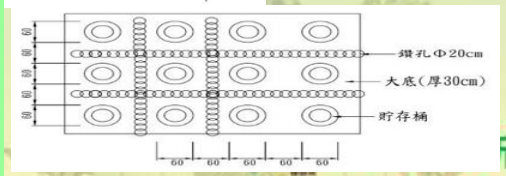




### III. Bottom RC crushing

- **Remote** handling (no worker go down) →Occupation safety concern
- Airborne (dust) prevention



# Cleaning of Spent Fuel Dry Storage Pit

## Schedule

**Sampling and analysis**
11 pits: $^{137}Cs > 10^{7}$ Bq/g
11 pits: $^{137}Cs \sim 10^{6}$ Bq/g

2014 2015 2016 2017 2018 2019 2020 2021 2022

permit Applied

Permit granted

The end of DSP Cleaning

SOPs

Radiation characterization

Insulation cabin & cutting room built

**Pre-removal & Preparation**

Element dismantle

Geological modify

Structural enforcement

Inside pits decontamination

Soil excavation and pits removal

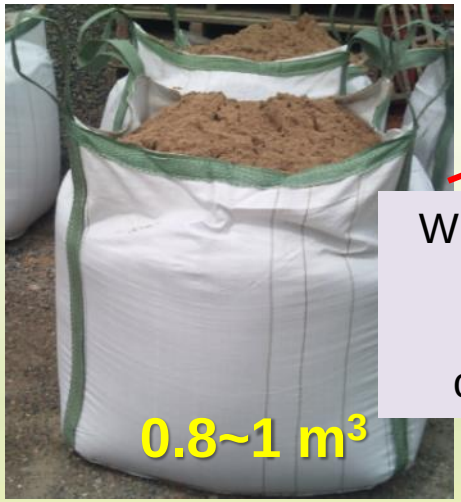
Environ. recover

Waste Management

# Cleaning of Spent Fuel Dry Storage Pit

## Wastes Management

| Wastes | Total Quantity | Estimated contaminated quantity | Clearance criteria |
|---|---|---|---|
| Concrete | 346.2 $m^3$ | 57.4 $m^3$ | <100 Bq/kg |
| Metal | 61,150 kg | ~21,000 kg | <100 Bq/kg |
| **Soil** | **1,084 $m^3$** | **~166 $m^3$** | **NA** |




≧ 1360 bags

Will be divided to 20~50 cases to eliminate contaminants

Measurement system

**Radioactive wastes Storage warehouse**

$^{137}Cs$ > 20,000 Bq/kg

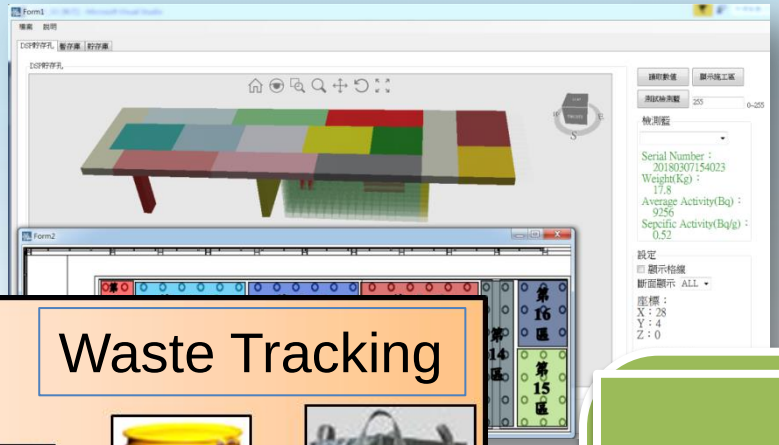
740 < $^{137}Cs$ < 20,000

**Soil wastes Storage vault**

$^{137}Cs$ < 740 Bq/kg

**In-situ (015W) Storage vault**

# Waste Management



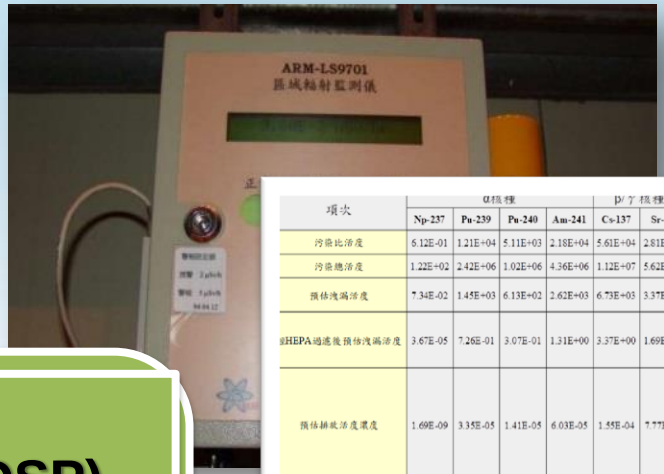
## Waste Tracking

## Dry Storage Pit(DSP)

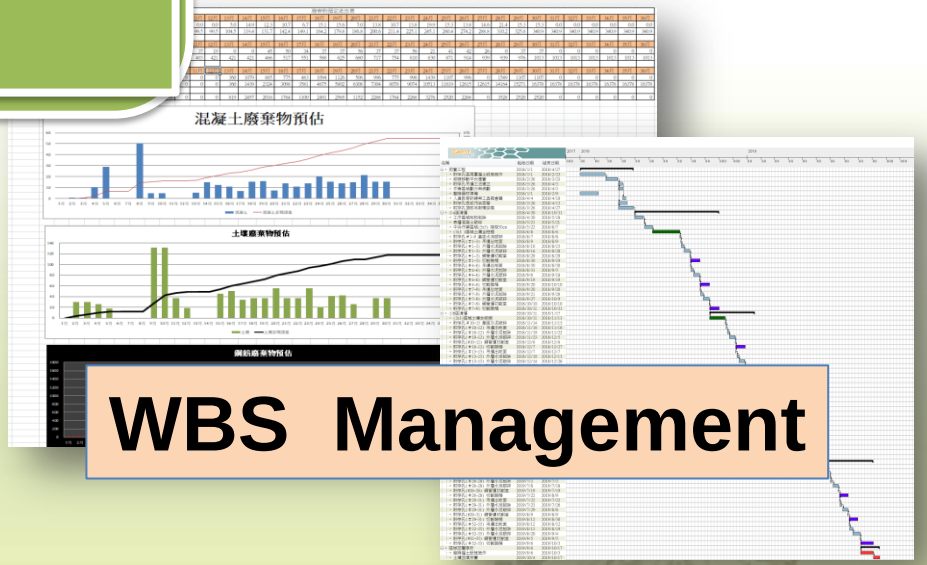
## 3D Visual and Information Management Platform

## Measurement System

# Radiation Characterization




| 項次 | α核種 | | | | β/γ 核種 | | 備註 |
|---|---|---|---|---|---|---|---|
| | Np-237 | Pu-239 | Pu-240 | Am-241 | Cs-137 | Sr-90 | |
| 污染比活度 | 6.12E-01 | 1.21E+04 | 5.11E+03 | 2.18E+04 | 5.61E+04 | 2.81E+04 | 單位:Bq/g |
| 污染總活度 | 1.22E+02 | 2.42E+06 | 1.02E+06 | 4.36E+06 | 1.12E+07 | 5.62E+06 | 污染比活度 x 200 g |
| 預估洩漏活度 | 7.34E-02 | 1.45E+03 | 6.13E+02 | 2.62E+03 | 6.73E+03 | 3.37E+03 | 污染總活度 x 0.06% |
| 經HEPA過濾後預估洩漏活度 | 3.67E-05 | 7.26E-01 | 3.07E-01 | 1.31E+00 | 3.37E+00 | 1.69E+00 | 1.HEPA 濾除效率99.95%。<br>2.過濾後預估釋出為 0.05%。<br>3.預估洩漏活度 x 0.05% |
| 預估排放活度濃度 | 1.69E-09 | 3.35E-05 | 1.41E-05 | 6.03E-05 | 1.55E-04 | 7.77E-05 | 考量排放總體積<br>陽離脈蓮換氣風量 = 434 $m^3$/min<br>作業時間：50 min<br>排放總體積：21700 $m^3$<br>排放評估：單位：Bq/$m^3$<br>經HEPA過濾後之預估洩漏活度 / 21700 |
| 核種活度濃度排放管制限度 | 2.47E-03 | 1.03E-03 | 1.03E-03 | 1.29E-03 | 3.16E+00 | 7.71E-01 | 單位：Bq/$m^3$ |
| 分率 | 6.85E-07 | 3.25E-02 | 1.37E-02 | 4.67E-02 | 4.91E-05 | 1.01E-04 | (預估排放活度濃度)/(活度濃度排放管制限度) |
| 分率合 | 9.31E-02 | | | | | | 各核種分率加總 |




## WBS Management

# Cleaning of Spent Fuel DSP Schedule

**Engineering and waste management**

**Progress Control**

**Radiation characterization**

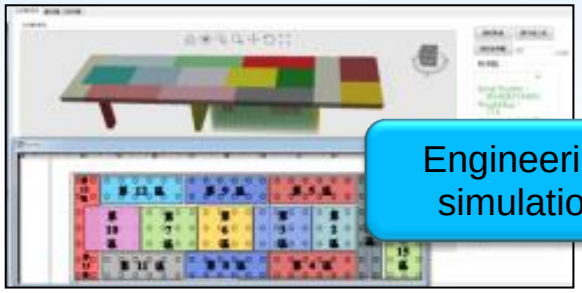
**>100 thousand Data**

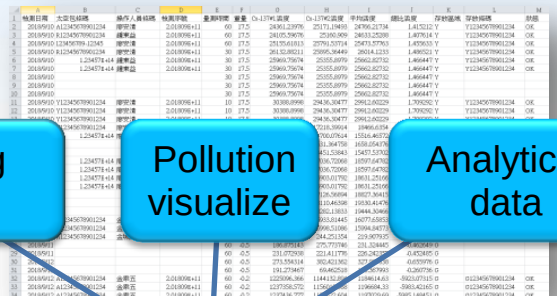
**Storage Room**

**Space, Moving plan, Instant**

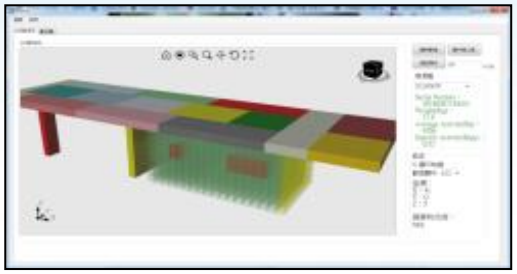
**Radioactive wastes Storage warehouse**

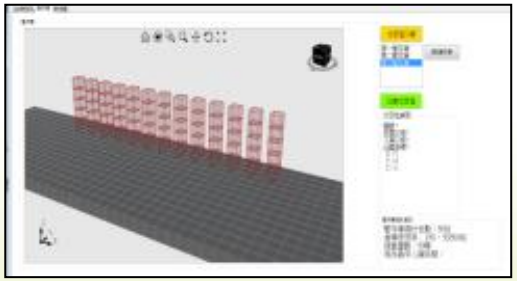
**Cross pollution prevention &Resume**











Engineering simulation

Pollution visualize

Analytical data

Control progress

DSP Pit

Environmental management

**DSP**
**3D Visual and Information Management Platform**

Radiation visualize

Sensor Links

DATA BASE

Radiology Prediction

Instant status

Storage Room

Resume

Management

Space bag Room

Barcode Process tracking

Visual warehousing

Moving Path planning

# Conclusion

- VR can help the life cycle of nuclear facility from its design, operation and decommissioning : concept proof and optimization before the construction, train people in operation and optimize scenarios in dismantling.
- INER has completed the 3D engineering simulation for systems, structures and components of TRR. Combine with the application of 3D engineering information and visualization technology will benefit the decommissioning of TRR.
- INER has studied dismantling techniques over decades and accumulated experience and capability for reactor dismantlement.
- Integration of emergent VR, AR, AI and 3D technology to establish platform for decommissioning management will enhance the personnel safety and operation efficiency for TRR decommission .