Nuclear Power Plant Digital Twinning for Efficient Operation

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As a subsidiary company of CNNC, RINPO is dedicated to providing full scope field services and engineering services throughout the lifecycle of nuclear power plants.

Catalog

Part 1

Status and Trend of Simulation Technology

Simulation technology has been deeply applied and have different stages

1979

Meth model and code, for NPP R&D.

1986

Three Mile Island accident

After the Three Mile Island accident, the full scope simulator（FSS）has become an important part of nuclear safety supervision.

Full scope Simulator

2000

After 2000, designing of new NPP has adopted simulation verification to improve the design quality and efficiency.

Design V&V Simulator

2011

Fukushima accident

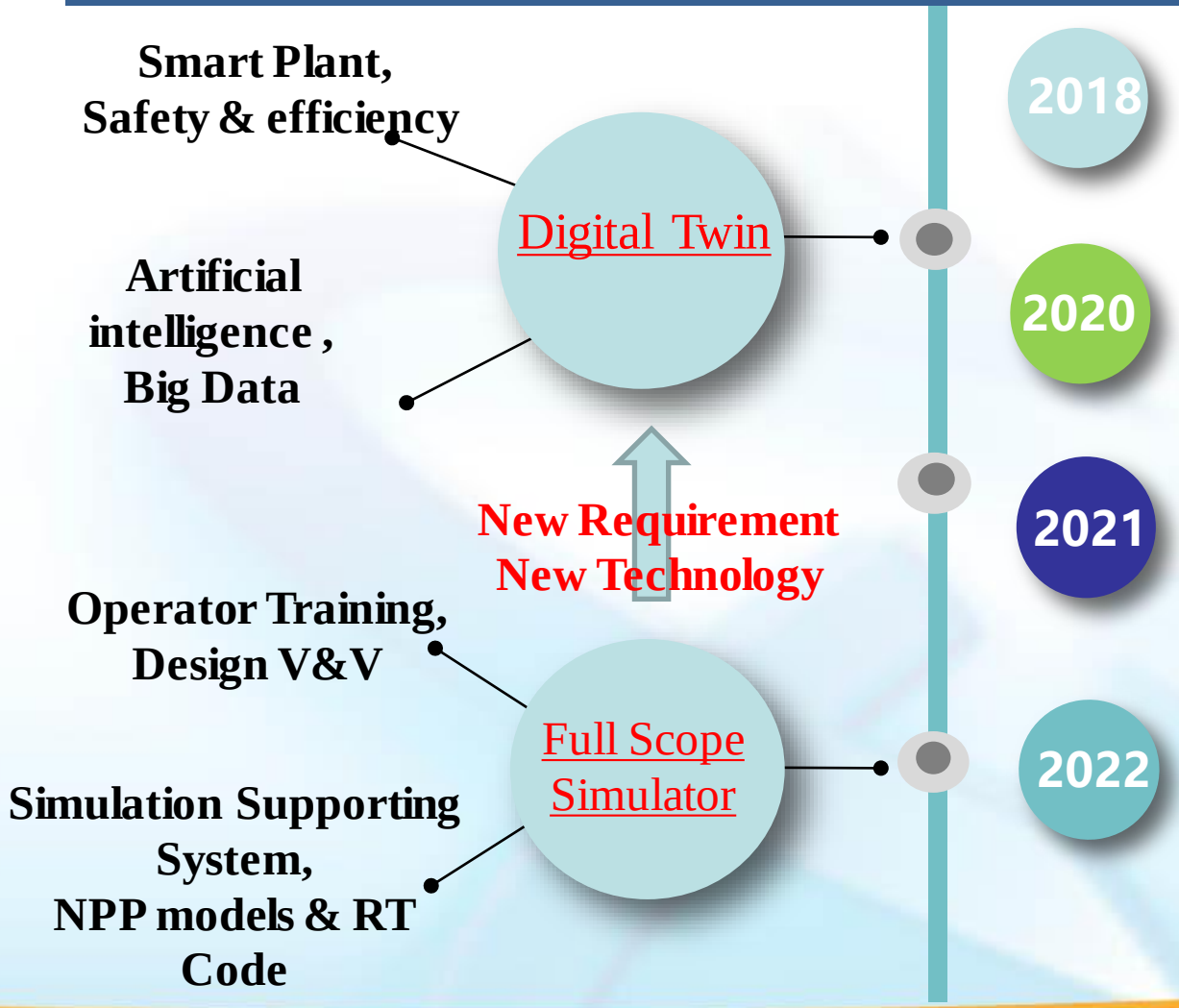
After the Fukushima accident, the severe accident simulator was used for safety management and emergency support at nuclear power plant（NPP）.

Severe Accident Simulator

2018

Digital Twin of NPP based on simulation technology has become a new frontier technology in the research of NPP.

Digital Twin of NPP based on simulation technology has become a new frontier technology



2018

the Institute of Nuclear Power Operation（RINPO）.
R&D on key technologies of operational digital twin for NPP , mainly addressing online simulation, data assimilation between simulator and unit, and artificial intelligence engine, etc.

2020

EDF, CAE and other institutions of FRANCE launched the PSPC Project, which will provide digital twin systems for nuclear reactor units for verification of changes in in-service NPP, training of operators, and evaluation of scenarios outside daily operation.

2021

the US DoE released GEMINA (Generating Electricity Managed by Intelligent Nuclear Assets) program to promote the development of next-generation advanced reactor digital twin technology. Enhance the operation and maintenance capabilities of NPP.

2022

IAEA Workshop, consideration & attention for DT by fusion power industry.

Part 2

Full Scope Simulator (FSS), Capability and Application

FSS General

"Nuclear Power Plant Simulator for Use in Operator Training and Examination"

ANSI/ANS- 3.5-2009, USA

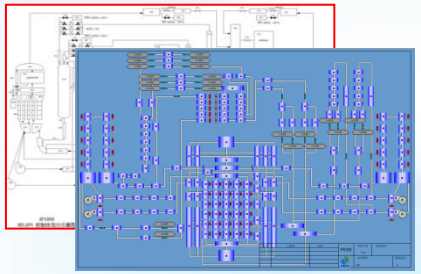
NB/T 20015-2010, CHINA

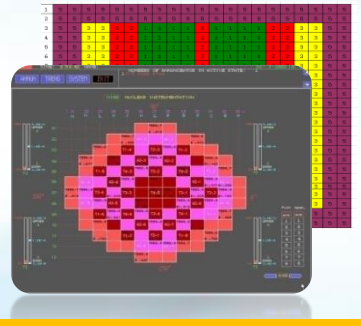
- Completely replicates the equipment in the NPP MCR, comprehensively simulates the systems and working conditions of a power unit.
- It can simulate the normal, abnormal and accident conditions without switching the models. The accident conditions include the beyond design basis accident and the severe accident.
- The simulation model cover the process of NPP start-stop, power operation and fault transient. includes primary thermal hydraulic, reactor physics, process fluid network, I&C, power distribution and other systems, as well as pumps, valves, fans, steam turbines, heat exchange equipment, etc.
- Capable of achieving the operation effects as the MCR in a real NPP. Used for pre-job training, license examination and on-the-job training for the MCR operators.

FSS Modeling with High Accuracy & Fidality

Multiple solutions for thermal hydraulic simulation model with highly secured accuracy.

PANTHER	3D with six equation, two phase, system grade
SimTherm	Thermal code with 5 equation two-phase, system grade





Two-group 3D reactor core physical real-time simulation SW which aims at square fuel assembly of pressurized water reactor and is based on advanced nodal method

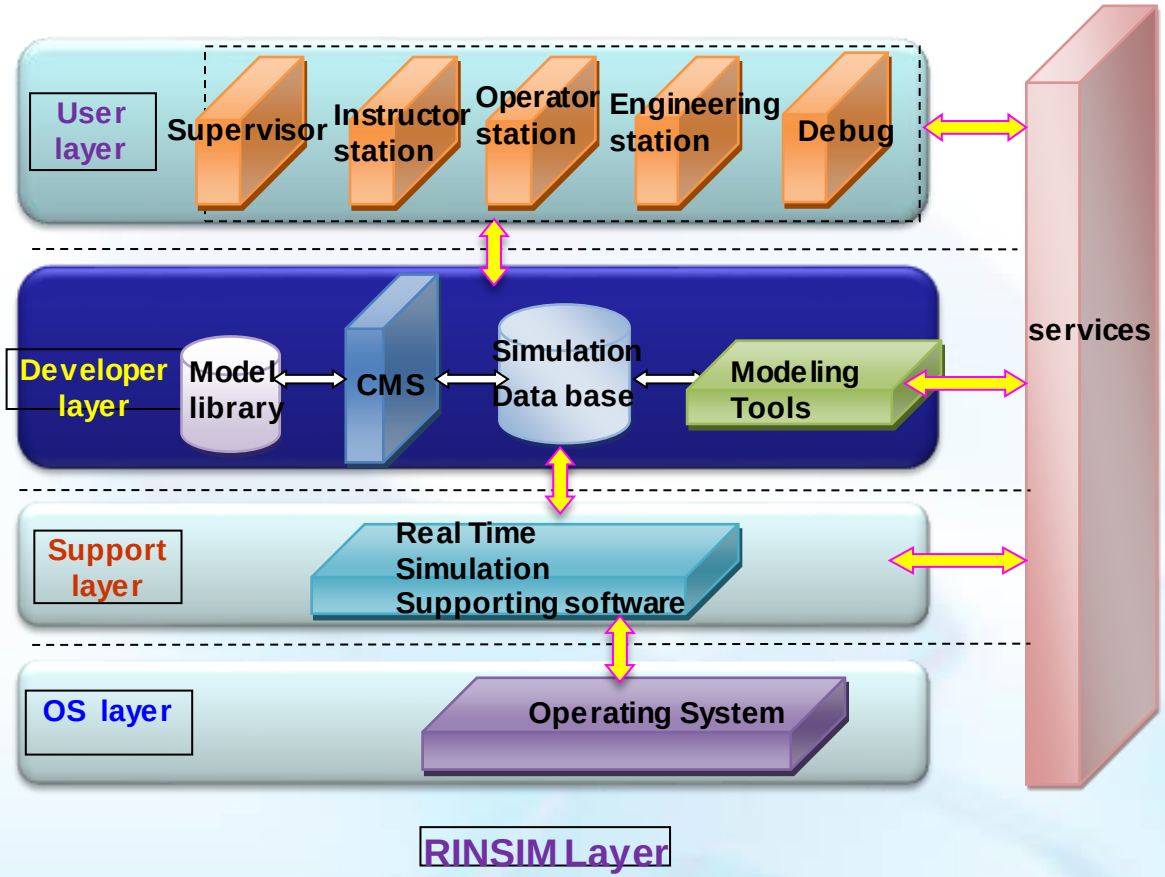
SimRAN	Advanced nodal method
SimCore	Two-group 3D reactor core physical real-time simulation SW

The simulation model has achieved high accuracy after multi reactor-year verification. At the same time, it needs to meet the requirements of real-time simulation.

Base on the design data (including the system design manuals, technical manuals, safety analysis, equipment technical document, control room plate materials, etc.) , and updates according to the actual data of a unit commissioning, operation . It has the ability to keep consistent with the object unit.

For example, the accuracy of the real-time simulation model of the reactor core physics and the primary thermal hydraulic simulation model is comparable to that of the core design program (e.g., Simulator-3) and the best estimation program for the reactor thermal hydraulic analysis (e.g., RELAP5).

FSS Simulation Platform SW



RINSIM is a Linux/Windows-based, object-oriented, fully graphical and entirely integrated environment for simulation.

Whole life cycle supporting.
Real time simulation environment .
Multi-user developing workspace .
Global share database and management.
Configuration management CMS .

FSS is also used in the verification of engineering, etc.

Latest engineering support in NPP operation

No.	Unit/Company	purpose	Event
1	Unit 3 , HNNPC	Design change	Evaluate the necessity of adding auxiliary electric heater during first-time primary loop heating.
2	FangJiaShan Unit 1, CNNO	Control scheme optimization	Verification for Control scheme optimization for double CP offline event
3	Full scope simulator, FQNPC	Operating procedure optimizing	Operating procedure executed abnormally during the examination on FSS.
4	Unit 1&2 , HNNPC	Technical transformation	Technical transformation Verification for rod control system.
5	Unit 2, Karachi	Technical transformation	Technical transformation Verification for DCS configuration.

HuaLong NPP Engineering Design V&V

1）Control logics；

2）DCS HMI ;

3）Operation procedure for alarm response, EOP, etc.

4) Control scheme.

FSS deficient for participate in control and regulation of a NPP

Operation State

Real Plant

uncertainty

≠

FSS

Real time synchronization

model accuracy has a ceiling

1) It cannot always keep consistent with the operating state of the unit. After simulator update, its state may gradually deviate from the actual state of the real NPP.

2) Although the simulation model adopts the mechanism algorithm and has been widely verified, there are still uncertainties. The mechanism of models is complex and needs to meet various simulation conditions. Limited by the theoretical development of fluid, heat transfer, numerical calculation and other related disciplines, the accuracy of the simulation model has a ceiling.

3) More complex simulation calculation can't get the optimal solution of the whole system, and it takes a lot of time to get the result, losing the real-time support capability.

Part 3

Digital Twin (DT), Principle, Key Tech., Scene

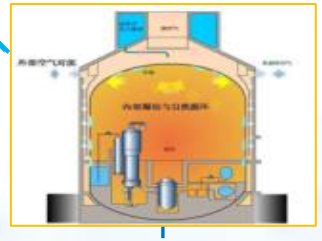
DT Status, Principle

Real Plant

Data processing & rapid initializing

Intelligent methods assimilating models to achieve high accuracy

NPP DT



Online intelligent analysis, diagnostic , predication, control

The development of digital twin is more mature in the field of intelligent manufacturing.

In the field of energy, it has more application in the operation and management of power grid.
On the power plant field, thermal power plants have some applications based on digital twin, but they are limited to local functions.

In the field of nuclear energy, digital twin is regarded as the key to solve the intelligent operation and maintenance of NPP.

NPP digital twin(DT) is based on FSS technology. The basic principle of NPP DT is accessing the real operation data of the reference unit to validate and optimize the FSS models. DT and reference unit has the same engineering data, the same initial condition, the same operation, and the same response.

In turn, intelligent applications can be developed based on the model system to support the operation, maintenance, management and technical transformation of NPP.

DT Characteristics, Capability

DATA

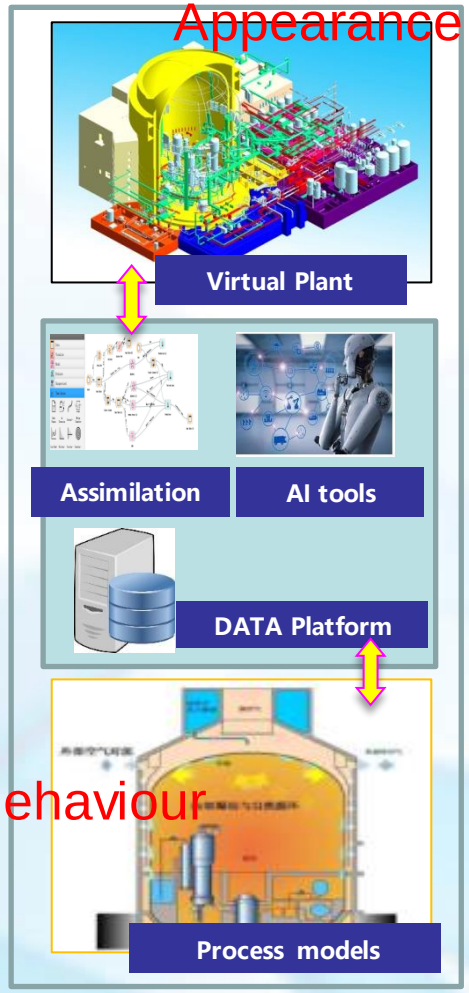
Guidance

Real Plant

DT is more "like" the actual unit than the FSS .

For DT, the uncertainty between the FSS and the actual unit is eliminated to the greatest extent.

It's possible to conduct intelligent operation analysis, diagnosis, prediction and even control of NPP through DT.



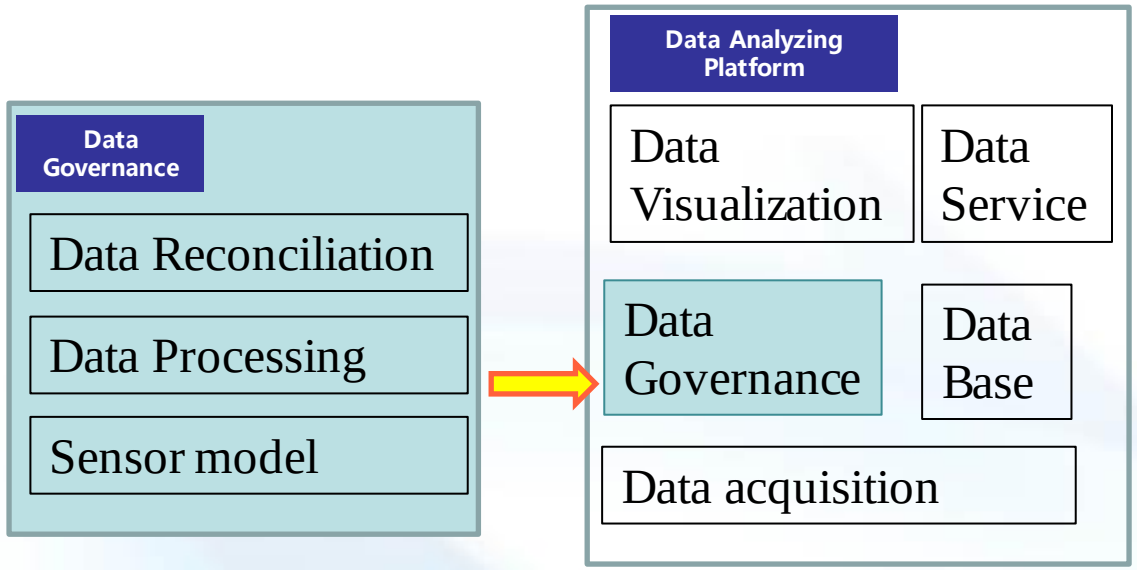
NPP DT

DT adopts unit operation data and online operation mode, which can track unit status in real time. The operation data includes the measurement point data and the operation data.

DT also utilizes the historical data of the unit to continuously optimize the simulation model by big data technique and artificial intelligence methods.

Therefore, DT has intelligent characteristics such as self-synchronization, self-tracking, self-learning, self-optimization, etc.

DT Key Tech.



ISO 23247 series ," Automation systems and integration — Digital twin framework for manufacturing" .

VDI 2048, "Uncertainties of measurement during acceptance tests on energy conversion and power plants" .

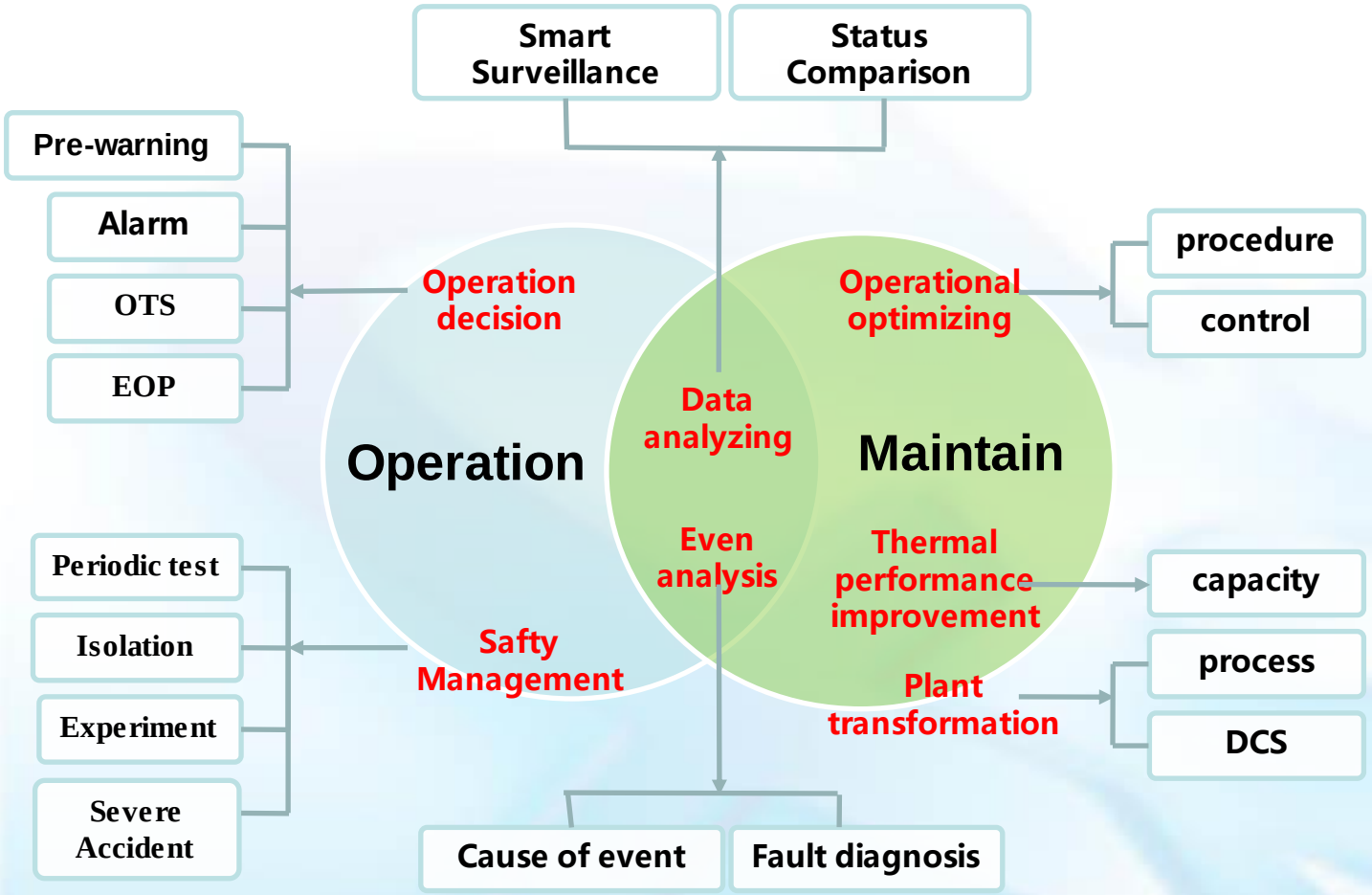
DT is the result of data assimilation between simulator and unit. The key technologies to be solved mainly include data processing, high-precision model, dedicated artificial intelligence engine , etc.

1) There is a deviation between the actual power plant measurement data and the object, in this case parameters will not meet the conservation principle, so the analysis based on the original measurement data cannot accurately reflect the real state of the power plant. Data Cleansing, Data Verification and Reconciliation (DVR) and other technologies are used to realize the coordination of the collected data and ensure the quality of the DT input data.

2) Data processing and model optimization subject to the limit of the engineering technology and scientific problems. Solving the problem of data and model is depend on artificial intelligence. For example, mechanism model combined with machine learning model can help solving the difficulties of improving DT model precision.

3) Digital twin consists of simulation platform, data acquisition and processing, artificial intelligence engine, system management, etc. It involves the collection, processing and storage of operation data, process modeling, data analysis services and other aspects. It is necessary to adopt the technical architecture of industrial Internet platform to establish the full life cycle support platform of DT.

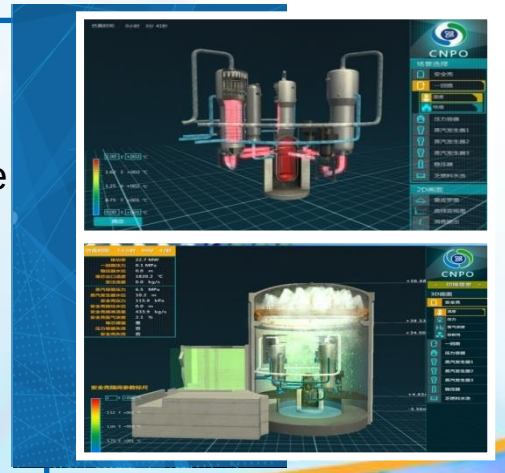
DT Application Scene



DT provides a means for realizing intelligent operation and maintenance of NPP. In the operation and management scene of NPP, DT can be used to Detect, Diagnose and Predict the operation abnormal of the units, and to verify the operation scheme under high risk conditions, such as the rapid verification of the reactivity management scheme under unexpected conditions. Digital twinning can also support verification of a unit optimization and improvement, such as unit performance analysis and power enhancement, technical transformation, developing digital intelligent operational procedures, etc.

Severe accident DT

The SA software has been integrated into the RINSIM to achieve online severe accident tracing , intervention and monitoring.



Part 4

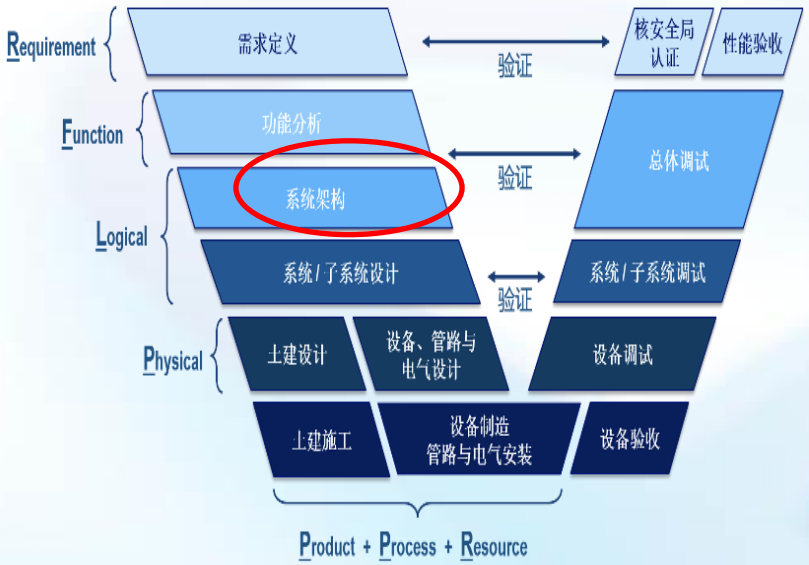
Conclusion，Suggestions

Conclusion, Suggestions

Data is the base

Model is the key

Platform is the carrier



Using Simulation Tech. to support the hole life cycle of NPP

Digital twin for NPP will become an indispensable support tool in the field of engineering design verification, operation and maintenance support, which can greatly shorten the design, development and construction time, reduce the cost, and ensure the safe and efficient operation of NPP.

To achieve Digital Twinning of NPP, the essential aspects include:

1) It is required to have high-precision simulation model, realize coupling with multi-professional and multi-domain models, and have real-time simulation capability.

2) It is necessary to solve the collection, governance and reconciliation of operation datasets to ensure the quality of input data of operation DT.

3) The operation of DT involves various data, models, tools and software, which requires the system software platform to achieve efficient management.



Thanks For Your Attention

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