UNIST
Ulsan National Institute of Science and Technology

원전해체 핵심 요소기술 원천기반 연구 개발 현황
(Current Status of Development of Core and Fundamental D&D Technology in UNIST)

김희령

2018. 10.24

KAERI 한국원자력연구원 DKU 단국대학교 CNU 충남대학교 CHUNGNAM NATIONAL UNIVERSITY UNIST 유니스트

Contents

Introduction

- Technology development for preparation of expansion of domestic and foreign D&D market
  - ➢ Domestic nuclear power plant (Kori # 1): before 2020, 2030 (estimated at about 10), overseas market size estimated at 0.4 trillion US$ as of 2014
- Cultivation of D&D industry, human resource training, infrastructure construction
- Development of core and elemental technology

  - D&D safety
    - D&D safety for reduction of accident and exposure by human error of works at D&D design
    - Development of D&D activity hazard estimation and reduction method to assess how much human error affects D&D safety
  - New technology and material for D&D radioactive waste treatment
    - Development of new technology for treatment of treatment-difficult waste which is not yet set up
    - Development of nano complex material and new process for treatment of treatment-difficult decontamination waste liquid including surfactant and chelating agent
    - Development of waste liquid treatment technology which self-propulsion nano/micrometer based selective nuclide removal and remote control is available
  - D&D site monitoring technology
    - Integrated in-situ beta/gamma monitoring technology for underground water of D&D site
  - Bedrock for D&D and environmental restoration industry human resources

Introduction

Project outline

- **Period : 2016. 11.30 ~ 2021. 10. 31**

	Institute	Project	Scope
General	UNIST	Source Base Research Center for the Core Elemental Technology for Decommissioning of Nuclear Power Plant	• Development of core technology for D&D safety/treatment of D&D waste/site restoration • Cultivation of D&D industrial workforce and infrastructure construction
WP1	UNIST	Development of In-situ Monitoring Technique for underground Water in D&D Site	• Development of D&D site underwater radiation measurement technology using scintillator • Beta and gamma integrated in-situ monitoring system
WP2	Dankook University	Base technology development for the decommissioning risk assessment by the probabilistic recognition method	• Development of D&D probabilistic cognitive model • Development of base technology for human error reduction
WP3	Chungnam University	Development of nanohybrid materials and processing technique for decommissioning waste that are highly difficult to treat	• Development of nano complex manufacturing technology to separate surfactant and chelating agent • Development of functional textile new material and procedure technology for nuclide removal in the decontamination waste liquid
WP4	KAERI	Development of the next generation fundamental technology for the treatment of radioactive wastes based on self-propelled micromotors	• Development of environment-friendly micromotor propellant and micromotor for selective nuclide removal • Development of technology for treatment procedure of high-salt underground water and high radioactive waste liquid using micromotor

Objective

Final goal

- **Development of original source technology for unsettled core and elementary technology in the area of D&D safety/waste treatment/site restoration**
- **Cultivation of D&D industrial workforce and construction of D&D industry infrastructure**

Base technology of underground water low level radiation monitoring in the D&D site

Integrated in-situ beta and gamma radiation monitoring technology including tritium in the underground water

D&D hazard estimation and reduction technology

D&D hazard assessment using probabilistic cognitive method and human error reduction using probabilistic calculation

Nanohybrid materials and processing technique for treatment-difficult decommissioning waste

Nano complex material and new treatment technology for the development of new absorbent on the treatment-difficult decontamination waste liquid including surfactant and chelating agency

Technology for the treatment of radioactive waste liquid based on self-propelled micromotors

Radioactive waste liquid treatment technology based on self-propelled micromotor which can propel, remove nuclides selectively, control the move and collect magnetism

Human resources and collaboration among academia and institute

R&D Contents and Scope

WP1 : Development of In-situ Monitoring Technique for Ground Water in D&D Site

WP2 : Base technology development for the decommissioning risk assessment by the probabilistic recognition method

WP3 : Development of nanohybrid materials and processing technique for decommissioning waste that are highly difficult to treat

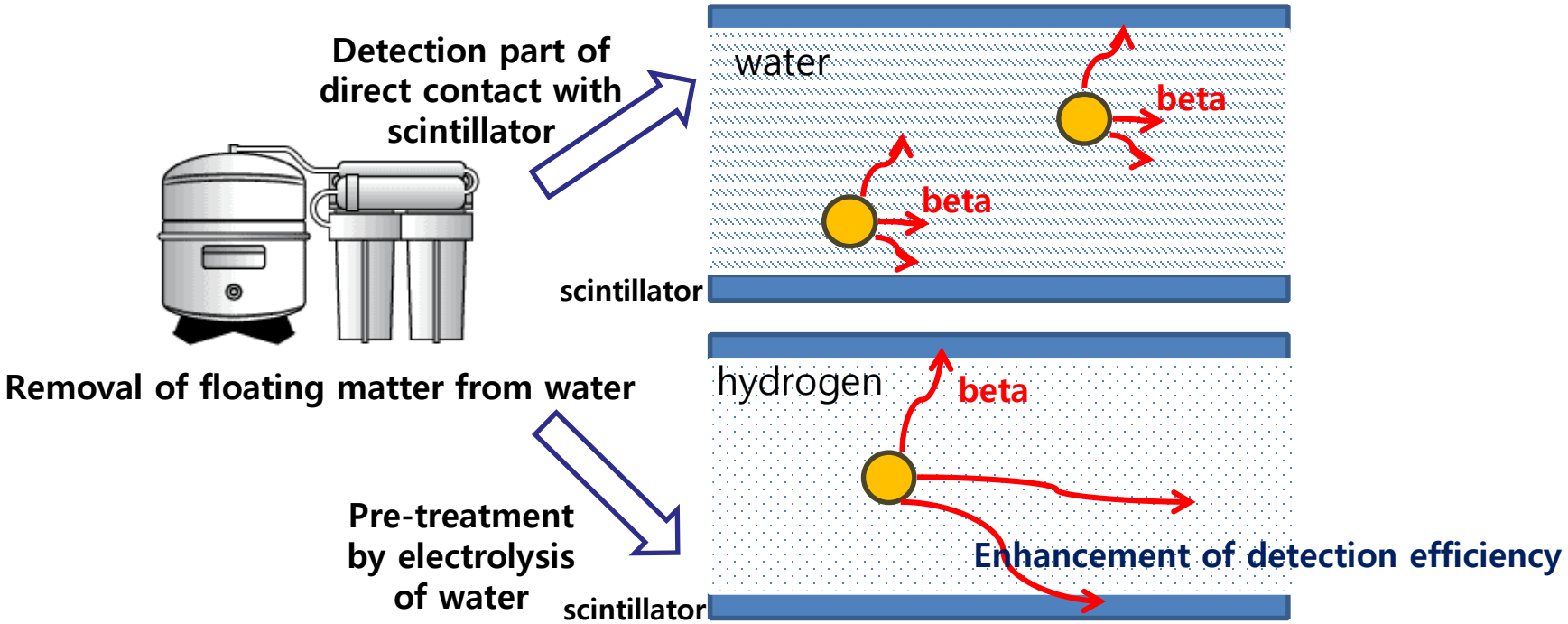
WP4: Development of the next generation fundamental technology for the treatment of radioactive wastes based on self-propelled micromotors

WP1 : Development of In-situ Monitoring Technique for Underground Water in D&D Site

Integrated in-situ beta and gamma radiation monitoring system including tritium in the underground water

- Detection part design with direct contact between scintillator and radiation for the measurement of short-range beta nuclides
- Efficiency enhancement of detection through pre-treatment of electrolysis of water

- In-situ monitoring system through measurement time reduction by enhancement of detection efficiency
- Integrated system of beta and commercialized gamma monitoring system and synchronous visualization between field and control tower
- Software design for error analysis and noise minimization



Objective and contents

Goal

Scintillator based in-situ underwater beta/gamma integrated monitoring system with enhanced sensitivity for underwater surveillance in the nuclear D&D site

Scope

Period 1 (2016-2018) : scintillator based underwater bets detection characteristic analysis and module

- Scintillator based underwater beta detection characteristic analysis
- Selection of scintillator according to beta energy
- Light collection optimization analysis
- Quantification of gross beta and tritium detection characterization on the change of flowrate

Period 2 (2018-2021) : Experimental characterization of in-situ underground water beta/gamma integrated monitoring system

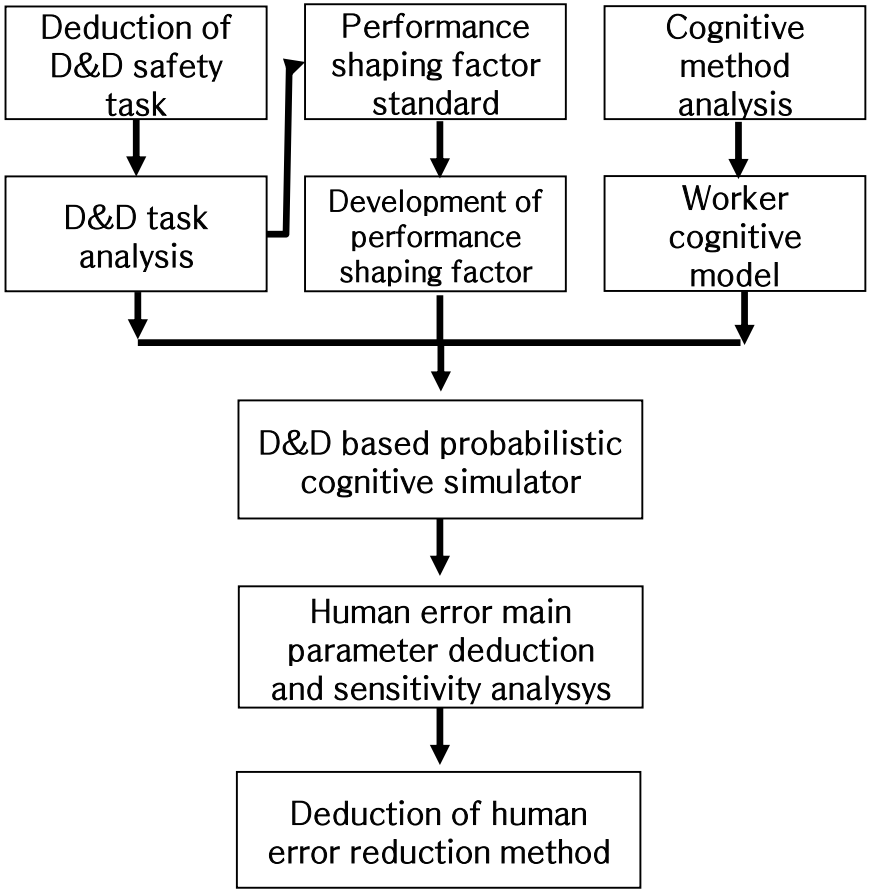
- Electrolysis based tritium detection system for enhancement of detection efficiency (10,000 times higher than conventional method)
- Background shielding and noise reduction algorithm
- In-situ underwater gross beat detection module design and manufacturing : ^{3}H (MDA: 10 Bq/g), ^{90}Sr (MDA: 0.1 Bq/g)
- Error analysis and correction
- Experimental characterization of in-situ underwater beta/gamma integrated monitoring system

WP2 : Base technology development for the decommissioning risk assessment by the probabilistic recognition method

Establishment of D&D activity hazard recognition system by human error cognitive model and reduction estimating hazard factor qualitatively and quantitatively for prevention of accident and protection of workers in nuclear D&D

Base technology of D&D activity hazard estimation by probabilistic cognitive method

- Qualitative human error analysis
  - Analysis of D&D hazardous situation and worker's task
  - D&D activity based performance shaping factor development and related human error deduction
- Quantitative human error analysis
  - D&D activity based human error estimation cognitive model development
  - Quantitative human error probability estimation
  - Human error reduction technology
  - Deduction of human error reduction method by D&D activity steps



Objective and contents

Goal

Development of human error reduction technology by human error probability calculation and sensitivity analysis using probabilistic cognitive method

연구 범위

Period 1 (2016-2018) : development of performance shaping factor considering D&D characteristics

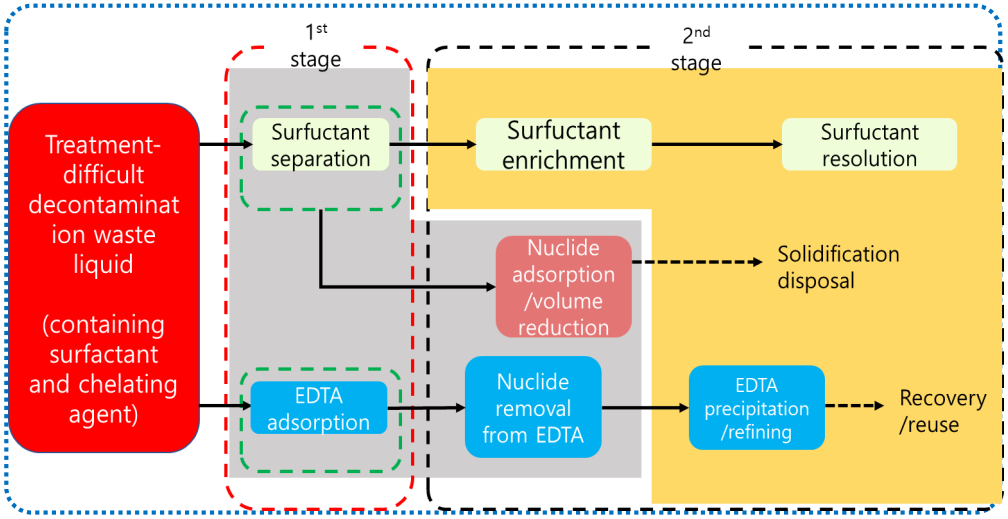
- Deduction of D&D safety related main issue and safety effect factor
- Task analysis
- Deduction of PSF and development of classification system
- Development of PSF analysis model and standard set

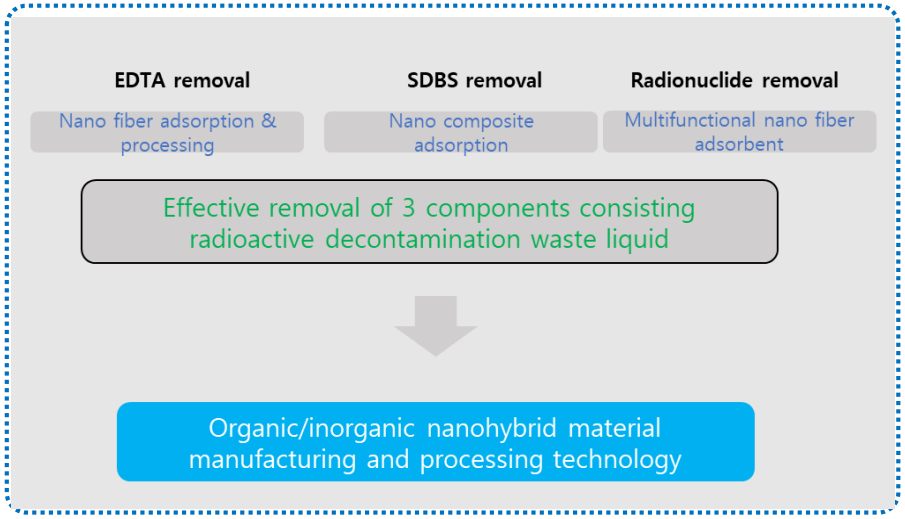
Period 2 (2018-2021) : development of probabilistic cognitive model and human error reduction technology

- Analysis of existing human error estimation recognition method
- Development of D&D activity based human error estimation cognitive model
- Probabilistic cognitive simulation and simulator development
- Data production for D&D activity human error estimation and Verification of simulator
- D&D human error reduction technology (design, manufacturing, operation, etc.)

WP3 : Development of nanohybrid materials and processing technique for decommissioning waste that are highly difficult to treat

Concept





- Nuclear D&D generates much decontamination waste liquid including radionuclides and surfactant and chelating agent difficult to treat using conventional processing.
- Conventional filtering, precipitation, evaporation and membrane should be compensated by new technology.
- Hybrid of organic and inorganic matter is needed to be applied to nuclear D&D.
- Nano complex material and new processing is developed for treatment of treatment-difficult decontamination waste liquid including surfactant and chelating agent

Objective and contents

goal

Development of nano complex material and new processing for treatment of treatment-difficult decontamination waste liquid including surfactant and chelating agent

Scope

Period 1 (2016-2018) :

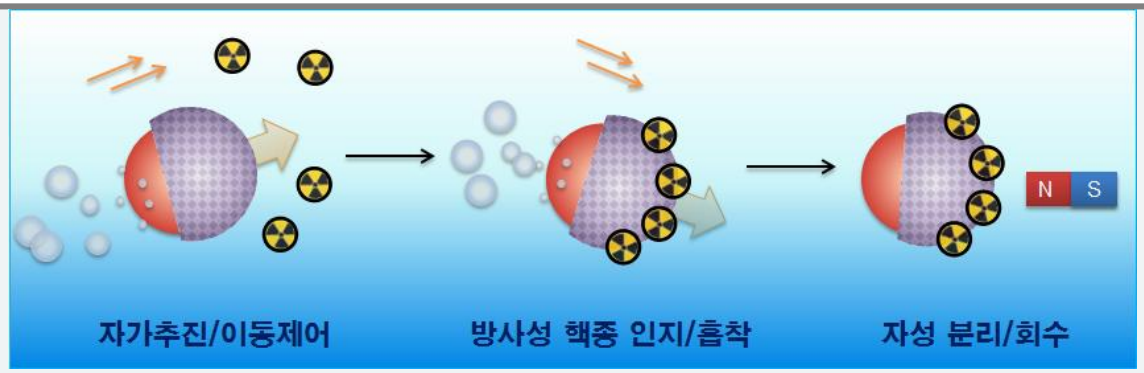
- ➢ **Separation and removal of surfactant in the radioactive decontamination waste liquid**
  - **Effective removal of surfuctant using porous organic, inorganic globulet**
    - ✓ **Specific area:400 m^2/g**
    - ✓ **Pore diameter:<20 nm**
    - ✓ **Separation efficiency: >70%**
- ➢ **Separation and removal of chelating agent in the radioactive decontamination waste liquid**
  - **Separation of chelating agent using an anion exchange resin**

Period 2 (2018-2021) :

- **Enhancement of adhesiveness of organic and inorganic complex through chemical bond and fabrication of precursor ligand to the surface of textile using nano fiber with various functional group**
- **Establishment of cleaning method for reuse of organic and inorganic complex**
- **Establishment of acid and base condition adhering and removing each component in the decontamination waste liquid**
- **Establishment of chemical treatment technology of wet oxidation, enrichment and membrane treatment element technology**

WP4: Development of the next generation fundamental technology for the treatment of radioactive wastes based on self-propelled micromotors

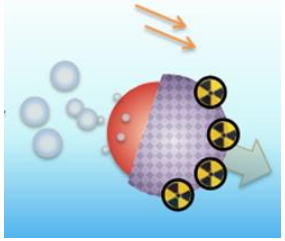
- Exposure reduction and remote decontamination waste liquid technology is required for treatment of high radioactive waste liquid (reactor internal and SF pool storage dismantling waste liquid) generated during nuclear D&D.
- New generation technology of remote control for move and collection of radionuclides by using self propelled micromotor in the underwater
- Development of core technology for treatment of D&D processing radioactive waste liquid including high salt, organic matter and high radioactive waste liquid by using self propelled micromotor



Self propelled micromotor (period 1)

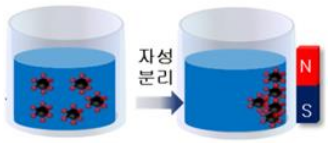
Self propelled micromotor based radioactive waste liquid treatment processing (period 2)

μ-motor absorbent



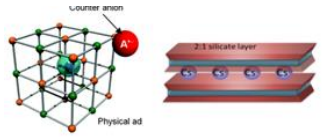
Self propellant for Cs removal

μ-motor collection



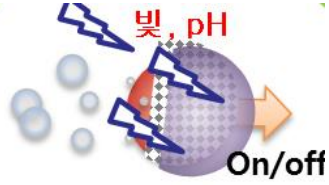
Collection of self propelled absorbent using external magnetic field

Multi species treatment



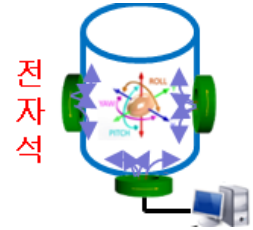
Selective absorption for Treatment of high radioactive and salt species

Propulsion & remote control



-Selective moter control
-Remote control

Waste liquid treatment processing



Self propelled μ-motor absorbent based processing

Objective and contents

Goal

Development of waste liquid treatment technology which self-propulsion nano/micrometer based selective nuclide removal and remote control is available in the underwater

Scope

Period 1 (2016-2018) :

Establishment of self propelled micromotor manufacturing and selection technology for selective nuclide removal

- Micromotor self propellent : velocity more than 50 μm/s
- Absorbent media with nuclide selectivity : removal rate : > 95%
- Collection of magnetism of absorbent matter : recovery : >90%

Period 2 (2018-2021) :

Micromotor control

- Drive control type micromotor propellant : response : <5min

Micromotor based high salt, radioactive waste liquid treatment processing concept

- Nuclide removal of the mockup waste liquid : >90%
- Deduction of radioactive waste liquid treatment processing design and working condition

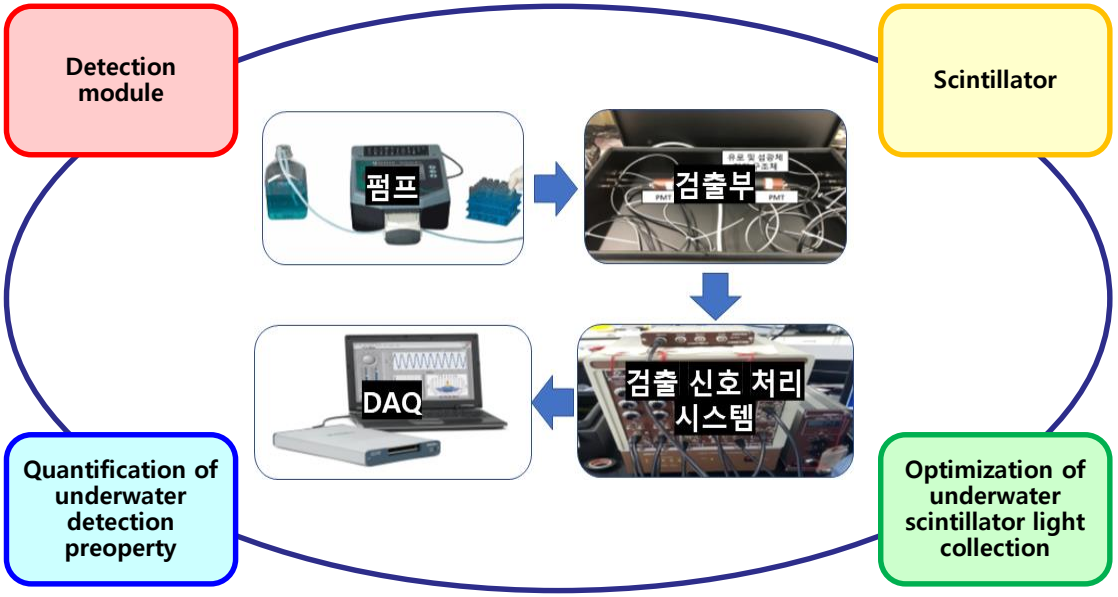
Results of 1st Stage
(2016. 11.30 ~ 2018. 8. 31)

WP 1_Outline

Goal

➢ **Scintillator based underwater beta detection property analysis and experimental characterization of the manufactured gross beta detection module**

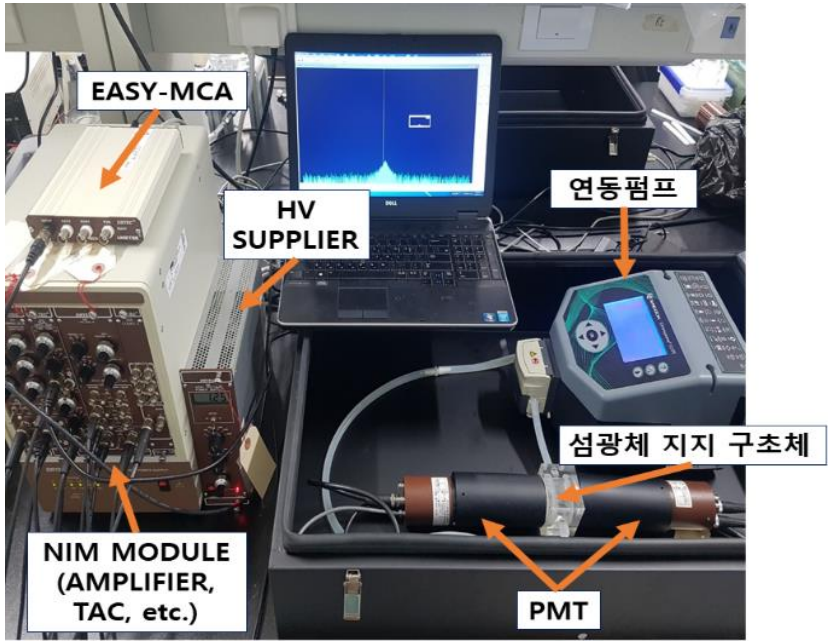
Year	Goal	Contents
1st year	Development of underwater beta detection module	Deduction of beta detection efficiency parameter
	Scintillator selection	Scintillator property analysis for low energy beta detection
2nd year	Optimization of underwater scintillator light collection	Beta detection characteristic analysis according to detection efficiency parameter
	Quantification of underwater beta detection property	Flow path and detection part design/manufacturing based MDA analysis



WP 1_Summary of Result

- Underwater gross beta monitoring design optimization analysis and manufactured module

- Gross beta detection module
  - ✓ Analysis of light collection optimization on water sample height, air gap, diameter and thickness of scintillator
  - ✓ Enhancement of tritium detection efficiency (23.4 times) according to increased amplication of 4 times -> MDA attainment time : reduced by 1/550
  - ✓ MDA attainment time (^{3}H : 400s, ^{90}Sr : 40s) is independent of flowrate

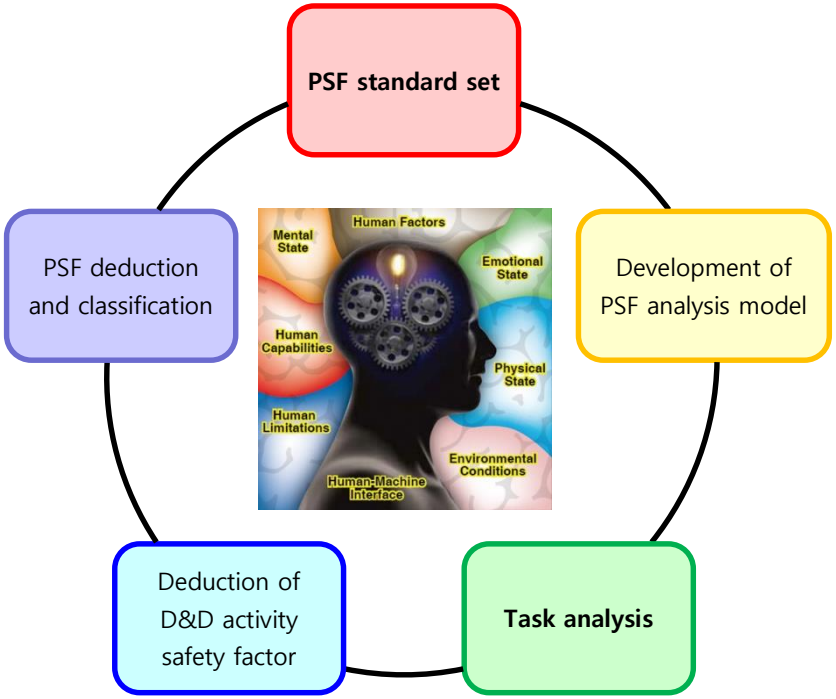


WP 2_Outline

Goal

➢ **D&D hazard estimation and human error reduction using probabilistic recognition method**

Year	Goal	Contents
1st year	D&D safety related task analysis	Deduction of D&D activity safety factor Task analysis
2nd year	D&D based PSFs model development	PSF deduction and classification Development of PSF analysis model and standard set

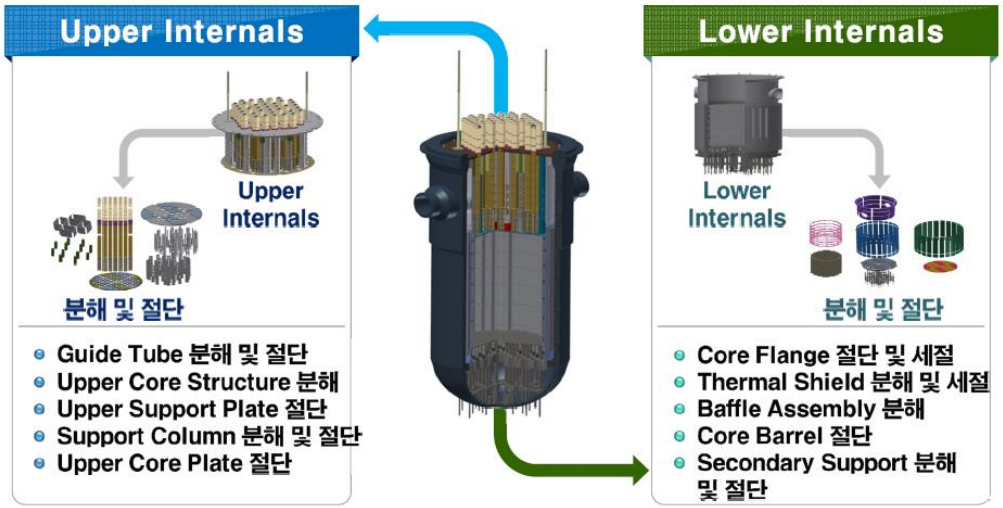


WP 2_Summary of Result

- **D&D safety related task analysis**
  - Security of D&D safety background data including physical and radiological property, working environment and waste package criteria
  - D&D safety related issue review and deduction (hazard mitigation and prevention, secondary waste management, ALARA analysis, qualification)
  - Task analysis affecting D&D safety and characteristic data security (cutting technology, cutting scenario)
  - Deduction of parameter affecting D&D safety (operation characteristic, system characteristic, work characteristic)
- **Development of PSF model for D&D based human error probabilistic assessment**
  - PSF deduction and classification system development by task analysis
  - Selection of main PSF through weighted calculation by PSFs considering mutual dependency

Kori unit-1

RPVI cutting scenario

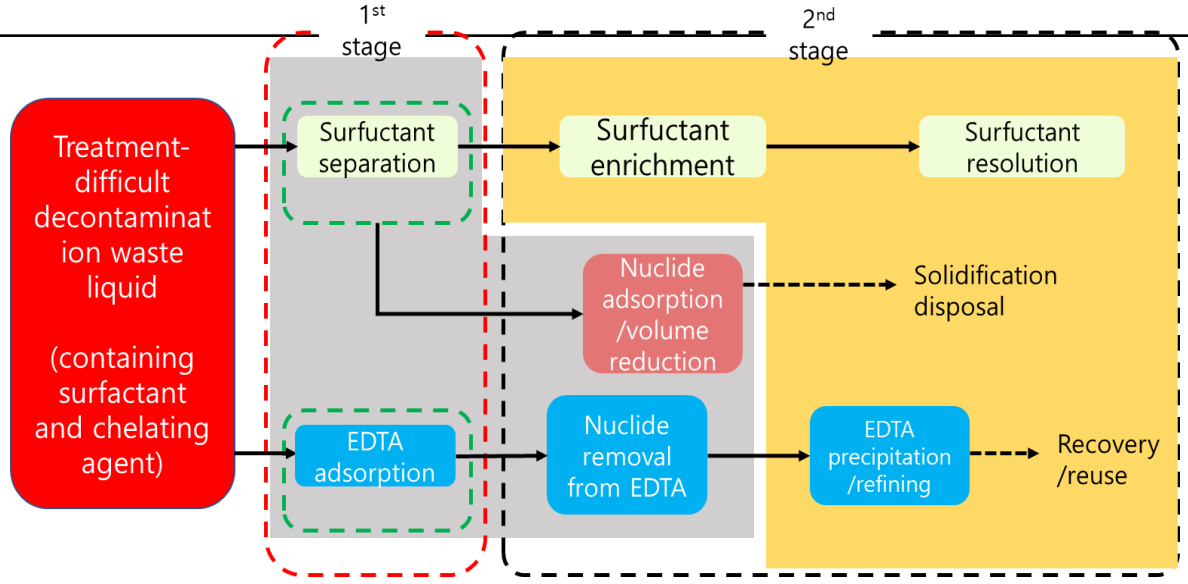


WP 3_Outline

Goal

➢ **Development of absorbent for removal of treatment-difficult surfactant and chelating agent in the decontamination waste liquid**

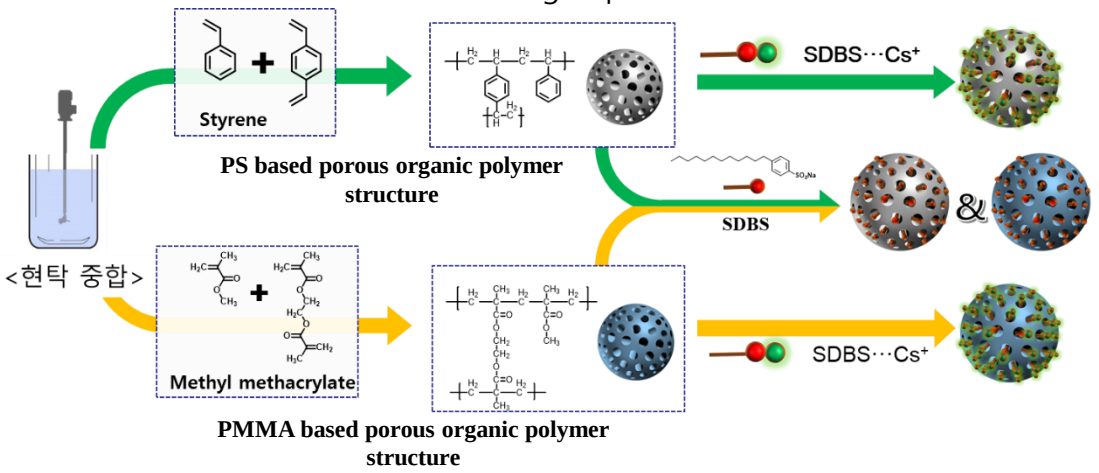
Year	Goal	Contents
1st year	Nanostructure for surfactant separation and removal	Fabrication of porous organic polymer structure and inorganic nanostructure
	Performance estimation of nanostructure for surfactant separation and removal	Performance assessment of surfactant removal using porous organic and inorganic structure
2nd year	Ion exchange resin for chelating removal	Fabrication of gel type and porous ion exchange resin
	Performance estimation of ion exchange resin for chelating agent separation and removal	Performance assessment of chelating removal using ion exchange resin and investigation of the principle



WP 3_Summary of Result

- **Material for surfactant removal**
  - **Successful fabrication of porous organic polymer resin and silica nano particle (sol-gel synthesis)**
    - ✓ Specific area : 600 m^2/g, pore diameter : 3.6 nm (for inorganic nano particle & 7 nm(for organic nano particle)
    - ✓ Removal efficiency higher than 80%
    - ✓ Adsorption performance of cationic porous microporous nanostructure : 600 mg/g

- **Material for chelating agent removal**
  - Comparative evaluation of the removal of complexing agent resulting from morphological difference through preparation of gel type or porous ion exchange resin
    - ✓ Separation efficiency : > 80%
    - ✓ Porous ion exchange resin with relatively large specific surface area adsorption separation performance is more than 150% better than gel type.
    - ✓ Unlike anion exchange resins, cation exchange resins surface-modified with anionic groups rarely remove complexing agents: confirmation of the need for surface modification of ionic groups.

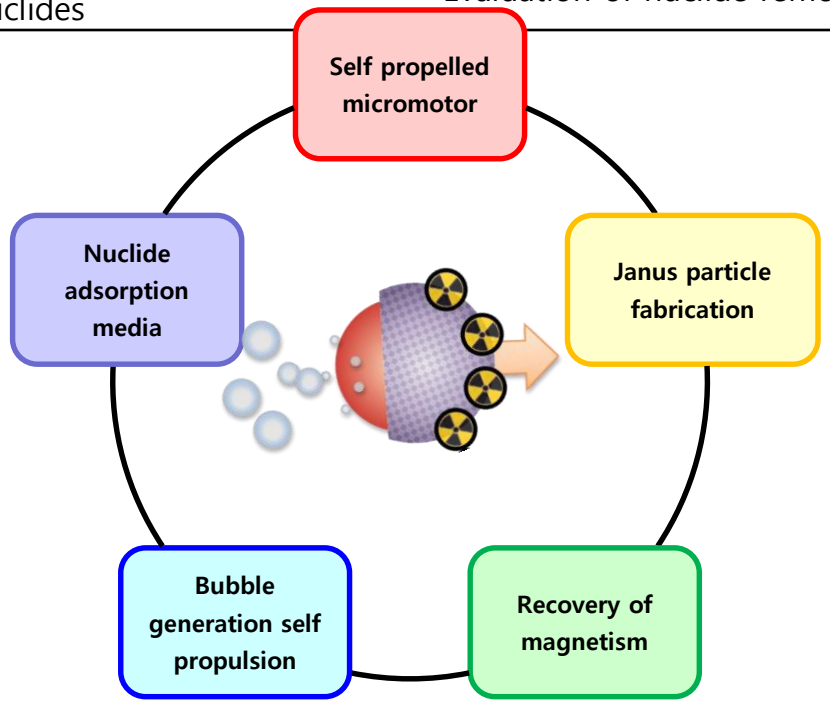


WP 4_Outline

Goal

➢ **Self propelled micrometer core technology which propels and remove radionuclides selectively**

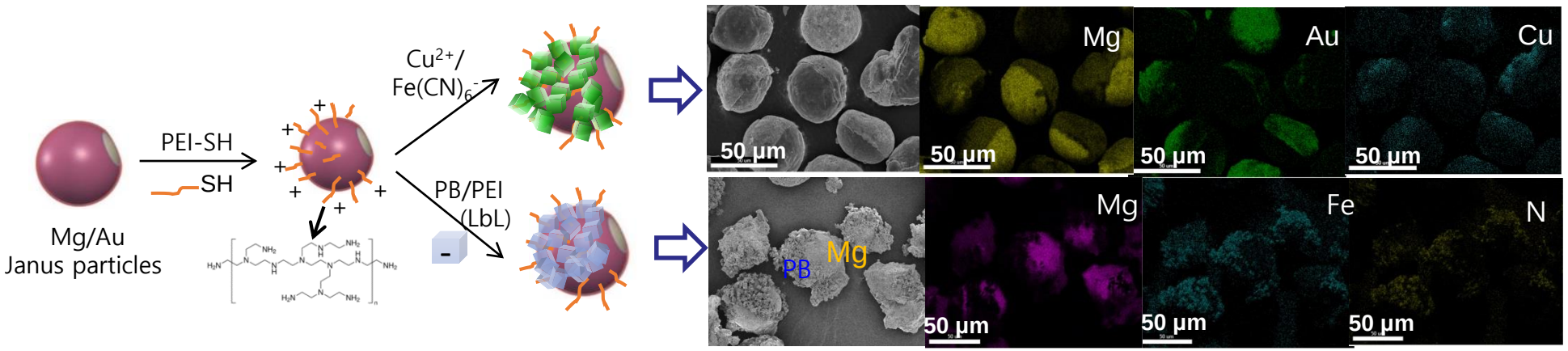
Year	Goal	Contents
1st year	Micromotor design for selective removal of nuclides	Design and configuration of micromotor self-propelled by bubble generation
	Functionalization of nuclide removal of micromotor	Development of synthesis control technology of nuclide adsorption medium for micromotor
2nd year	Micromotor propulsion and collection technology	Self-propulsion and magnetic recovery conditions of micromotor and performance estimation
	Performance estimation of micromotor for selective removal of nuclides	Evaluation of nuclide removal performance of micromotor



WP 4_Summary of Result

- **Successful development of self-propelled micromotor for removing radioactive cesium by modifying half of the surface of Mg particles generating bubbles by reacting with water with metal-ferrocyanide**
  - ➢ Maximum velocity : 90 μm/s
  - ➢ ^{137}Cs removal of maximum 99.8%

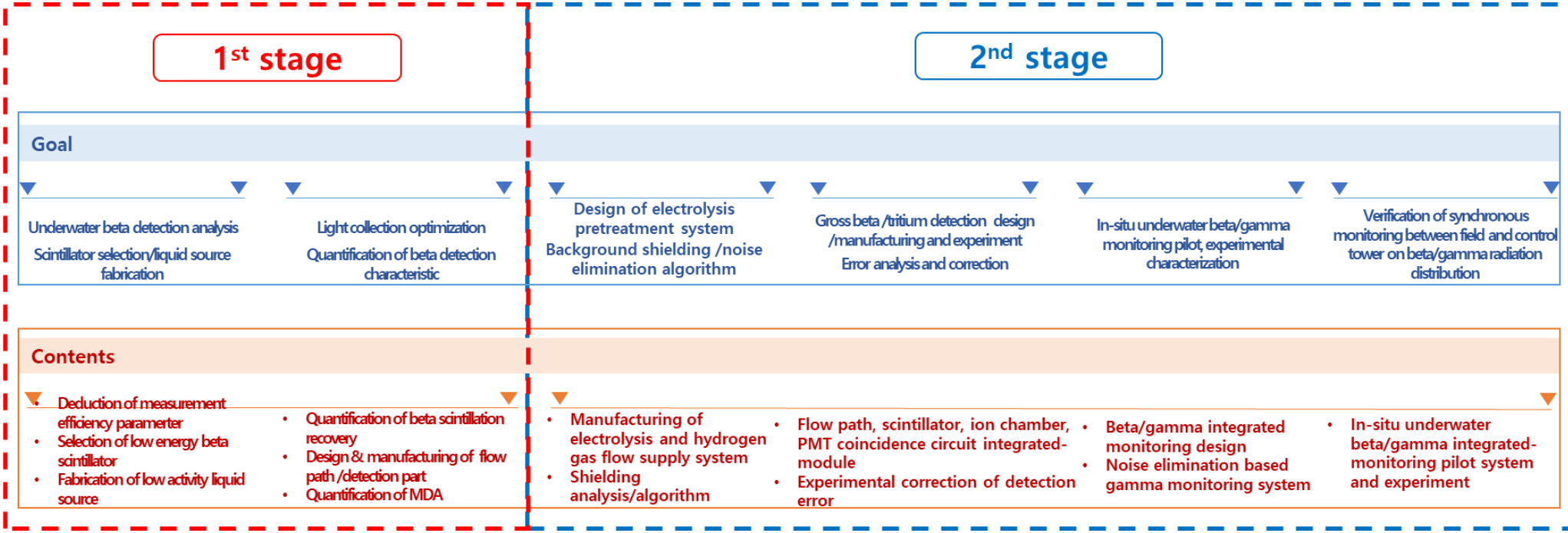
- **Development of self-propelled micromotor for removing nuclides by bubbles generated from reaction of hydrogen peroxide (chemical for treatment of organic matter in waste liquid) after Pt coating of half of the surface of adsorbent particles for removing nuclides**
  - ➢ Enhancement of removal rate of Cs by 10 times(>95%) compared with non-self propelled micromotor and recovery of 97%
  - ➢ For zeolite particles, the maximum average migration rate : 134 μm/s



R&D Plan for 2nd Stage
(2018. 9. 1 ~ 2021. 10. 31)

WP 1_Outline

- Development of integrated in-situ beta/gamma radiation monitoring system combining electrolysis based tritium pre-treatment and gamma measurement
- Background shielding characteristic analysis and statistical data determination algorithm
- Synchronous monitoring technology of in-situ underwater beta and gamma radiation distribution between field and control tower



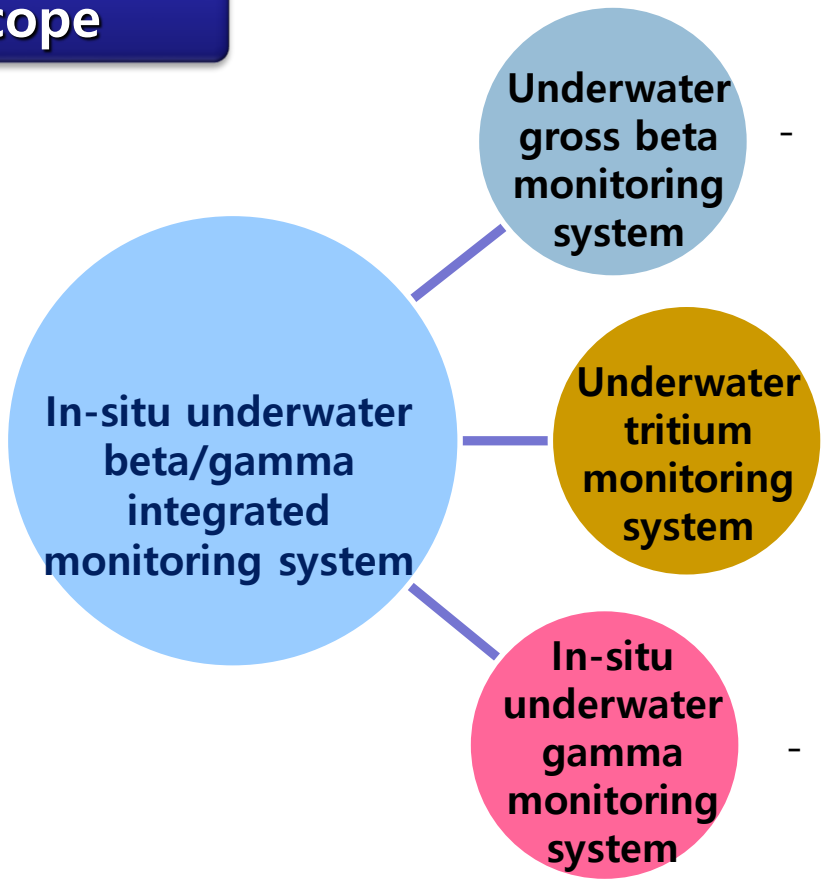
WP 1

Objective and scope

Goal

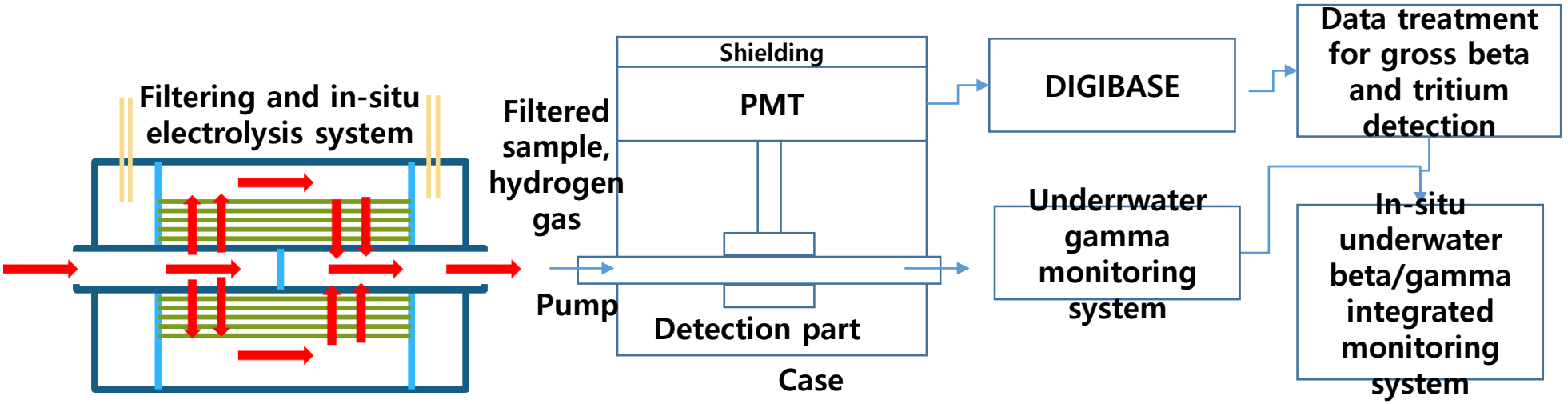
➢ Core technology of underwater gross beta, gamma radiation and self absorption effect removal based tritium monitoring with enhanced sensitivity

Scope



- Underwater gross beta detection MDA: 0.1 Bq/g
- Underwater tritium detection MDA: 10 Bq/g
- In-situ underwater beta/gamma integrated monitoring system

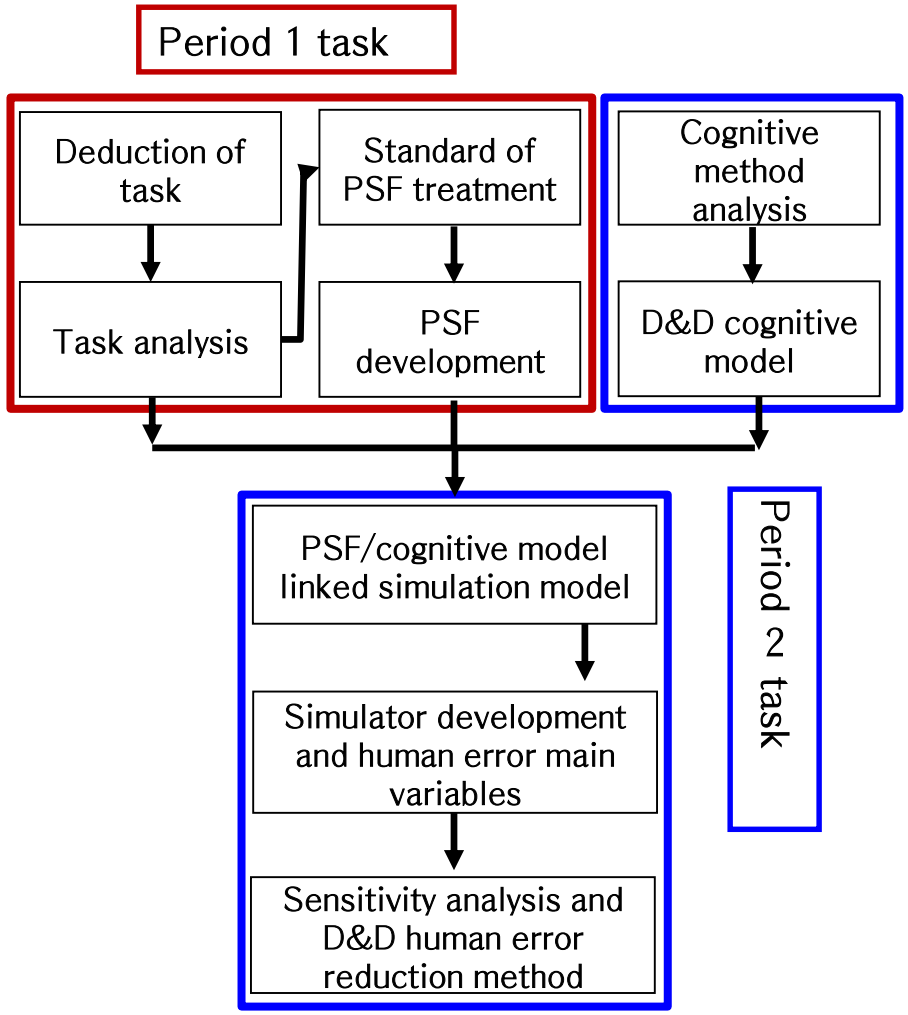
Method



- **Introduction of in-situ gross beta and tritium measurement pre-treatment system**
  - Filtering system using membrane and gasification of tritium using electrolysis
  - Tritium treatment system for safe measurement of gaseous tritium
- **Design and fabrication of detection part of high sensitivity**
  - Application to in-situ spectrum analysis module based on DIGIBASE
  - Maximization of contact area to maximize reaction between scintillator and beta nuclide and flowrate

Outline

- **Probabilistic recognition simulation model and hazard estimation base technology**
  - **D&D probabilistic recognition model**
    - Model review and selection of recognition model for D&D human error estimation
    - Component-specific cognitive model improvement and integrated cognitive model developmen
  - **Development of optimal simulator for nuclear D&D**
    - Development and verification of comprehensive simulation model for human error evaluation
    - Development of a simulator for evaluating human error probability
  - **Development of human error reduction base technology**
    - Human error major variable deduction and sensitivity analysis
    - Deduction of human error reduction plan by D&D stages



WP 2

Objective and scope

Goal

➢ Development of human error reduction technology by human error probability calculation and sensitivity analysis using probabilistic cognitive method

Scope

Base technology for human error reduction

D&D probabilistic cognitive model

- Human error trend data analysis and component-specific improvements
- Development of integrated cognitive model for D&D activity

D&D optimized cognitive simulation model

- PSF evaluation model/cognitive mode linked simulation model
- Development of human error probability evaluation simulator

Human error reduction

- Simulator verification and human error evaluation data production
- Development of human error improvement plan (reduction of human error by 90% or more)

WP 2

Method

Probabilistic cognitive model

- Analysis of human error tendency data
- Improvement of cognitive model per element and development of integrated cognitive model

Simulation model

- Development of simulation model linking PSF evaluation model and cognitive model
- Simulation model verification

Human error simulator

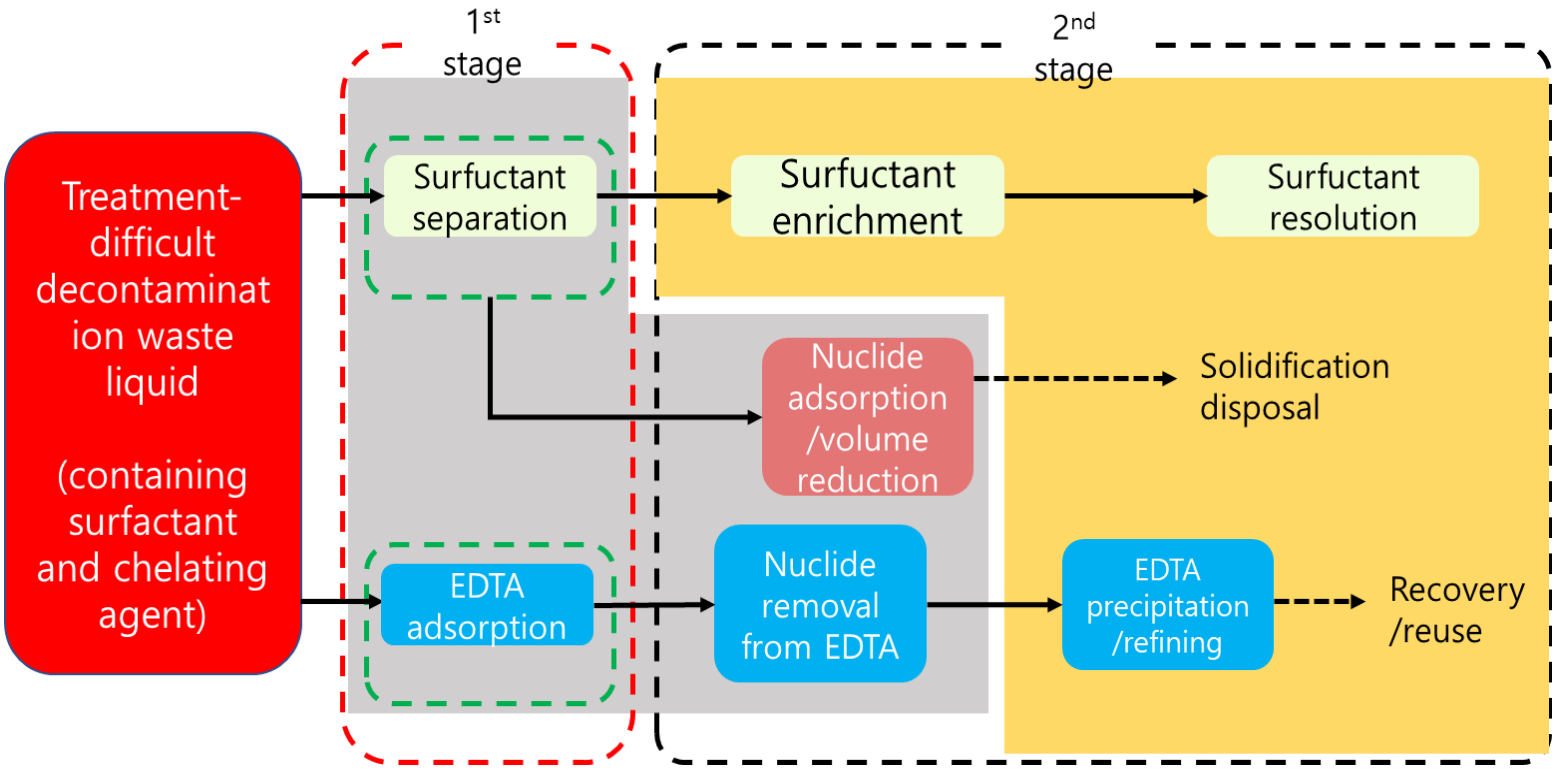
- Development of probabilistic recognition simulator for D&D
- Data production and sensitivity analysis for human error evaluation

D&D activity base HRA development and human error reduction infrastructure technology

- Probabilistic awareness simulator verification and documentation
- Development of technology to reduce human error of D&D (design, equipment production, operation, etc.)
- Deduction of human error reduction measure

WP 3

Outline



- Successful acquisition of porous organic/inorganic structure manufacturing core technology to remove surfactant and chelating agent with high concentration
- Development of nano hybrid complex to remove radionuclides in the decontamination waste liquid

WP 3

Objective and scope

Goal

➢ Development of nano complex material and new processing for treatment of treatment-difficult decontamination waste liquid including surfactant and chelating agent

Scope

- Specific area of porous organic structure : >500 m^2/g
- Pore diameter : <15 nm
- Removal rate of nuclide : 20 mg/g

- SDBS processing treatment removal :>85%
- EDTA processing treatment recovery: >70%
- Separation efficiency of radionuclide : >80%
- Volume reduction : 200%

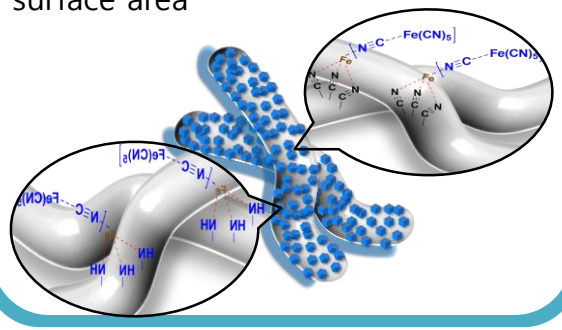
- Manufacturing of nanofibers for adsorption of multi-species
- Evaluation of adsorption performance of multi-species using nanofiber

WP 3

Method

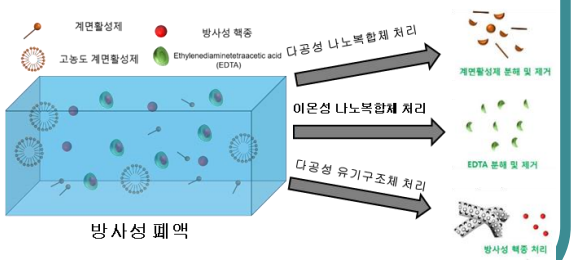
Contaminated nuclide treatment in the waste liquid

Preparation of porous organic structure strongly adsorbing and removing radioactive contaminated nuclides and introduction into the nanofiber surface having a large surface area



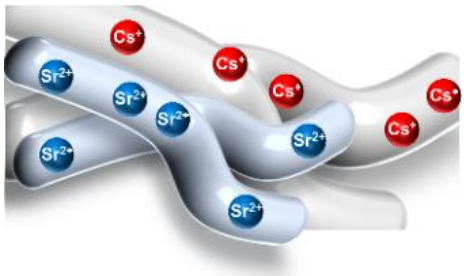
Waste liquid treatment processing

Development of a new processing capable of removing surfactants, complexing agents and radionuclides in radioactive waste liquid based on nanohybrid materials



Simultaneous treatment processing of multi species

Simultaneous removal of two radionuclides by complex spinning of cesium-adsorbing fibers and strontium-adsorbing fibers



Development of nanocomposite material and new processing for treatment of treatment-difficult decontamination waste liquid

- Design concept of porous nanohybrid fiber material
  ⇒ Removal of radioactive nuclides by removal of selective decontaminants
- Development of new processing technology for treating radioactive decontamination waste using nanohybrid materials

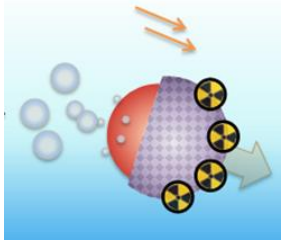
Outline

- Radioactive waste disposal technology using self-propelled micromotor is a unique technology that has not been tried in the world. It has successfully secured core technology of self-propelled micromotor for removing nuclides during the first stage research.
- In the second stage study, a self-propelled micromotor capable of simultaneously removing polynuclear species was newly developed.
- In order to maximize the effluent treatment efficiency, it is the first in the world to develop the driving control source technology of self-propelled micromotor.
- We conduct research on performance evaluation and applicability of high radioactive waste liquid such as groundwater, and various high radioactive waste liquids generated in the dismantling of nuclear power plant to secure the base technology for processing technology development.

Self propelled micromotor (1st stage)

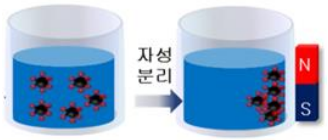
Self propelled micromotor based radioactive waste liquid treatment processing (2nd stage)

μ-motor absorbent



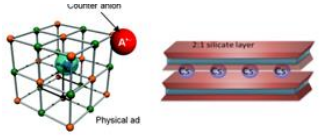
Self propellant for Cs removal

μ-motor collection



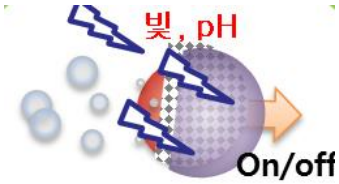
Collection of self propelled absorbent using external magnetic field

Multi species treatment



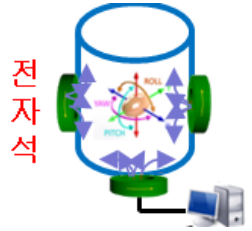
Selective absorption for Treatment of high radioactive and salt species

Propulsion & remote control



-Selective moter control
-Remote control

Waste liquid treatment processing



Self propelled μ-motor absorbent based processing

WP 4

Objective and contents

Goal

➢ Development of driving control technology of self-propelled micromotor for removing nuclides and development of D&D processing-based technology by improving application of radioactive waste liquid treatment

Scope

Driving and remote control

- Design and development of propellant for eco-friendly and long-term driving
- Driving control type micromotor propulsion: response time within 5 minutes

Multi-species treatment

- Simultaneous removal of major nuclides in the actual waste liquid
- Selective adsorption technology in high radioactive / high salt conditions

High radioactive waste liquid treatment processing

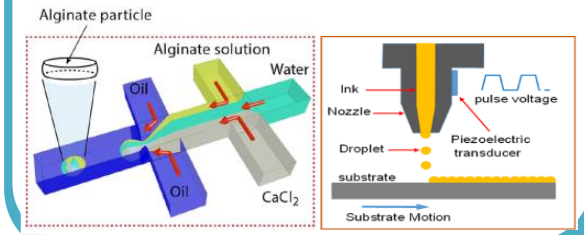
- High absorption capacity / radiation-resistant micromotor manufacturing technology
- Development of processing technology

WP 4

Method

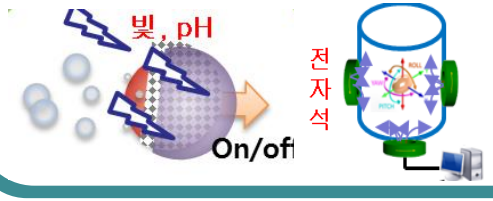
μ-motor multi-species treatment

-Development of functional zeolite-based μ-motor for simultaneous removal of Cs and Sr
-Development of continuous processing (ex: ink-jet) technology for mass production of micromotor



Driving and remote control

- Development of micromotor drive control technology driven by external stimuli such as electromagnetic signals, ultrasonic waves or light
- Control of mobility using external magnetic field by introducing magnetic material



Evaluation of applicability of mockup waste liquid

- Improvement of applicability by comparing and analyzing the performance of self-propulsion and radionuclide removal of micromotor according to the contents of non-radioactive species in radioactive waste liquid such as spent fuel storage tank, organic mixed waste liquid and underground water

Self-propelled μ-motor based D&D waste liquid new processing technology

- Micromotor based D&D waste liquid treatment processing design
- Derivation of processing conditions for radioactive waste liquid treatment
- Evaluation of applicability of radioactive, high salt (underground water) waste liquid treatment

Expected Research Output

- General
  - ❖ Development of source technology on D&D core technology and establishment of infrastructure base of D&D professionals
- In–situ integrated underwater gross beta/gamma and enhanced sensitivity tritium monitoring system in the D&D site
  - ❖ In-situ tritium monitoring system with enhanced sensitivity
  - ❖ Background shielding characteristic data and background elimination algorithm
- D&D hazard evaluation technique and human error reduction technology using probabilistic cognitive method
  - ❖ Probabilistic awareness simulator for D&D
  - ❖ D&D human error reduction base technology
- D&D processing waste treatment new technology for surfactant and chelating agent
  - ❖ Manufacturing technology and condition of nanohybrid composite for separation of surfactant and chelating agent
  - ❖ Functional nano fiber composite manufacturing and decontamination waste liquid treatment new processing for removal of radionuclide
- Self propelled micromotor based radioactive waste liquid treatment technology
  - ❖ Micromotor manufacturing for nuclide removal, control and recovery technology and optimization
  - ❖ High radioactive waste liquid treatment processing technology

Thank You