Conceptual design on the safety management of radioactive waste using by cutting-edge technologies

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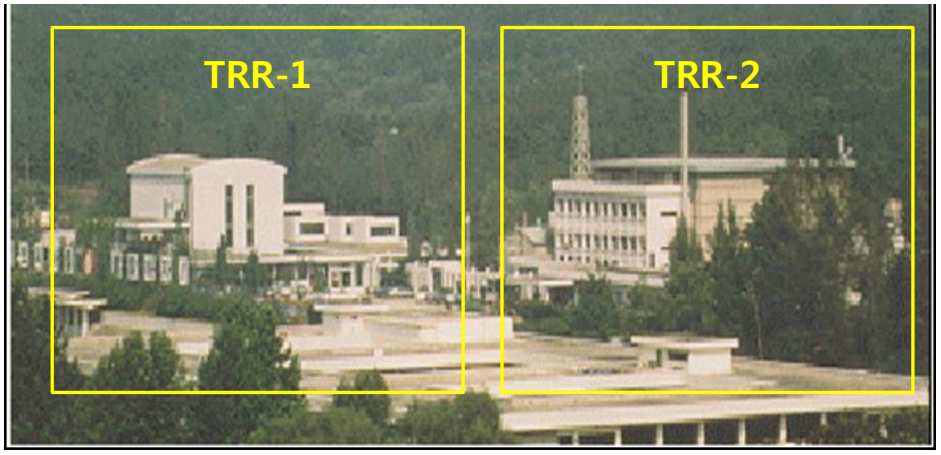
KOREA Research Reactors



Metal

Soil & Concrete

KRR-2

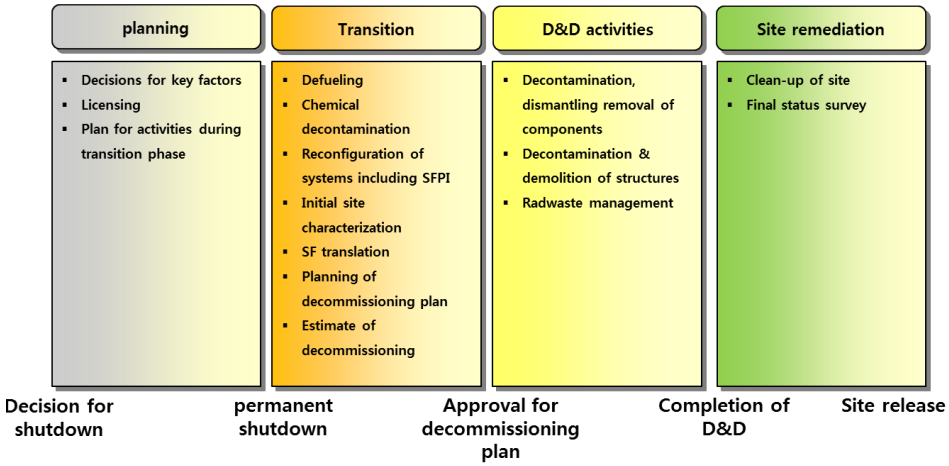
- TRIGA Mark-III type, 2MWt, RI production and R&D
- Open pool, movable core
- Operation time: 55,000 hr (1972 ~ 1995)
- Total generation power: 9,000 MWh
- Decommissioning: 1997. 1 ~ 2009. 12

KRR-1

- TRIGA Mark-II type, 250Kw
- Open pool, fixed core
- Operation time: 36,000 hr (1962 ~ 1995)
- Total generation power: 3,700 MWh
- Decommissioning: 2011 ~ 2015

Site remediation and clearance : 2018 ~ 2021

KOREA NPP & Decommissioning Schedule



Operation: 24 Units (22,529 MW)

Under Construction: 5 Units (6,600 MW)

2017. 6 : permanent shutdown GORI NPP

transition period

2023. 7 : decommissioning activities

DIMS(Decommissioning Information Management System)

Nuclear industry: advanced system on decommissioning of GORI Unit 1 NPP

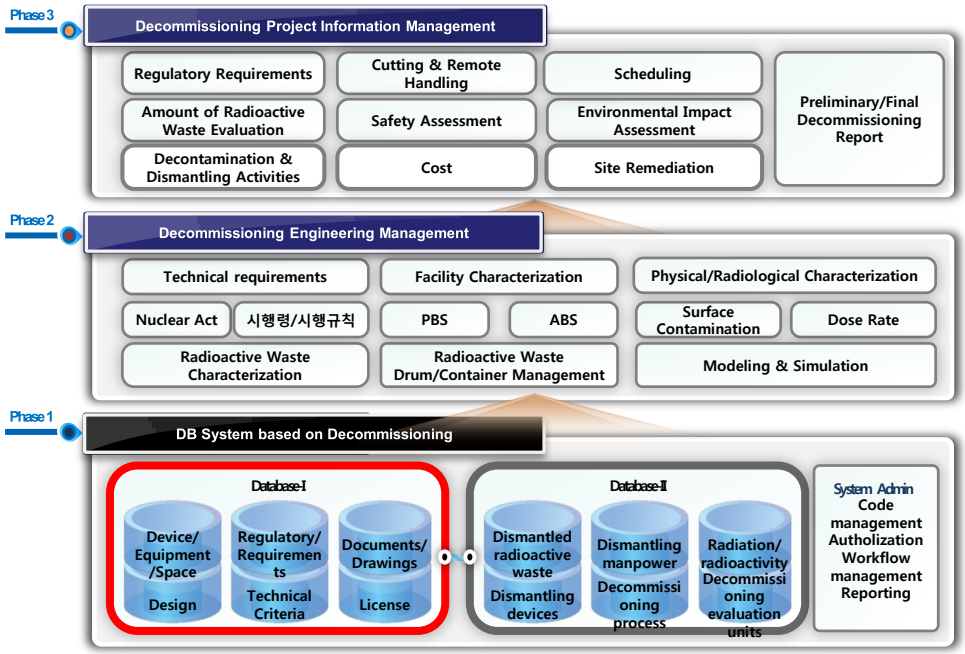
Organizing of guideline, regulatory and technical requirements

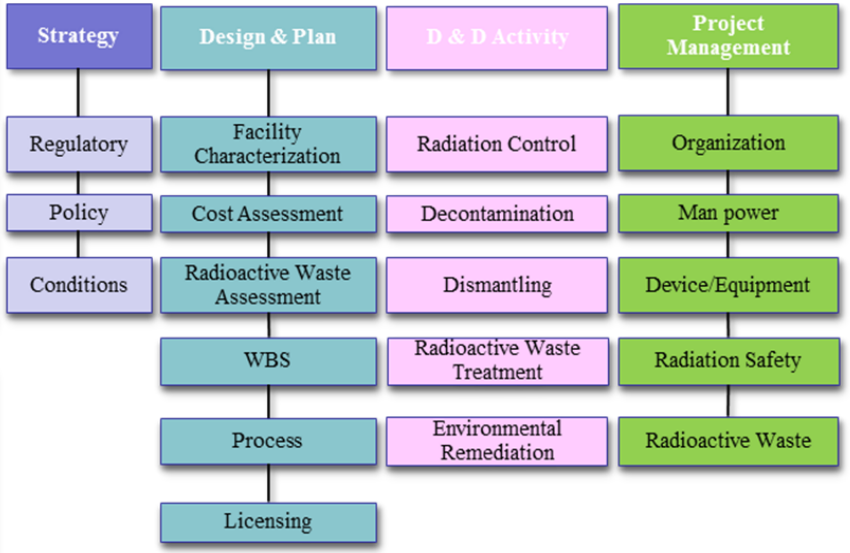
- regulatory requirements → project requirements → technical criteria

Calculating of main dismantling process on the dismantling field

- radiological inventory, amount of RAW, worker's dose rate, cost and schedule

Requirements of decommissioning life-cycle





Facility Characterization & Inventory

Expectation of amount of radioactive waste based on radiological characterization

Foundation of RAW characterization through physical and radiological inventory

Facility characterization

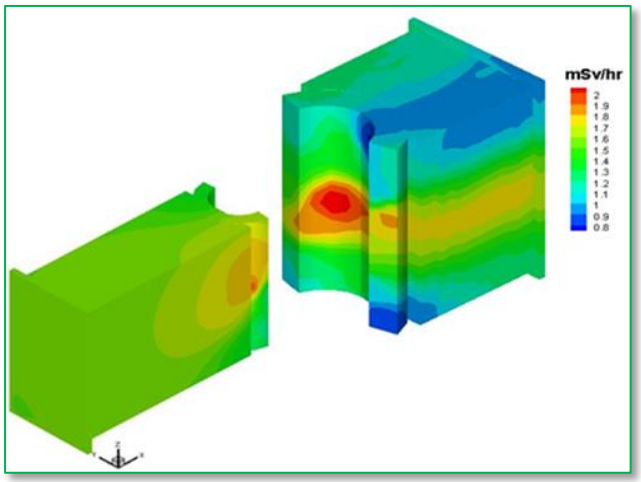
- OPR-1000: PWR, 1000MWe
- PBS: Layer & Area(37)/Room(431)/Equipment(1,583)

Physical/radiological characterization

- Facilities, structures, devices and documents
- Physical data: materials, density, weight, volume, area
- Radiological data: operational history, surface contamination, dose rate, radiation zoning

OPR1000 Two-Unit Plant Layout of Major Structures

Room Name	Equipment Name
RPV	RPVS Reactor Pressure Vessel Structure
	CEDM 제어봉구동장치(Control Element Dr
	ST-CEAE 제어봉집합체연장축(CEA Extension
	RxUH 원자로용기덮개(Rx Upper Head)
	CEDMC 제어봉구동장치 냉각장치(CEDM Co
	UGS 상부안내구조물(Upper Guide Struct
Reactor Pressure Vessel	NO-I 입구노즐(Inlet Nozzle)
	CSB 노심지지배럴(Core Support Barrel)
	NO-O 출구노즐(Outlet Nozzle)
	FA 연료집합체(Fuel Assembly)
	CS 노심슈라우드(Core Shroud)
	IC 검사캡슐(Inspection Capsule)
	RxC 원자로 노심(Reactor Core)
	NO-II 노내계측기노즐(Incore Instrumentat
	LSS 하부지지구조물(Lower Support Stru
	CSP 노심정지 플러그(Core Stop Plug)
	CEA 제어봉집합체(Core Element Assemt
	SGS Steam Generator Structure
	SO 증기아웃렛(Steam Outlet)



Inventory

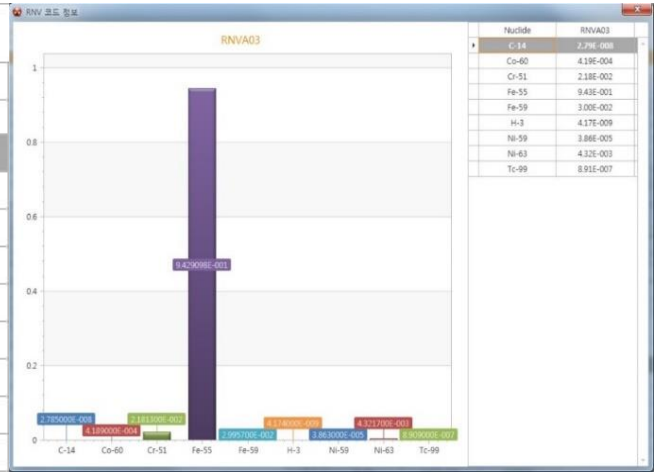
Calculating of inventory in RPV-RCB-OPR1000

RNV (Radioactive Nuclide Vector)

- normalized value of the nuclear species contained in the waste
- calculating the total radioactivity of the nuclides

Add Item

Nuclide	RNVA01	RNVA02	RNVA03
C-14	0.00	0.00	0.00
Co-60	0.00	0.00	0.00
Cr-51	0.00	0.00	0.02
Fe-55	0.00	0.00	0.94
Fe-59	0.00	0.00	0.03
H-3	0.00	0.00	0.00
Ni-59	0.00	0.00	0.00
Ni-63	0.00	0.00	0.00
Tc-99	0.00	0.00	0.00



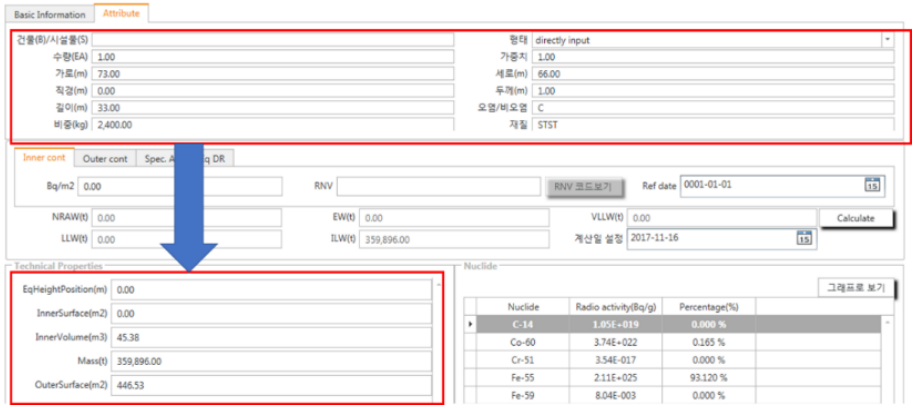
Level of RAW

- determination of waste level based on the total activity of the calculated waste
- comparing the RAW limits
- ILW-360ton in dismantling of RPV into one-piece

Decommissioning Cost

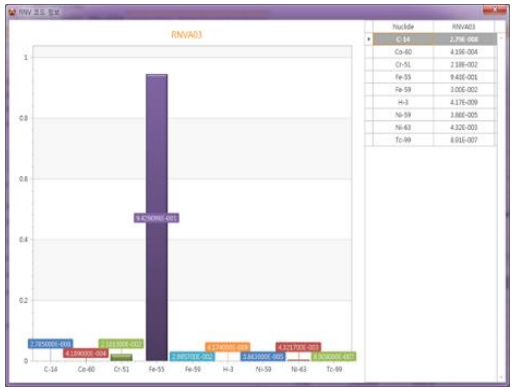
Calculation of physical property

- area, volume, weight using specification value of the facility

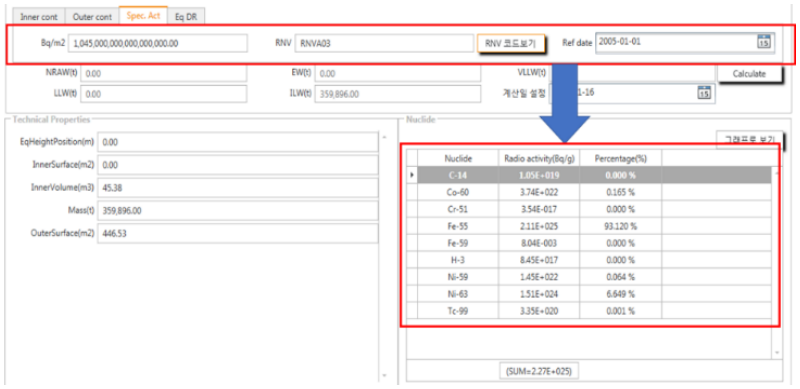


Activity value of nuclide

- Input: radiation/radioactivity and nuclide activity



Radiation/radioactivity measured value



Activity value of each nuclide

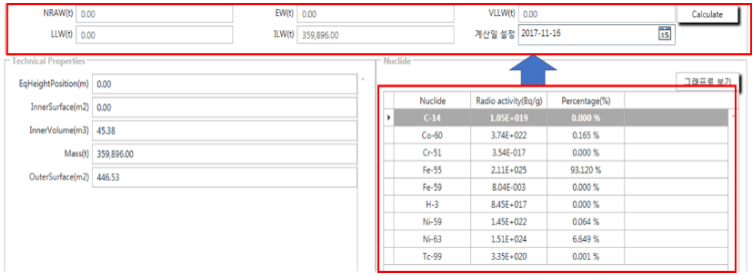
Decommissioning Cost

Amount of RAW determine by level based on

- the value of radioactivity
- classification standard notified by the Nuclear Safety Act

Nuclide	EW Limit	VLLW Limit	LLW Limit	ILW Limit
C-14	1.00	10.00	100.00	0.00
Co-60	0.10	1.00	10.00	0.00
Cr-51	100.00	1,000.00	10,000.00	0.00
Fe-55	1,000.00	10,000.00	100,000.00	0.00
Fe-59	1.00	10.00	100.00	0.00
H-3	100.00	10,000.00	10,000.00	0.00
Ni-59	100.00	1,000.00	10,000.00	0.00
Ni-63	100.00	1,000.00	10,000.00	0.00
Tc-99	1.00	10.00	100.00	0.00

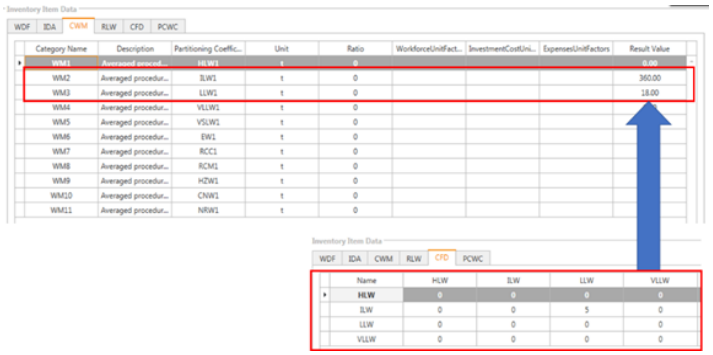
Limit of nuclide concentration by level

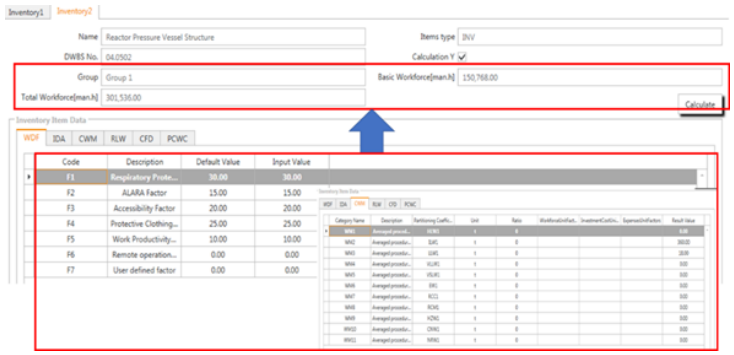


Calculated amount of radioactive waste by level

Calculation of 2nd waste and workforce

- calibrated value of amount of waste on partitioning coefficient
- total work-force using work difficulty factors



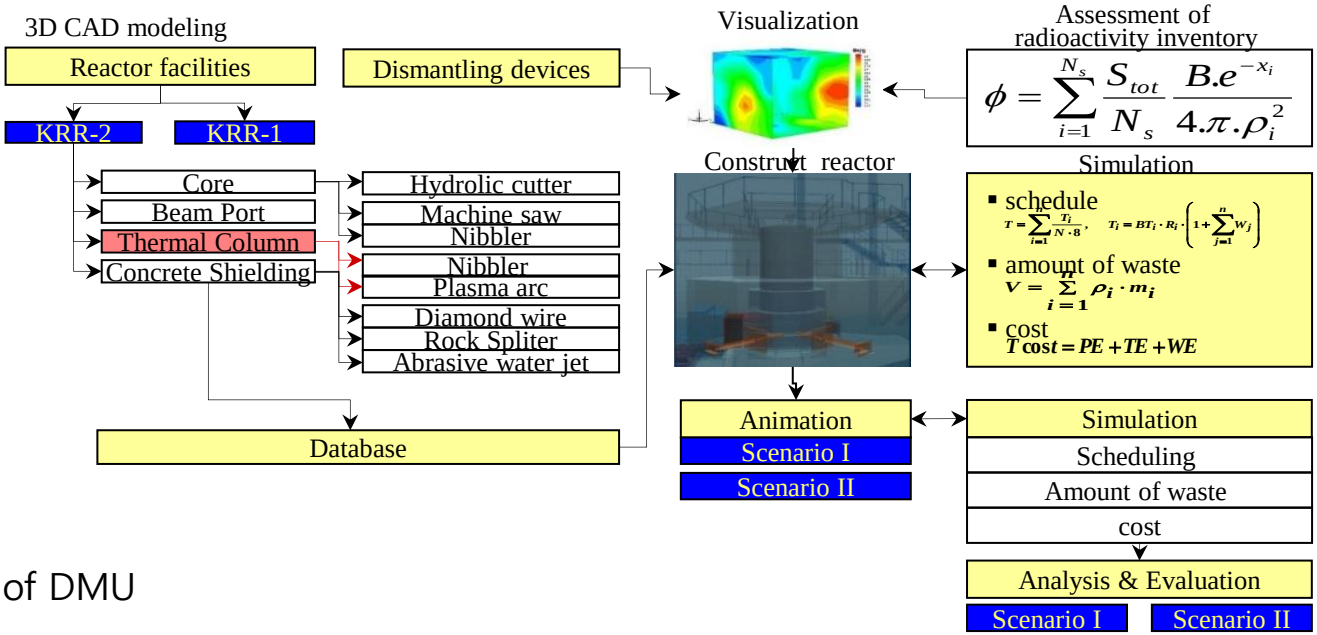


DMU(Digital Mock-Up)

Modeling: build a virtual mock-up for dismantling the facility

Simulation: analyze important factors to be affect decommissioning cost and exposure dose

Goal: reduce decommissioning cost and minimize worker dose



Procedure of DMU

- Produce the facility and device and store the results to DB
- Calculating radioactivity inventory and visualizing the area irradiated by radiation
- Displaying the procedure of dismantling activities under the contaminated environment
- Simulation of worker's dose and decommissioning cost

Decommissioning Activities

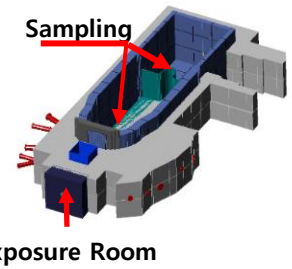
Decommissioning activities

- RSR (Rotary Specimen Rack)
  - Separate from the core structure and moved to the KRR-1 building
  - SS: intermediate level waste

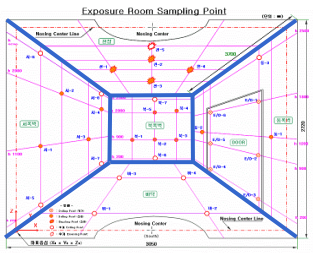


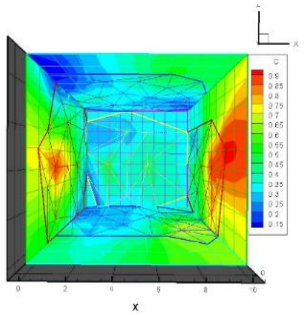


- Bio-shielding concrete
  - Sampling test: check the level of radioactivity
  - Collecting of activation data from the result of sampling
  - Exposure room: visualization of the radiation distribution





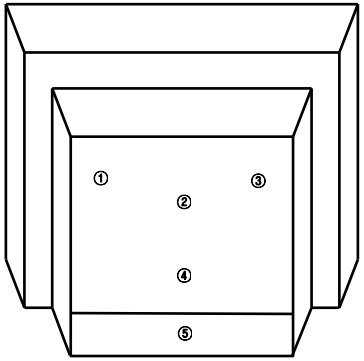


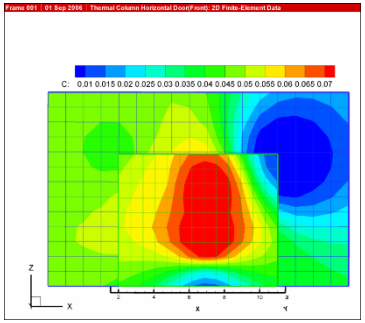


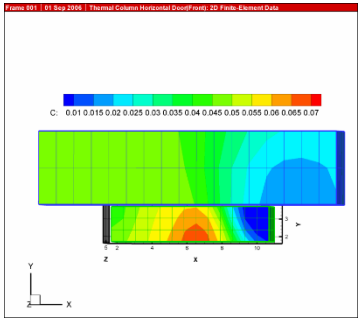
Modeling & Simulation

Worker's external exposure dose

- dismantling of T/C horizontal door of KRR-2
- 3D contour map of the distribution of radioactivity







No. sampling		Measured radionuclide	Revised radioactivity concentration(Bq/g)	Remark (MDA)	Day of Measurement
Horizontal-1		^{60}Co	0.152	0.00439	10.22
Horizontal-2		N/D	-	-	10.22
Horizontal-3		N/D	-	-	10.22
Horizontal-4		N/D	-	-	10.25
Horizontal-5		N/D	-	-	10.27
After polishing on surface	H1-1	^{60}Co	0.044	0.0379	11.05
	H1-2	^{60}Co	0.074	0.00424	11.05
	H1-3	^{60}Co	0.042	0.00374	11.05
	H1-4	^{60}Co	0.076	0.00426	11.05
	H1-5	^{60}Co	0.01	0.00228	11.05
After crushing in depth 7cm	H1-1	N/D	-	-	11.03
	H1-2	^{60}Co	0.0049	0.00233	11.03
	H1-3	^{60}Co	0.0055	0.0022	11.03
	H1-4	N/D	-	-	11.03
	H1-5	^{60}Co	0.005	0.00312	11.03

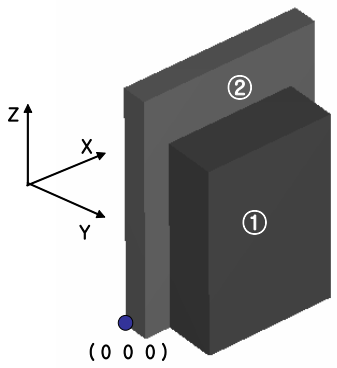
Results of gamma nuclide analysis

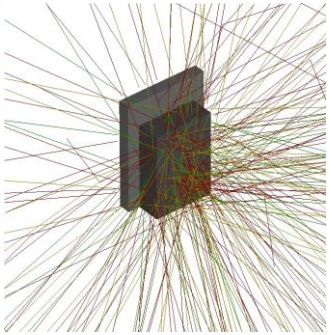
Elements: Node-150 x 195
Modeling: Triangulation mesh

Modeling & Simulation

Radiation dose rate of near the activated T/C horizontal door

- Monte Carlo N-Particle (MCNP-4C)





Rendering of the geometry and particle tracks

	100	150	200	250	300	350	400	450	500
-280	2.92E-01	3.14E-01	3.18E-01	3.07E-01	2.85E-01	2.60E-01	2.33E-01	2.08E-01	1.84E-01
-230	4.10E-01	4.36E-01	4.28E-01	3.99E-01	3.59E-01	3.16E-01	2.77E-01	2.40E-01	2.08E-01
-180	6.12E-01	6.34E-01	5.94E-01	5.27E-01	4.53E-01	3.84E-01	3.25E-01	2.75E-01	2.34E-01
-130	9.91E-01	9.66E-01	8.46E-01	7.01E-01	5.70E-01	4.62E-01	3.78E-01	3.10E-01	2.59E-01
-80	1.78E+00	1.55E+00	1.21E+00	9.22E-01	7.03E-01	5.42E-01	4.28E-01	3.43E-01	2.81E-01
-30	3.61E+00	2.54E+00	1.70E+00	1.16E+00	8.32E-01	6.15E-01	4.70E-01	3.69E-01	2.97E-01
20	7.55E+00	3.81E+00	2.17E+00	1.36E+00	9.21E-01	6.63E-01	4.96E-01	3.84E-01	3.06E-01
70	1.16E+01	4.74E+00	2.45E+00	1.47E+00	9.64E-01	6.89E-01	5.11E-01	3.93E-01	3.12E-01
120	7.50E+00	3.81E+00	2.17E+00	1.36E+00	9.22E-01	6.62E-01	4.96E-01	3.84E-01	3.07E-01
170	3.61E+00	2.54E+00	1.70E+00	1.16E+00	8.31E-01	6.15E-01	4.70E-01	3.69E-01	2.97E-01
220	1.78E+00	1.55E+00	1.21E+00	9.21E-01	7.01E-01	5.42E-01	4.27E-01	3.43E-01	2.81E-01
270	9.87E-01	9.63E-01	8.46E-01	6.99E-01	5.76E-01	4.63E-01	3.77E-01	3.11E-01	2.59E-01
320	6.12E-01	6.31E-01	5.94E-01	5.27E-01	4.53E-01	3.85E-01	3.25E-01	2.75E-01	2.33E-01
370	4.12E-01	4.35E-01	4.29E-01	3.99E-01	3.66E-01	3.16E-01	2.76E-01	2.41E-01	2.08E-01
420	2.91E-01	3.13E-01	3.18E-01	3.07E-01	2.85E-01	2.60E-01	2.33E-01	2.07E-01	1.84E-01
470	2.17E-01	2.35E-01	2.42E-01	2.40E-01	2.29E-01	2.13E-01	1.96E-01	1.79E-01	1.61E-01

Radiation dose of the front TC horizontal door (pSv/sec)

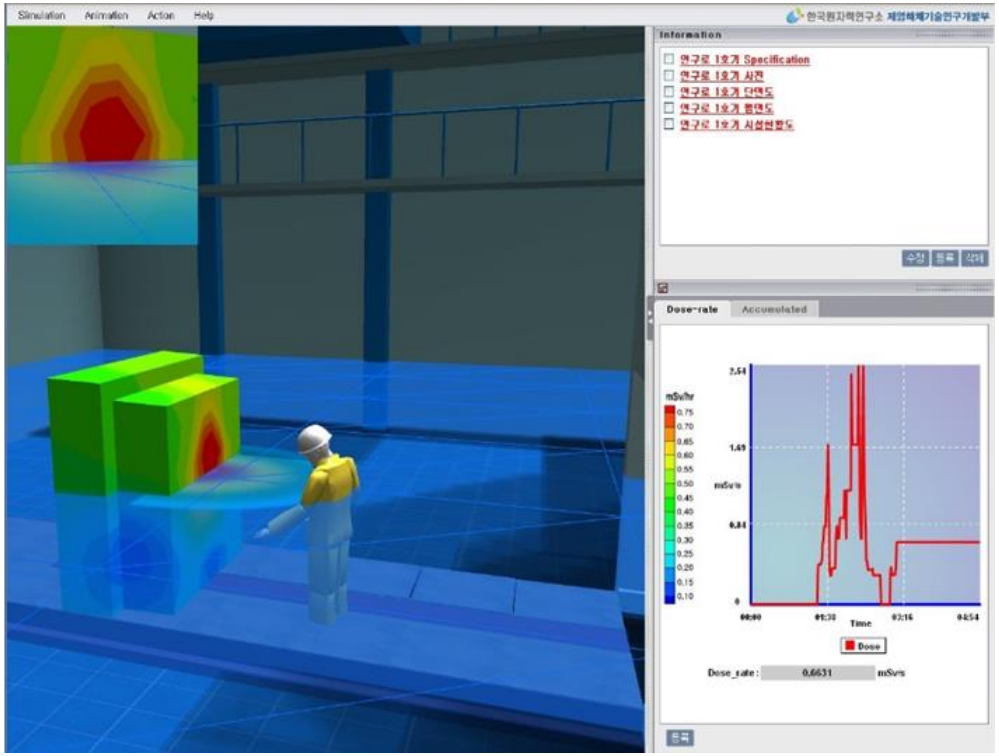
Simulation of worker's external exposure dose in real time

- Activity range: transform radiation value into 3-coordination
- Matching the radiation dose to the dismantling area of the worker
- Program of expressing dynamic graph using Java Script Function and Action Script

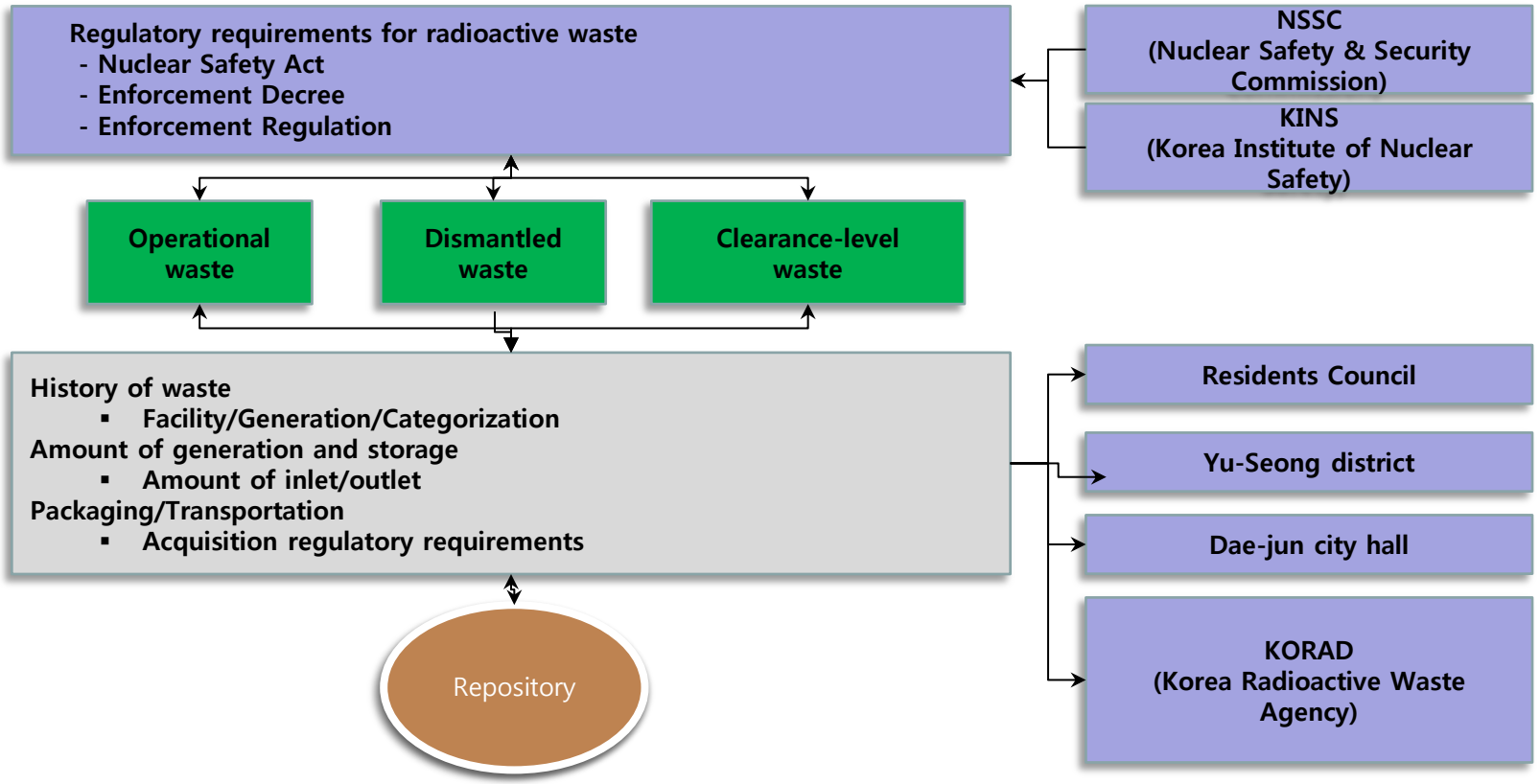
Modeling & Simulation

Scenario of worker's dismantling activities

- Pulls out graphite bundle
  - Work range: start location(-36, -26, -18), left upper(-4, -2, -18), left lower(-10, -2, -18), right upper(-4, -6.8, -18), right lower(-10, -6.8, -18)
  - exposure dose rate from gamma ray per hour in real time
  - Expose dose rate: 0.6631 mSv/hr



RAW Integrated Management System



Aging radioactive waste information management systems

- cannot guarantee the prevention of uncertainty and theft of radioactive waste
- require core technologies

RAW Workflow

Generation of RAW

- Request drums
- Specimen & nuclide analysis
- Packaging of drums

RAW facility

- Carry-out/in information
- Worker access information
- Drums & containers

RAW process

- Reclassification
- Volume reduction
- Repackaging of drums

RAW characterization

- Characterization
- Specimen & nuclide analysis
- Characterization of drums

Transportation of RAW

- Acceptance requirements
- Evaluation of suitability of disposal

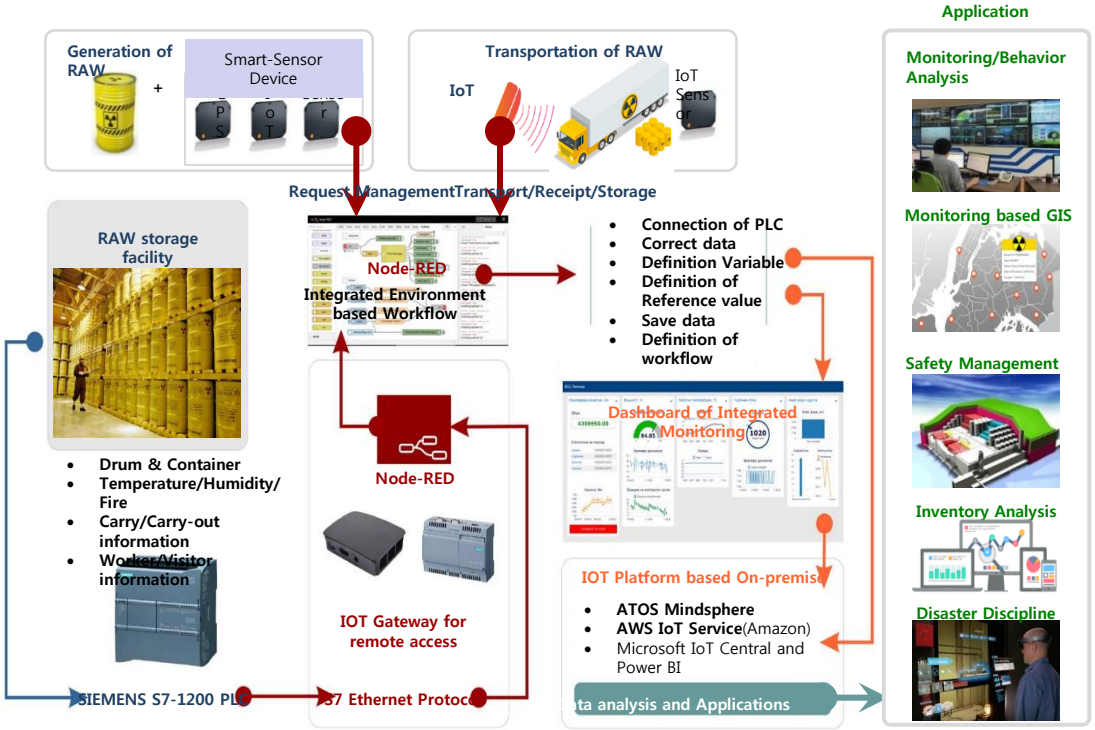
RAW repository

Data analysis and application

Safety management of RAW

- Configuration management
- Inventory evaluation & estimation
- Transportation monitoring
- Maintenance & disaster response

Cutting-edge Technologies



Tracking of RAW based on IoT
- Smart sensor devices
- Paths of movement
- Location of drums and reclassification of wastes
- Trace the flow of wastes

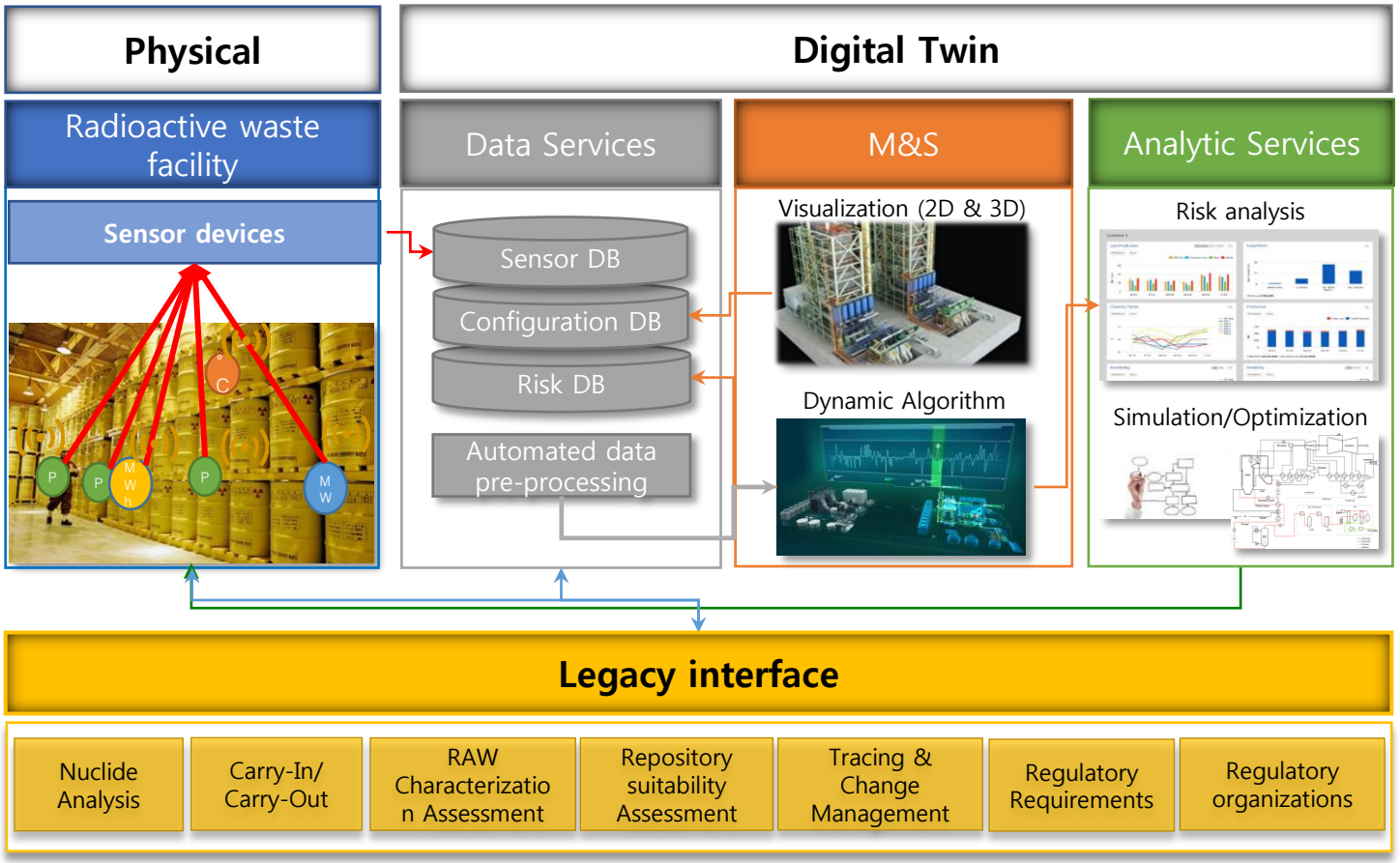
AR/VR Simulator
- Prior to disciplining accidents
- Enhance the safety consciousness of RAW

Digital-based RAW safety Platform
- Monitor the storage facilities and drum
- Strengthen the security

Digital Twin-based RAW Safety Platform

Monitoring of facilities and drums

- Radiation controlled area and carry-in/out
- Combining simulated waste operation with actual virtual reality
- Requirements: physical model, subsystem information, simulation, dynamic algorithms

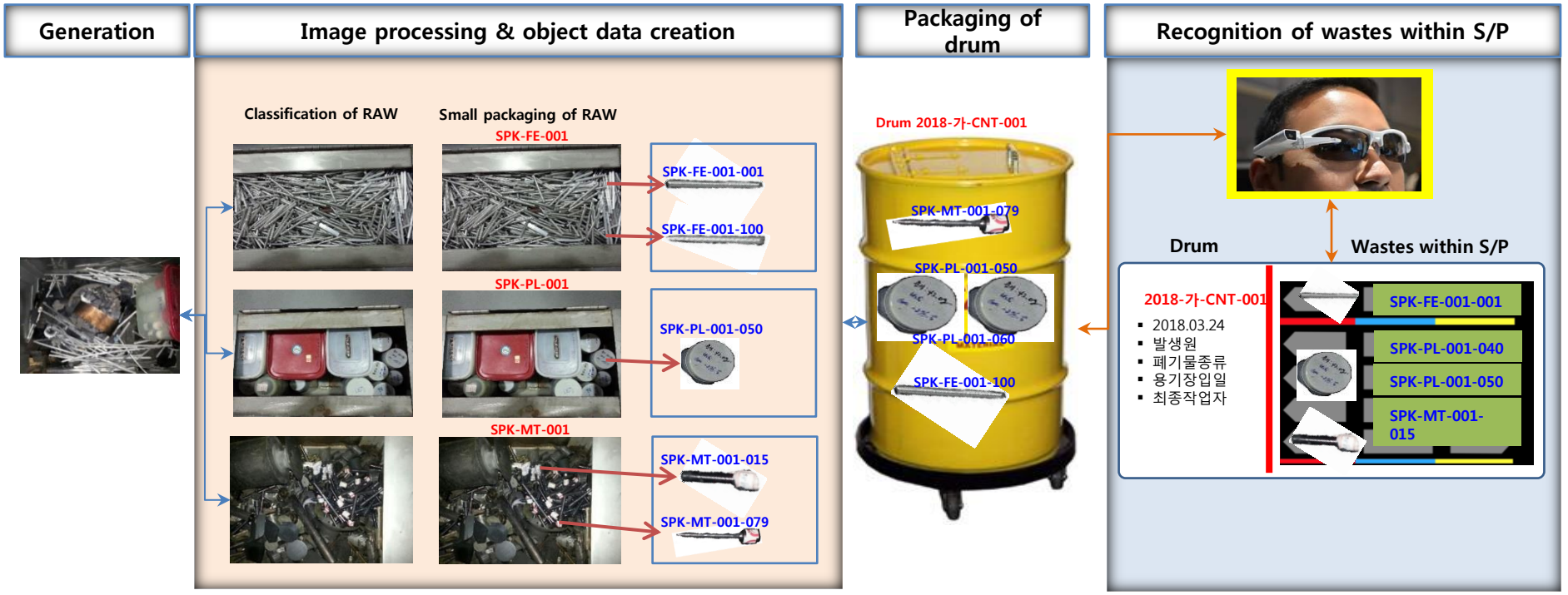


RAW Object Recognition

Waste information in drum

Object recognition based on AR

- Implementation of library and extraction of characteristic value to train M/L algorithm
- Enter characteristic value and mounted on devices and perform object recognition by inference
- Extract and visualization of RAW information from AR DB using recognized results



Conclusion

ICT-based nuclear safety innovative technology

- IoT/VR(AR)/AI/Big data/Block Chain
- Safety platform
  - ✓ Intelligent Nuclear safety operation support system
  - ✓ Nuclear facility dismantling process optimization technology
  - ✓ Radioactive waste safety management

Sharing technologies and Cooperation

Advanced methods for KM, training and education for nuclear decommissioning

- Decommissioning
- Radioactive waste management
- Site remediation

Thank you for your attention..!