2024 5th ISPMNA
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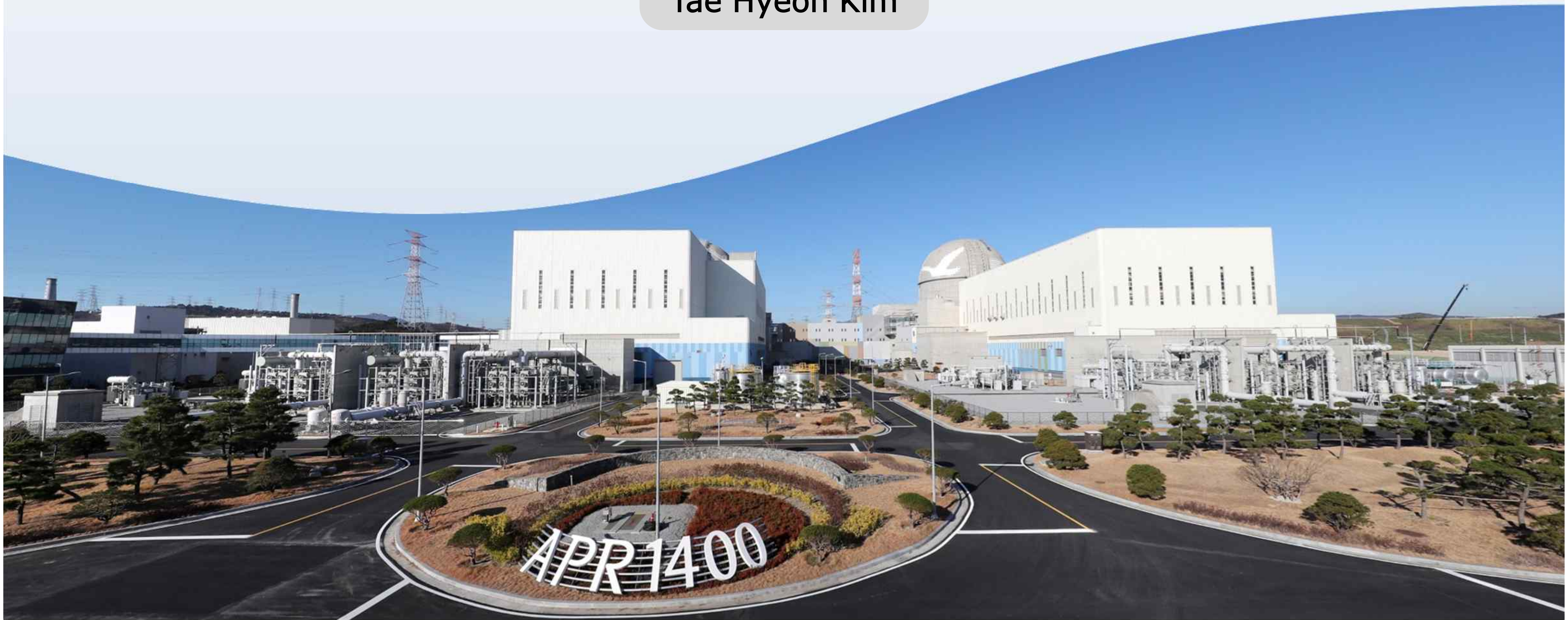
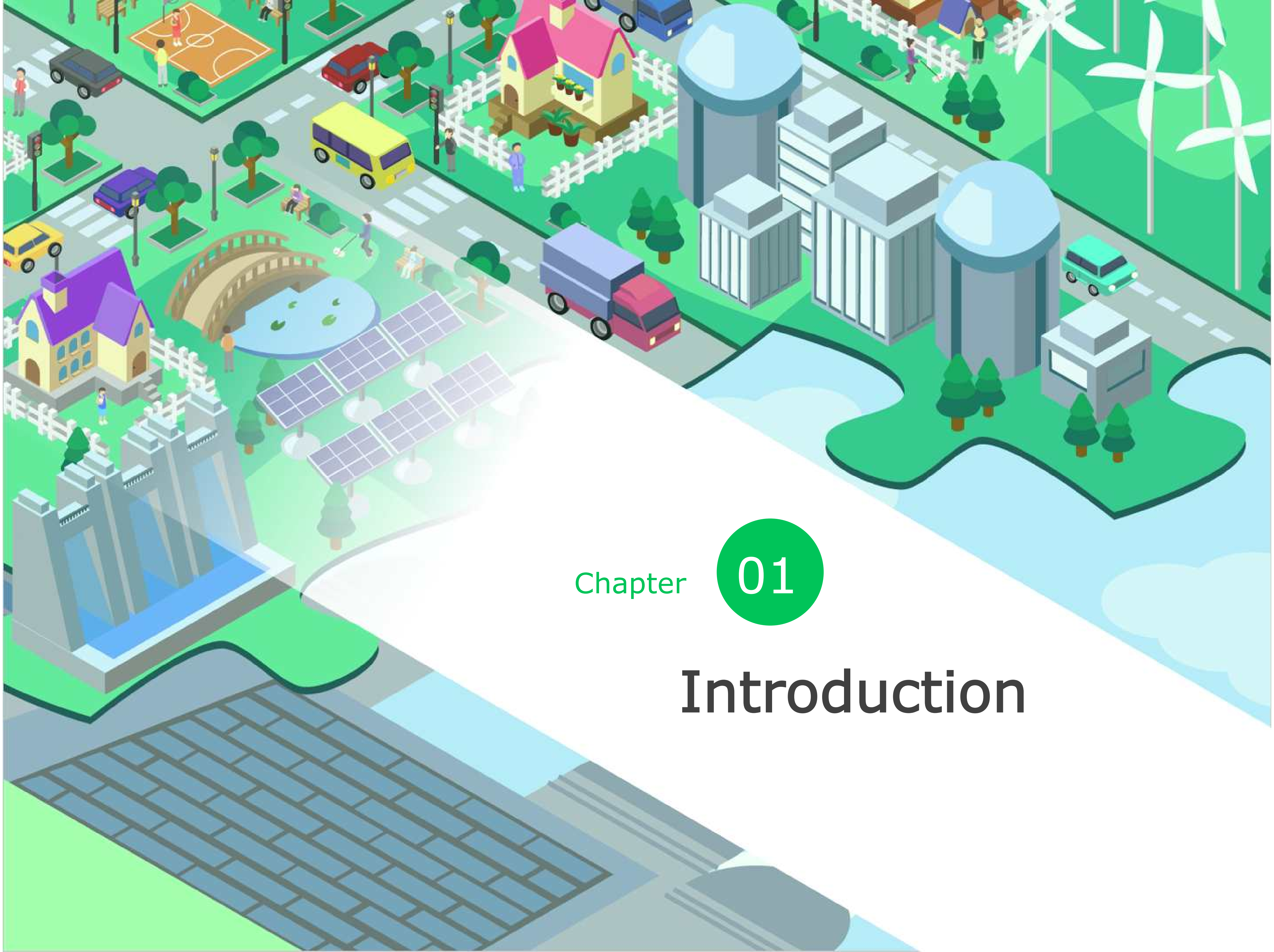
Application of Pipe Rupture Exclusion Methodology using PFM code for LBLOCA Reclassification

Tae Hyeon Kim



Love KHNP
Wonderful KHNP



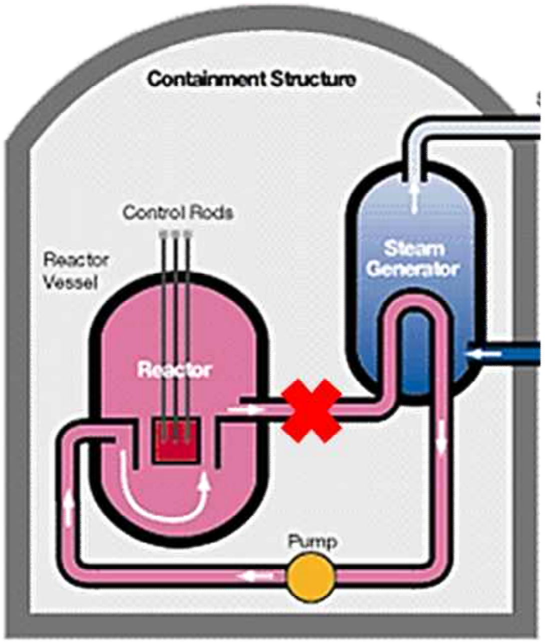
Chapter 01

Introduction

01. Overview of LOCA and LBB

Loss of Coolant Accident (LOCA)

- Postulated RCS pipe break resulting in loss of primary coolant
- Most severe design basis accident
- Depending on break size, classified as large break and small break LOCA
  - ✓ Maximum size : double-ended guillotine break (DEGB) of largest RCS pipe



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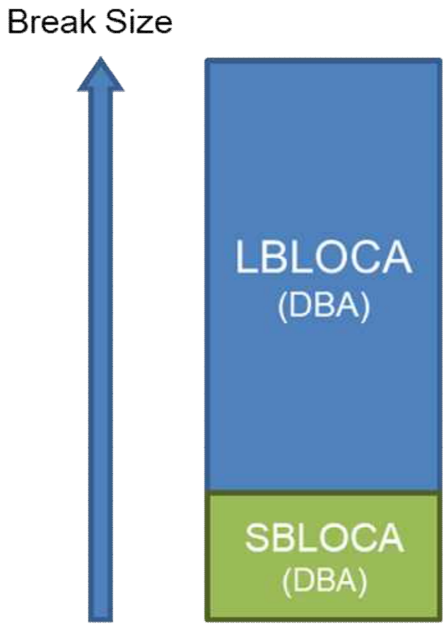
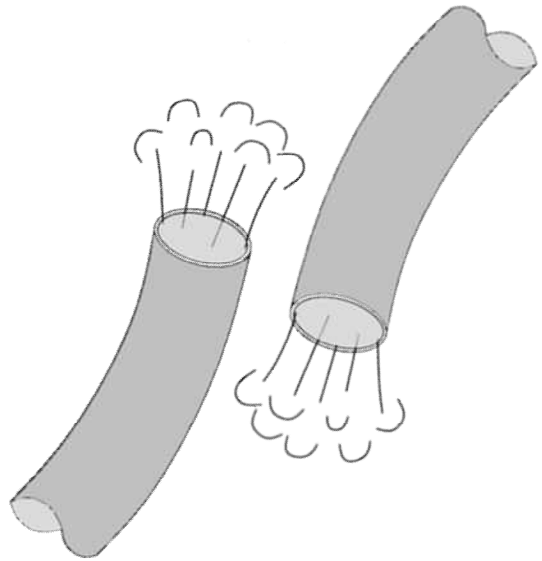


<LOCA Classification>



<Double–ended guillotine break>

01. Overview of LOCA and LBB

History of LOCA Regulation in US

- 2010, Risk informed ECCS(final rule, but not applied)
- 2016, Change oxidation criteria, 10CFR50,46c(draft final rule, but not applied)

Risk Informed ECCS Rule

- Define max. size of DBA LOCA : TBS(Transition Break Size)
- Breaks up to TBS : Use current analysis methods and assumptions
- Breaks larger than TBS : Realistic analysis
  - ✓ More realistic analysis methods and initial conditions
  - ✓ No loss of offsite power or worst single failure
- References
  - ✓ NUREG-1829, Estimating LOCA Frequencies Through the Elicitation Process, 2008
  - ✓ NUREG-1903, Seismic Considerations for the Transition Break Size, 2008
  - ✓ DG-1216, Plant-Specific Applicability of Transition Break Size Specified in 10CFR50.46a, 2010

01. Overview of LOCA and LBB

LBB (Leak Before Break) Concept

- Before pipe break, fluid leakage occurs
- By monitoring fluid leakage, through wall cracks in pipes can be detected before pipe break, preventing catastrophic pipe failure
  - ✓ Pipe break occurs when cracks in pipe grow and exceed certain critical size
  - ✓ Crack growth takes time. By detecting small cracks, reactor shutdown or pipe maintenance can be done before pipe break
  - ✓ RCS coolant leakage is detected by plant leakage detection system

01. Overview of LOCA and LBB

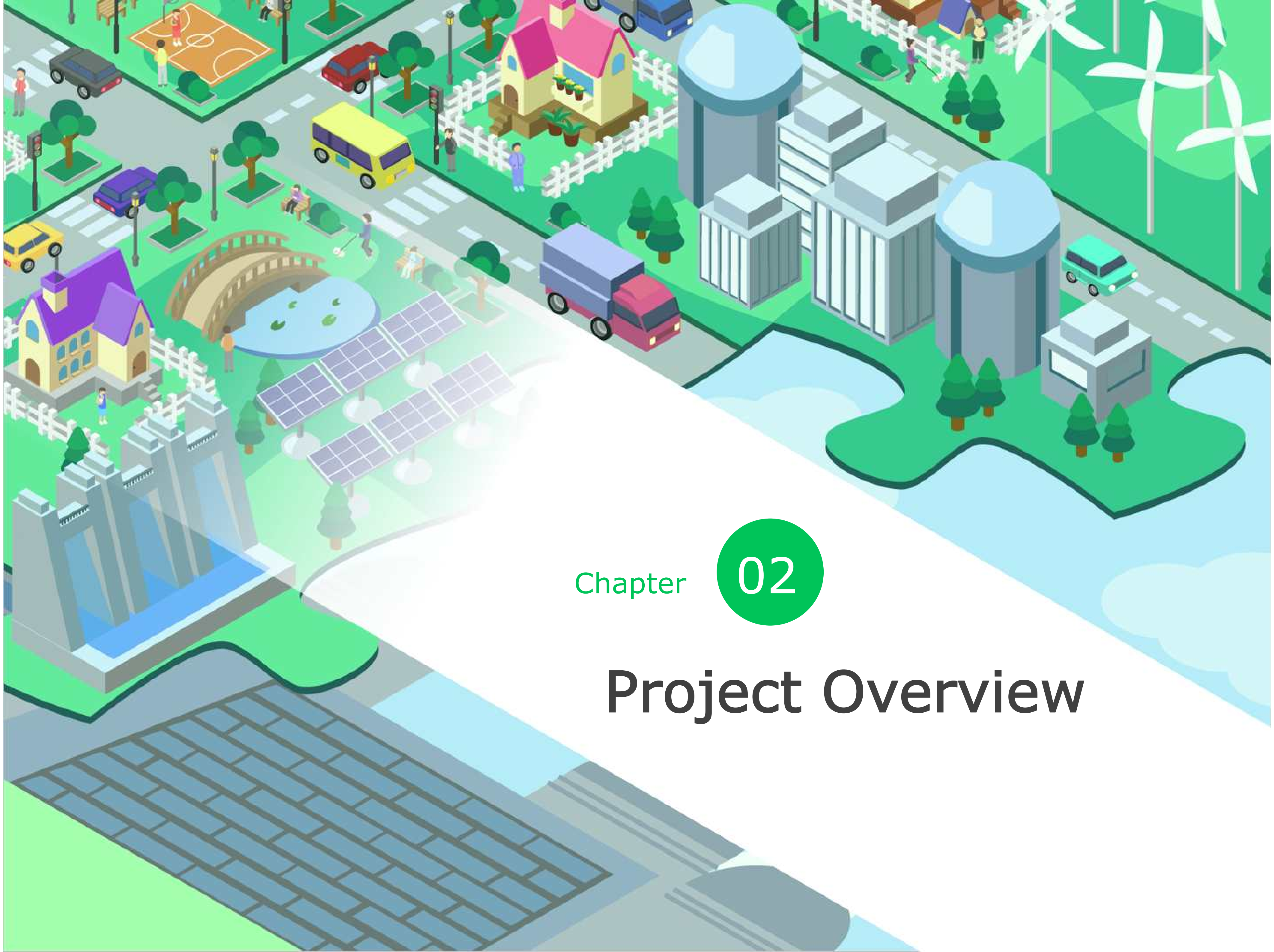
LBB Application

- Structural design
  - ✓ Eliminate dynamic forces associated with pipe break
  - ✓ Eliminate pipe whip restraints, jet barriers
- 10CFR50 App. A, GDC 4
  - ✓ Criterion 4 - Environmental and dynamic effects design bases
  - ✓ Revised in 1987 to allow LBB

> However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.

OPR1000 and APR1400

- LBB applied to main pipes in primary loop from the initial structural design
- Pipe whip restraints not needed



Chapter 02

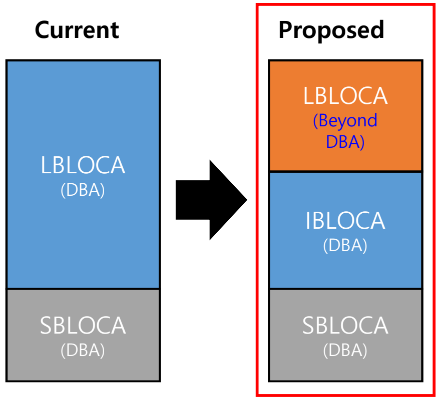
Project Overview

02. Project Overview

Need for reclassifying LOCAs and excluding DEGB from DBA

- Emerging issues due to revision of regulatory requirements for <u>Safety Analysis</u>
  - ✓ Consideration of impact on nuclear fuel relocation* and dispersal**
    - * When the RCS pressure is lowered due to the occurrence of <u>LBLOCA</u>, sintered pellet piece moves due to the pressure difference of inside and outside the fuel rod
    - ** The cladding is ruptured due to pressure difference of inside and outside the fuel rod and the sintered pellet pieces are lost
  - ✓ No problems within the upper limit of duty of operating NPP, but expected when duty increases

- Reclassification of LOCA
  - ✓ Probability of double-ended guillotine break is extremely low
  - ✓ Divide current LBLOCA to LB and IBLOCA(Intermediate Break)
  - ✓ Change new LBLOCA to beyond design basis accident (DBA)



- IBLOCA analysis methodology development
  - ✓ Current LBLOCA methodology focuses on large break size (60~100% of DEGB)
  - ✓ Develop IBLOCA analysis methodology focusing on intermediate break size

02. IBLOCA project

Overview

Goal	Redefine Design Basis LOCA as IBLOCA and Develop IBLOCA Analysis Best-estimate Methodology		
Phase	Phase 1(2022~2024) Develop Technology for LOCA Reclassification	Phase 2(2025~2026) Develop Preliminary IBLOCA Methodology and Uncertainty Evaluation Method	Phase 3(2027~2029) Preparation for IBLOCA Methodology Regulatory Review
Major Activities	•**Develop LOCA Reclassification Technology** •IBLOCA PIRT* Development and Integral Effect Test •SPACE Code Improvement	•Model Improvement •Model Uncertainty Evaluation Method •Preliminary IBLOCA Methodology •**Technical Basis for Eliminating DEGB from DBA**	•IBLOCA Methodology Topical Report •Realistic Analysis of LBLOCA •SPACE Code QA •Improvement of Leakage Detection

02. IBLOCA project

Participating Organization

Organization	Activities
KHNP CRI	Project management SPACE Code Configuration Control
KAERI	IBLOCA PIRT Development, IET Experiment, Model Development
KEPCO NF	IBLOCA Methodology Topical Report Development
Sejong University	Develop Technology for LOCA Reclassification LBB and Break Probability
Sentech	SPACE Code Improvement
Chungnam University	SPACE 3D model improvement

Chapter 03

Methodology Overview

03. Overview of rupture exclusion methodology

- Concepts of rupture exclusion are DG-1216 and Direct methodology
  - The DG-1216 methodology needs to analyze the design/operation difference between the U.S. and the domestic nuclear power plant
  - The direct methodology basically utilizes the results of DFM LBB evaluation, and the elicitation process is conducted through PFM evaluation and expert panel discussion on operational experience

- Probabilistic Fracture Mechanics Evaluation
  - Selection of welds subject to PFM analysis(RCS piping priority with LBB)
  - Evaluation of pipe rupture(probability, time lapse, etc) by PFM analysis
  - Expert panel discussion to determine the TBS draft

03. Application of PFM tools

mainly xLPR code

- Developed by EPRI & NRC, using under KHNP-EPRI business cooperation
- Utilized 2.2 version(recently 2.3 version released)
- For evaluating PFM for domestic NPPs

supplementary PRO-LOCA Code

- Participation in the PARTRIDGE* program as a Korean consortium

  * Probabilistic Analyses as a Regulatory Tool for Rick-Informed Decision GuidancE
- No separate QA, but many same modules of xLPR
- Utilized 7.1 version revised in Aug. 2022
- For comparison with xLPR results, sensitivity analysis.

03. Preliminary evaluation results(1/6)

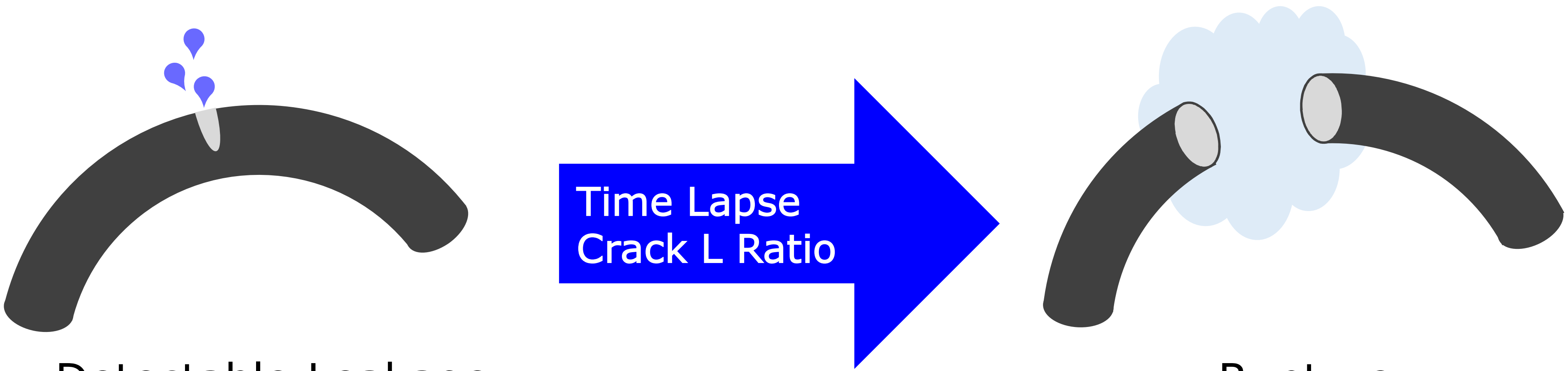
- Benchmark analyses for PRO-LOCA utilization validation(vs. TLR Report)
  - RVON (WH 4-loop Reactor Vessel Outlet Nozzles DMWs) 10 Cases
  - RVIN (WH 4-loop Reactor Vessel Inlet Nozzles DMWs) 1 Case

Weld	Case No.	Crack Orientation	Crack Initiation Method	Crack Growth Mechanism	Objective
RVON	1.1.0	Circumferential	PWSCC(DM1)	PWSCC	Assess the **base** likelihood of failure caused by PWSCC initiation and growth with no ISI, mitigation, or seismic effects
	1.1.1	Circumferential & Axial	Initial Flaw Density	PWSCC	Assess the sensitivity of the likelihood of failure due to whether the **crack initiation process** is modeled in the analysis
	1.1.2	Circumferential	PWSCC(DM1)	PWSCC	Assess the sensitivity of the likelihood of failure due to severe, yet plausible, **WRS**
	1.1.7	Circumferential	PWSCC(DM1)	PWSCC	Assess the sensitivity of the likelihood of failure due to the **normal operating loads**
	1.1.9	Circumferential	PWSCC(DM1)	PWSCC	Assess the impacts of **MSIP** on the likelihood of failure
	1.1.10	Circumferential	Initial Flaw Density	PWSCC	Assess the impacts of **ISI** on the likelihood of failure
	1.1.11	Circumferential	Initial Flaw Density	PWSCC	Assess the impacts of **ISI model parameter** uncertainty(POD)
	1.1.14	Circumferential	Initial Flaw Density	PWSCC	Assess the impacts of **hydrogen water chemistry** on the likelihood of failure
	1.1.20	Circumferential	Initial Flaw Density	PWSCC	Assess the sensitivity of the likelihood of failure due to **operating temperature**
	1.1.21	Circumferential	Initial Flaw Density	PWSCC	Assess the sensitivity of the likelihood of failure due to the **initial flaw dimensions**
RVIN	1.2.0	Circumferential	PWSCC(DM1)	PWSCC	Assess the **base** likelihood of failure caused by PWSCC initiation and growth with no ISI, mitigation, or seismic effects

[Ref] U

03. Preliminary evaluation results(2/6)

- Benchmark analyses for PRO-LOCA utilization validation(vs. TLR Report)
  - Probability of rupture, TWC(leak), Initiation(crack)
  - LBB QoI(LBB Time Lapse, LBB Ratio)

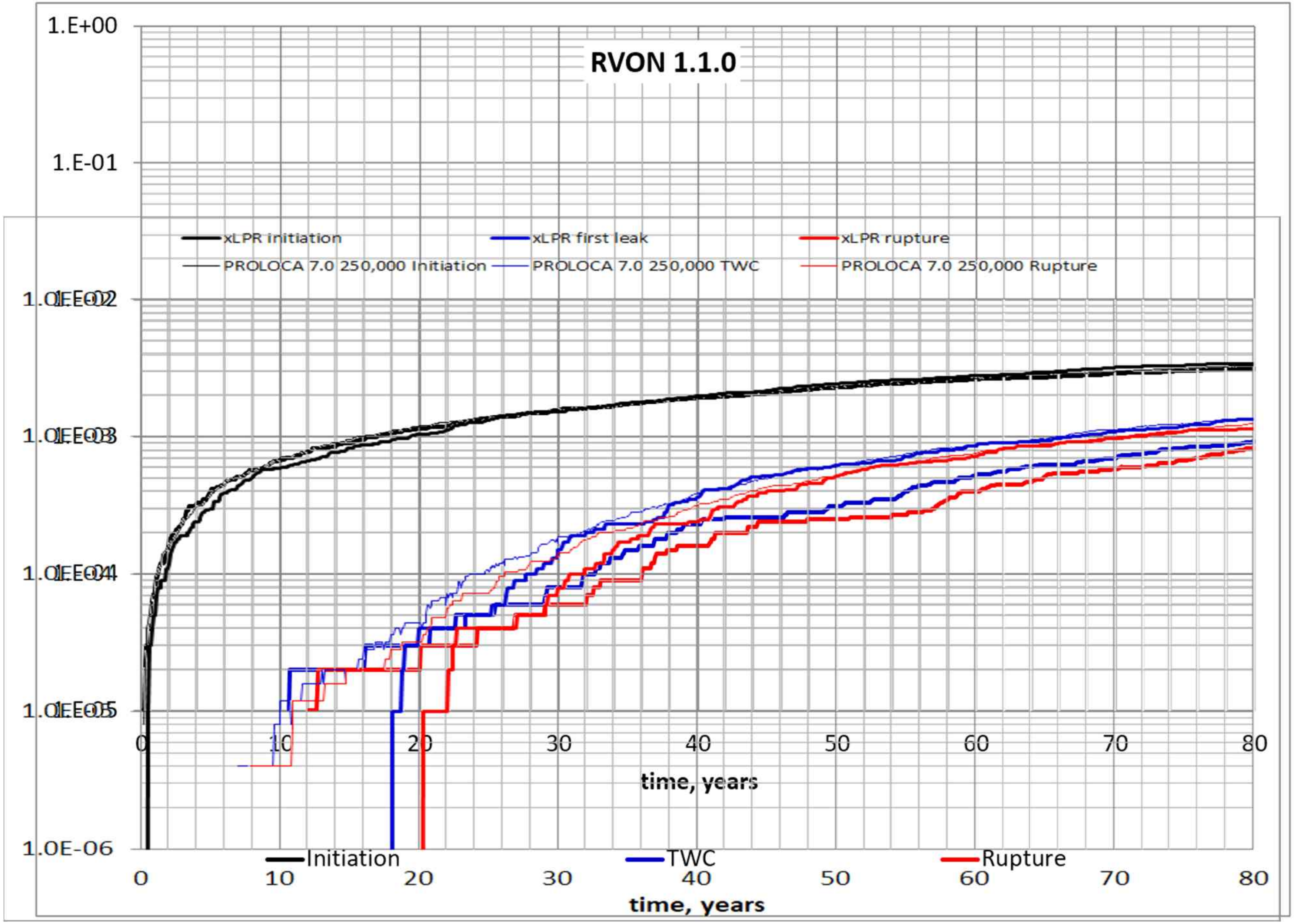


Detectable Leakage

Rupture

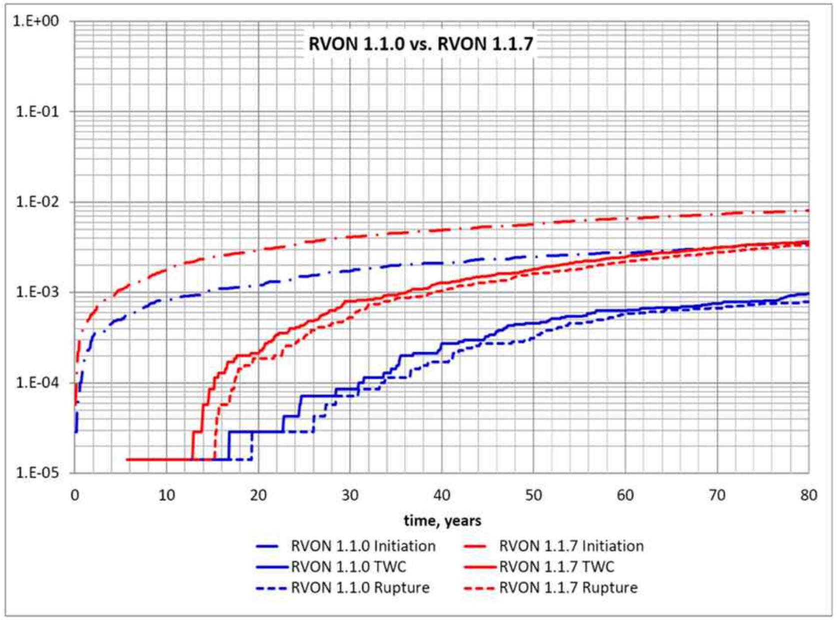
03. Preliminary evaluation results(3/6)

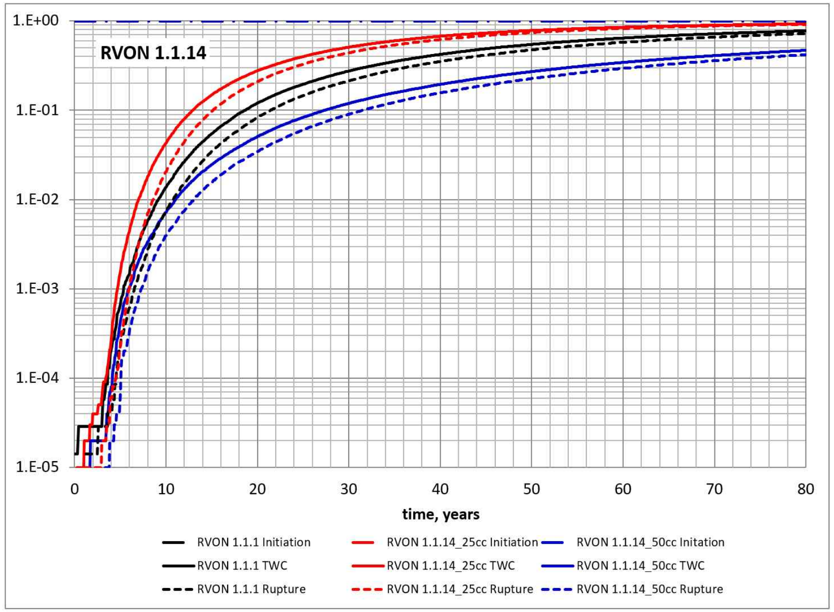
- Probability results comparison with PRO-LOCA and xLPR

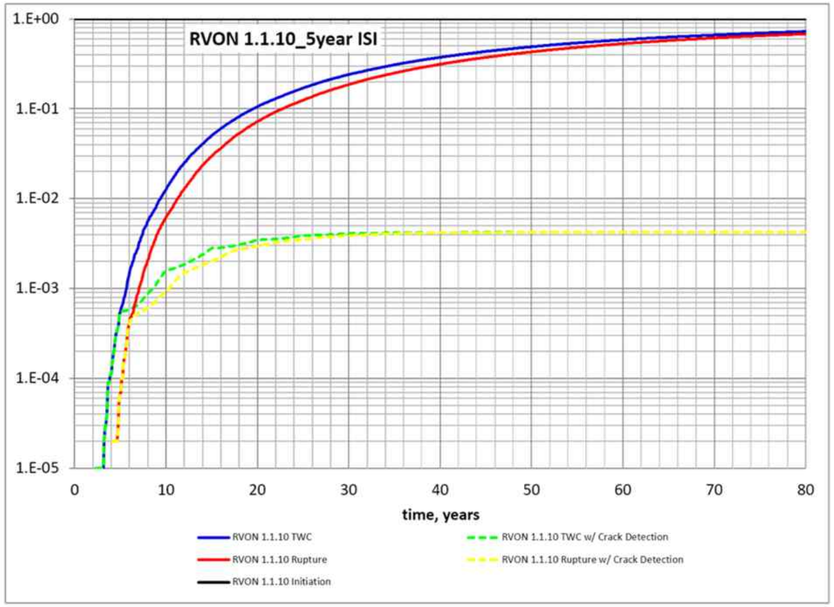


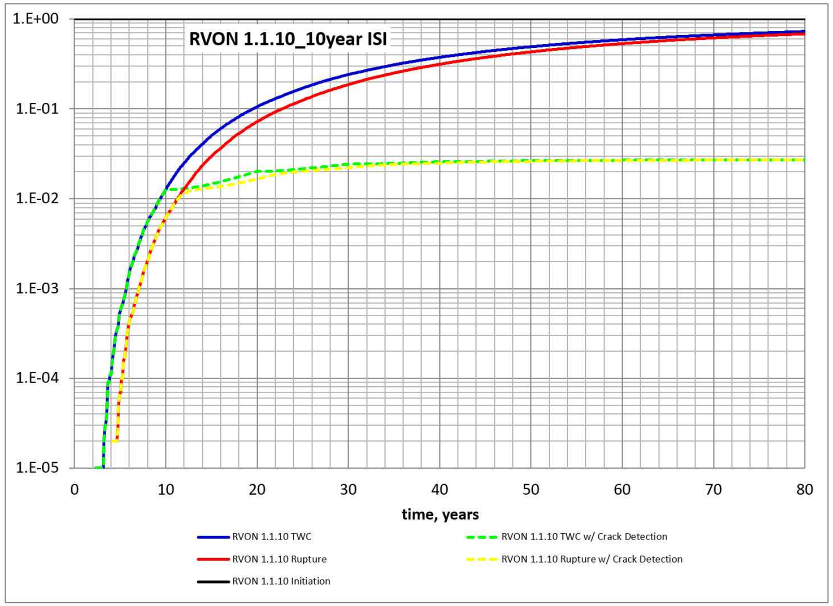
03. Preliminary evaluation results(4/6)

Probability results of other sensitivity cases





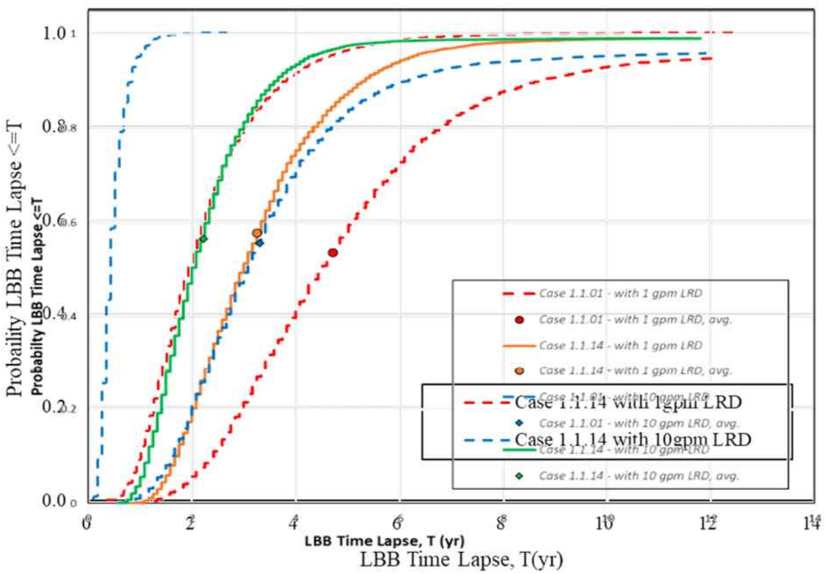




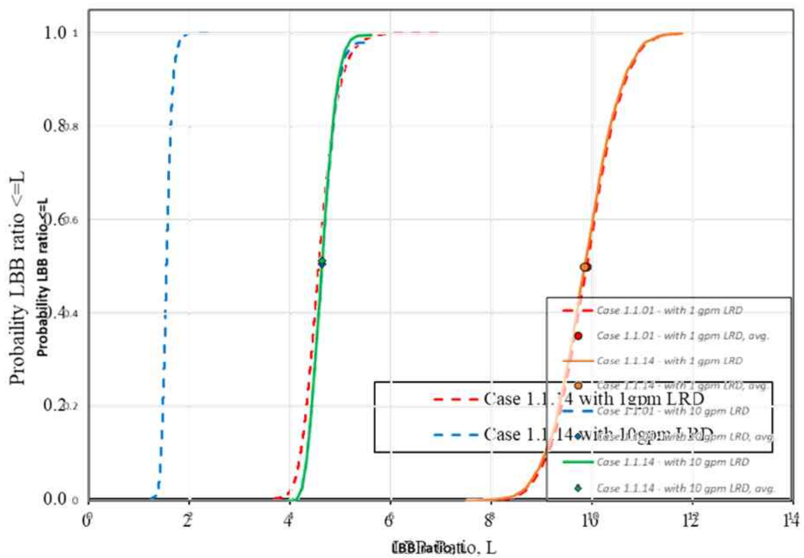
03. Preliminary evaluation results(5/6)

LBB QoI results

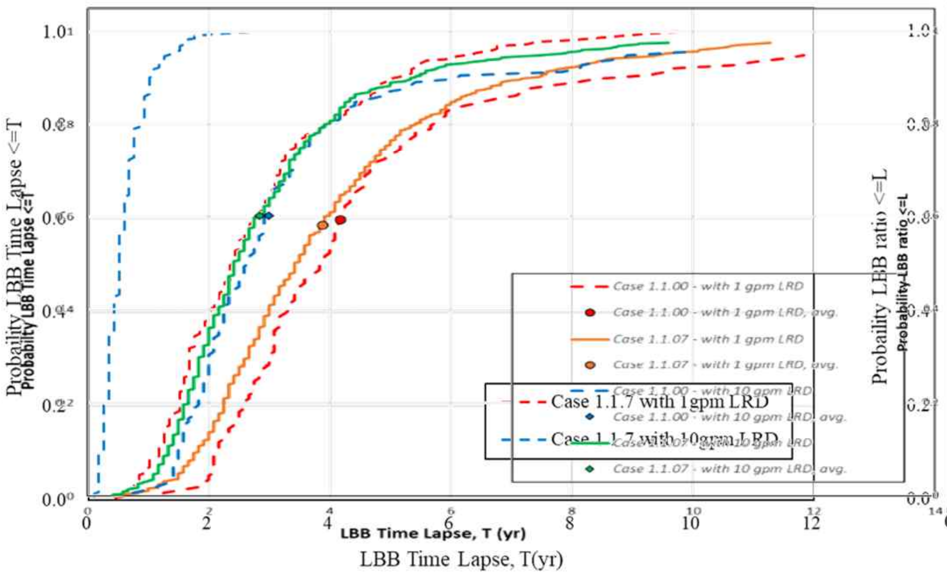
Case 1.1.14 LBB time lapse distribution



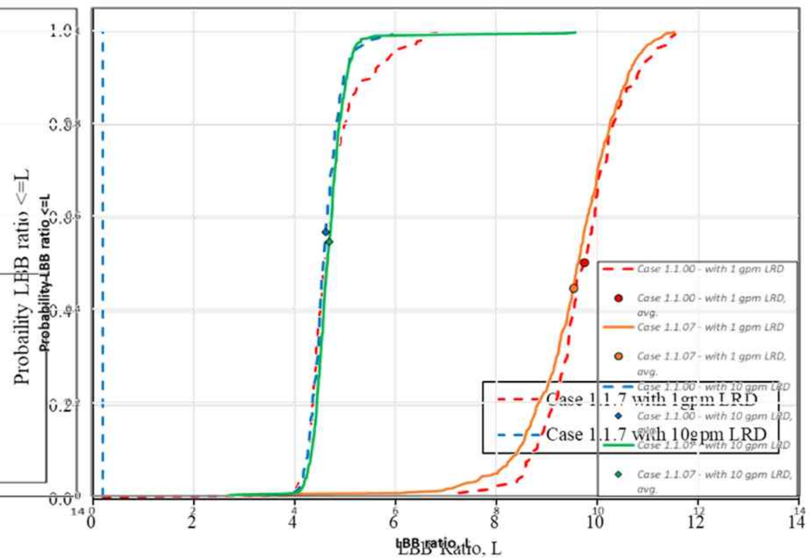
Case 1.1.14 LBB ratio distribution



Case 1.1.7 LBB time lapse distribution



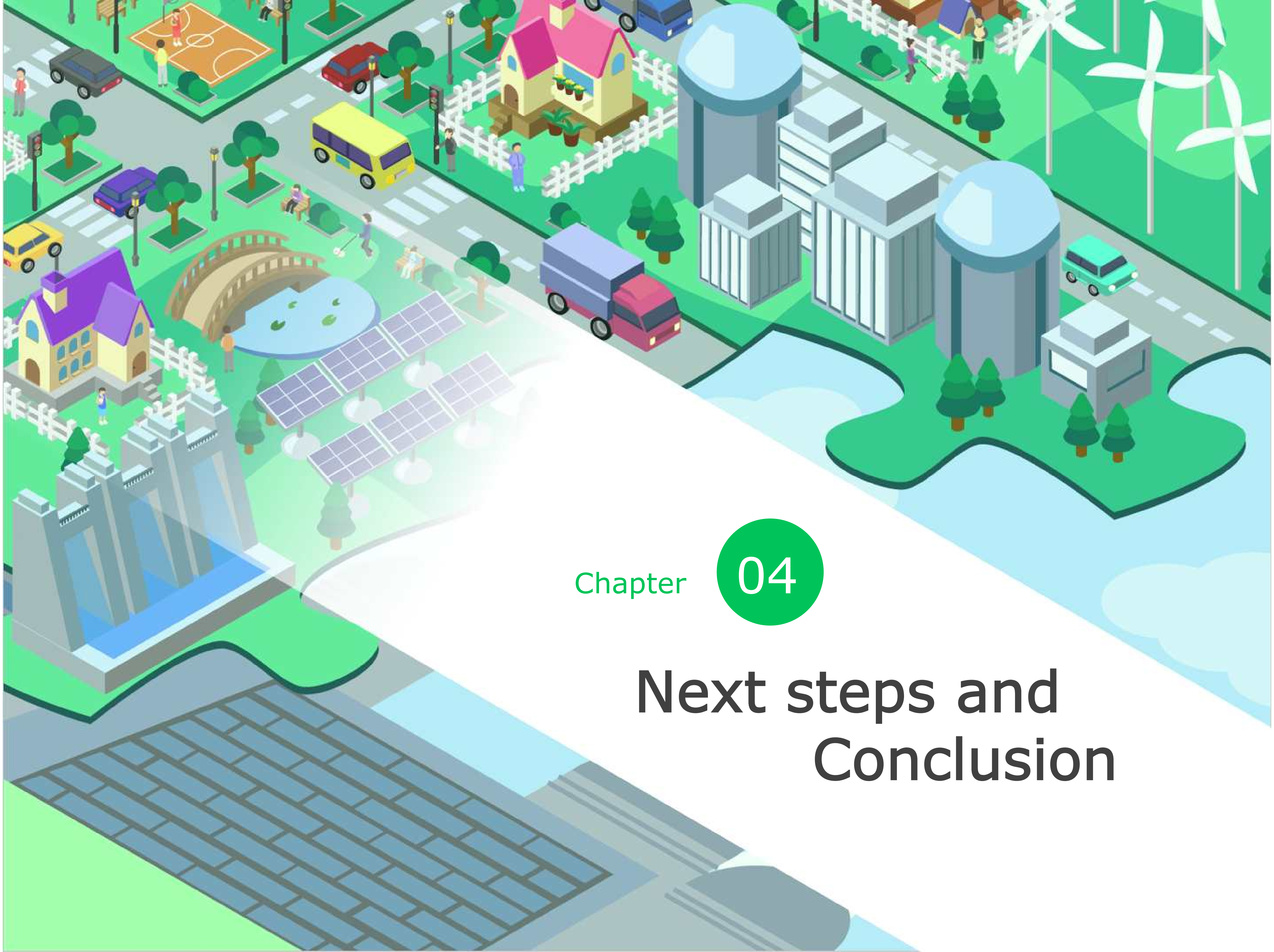
Case 1.1.7 LBB ratio distribution



03. Preliminary evaluation results(6/6)

Summary of Probability of Rupture comparison

Case No.	Prob. Of Rupture		Sensitivity
	PROLOCA	xLPR[1]	
1.1.0	8.20E-4	**1.25E-3 (±1.1E-4)**	Base
1.1.1	3.29E-1	**7.68E-1 (±6.0E-3)**	Crack Initiation Process
1.1.2	**5.00E-3**	1.23E-3 (±1.1E-4)	WRS
1.1.7	2.27E-3	**5.33E-3 (±2.3E-4)**	Normal Operating Load
1.1.9	**5.20E-4**	3.05E-4 (±5.4E-5)	MSIP
1.1.10	**2.70E-2**	6.86E-3 (±1.2E-3)	10-y period(w/ Crack Detection)
	4.22E-3	3.30E-4 (±2.6E-4)	5-y period(w/ Crack Detection)
1.1.11	**1.27E-2**	5.29E-3 (±1.0E-3)	ISI Model Parameter(10-y period)
	5.60E-4	2.01E-4 (±2.0E-4)	ISI Model Parameter(5-y period)
1.1.14	9.12E-1	**9.56E-1 (±2.9E-3)**	H_2 25cc/kg
	4.17E-1	-	H_2 50cc/kg
1.1.20	1.56E-3	**3.02E-3 (±1.7E-4)**	Operating Temperature
1.1.21	6.94E-1	**8.80E-1 (±4.6E-3)**	Initial Flaw Dimension
1.2.0	0	0	Base



Chapter 04

Next steps and Conclusion

04. Next steps

- Currently, PFM preliminary evaluation using xLPR is being conducted for domestic nuclear power plants Hanul 5 and 6(~ ’24. 10.)
  - RCS piping, SIS, SCS piping

- A panel of domestic experts will be formed and discussions on PFM results will be held

- Formation of prior consensus with domestic regulatory agencies on this series of methodologies(’24.11.)

04. Concluding Remarks

- The possibility of future regulatory issues has emerged due to the revision of regulatory requirements for safety analysis

- In preparation for this, KHNP intends to classify LBLOCA as Beyond DBA and develop IBLOCA optimal methodology to secure safety margin

- To this end, in the first stage, a preliminary PFM evaluation for LBLOCA rupture exclusion is carried out and an evaluation procedure is being developed

THANK YOU

KHNP