울산과학기술원
ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

Preliminary Radioactive Contamination Assessment for Decommissioning on Kori unit 1 Bioshield

Korea Nuclear Society Autumn Meeting

Donghyun Lee, Hee Reyoung Kim

calvinj1@unist.ac.kr

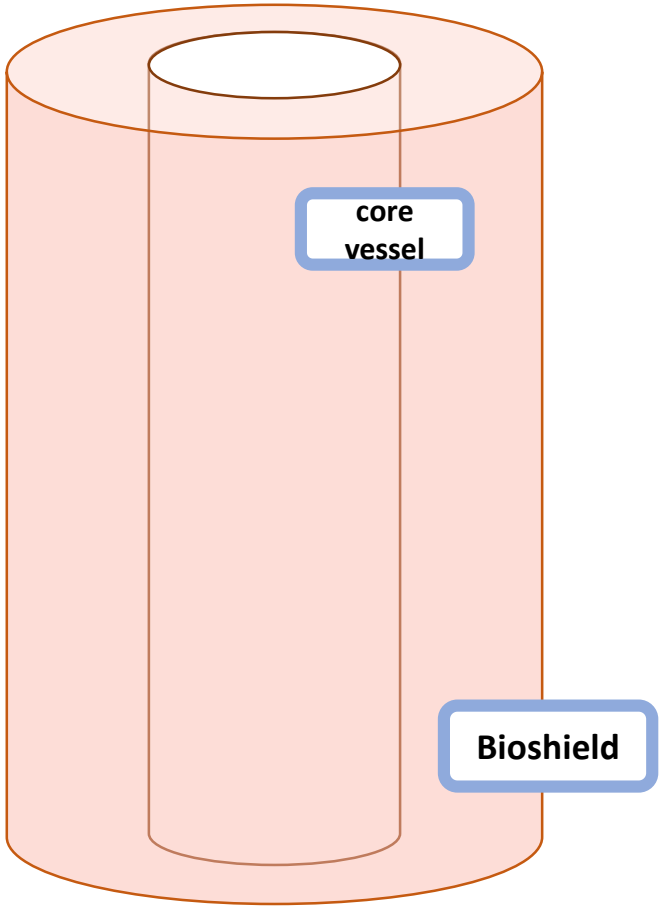
Outline

- **Introduction**
  - Nuclear power plant bioshield concrete structure
  - Research object
  - Research implementation strategy
- **Case study on similar foreign nuclear power plants**
  - Comparison on nuclear power plants decommissioning and decontamination environment
  - Literature review on radioactive nuclide kind/ concentration assessment
- **Assessment on bioshield activation**
  - Simplification of 3D geometry
  - Reactor vessel division cell material properties
  - Targeting major radioactive nuclide of interest
  - MCNP6 based activation assessment
- **Bioshield activation distribution analysis**

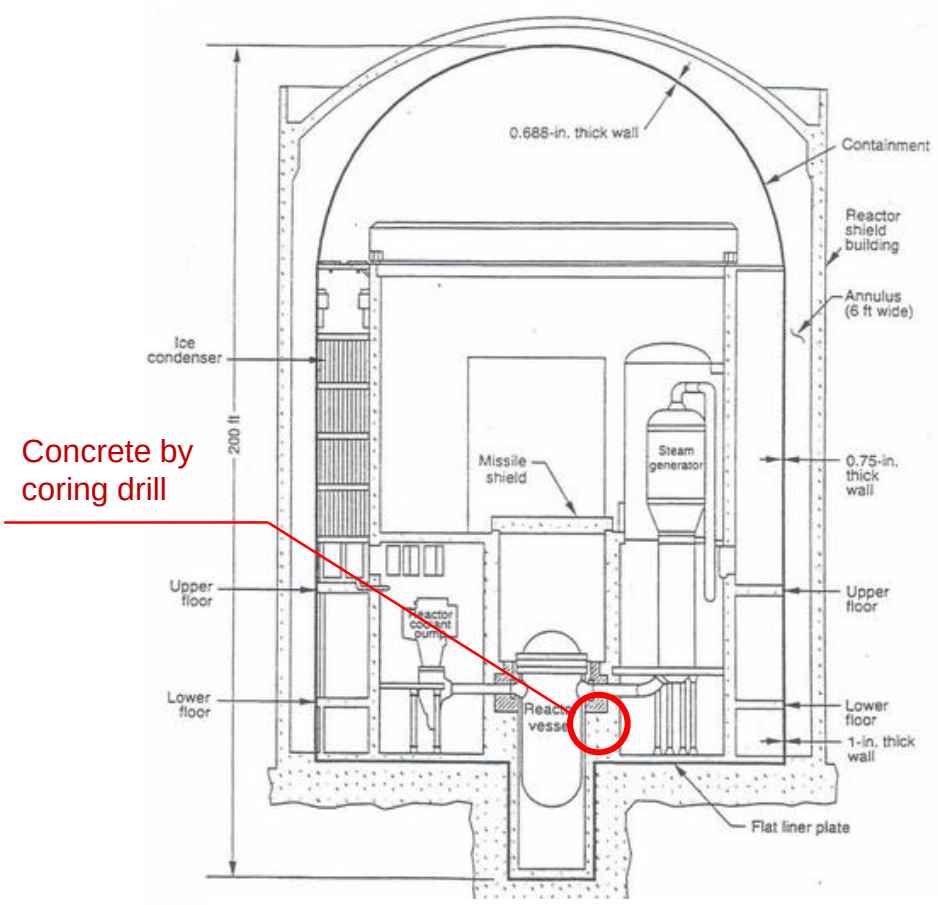
Introduction

Nuclear power plant bioshield concrete structure

- Kori1. N.P.P. reactor vessel 3D geometry-simplification



[Fig1. Kori unit 1 reactor vessel 3D geometry]

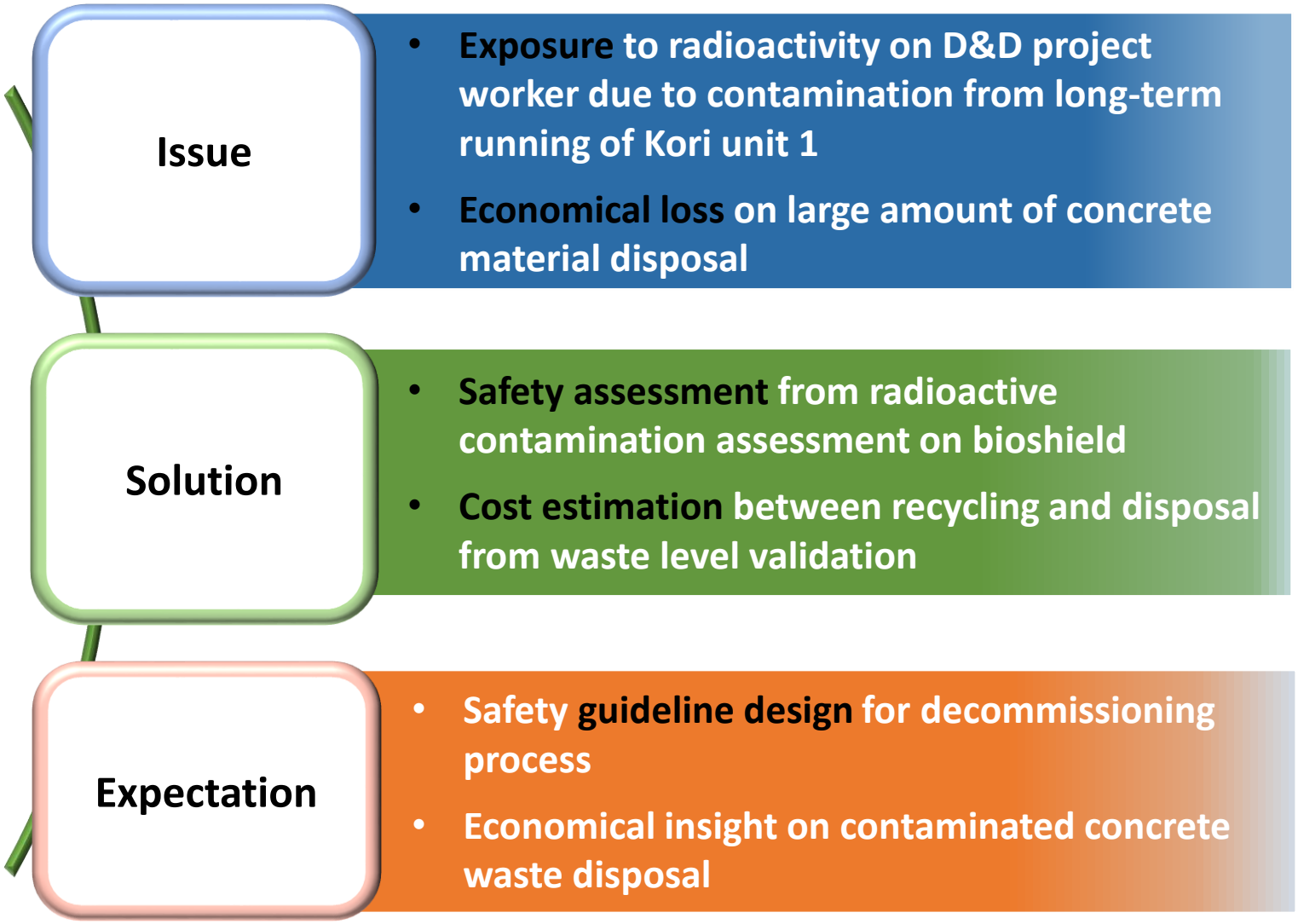


[Fig2. PWR reactor vessel blueprint]

[KAERI-Material Data Portal for Nuclear Application "http://mdportal.kaeri.re.kr/materials-safety/degradation-lwr/degradation-lwr-rpv/132-d20120058"]

Introduction

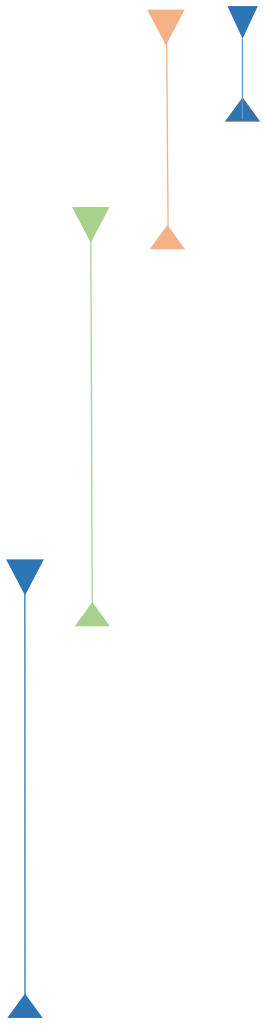
Research object



Introduction

Research implementation strategy

1st year



- **NPP D&D project case study**
  - IAEA technical report
  - Trojan (US): Pressure vessel , Kewaunee (US)
- **Targeting major radioactive nuclei**
  - Internal/ External exposure rate compare
  - ^{60}Co (^{152}Eu and ^{154}Eu)
- **Analyzing neutron flux distribution**
  - Source term: Volumetric, Watt fission spectrum
  - Thermal Neutron Flux Distribution (MCNP6)
- **Assessment on radioactivity**
  - Cross check with case study
  - GS heavy metal technical report case study
- **Verification on radioactivity result**
  - NEREG/CR NRC Technical report reference
- **Assessment on result uncertainty**
  - Assessment result reliability verification

Case study on similar foreign nuclear power plants

Benchmarking based on previous research

- Former NPPs

[Table1. Foreign PWR nuclear power plants]

Plant name	Reactor type	Power (Mw(e))	Operation period (EFPY) (y)	Bioshield range (m)
Kori 1	PWR	576	40 (27.4)	3.16-5.30
Trojan	PWR	1095	16 (9)	3.08-5.03
Kewaunee	PWR	556	39 (21.9)	2.08-
Connecticut Yankee	PWR	560	28	
Rancho Seco	PWR	913	14 (6)	3.94-4.61
Shippingport	PWR	72	26 (12)	
Yankee-Rowe	PWR	167	31	
San onofre	PWR	436	24	
Indian Point 1	PWR	257	10	
Three Mile Island	PWR	792	2	

Lack of design parameters

※EFPY (Effective Full Power Years)

[Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purpose, IAEA, Technical Reports Series No.389, 1998]

Case study on similar foreign nuclear power plants

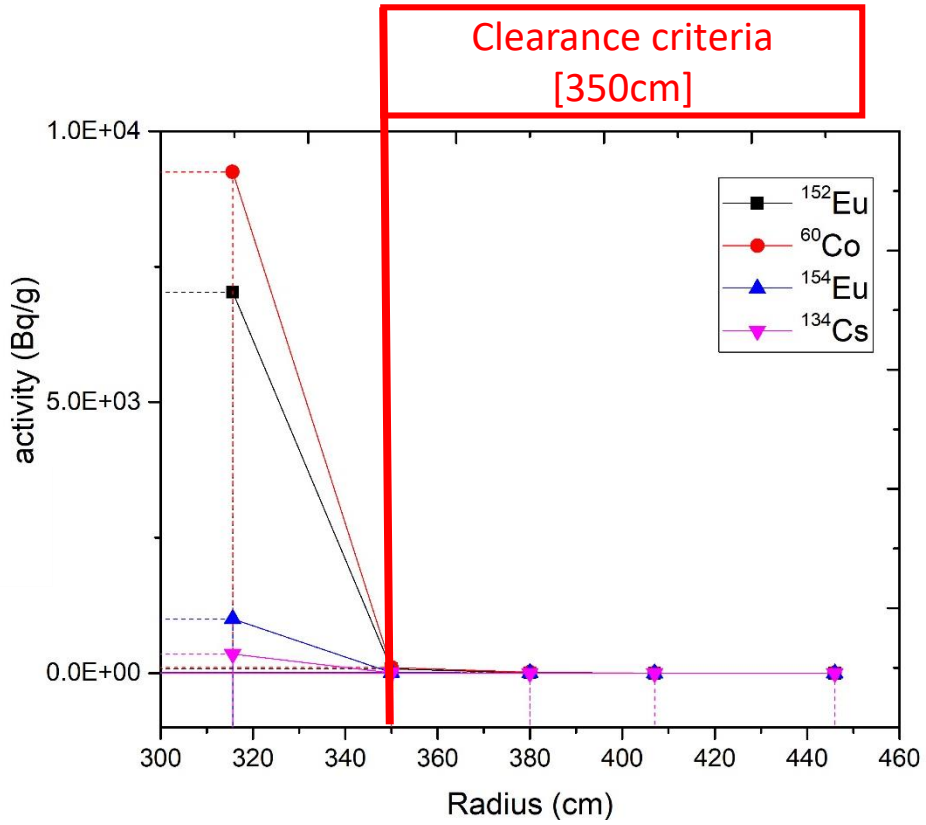
Literature review on similar nuclear power plant

- Trojan nuclear power plant

[Table2. Trojan nuclear power plant activation history]

	30 EFPY (Effective Full Power Year)		
Cooling time	0 years	10 years	100 years
Core shroud	1.13E+17	9.32E+15	1.66E+15
Core barrel	2.17E+16	1.79E+15	3.19E+14
Thermal shield	4.82E+15	3.98E+16	7.09E+13
Vessel cladding	4.20E+13	3.47E+12	6.17E+11
Vessel wall	4.33E+14	3.15E+13	9.92E+11
Upper grid plate	8.03E+14	6.62E+13	1.18E+13
Lower grid plate	1.82E+16	1.50E+15	2.68E+14
Bioshield	4.45E+13	2.89E+13	6.12E+11
Containment	1.80E+14	2.88E+13	6.12E+11
Totals	1.59E+17	1.31E+16	2.33E+15

Sample location(cm)	Radioactivity level in Bq/g			
	^{60}Co	^{152}Eu	^{154}Eu	^{134}Cs
315.6	7.03E+03	9.25E+03	9.99E+02	3.52E+02
350	8.14E+01	1.04E+02	1.04E+01	1.85E+00
380	1.15E+00	1.70E+01	2.04E+00	2.78E-01
407	2.11E-01	2.96E-01	3.37E-02	7.40E-03
446	7.03E-03	8.51E-03	None	None



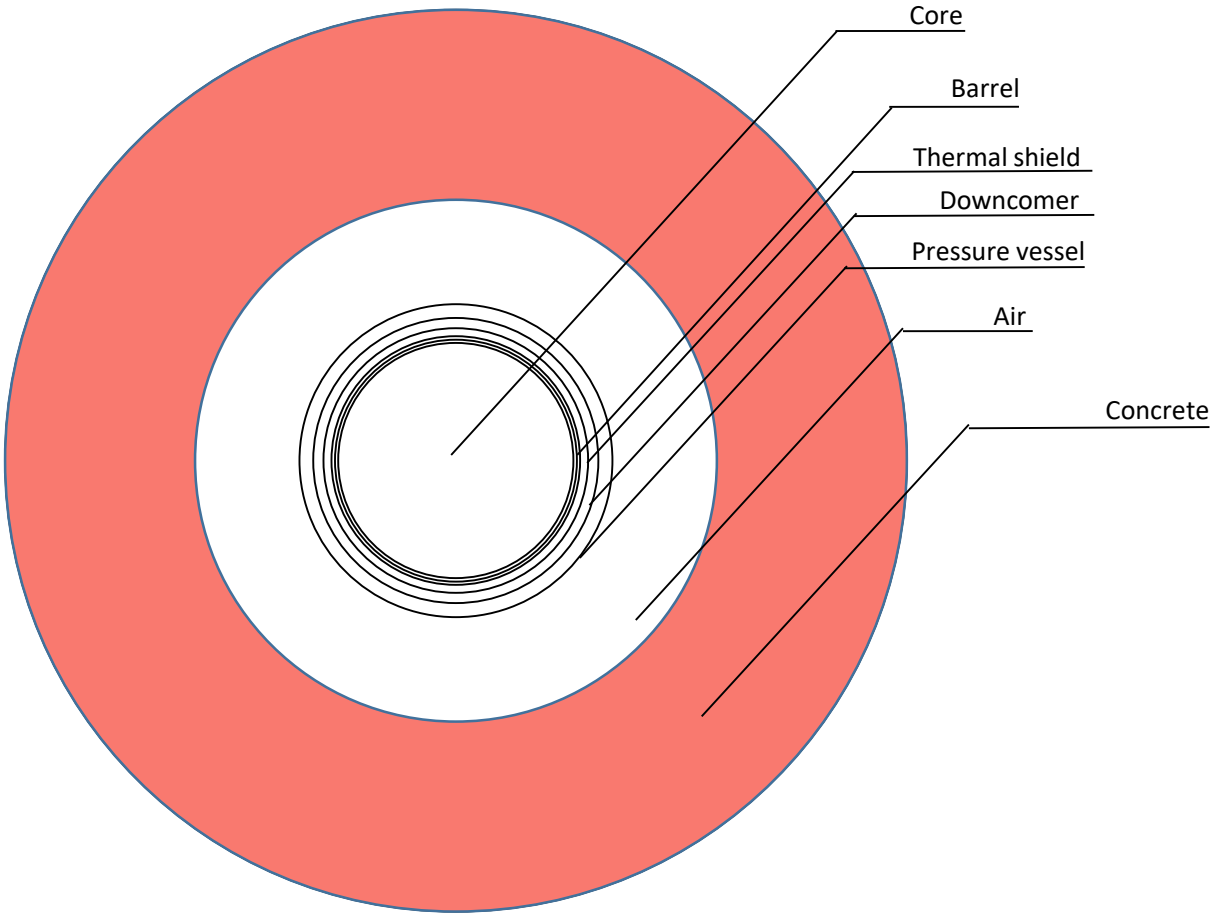
[Fig 3. Trojan nuclear power plant activation degree]

[Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purpose, IAEA, Technical Reports Series No.389, 1998]

MCNP6 modeling scheme

3D geometry modeling

- Kori1. N.P.P. reactor vessel 3D geometry



[Fig4. Kori 1 3D geometry (top view, cm)]

[Table2. Kori1. Cell geometry]

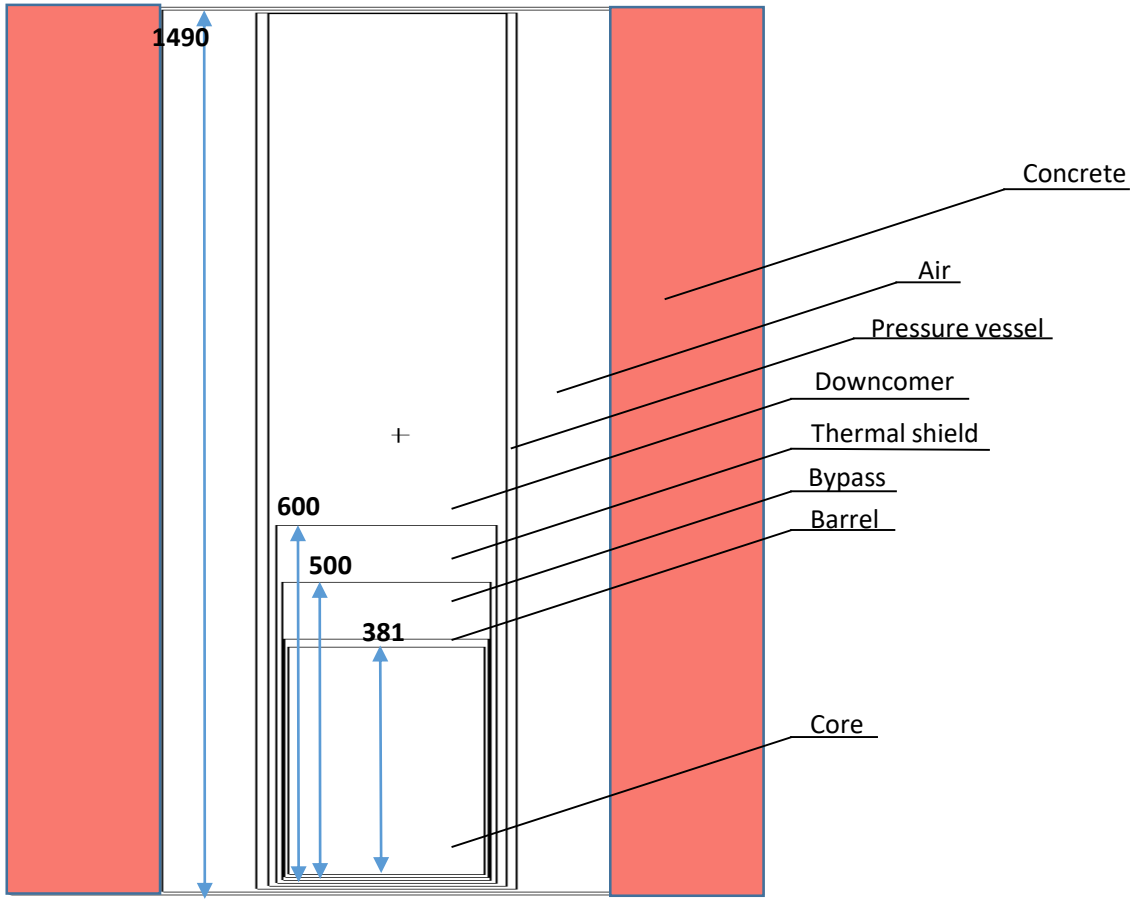
Cell	Distance from the core (cm)
Core	138
Barrel	142
Bypass	146
Thermal shield	155
Downcomer	167
Pressure vessel	184
Air	316
Concrete	530

[Kyung-Jin Lee(2003), "Preliminary Estimation of Activation Products Inventory in Reactor Components for Kori unit 1 decommissioning", J. Korea Asso, Radiat, Prot. Vol. 28 No. 2: 109-116]

MCNP6 modeling scheme

3D geometry modeling

- Kori1. N.P.P. reactor vessel 3D geometry



[Fig5. Kori 1 3D geometry (side view, cm)]

[Table3. Kori1. Cell material]

Structure	Medium
Core	UO_2, Pu, H_2O, Zr
Barrel	304 stainless steel
Bypass	H_2O
Thermal shield	304 stainless steel
Downcomer	H_2O
Pressure vessel	Carbon steel
Air	Air
Concrete	Concrete

[KEPCO-ENC. (2017). "Business/R&D_ Nuclear Power_ OPR1000" https://www.kepco-enc.com/eng/contents.do?key=1532 (accessed June 13, 2017)]

MCNP6 modeling scheme

Reactor vessel input design

- Kori1. NPP reactor vessel nuclei concentration data base

[Table4. Kori NPP unit 1 reactor vessel structural nuclei concentration]

Nuclide	Mass number	Core		Stainless steel		Pressure vessel		Bypass Downcorner(water)		Concrete		air	
		Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
^{235}U	235	1.15E-04	4.50E-26										
^{238}U	238	6.64E-03	2.63E-24										
^{239}Pu	239	3.70E-05	1.47E-26										
^{240}Pu	240	8.86E-06	3.53E-27										
^{241}Pu	241	3.57E-06	1.43E-27										
^{1}H	1	2.76E-02	4.59E-26					4.83E-02	8.02E-26	7.41E-03	1.23E-26		
^{16}O	16	2.68E-02	7.13E-25					2.41E-02	6.42E-25	4.21E-02	1.12E-24	1.05E-03	2.79E-26
^{10}B	10	2.30E-06	4.E-29					4.31E-06	7.15E-29				
^{11}B	11							1.77E-05	3.23E-28				
^{27}Al	27	1.13E-06	5.05E-29							2.28E-03	1.02E-25		
^{12}C	12	3.57E-06	7.11E-29	3.17E-04	6.32E-27	8.67E-04	1.73E-26					7.49E-07	1.49E-29
^{28}Si	28			1.69E-03	7.88E-26	4.38E-04	2.04E-26			1.52E-02	7.09E-25		
^{50}Cr	50	5.51E-07	4.58E-29	7.56E-04	6.28E-26	1.27E-05	1.05E-27						
^{52}Cr	52	1.06E-05	9.17E-28	1.46E-02	1.26E-24	2.44E-04	2.11E-26						
^{53}Cr	53	1.21E-06	1.06E-28	1.65E-03	1.45E-25	2.77E-05	2.44E-27						
^{54}Cr	54	3.00E-07	2.69E-29	4.11E-04	3.69E-26	6.89E-06	6.18E-28						
^{55}Mn	55	2.16E-06	1.97E-28	1.73E-03	1.80E-50	5.43E-06	4.96E-28						
^{54}Fe	54	3.60E-06	3.23E-28	3.44E-03	3.09E-25	4.86E-03	4.36E-25						
^{56}Fe	56	5.60E-05	5.21E-27	5.35E-02	4.98E-24	7.55E-02	7.02E-24			2.98E-04	2.77E-26		
^{57}Fe	57	1.28E-06	1.21E-28	1.23E-03	1.16E-25	1.73E-03	1.64E-25						
^{58}Fe	58	1.71E-07	1.65E-29	1.63E-04	1.57E-26	2.31E-04	2.22E-26						
^{58}Ni	58	9.91E-05	9.55E-27	5.10E-03	4.92E-25	4.01E-04	3.86E-26						
^{60}Ni	60	3.08E-05	3.07E-27	1.97E-03	1.96E-25	1.54E-04	1.54E-26						
^{61}Ni	61	1.66E-06	1.68E-28	8.55E-05	8.66E-27	6.71E-06	6.80E-28						
^{62}Ni	62	5.52E-06	5.68E-28	2.72E-04	2.81E-26	2.14E-05	2.20E-27						
^{64}Ni	64	1.35E-06	1.43E-28	6.94E-05	7.38E-27	5.45E-06	5.79E-28						
^{96}Mo	96					2.81E-04	4.48E-26						
^{91}Zr	91	4.52E-03	6.83E-25										
^{23}Na	23									1.00E-03	3.82E-26		
^{24}Mg	24									1.42E-04	5.65E-27		
^{32}S	32									5.38E-05	2.86E-27		
^{39}K	39									6.61E-04	4.28E-26		
^{40}Ca	40									2.78E-03	1.85E-25		
	Total	6.60E-02	4.15E-24	8.70E-02	7.74E-24	8.48E-02	7.81E-24	7.24E-02	7.22E-25	7.20E-02	2.24E-24	1.05E-03	2.79E-26
	Density		4.15		7.74		7.81		0.722		2.24		0.0279

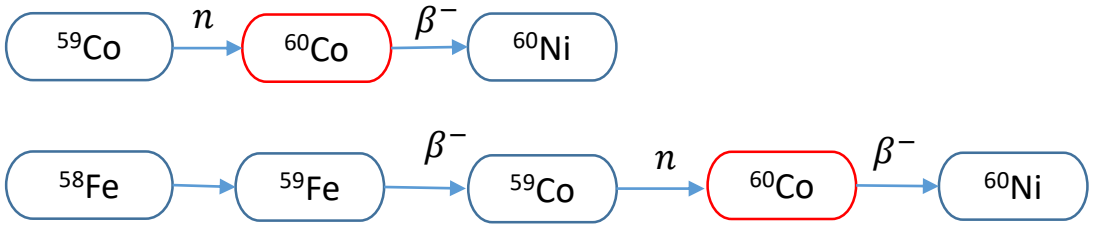
- **MCNP6 input**
  - Weight fraction
  - Atom density fraction
  - Structural density
  - Structural volume

[Kyung-Jin Lee(2003), "Preliminary Estimation of Activation Products Inventory in Reactor Components for Kori unit 1 decommissioning", J. Korea Asso, Radiat, Prot. Vol. 28 No. 2: 109-116]

Activation degree analysis

Targeting major radioactive nuclide

- Target radioactive nuclei selection
  - Selection criteria (^{60}Co)
    - Major long-living γ radiation nuclei
    - Relatively simple decay chain
    - Assumption: Large impurity



[Table5. Former radioactive nucleus on bioshield]

Nuclide	Half life (yr)	Radioactivity (Bq/g)	After shutdown (yr)			
			10	30	50	100
^{51}Cr	0.07	1.50E+02				
^{54}Mn	0.85	3.20E+02	4.20E-07			
^{55}Fe	2.737	5.10E+03	1.70E-03	9.90E-06	5.70E-08	
^{59}Fe	0.12	1.90E+02				
^{58}Co	0.19	1.60E+03				
^{60}Co	5.27	1.70E+04	2.00E-02	1.40E-03	1.00E-04	1.40E-07
^{89}Sr	0.14	2.60E+00				
^{90}Sr	28.79	9.30E+01	5.40E-04	3.40E-04	2.10E-04	6.30E-05
^{90}Y	0.007	9.30E+01	5.40E-04	3.40E-04	2.10E-04	6.30E-05
^{95}Zr	0.18	5.70E+01				
^{95}Nb	0.09	5.70E+01				
^{129m}Te	0.09	6.90E+01				
^{131}I	0.02	3.10E+03				
^{134}Cs	2	2.70E+04	4.10E-03	4.80E-06	5.40E-09	
^{136}Cs	0.04	2.50E+02				
^{137}Cs	30	1.70E-01	5.90E-01	3.70E-01	2.40E-01	7.40E-02

Activation degree analysis

Targeting major radioactive nuclide

- Radioactive decay with production (time dependence)
  - $\frac{dn(t)}{dt} = \sigma * \phi * capacitiy\ factor - \lambda n(t)$
  - rate of production - rate of loss
  - $n(t)$: number of nucleus on time t
  - σ : microscopic cross section
  - ϕ : neutron flux
  - $capacity\ factor$: 0.9 (40 year)
  - λ: decay constant ($\frac{ln2}{half\ life}$)
  - $n(t) = \frac{R}{\lambda}\left(1 - e^{-\lambda t}\right)$

[Table6. Assumed radioactive nucleus on bioshield]

Element	Weight Fraction	Weight (g)
H	0.006	13.8
C	0.175	402.4
O	0.41	942.75
Mg	0.033	75.88
Al	0.11	25.29
Si	0.035	80.48
K	0.001	2.3
Ca	0.321	738.11
Fe	0.008	18.4
Eu	2.94E-07	6.77E-04
Co	2.55E-06	5.86E-03
Total		2299.4
Density	2.2994 g/cc	

[" Radioactive structure decommissioning assessment system development", GS, 2015.10.31]

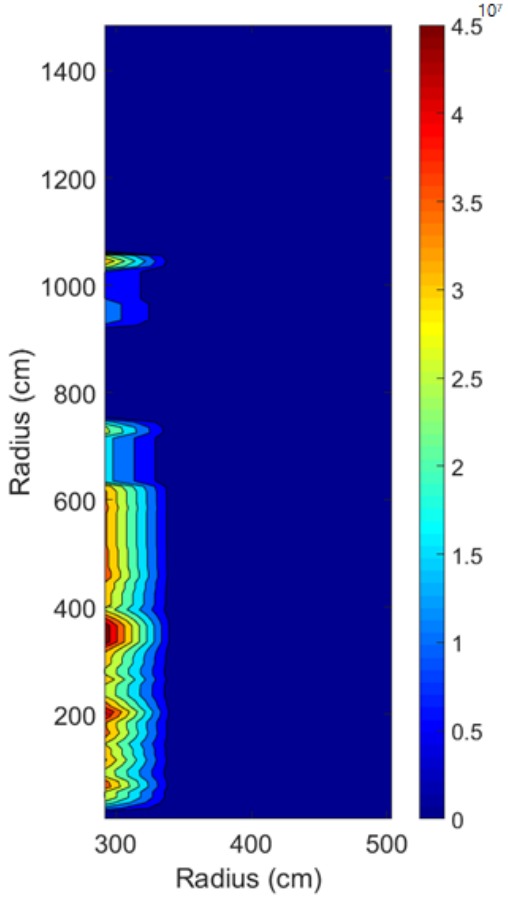
Results and discussion

Bioshield activation assessment

- Average cell neutron flux distribution (#/cm^{2}sec)
  - Max: 4.62E+07
  - Min: 6.54E-45
  - Space: Non detected

[Table7. ^{60}Co neutron flux distribution]

	291.5	344.5	397.5	450.5	503.5	Radius (cm)
1485-1375	2.62E-20	3.44E-26	2.39E-38	0.00E+00	0.00E+00	
1375-1255	3.98E-18	6.10E-22	8.39E-49	0.00E+00	0.00E+00	
1255-1135	1.72E-14	2.08E-14	0.00E+00	0.00E+00	0.00E+00	
1135-1015	3.15E+02	1.87E-16	0.00E+00	0.00E+00	0.00E+00	
1015-895	9.91E+00	5.33E-13	0.00E+00	7.60E-29	1.21E-24	
895-775	5.59E-07	6.48E-09	6.11E-23	2.98E-21	1.23E-16	
775-655	1.06E+02	4.12E+01	3.87E-16	7.38E-13	1.32E-12	
645-535	3.55E+03	2.04E+00	6.31E-11	2.84E-10	5.25E-10	
535-415	4.47E+03	8.65E+00	1.64E-07	1.60E-07	1.57E-07	
415-295	2.69E+04	1.92E+02	9.22E-06	3.94E-08	3.00E-08	
295-175	7.37E+03	1.90E+03	1.21E-04	2.22E-07	1.84E-07	
175-5	2.20E+03	4.38E+02	4.13E-03	6.34E-06	1.07E-07	
Height (cm)						



[Fig6. Neutron flux distribution on Kori NPP unit 1]

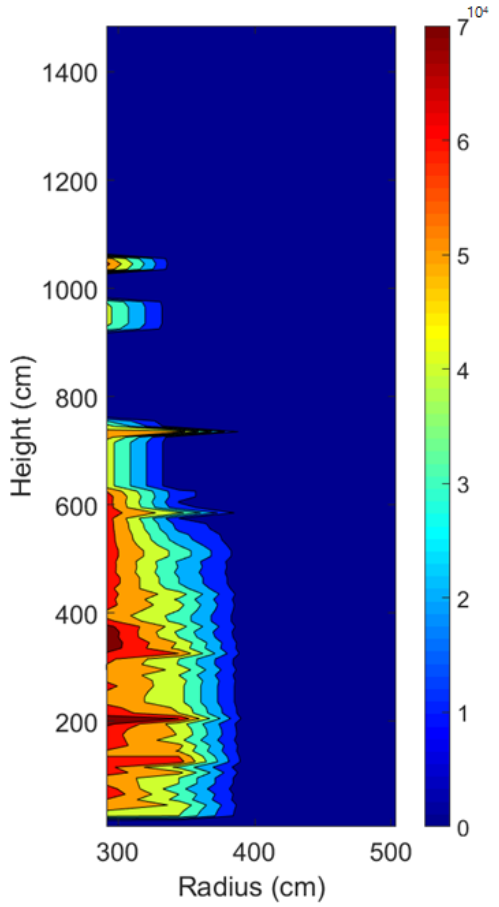
Results and discussion

Bioshield activation assessment

- ^{60}Co radioactivity distribution on Kori NPP Unit 1
  - Max: 7.11E+04 Bq/g
  - Min: 1.01E-47 Bq/g
  - Space: Not detected

[Table8. ^{60}Co radioactivity validation]

Distance (cm)	Kori-1 (Bq/g)	Trojan (Bq/g)	Difference Ratio (Trojan/Kori-1)
291.5	4.E+03	7.E+03	2.E+00
344.5	2.E+02	8.E+01	4.E-01
397.5	4.E-04	1.E+00	3.E+03
450.5	6.E-07	2.E-01	4.E+05
503.5	4.E-08	1.E-03	3.E+04

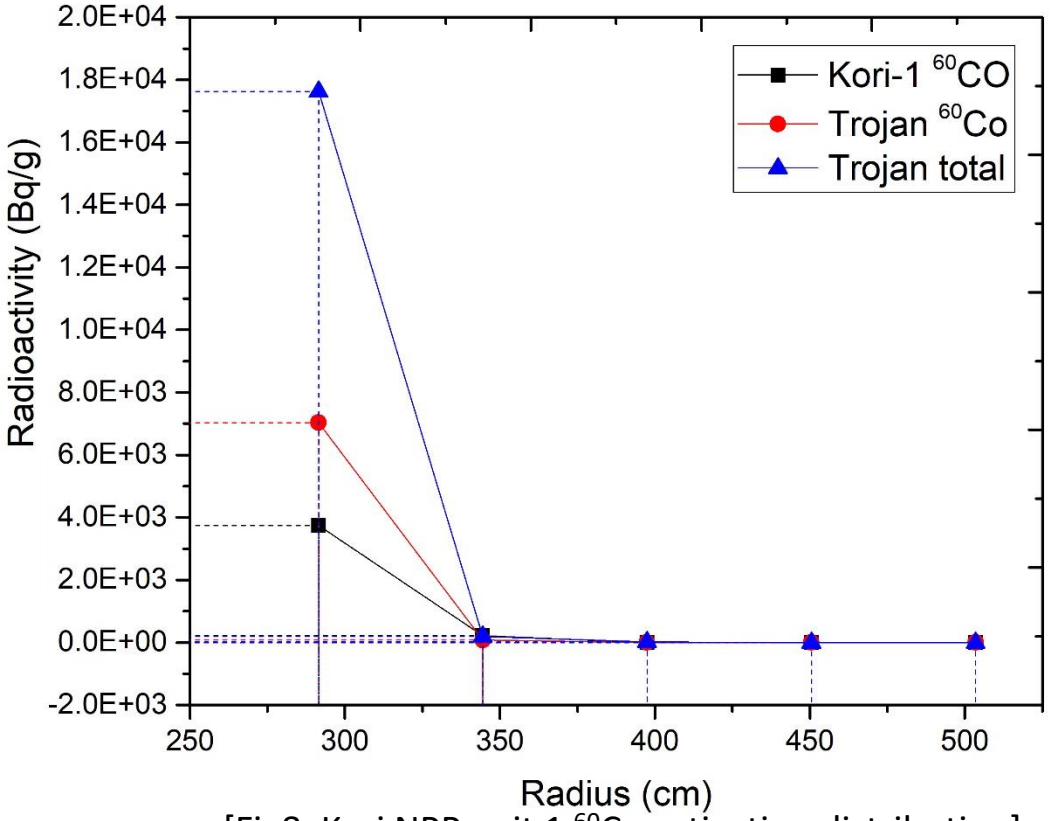


[Fig7. Activation distribution on Kori NPP unit 1]

Results and discussion

Bioshield activation distribution analysis

- Mesh average ^{60}Co Radioactivity on Bioshield region
  - Clearance criteria
    - KAERI/AR-800/2008 [1bq/g]: 70% volume
  - Clearance value
    - Radius range: 150cm (350cm - 500cm)
    - Height range: 470cm (1015cm - 1485cm)
    - Radius < Height



[Fig8. Kori NPP unit 1 ^{60}Co activation distribution]

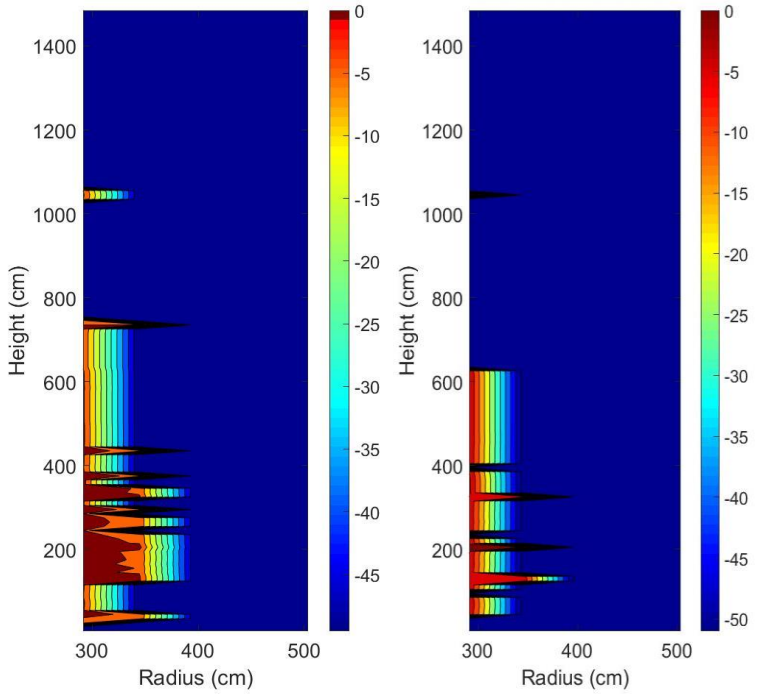
[Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purpose, IAEA, Technical Reports Series No.389, 1998]

Conclusion

Conclusion & Future plan

- Conclusion
  - ^{60}Co radioactivity distribution on Kori unit 1 Bioshield
    - Max: 7.11E+04 Bq/g
    - Min: 1.01E-47 Bq/g
    - Clearance volume: 70% (Further analysis required)

- Future plan
  - Multi nucleus decay system consideration
    - ^{152}Eu and ^{154}Eu
  - Geometry specification
    - Reinforcing bar modeling (Fe)
    - Concrete type (impurity concentration)



[Fig9. Extra radionuclide assessment ex)]