원자로 자율운전을 위한 가상원자로 개발

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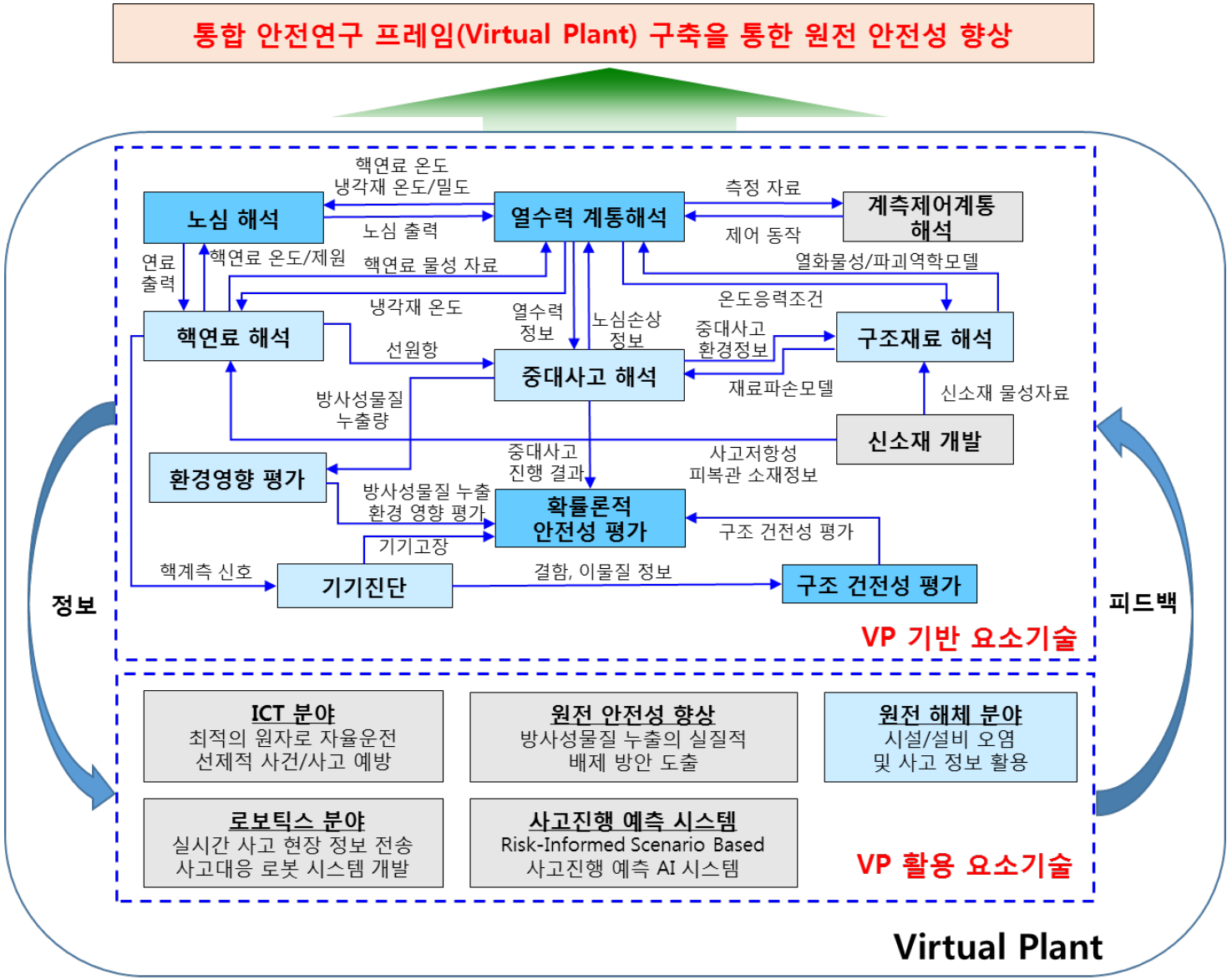
Background and Objectives

- Limitations of current analysis
  - All analysis codes for PWR were fragmented
    - ✓ Separate analysis of material, fuel, structure, thermodynamics, severe accident, probabilistic risk, environment, instrumentation and control and decommissioning
  - Not easy to integrated safety assessment of plant because each separate code can use only boundary conditions from outputs of other codes
  - Concerns of integrated safety assessment would be more important after Fukushima
- Needs for integrated assessment tool for assuring safety of plant
- Considering increase of computing power, an integrated safety assessment code(so-called virtual plant) would be possible
- Key elements of virtual plant and interface between separate code were introduced
- Application of virtual plant was introduced

Definition of Virtual Plant

- Integrated software which can analyze multi-physics model to estimate more accurate safety margin of plant
- Since each code has its own boundary conditions which come from other analysis code and can analyze specific area, uncertainty which comes from boundary conditions is larger than real physical world.
- So, safety margin is estimated lower than true value
- To overcome this disadvantages, integrated code framework of virtual plant was introduced
- Basic element of virtual plant is composed of analysis methodology, estimation technology and interface between physical models
- To maximize analysis accuracy and usability for integrated safety assessment and enhancement, basic element gives and takes real information to/from application element

Strategy for Virtual Plant Development

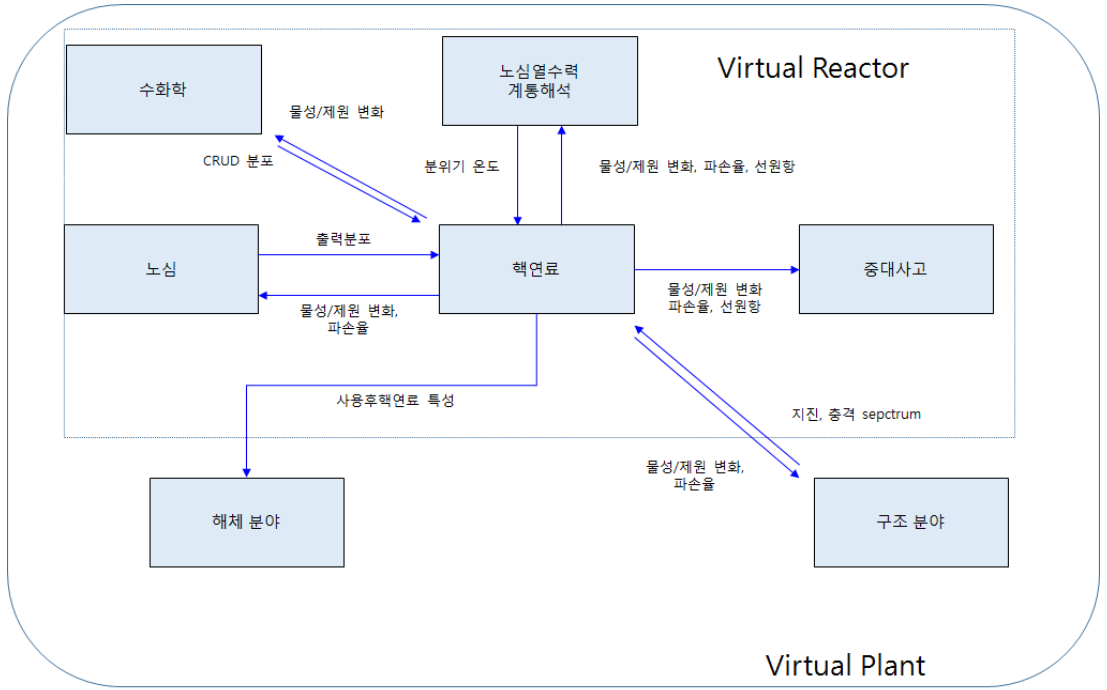


Element of Virtual Plant

- Core Technology
  - Fuel analysis
  - Material analysis
  - Thermodynamics
  - Severe accident analysis
  - Environment analysis
  - Probabilistic Safety Analysis (PSA)
- Application of virtual plant
  - Information and Communication Technology (ICT)
  - Robotics and Equipment Diagnosis
  - Decommissioning

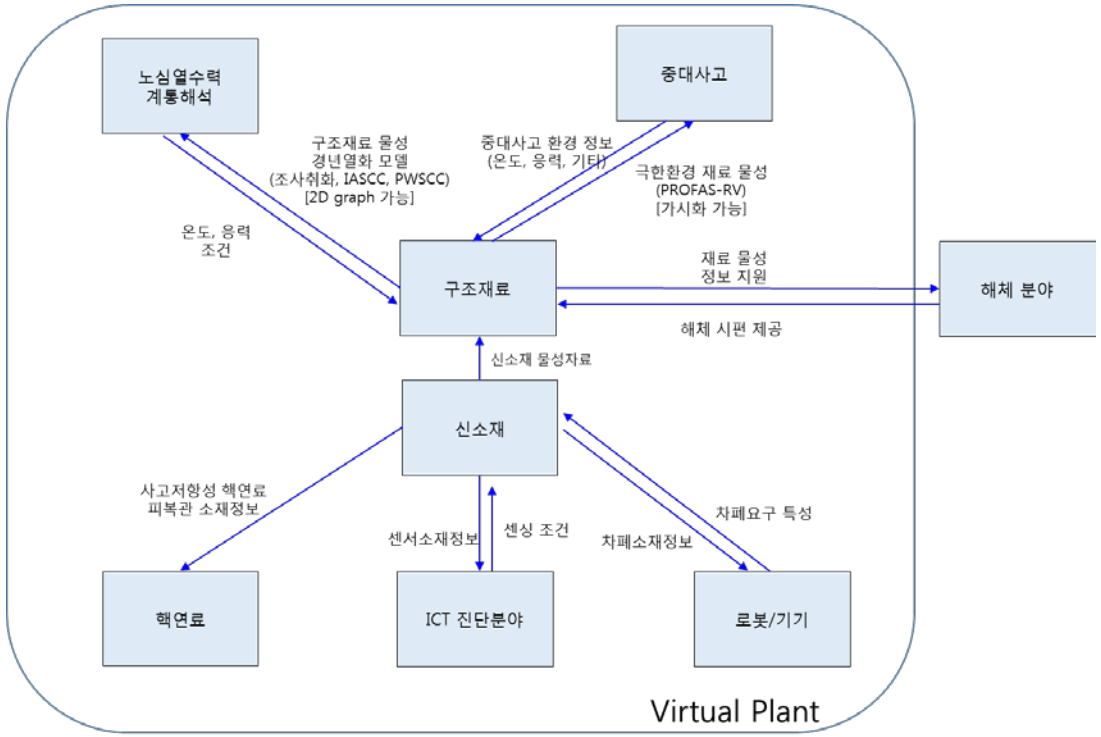
Core Technology of Fuel Analysis

- Normal operation condition
  - Clad/pellet/slug of metal fuel degradation analysis with 3-D power distribution as well as temperature and chemistry of coolant
  - Initial condition of spent fuel
- DBA condition
  - Combination of 3-D dynamics and normal analysis code is being progressed
  - Calculation of inventory of radioactive materials for severe accident analysis
- LBLOCA condition
  - Integration of thermodynamics and fuel analysis is important to analyze fuel integrity
  - Integration of core analysis and fuel analysis is important to estimate decay heat
- DEC condition
  - Similar to LBLOCA condition
  - New analysis technology in case of fuel temperature > 1204 ℃



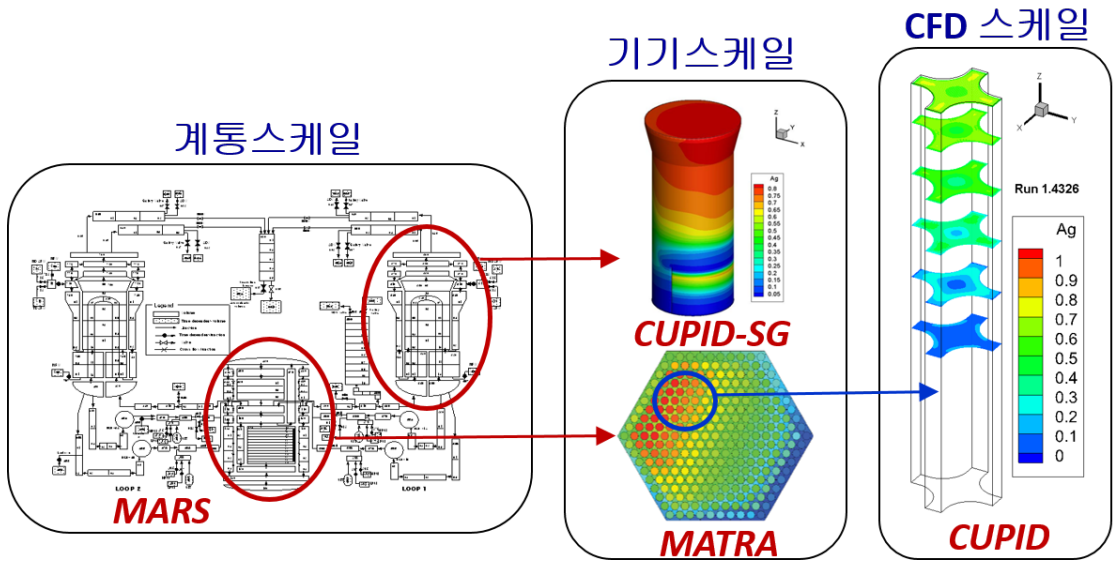
Core Technology of Material Analysis

- ASME code based
  - For safety analysis, new estimation model for impairment rate from degradation mechanism is required
- Interface with other analysis
  - Currently, only boundary conditions are given without on-line interface
  - In severe accident condition, database of material properties are very rare -> to be developed
- New material development
  - For better safety, new materials are required and being developed



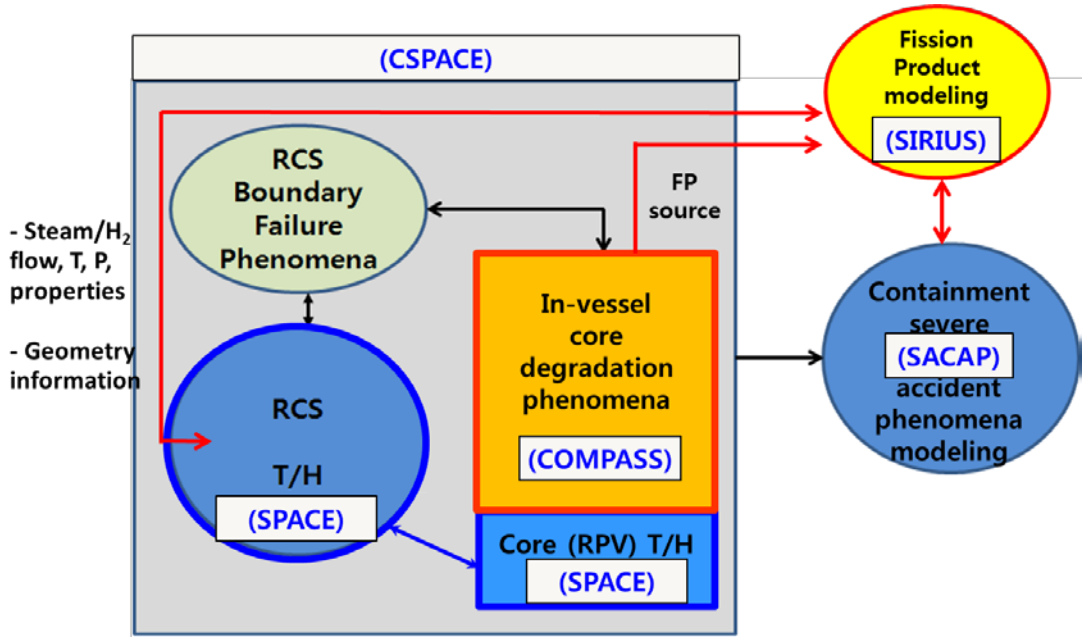
Core Technology of Thermodynamics

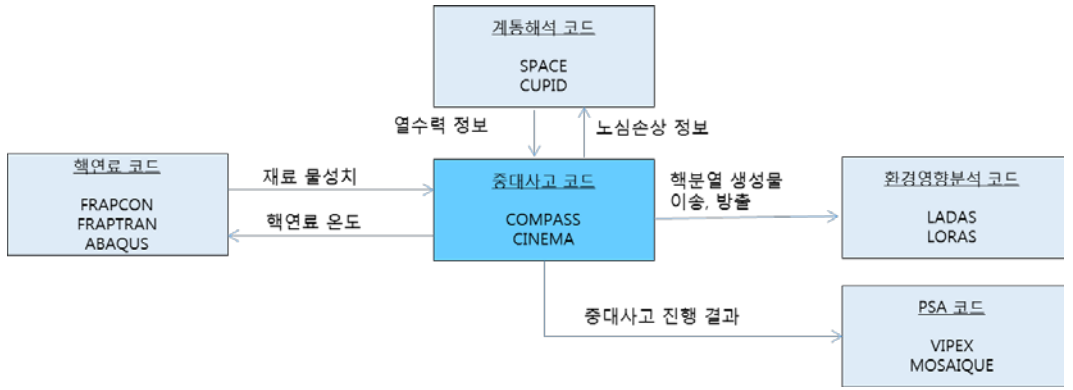
- Key element for safety analysis
  - In both normal and transient condition
  - According to mesh size, analysis of system level(~m), component level(~cm) and CFD scale(~mm) System level analysis : For considering uncertainty, conservative approach
  - Component level analysis : multi-dimensional analysis using porous media model in thermal mixing, 2ndary cooling system, inside of reactor building
  - CFD scale analysis : analyze local phenomena in limited area
    - ✓ Single phase : high accuracy
    - ✓ Two phase : limitation, systematic validation is required
  - Multi-scale methodology is being developed for higher accuracy
    - ✓ Component or CFD analysis where multi-dimensional analysis is required and system level analysis is integrated with them



Core Technology of Severe Accident Analysis

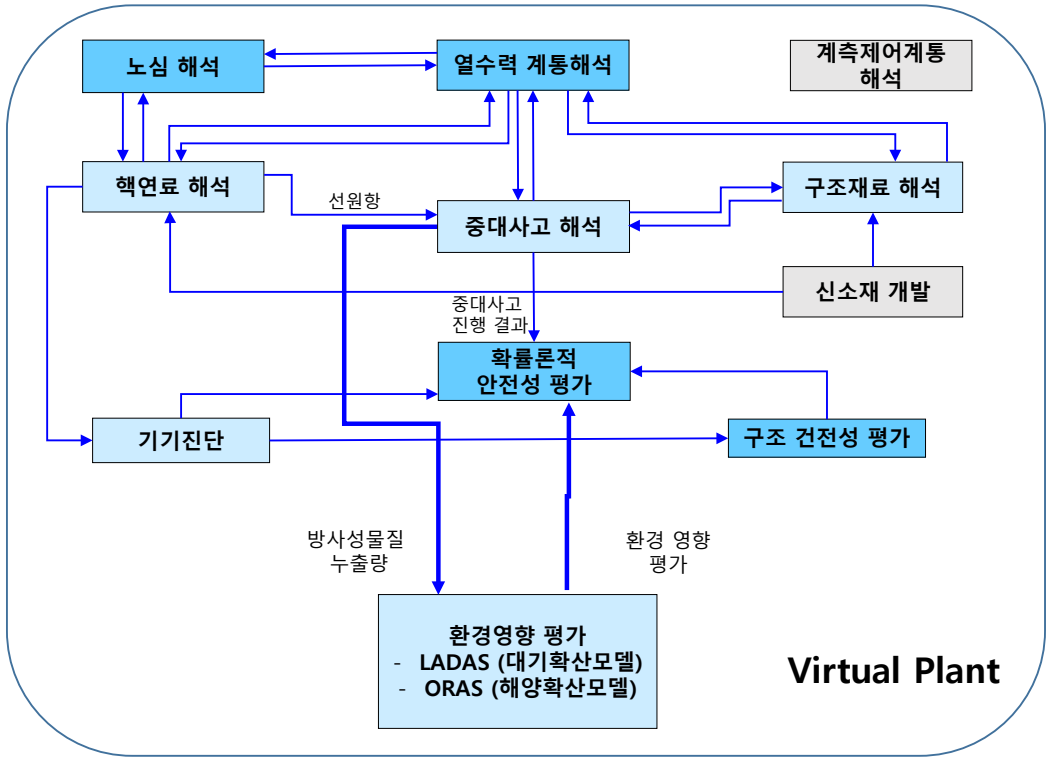
- For total risk analysis
  - CINEMA(Code for INtegrated severe accident Evaluation and MAnagement) is developed
    - ✓ Normal operation, core heating, core melt, core reconfiguration, reactor vessel break, fission product release, reaction fission product with concrete of reactor building, pressurization and damage of reactor building
    - ✓ Calculation tool with GUI for severe accident phenomena
    - ✓ COMPASS : core meltdown progress accident simulating software
    - ✓ SIRIUS : simulation of radioactive nuclide interaction under severe accident
    - ✓ SACAP : containment severe accident phenomena modeling
    - ✓ SPACE : safety analysis code
    - ✓ Interface with other codes as shown bottom figure





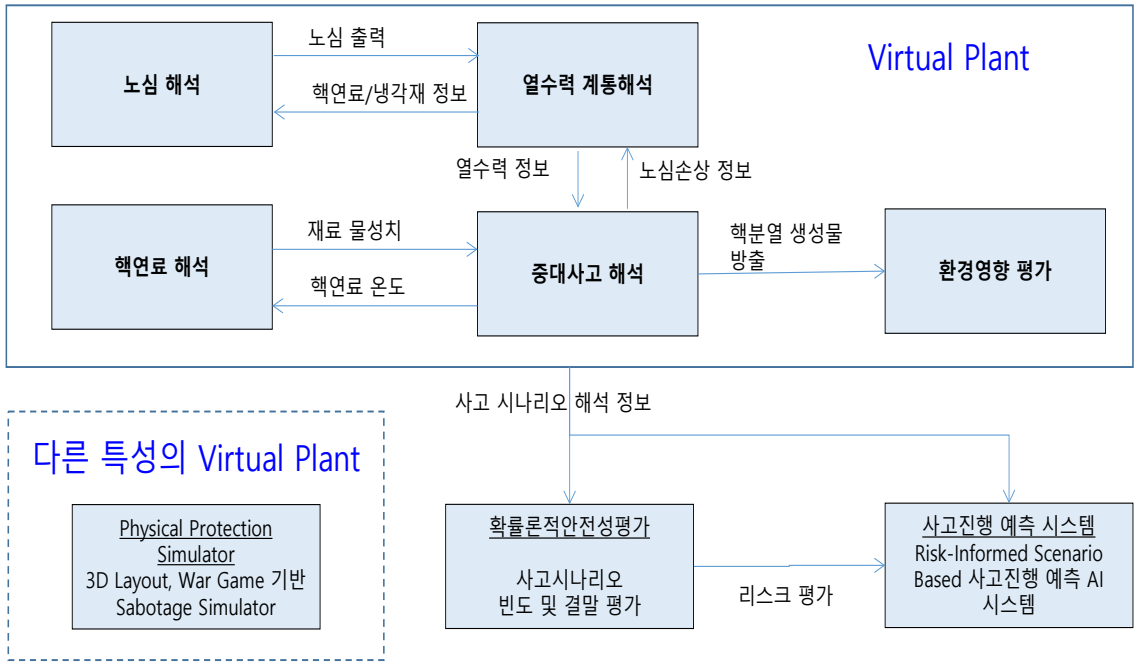
Core Technology of Environment Analysis

- Effect analysis of released radioactive material after severe accident
  - LADAS(Long-range Accident Dose Assessment System)
    - ✓ Estimation of diffusion path and prediction of time-space radioactive material distribution and dos rate in atmosphere
    - ✓ Global diffusion estimation
    - ✓ Real-time interface with weather forecasting
  - ORAS(Lagrangian Oceanic Radiological Assessment System)
    - ✓ prediction of time-space radioactive material distribution and dos rate in ocean
    - ✓ Global diffusion estimation



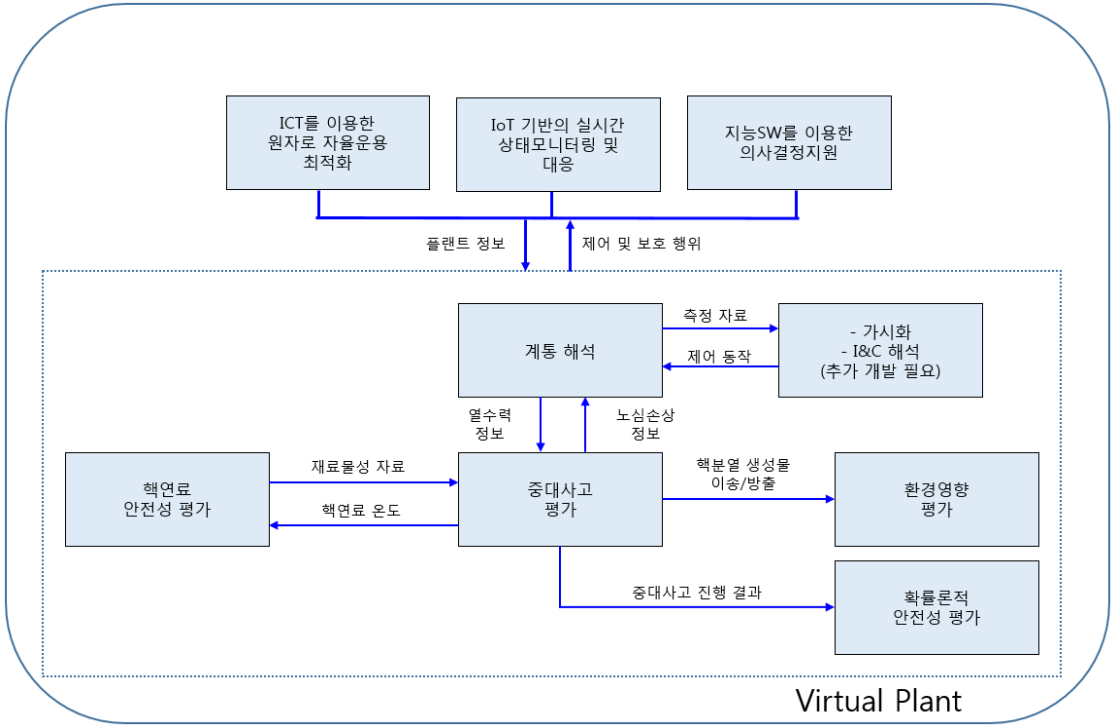
Core Technology of PSA

- Effect analysis of released radioactive material after severe accident
  - AIMS-PSA/CONPAS/FTREX
    - ✓ Introduction of accident scenario
    - ✓ Estimation of frequency and consequence



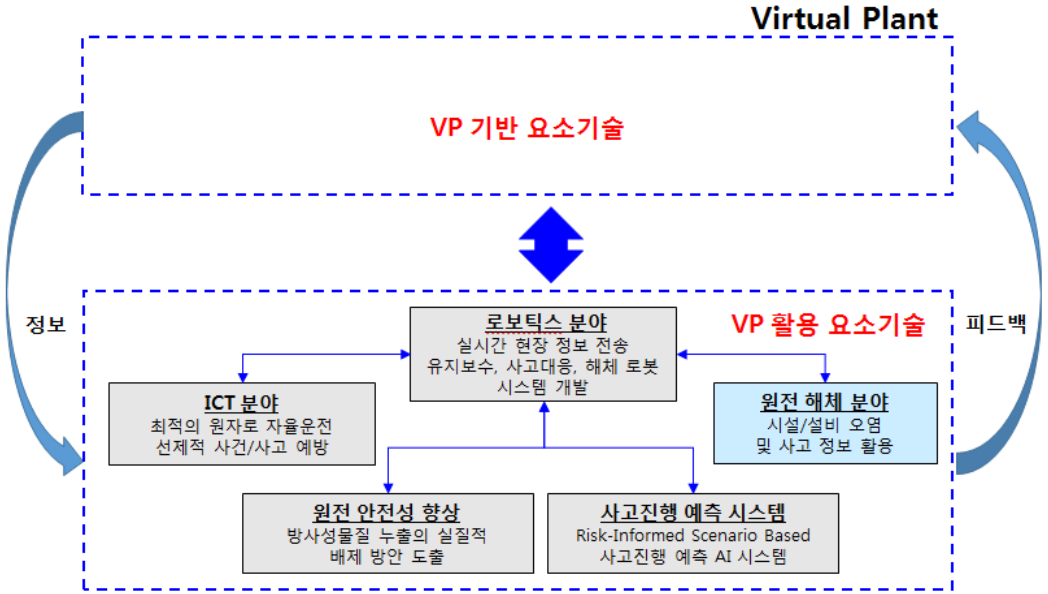
Application to ICT

- No performance or safety analysis tool of system level
- I&C dynamics analysis tool should be developed for virtual plant
  - Analyze performance and degradation of I&C systems
  - To generate big data set for diagnostics and prediction of plant behavior
  - To assist digital twin for autonomous operation
    - ✓ Digital twin : model-based, data-driven, empirical(operating history)-based
    - ✓ cf) simulator

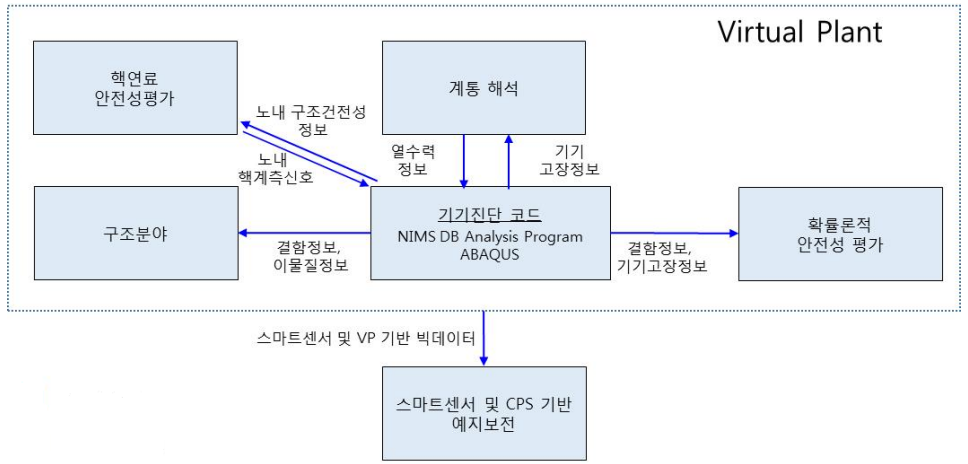


Application to Robotics and Diagnostics

- Robot Area
  - Receive field information given from virtual plant to access exact location to identify accurate status and give safety measures
  - Send real time and accurate field information to virtual operation to evaluate safety of plant condition

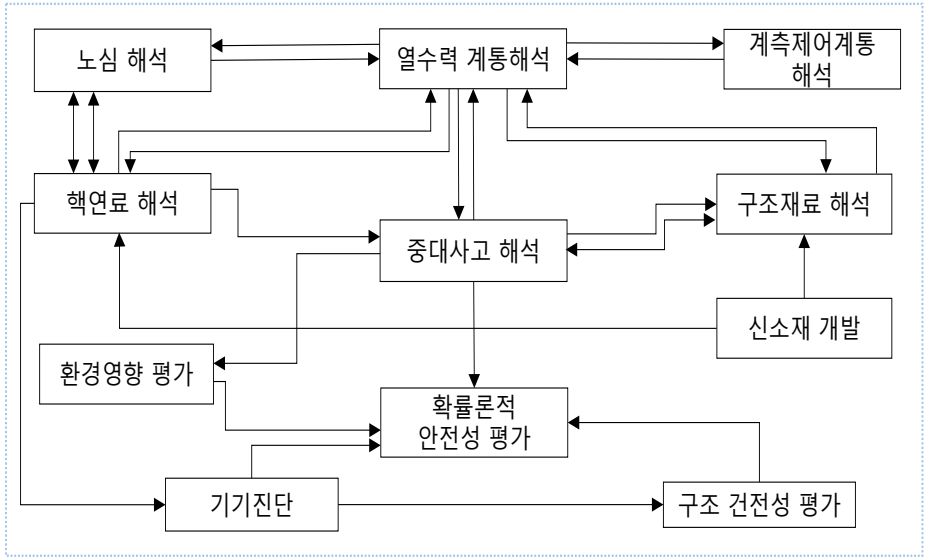


- Diagnostics
  - Give information such as fault and malfunction of equipment and foreign object to virtual plant
  - New diagnostic methodology will be developed based on virtual plant and machine learning

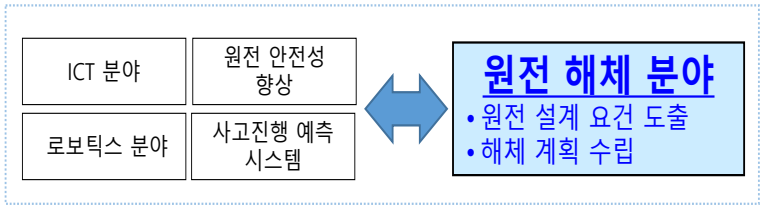


Application to Decommissioning

- Evaluation of Radioactive Characteristics
  - Information of accident and contamination are given from virtual plant is given in order to build safe and economic decommissioning plan



- 시설/설비 오염 정보
- 사고 정보



Conclusions

- Plan of virtual plant composed of multi-physics, multi-area analysis code to evaluate more realistic safety level of PWR is introduced
- Virtual plant give accurate data set to nuclear ICT, nuclear robotics and diagnostics and decommissioning
- Digital twin could be developed based on physical model, generated data set using virtual plant with empirical data
- Virtual plant will be applicable to various field in estimating safety margin, autonomous operation and diagnostics