Visualization Technology and Preliminary Practice of Radiation Protection

China Institute for Radiation Protection

CNNC Nuclear Power Operations Management Co., Ltd., China

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Background

- The industry has gradually moved towards the mode of digital operation and management. The main features include:
  - ➢ 3D visualization
  - ➢ virtual simulation
  - ➢ etc.
- Also true in nuclear industry.
  - ➢ EDF (France)
  - ➢ PROATOM (Russia)
  - ➢ CNNC (China)
  - ➢ etc.

Background

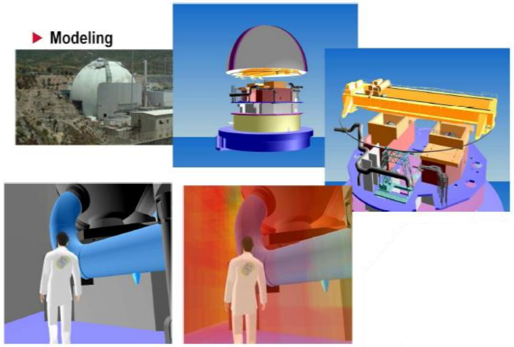
- Radiation protection management based on visualization technology is one of the important development directions of radiation protection optimization in nuclear power plants in the future.
- Radiation protection visualization technology mainly relies on the three-dimensional virtual reality technology.
- The spatial radiation data information can be visually displayed by color and transparency in a three-dimensional way.
- The three-dimensional distribution information of radiation field and operational process can be viewed in real time, and the radiation protection data, such as radiation dose, can be calculated automatically in the process of operation.

Background

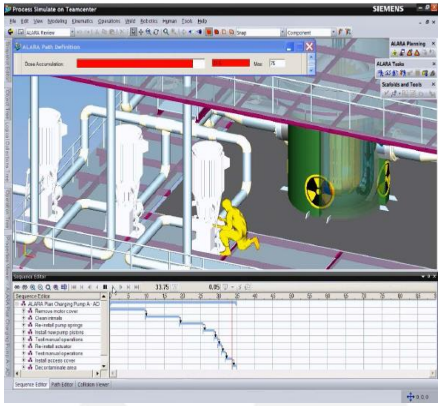
- Thus, this technology can be used to realize the sharing of radiation protection information among different types of personnel, such as decision-making, management, radiation protection personnel and staff,
- and to mine comprehensive field radiation information as far as possible, such as dose estimation and shielding calculation for high radiation risk operations,
- and to train and simulate operators, so as to improve the radiation protection management efficiency, promote on-site radiation protection optimization, and provide schemes for radiation protection decision-making.

Background

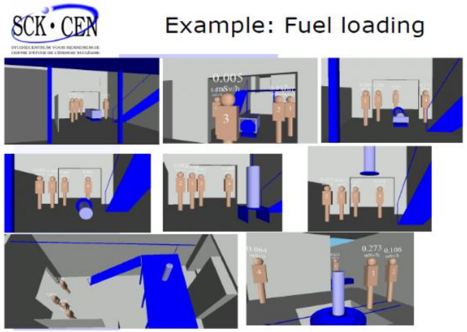
- Practices in the past, such as:
  - ➢ ALARA tools
    - Gamma radiation field calculation;
    - 3D visualization;
    - Dose simulation;
  - ➢ Digital devices
  - ➢ VR
- However, most of the time the data comes from design or simulation.
- How could we get more operating data?



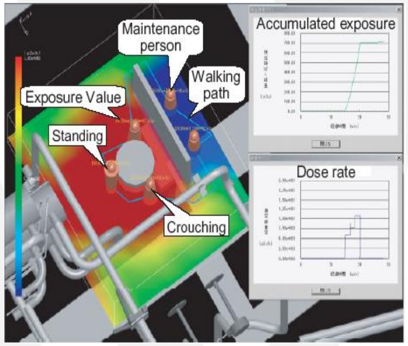
NARVEOS, CEA



PLM, SIEMENS



VISIPLAN, SCK·CEN

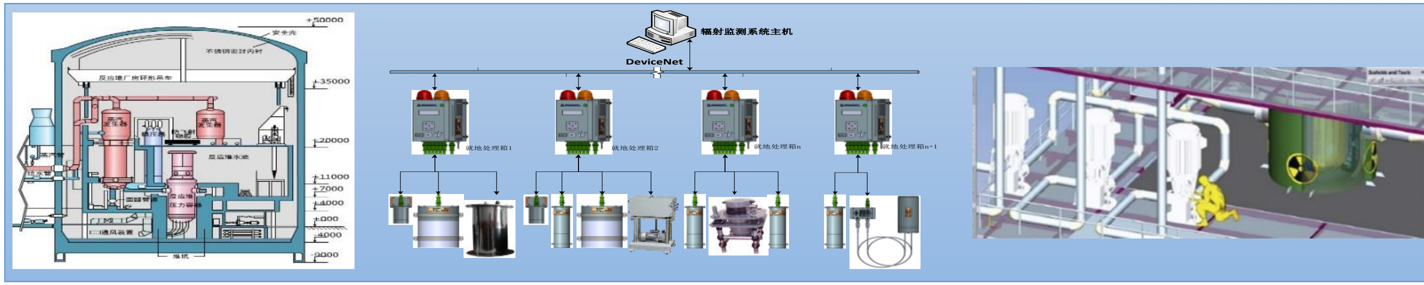


VR-DOSE，Japan

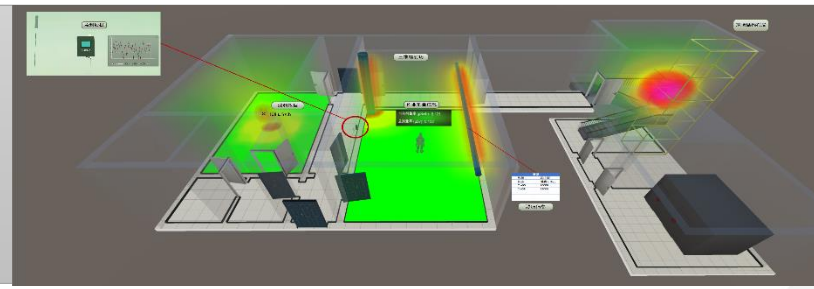
What is digital radiation protection?

Data flow:

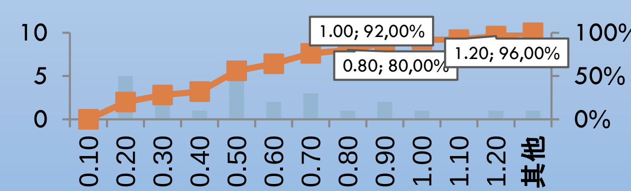
Data Collection



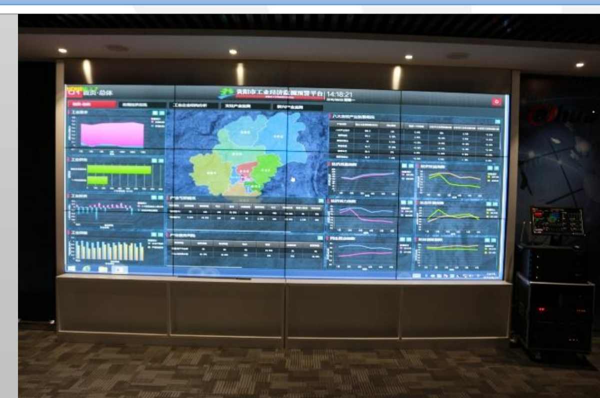
Monitoring & Simulation



Information Management

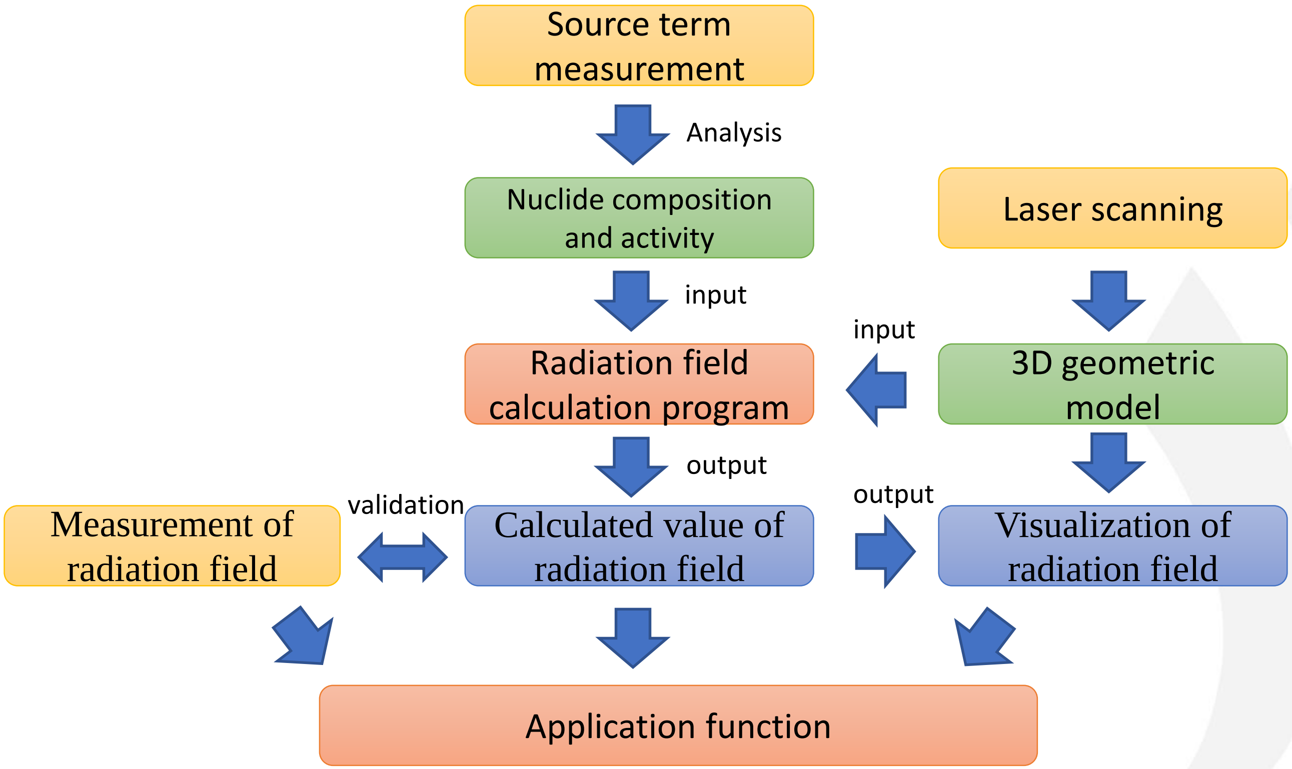


Control & Decision support



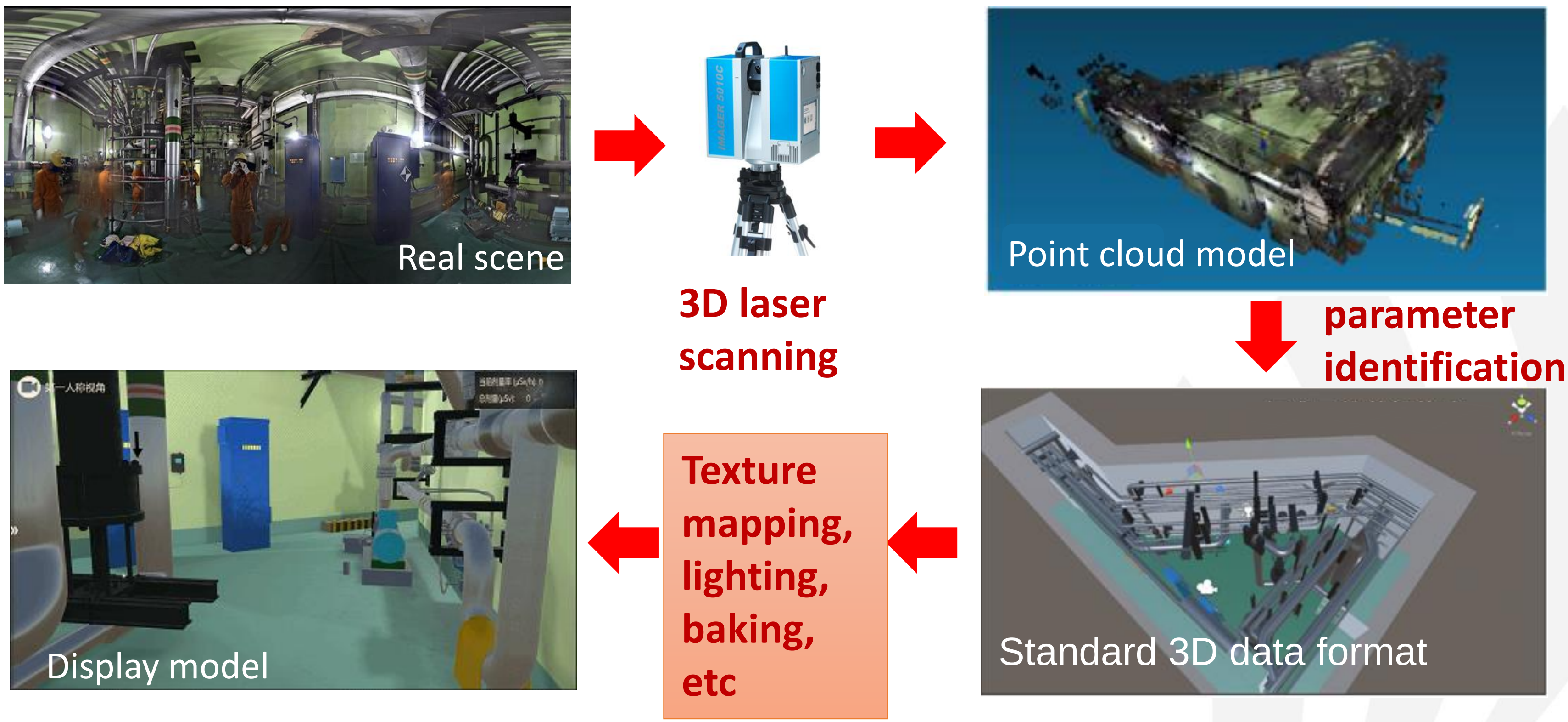
Implementation process

- The "skeleton" of the system is the three-dimensional layout of the site, including rooms, equipment, valves, pipes, containers, etc., "flesh and blood" is the field radiation measurement data and the decision support data obtained by the measurement data and simulation calculation.
- On-site measured data are very important.



1. Modeling

Modeling is a process. According to the purpose, the models can be divided into four types: design model, scanning model, display model and calculation model. A standard model needs to be established to realize unified transformation.



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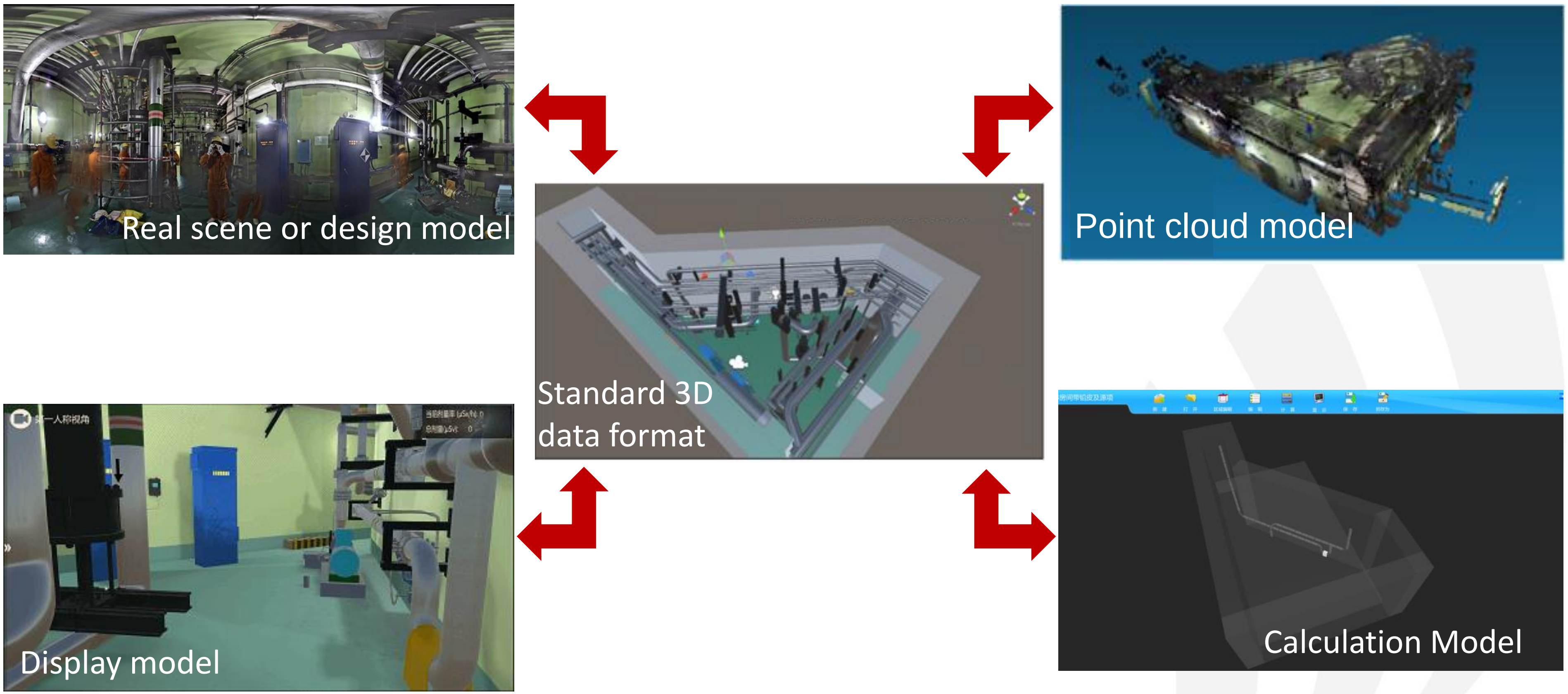
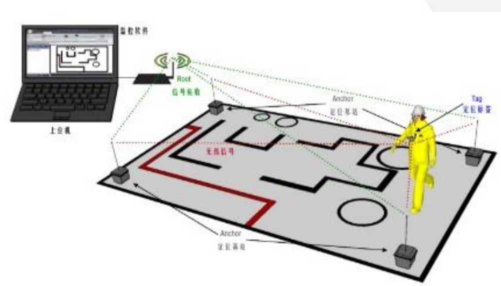


2. 3D radiation field measurement technology

- At present, there is no mature commercial 3D radiation field measurement product in the world.

Method	Based on ruler	Based on Wireless Location Technology	Based on laser positioning technology
Advantages	The easiest to think of	The operation is simple and automatic	relatively simple, position accuracy is the highest.
Disadvantages	Not easy to implement, large error.	The position error is too large.	Can't be fully automated



2. 3D radiation field measurement technology

Our solution:

① A total station was used as the 3D positioning means, which can be measured remotely with the accuracy of mm.

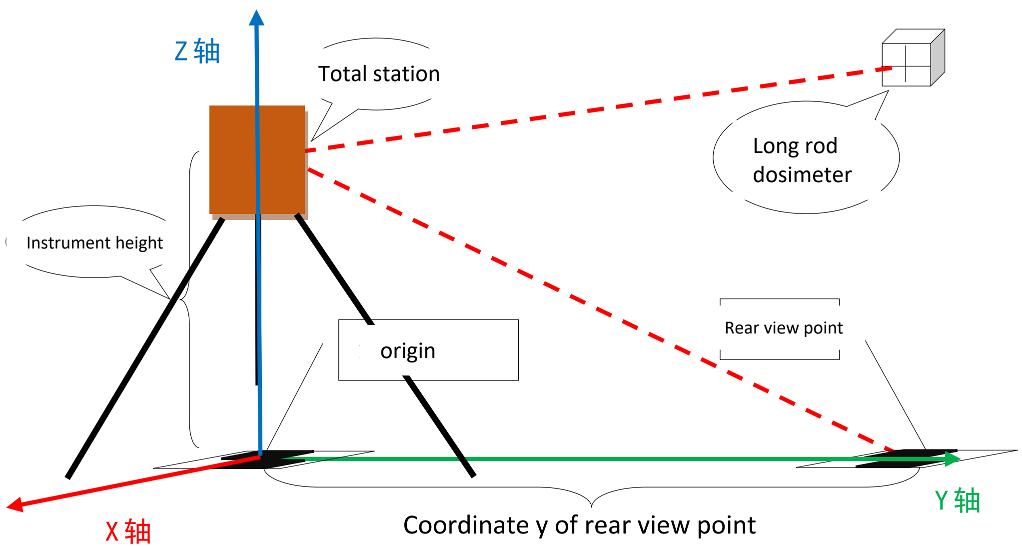
② Reconstruct the portable dosimeter to realize wireless data transmission；

③ Develop control system to realize synchronous measurement of total station and portable dosimeter；

④ Data recording and storage .

2. 3D radiation field measurement technology

Schematic diagram of space coordinates of dosimeter measured by total station



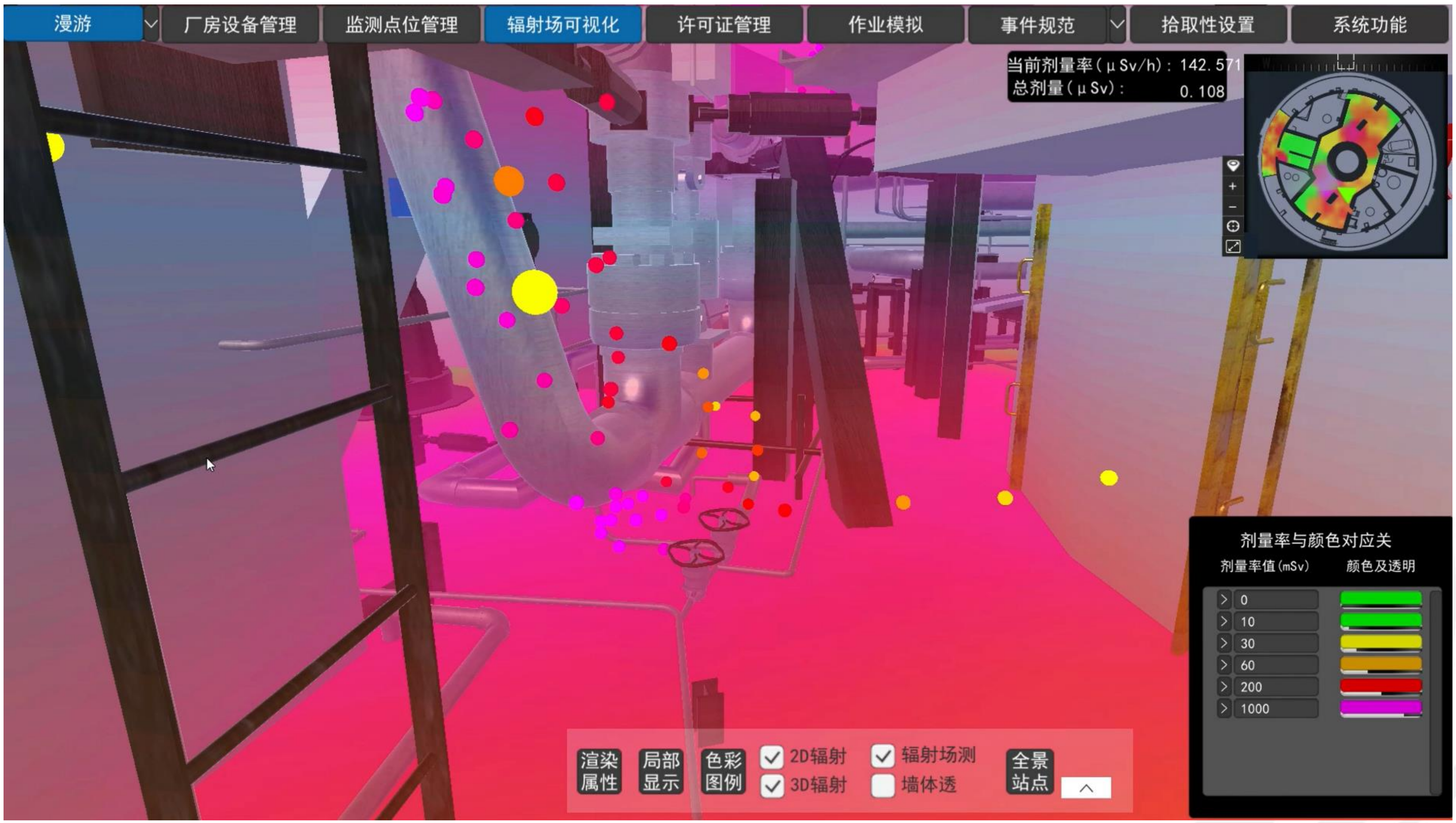
$$P_0 = \begin{bmatrix} X_p \\ Y_p \\ Z_p \\ 1 \end{bmatrix} = \begin{bmatrix} | & | & | & O_X \\ X_c & Y_c & Z_c & O_Y \\ | & | & | & O_Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ 1 \end{bmatrix}$$

The coordinate transformation matrix, from total station coordinate system to world coordinate system

2. 3D radiation field measurement technology

Through this measurement method, abundant spatial dose rate measurement data can be obtained.

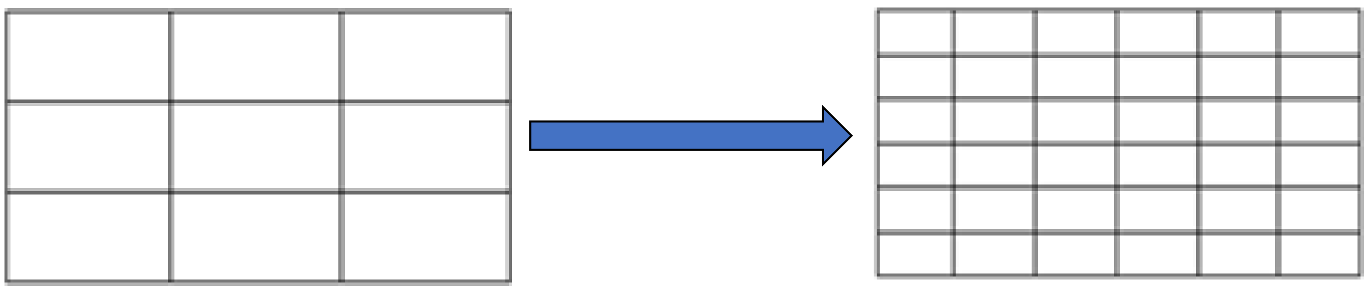
Then we can use some algorithm to convert these data into 3D radiation field.



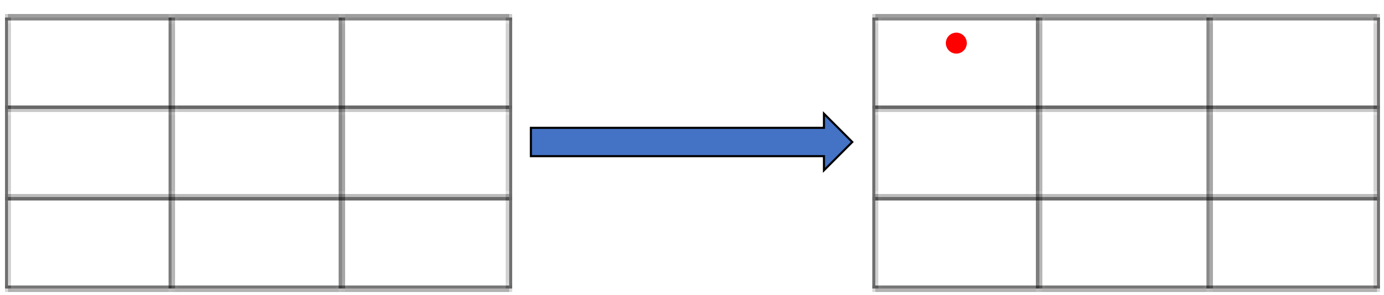
3. Interpolation method

- Why do we need to perform interpolation of dose-rate dataset?

- To obtain a good visualization performance



- To predict the dose-rate value at the un-measured position (then, to calculate the trajectory dose)

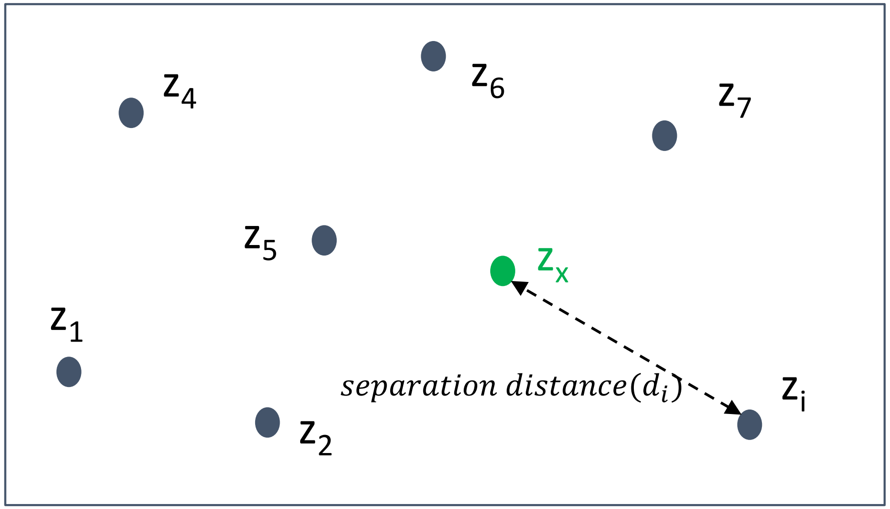


Interpolation method

- The locations of measured data are usually not so regular, even randomly distributed in the 2D(X-Y) or 3D(X-Y-Z) space.

- How to predict the value Z at position x?.

Three interpolation methods have been studied, i.e., Linear, IDW, and Kriging.



$$z(x) = \sum_{i=1}^{n} \lambda_i \cdot z(x_i)$$

where,

z(x) is the predicted value at position x,

λ_i is the weighting factor,

$z(x_i)$ is the measured (experimental) value at position x_i.

Interpolation method: IDW

- The first law of Geography
  - "Everything is usually related to all else but those which are near to each other are more related when compared to those that are further away" (Waldo Tobler,1970).
- IDW (Inverse Distance Weighted) method

$$z(x) = \sum_{i=1}^{n} \lambda_i \cdot z(x_i)$$

$$\lambda_i = d_i^{-\alpha} \Big/ \sum_{i=1}^{n} d_i^{-\alpha}$$

where,

d_i is the distance between x_i and x,

α is the power order, usually 1~3,

but not larger than 30.

- IDW is a deterministic method
  - Simple and straight forward;
  - Fast calculation speed

Interpolation method: Kriging

- Kriging method is a **statistic** interpolation method originally used in geostatistical field, which was founded by Danie Krige and Georges Matheron in 1960s.

- Under suitable assumptions on the priors, Kriging gives the best unbiased estimation of the unknown value, it can also gives the statistic uncertainty of the prediction value.

$$\hat{z}_{\mathrm{x}} = \sum_{i=1}^{n} \lambda_i z_i$$

$$\min_{\lambda_i} Var(\hat{z}_{\mathrm{x}} - z_{\mathrm{x}})$$

(best estimation)

$$E(\hat{z}_{\mathrm{x}} - z_{\mathrm{x}}) = 0$$

(un-biased)

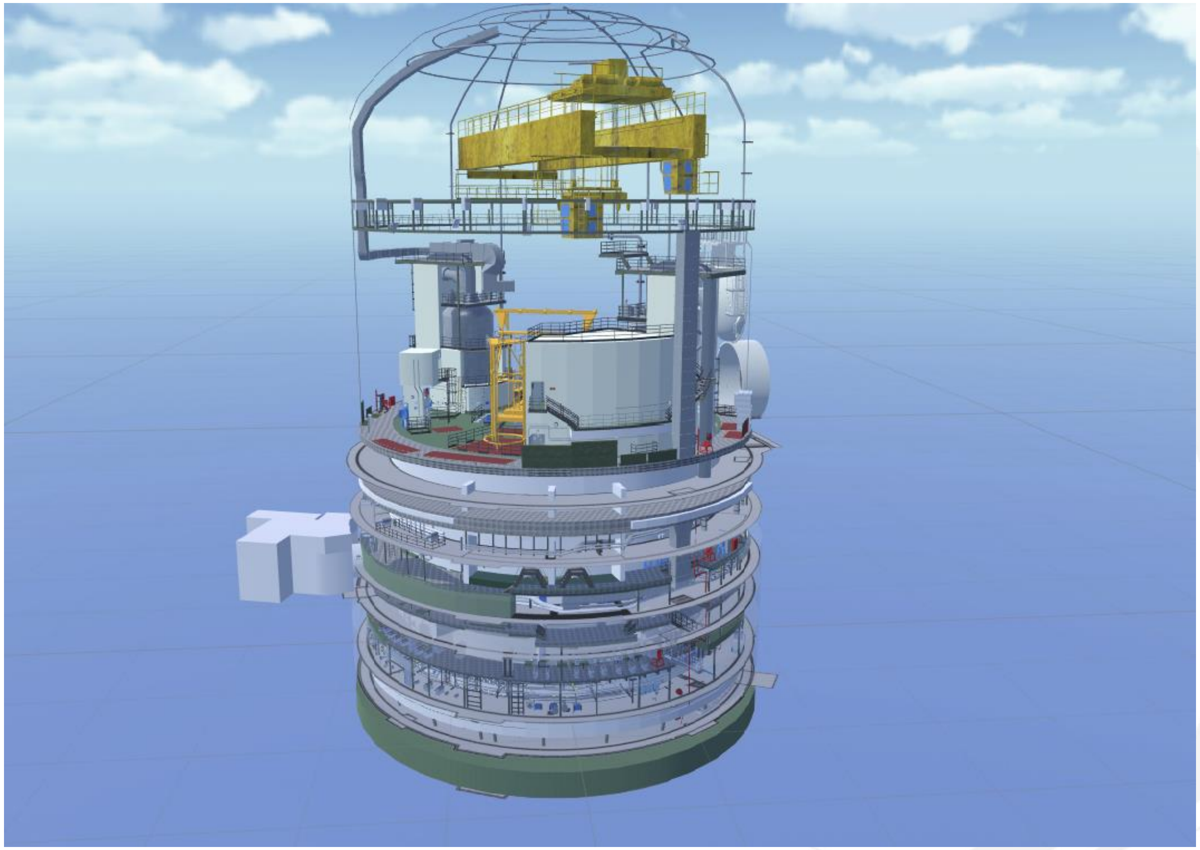
There are several Kriging methods on different assumptions: Simple Kriging, Ordinary Kriging, Universal Kriging, etc.

Discussions

- IDW: Acceptable for most radiation field, though not so good.
  - Deterministic method, Simple and straight forward, always obtain the same value as measured value at the measurement position.
  - However, the selection of α value is **arbitrary**. "Bull-eye" effect would be observed for clustering data (so it is better to use IDW for regular measured dataset).
  - It only take into account the distance information between estimate position and experimental position.
- Kriging: More suitable for most radiation field
  - It takes advantage of the distance-spectrum of all experimental data, and assigns weights according to a (moderately) **data-driven weighting function**, rather than an arbitrary weighting function (as that in IDW method).
  - Variogram is a quantitative descriptive statistic which characterizes the **spatial continuity (i.e. roughness)** of the dataset (from Golden's variogram-tutorial).
  - **More smoothing**! (thanks to the regression process of Variogram curve)
  - Helps to compensate for the effects of **data clustering** (i.e., treating clusters more like single points), which IDW can not do!
  - Time-consuming and complex calculation process (commercial software)
  - Usually, the calculated value at the measured position is not same as the measured value, due to its statistic characteristic.

4. Preliminary application

- Based on the visualization technology, a preliminary application study was carried out, jointly with the company CNNC Nuclear Power Operations Management Co., Ltd., . The objects of the test are the reactor building and auxiliary building of unit 1, phase 2.

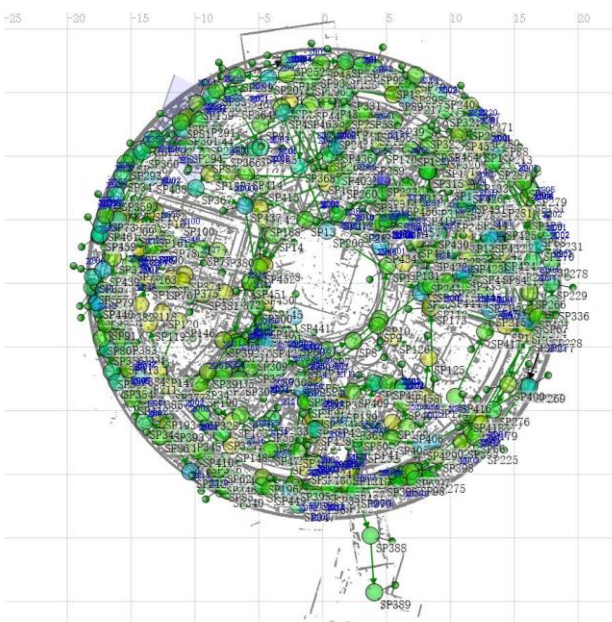


Progress in Radiation Field Measurement

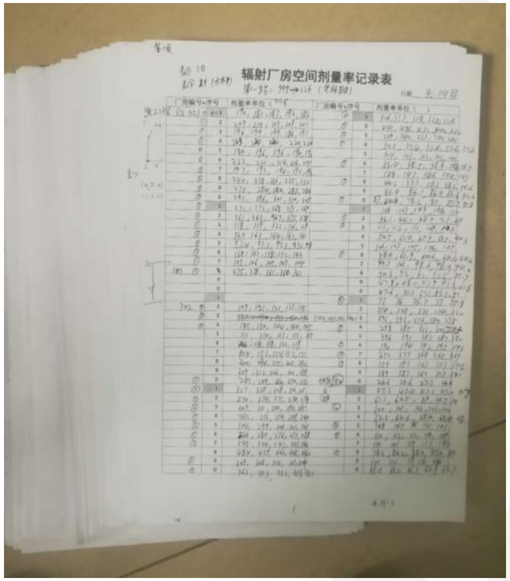
工作进展

In 1RX reactor building:

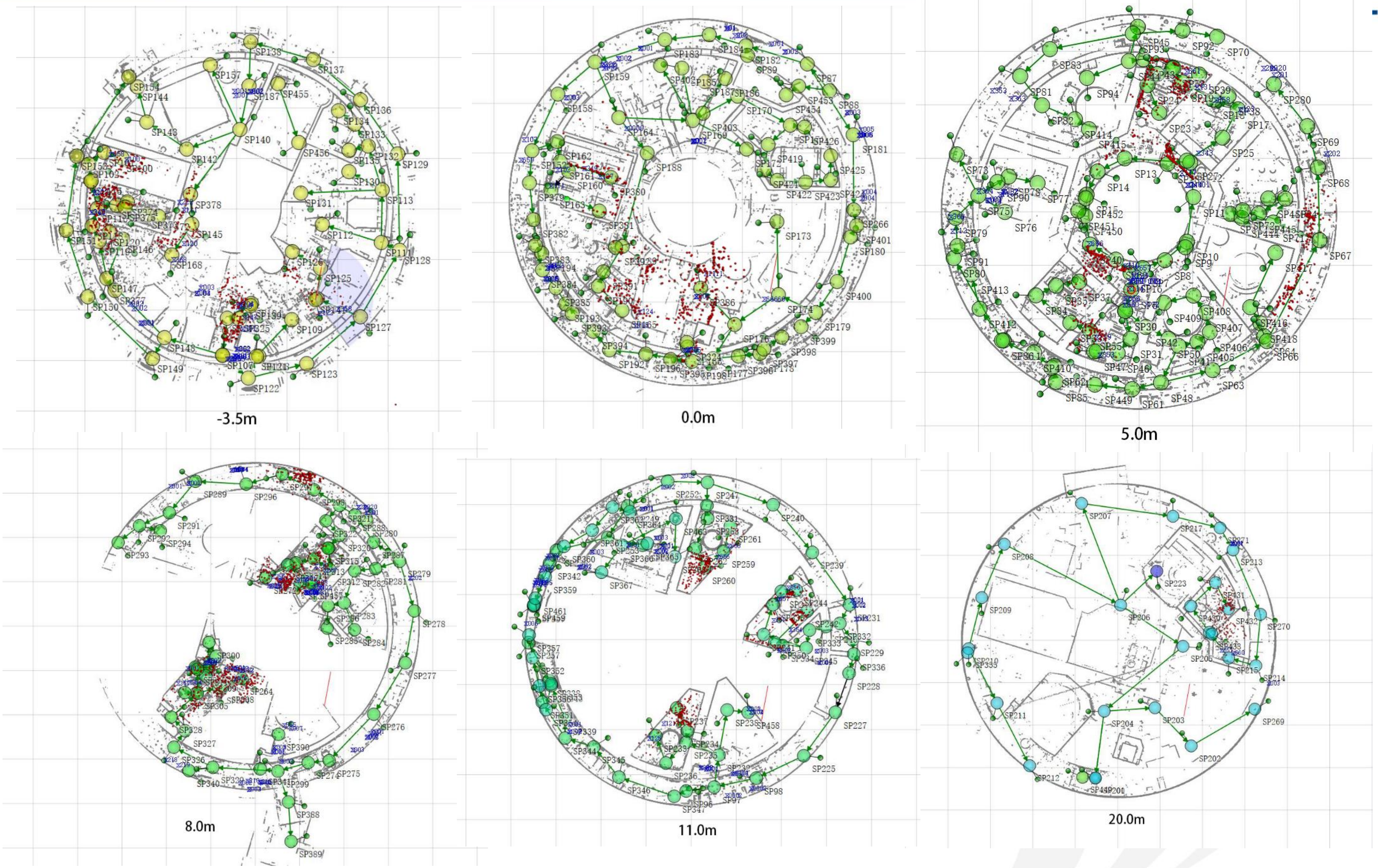
- 451 effective scanning station,
- more than 70 GB point cloud data ,
- 4033 dose rate measuring points.
- 35 space radiation fields has been obtained.



451 effective scanning points



4033 measuring points



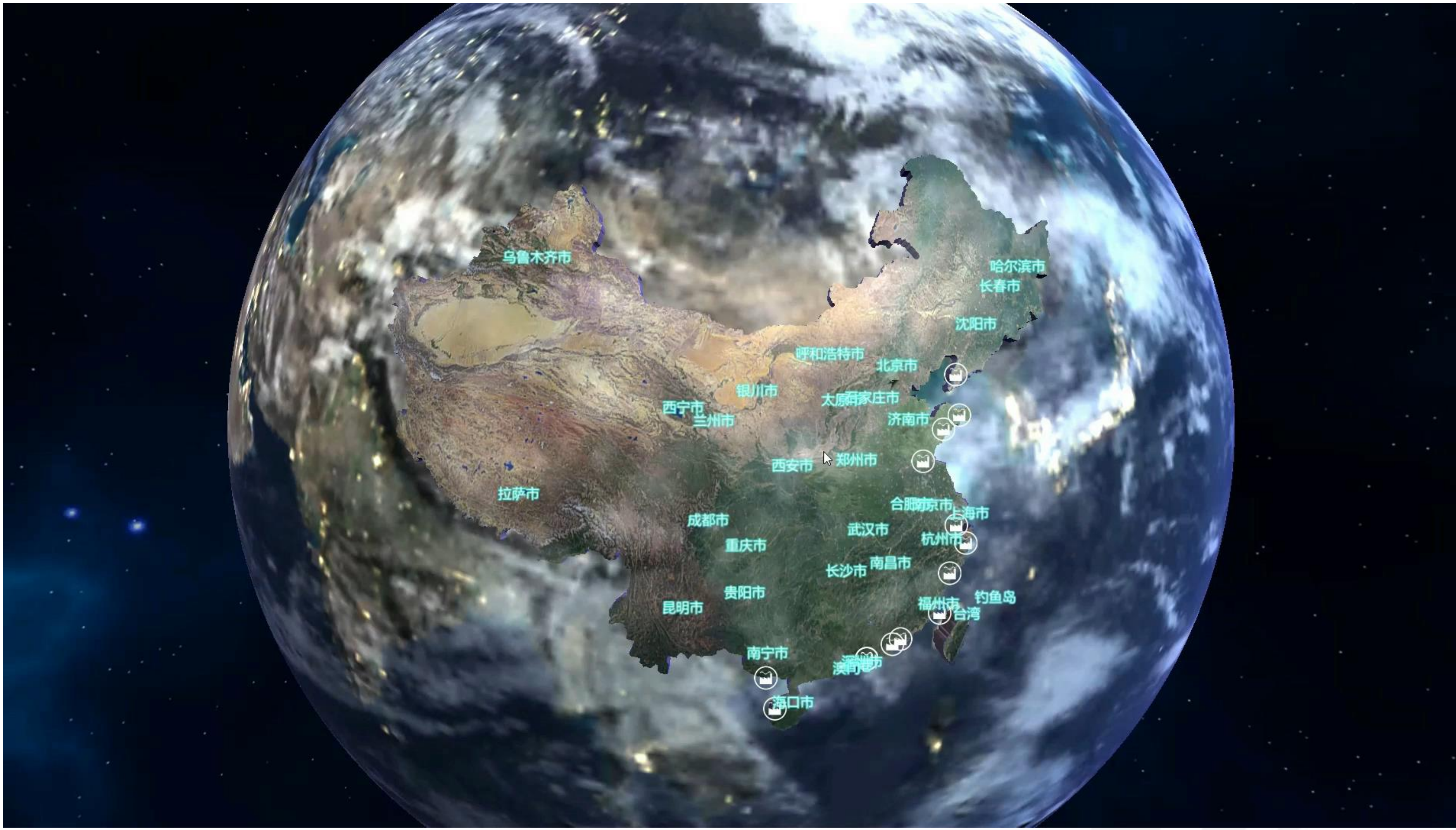
451 effective scanning points (balls) and 4033 measuring points (in red points)

The 3D visualization platform contains:

- an overall three-dimensional display module,
- a plant equipment management module,
- a dynamic plan diagram module,
- a radiation work permit (RWP) display module,
- a radiation field visualization module,
- a radiation field calculation module,
- a radiation safety identification management module,
- a high-risk radiation work dose pre-assessment module,
- a user and system management module,
- etc.

Results

Roaming Equipment management Monitoring point management Radiation field visualization RWP management Job simulation

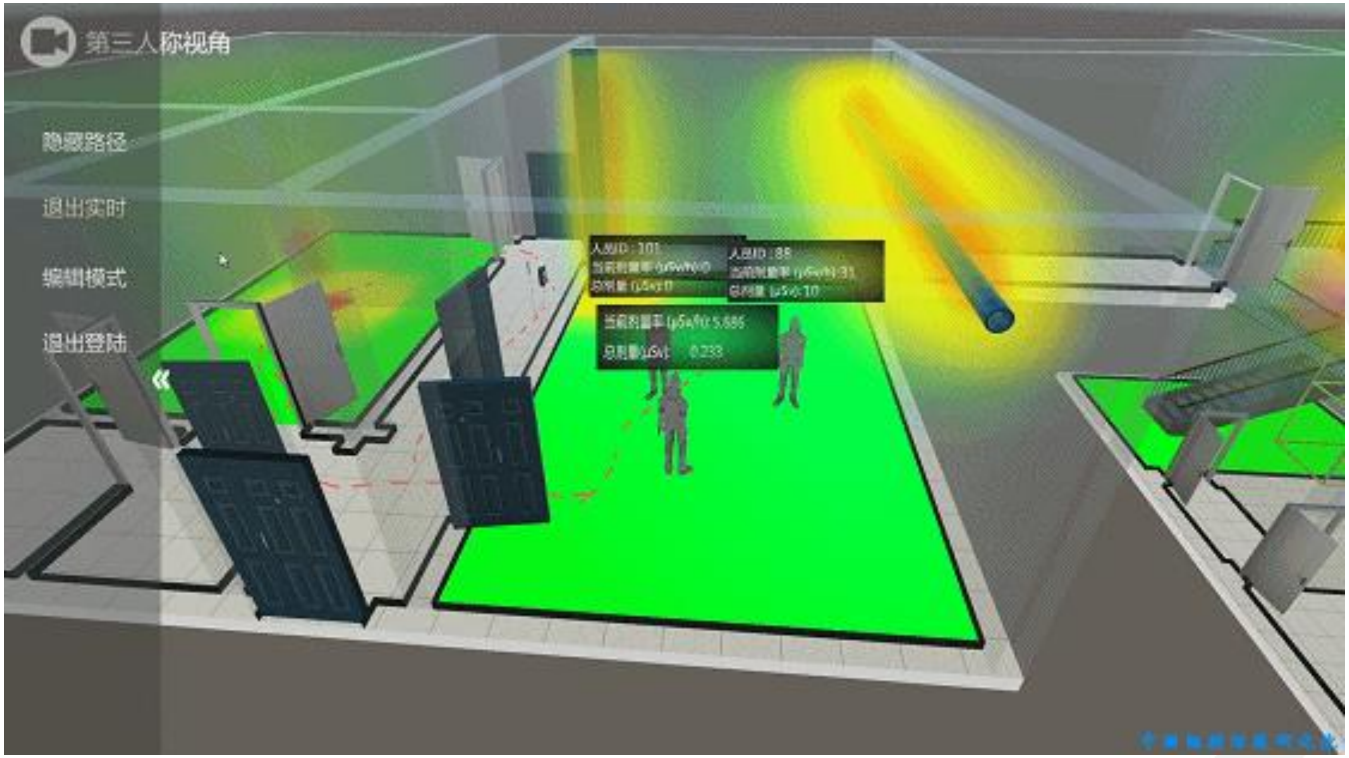


The next researches will be:

- The radiation field calculation technology based on source term distribution;
- A method for correcting radiation field by using characteristic points;
- more convenient radiation field measurement technology.

Remote monitoring

- Remote ***personal radiation monitoring***.
  - Using Wireless Indoor Locating Electronic Personal Dosimeter (WIL-EPD).
  - The position, local dose rate and accumulated dose of the workers are monitored.



THANK YOU FOR LISTENING!

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Discussions

- General knowledge of interpolation (from Geoff Bohling lecture)
  - All interpolation algorithms estimate the value at a given location as a weighted sum of data values at surrounding locations. Almost all assign weights according to functions that give a decreasing weight with increasing separation distance.
  - Different interpolation algorithm usually will give very similar results to others in many cases, in particular:
    - If the data locations are fairly dense and uniformly distributed throughout the study area, you will get fairly good estimates regardless of interpolation algorithm.
    - If the data locations fall in a few clusters with large gaps in between, you will get unreliable estimates regardless of interpolation algorithm.
    - Almost all interpolation algorithms will underestimate the highs and overestimate the lows; this is inherent to averaging and if an interpolation algorithm didn't average we wouldn't consider it reasonable.