NRRC R&D Roadmap

As of March, 2025

Nuclear Risk Research Center (NRRC)

R&Ds to contribute to voluntary efforts to improve nuclear safety

- Learn more about low-frequency, high-consequence natural events and develop measures to safeguard against them.
- Apply risk-informed technology in addition to the conventional deterministic approach.

R&D Items

Application / Feedback

1.Event assessment technology

- 1) Severe accident
- 2) Fault activity
- 3) Seismic motion
- 4) Fault displacement
- 5) Seismic resistance of grounds / structures
- 6) Seismic resistance of buildings / equipment
- 7) Tsunami
- 8) Volcano
- 9) Extreme weather (*e.g.* high wind)
- 10) Internal Fire/Flooding

2. Risk assessment technology

- 1) PRA method (Internal/External)
- 2) Human reliability analysis (HRA)
- 3) Environmental release assessment

3. Risk communication

Contribute to

Feedback

Utilities' efforts to improve safety

*Number ①~⑤ correspond to applications in Roadmap

<Continuous safety improvement>

③ Risk reduction/defense-in-depth
(Reinforcement measures for safety)
④ Risk information utilization in risk management process

<Stable operation>

② Risk assessment
(PRA implementation)

<Restart of NPPs>

① Compliance with new regulatory requirements
(e.g. additional countermeasures / modifications)

<Fukushima Daiichi accident / New regulatory requirements>

In-house ··· **⑤ Risk communication** ··· Stakeholders

Current Status of PRA Method Improvement

- No dedicated R&D
- Planning R&D
- R&D in Progress
- Pilot/Model Project

		Level 1	Level 2	Level 3
Internal Event	At Power PRA	2021 Generic Parameter Estimation 2023 Data Collection Guide 2023 Revision of HRA Guide 2024 PRA Implementation Guide 2024 Revision of Peer Review Guide	2021 FP Release BE Method 2024 Trial Level2 PRA (Case Study) 2024 Level 2 PRA Case Study Collection 2026 Level 2 MUPRA Method	2023 Revision of WinMACCS Utilization Guide 2025～ Trial Level 3 PRA (Model Area)
	Shutdown PRA			
	Fire/Flooding PRA	2019 ～ 2021 IFPRA (Model Plant) 2024 Revision of IFPRA Implementation Guide 2020 Fire Modelling/Fire Ignition Frequencies 2021 ～ 2026 FPRA (Model Plant) 2026 Revision of FPRA Implementation Guide		
External Event	Seismic PRA	2020 Implementation of SSHAC Process 2019～ Seismic PRA Model Plant 2023 Seismic Level 1 MUPRA Method Implementation of Improved Hazard/Fragility Evaluation Method (as soon as available)		
	Tsunami PRA	2017-2020 Tsunami PRA (Model Plant)		
	Multi-Hazard PRA	2021-2023 MHPRA (Seismic & Seismically-Induced Tsunami PRA, Model Plant)		
	Other External Event PRA (Tornado/High Wind/Volcano)	2022～ High Wind PRA Model Plant 2025～ Volcanic Ash-Fall PRA Model Plant		
Spent Fuel Pool (SFP) PRA		2022 Fuel Cladding Rupture Model	2025 PRA Method	

[Note] BE: Best Estimate
IFPRA: Internal Flooding PRA
FPRA: Fire PRA
MUPRA: Multi-Unit PRA
MHPRA: Multi-Hazard PRA

Projected Schedule of PRA Method Improvement

R&D ⇒ Model Plant Evaluation ⇒ Practical Application ≀ Application of each key method as soon as it becomes available

PRA Item	R&D Item \ Fiscal Year	~2023	2024*	2025	2026	2027	2028~
Internal Events	Internal Event Level1 PRA Method Improvement		●				
	Human Reliability Analysis (HRA) Method Improvement		●				
	HRA Method Development for Extreme Condition		●				
	Multi-Unit PRA Method Development						
	Radioactive Material Release Risk Analysis Method Improvement (Level 2)		●				
	Environmental Impact Risk Analysis Method Development (Level 3)		●				
Internal Fire	Internal Fire Risk Analysis Method Development (Level 1)		●				
Internal Flooding	Internal Flooding Risk Analysis Method Development (Level 1)		●				
Seismic	Seismic Risk Analysis Method Improvement (Level 1-2)		●				
	SSHAC Process Establishment		●				
	Hazard/Fragility Analysis Method Improvement		●				
Tsunami	Tsunami Risk Analysis Method Improvement (Level 1-2)		●				
	Hazard/Fragility Analysis Method Improvement		●				
Tornado/High Wind	Tornado/High Wind Risk Analysis Method Improvement (Level 1-2)						
	Hazard/Fragility Analysis Method Improvement		●				
Volcano	Volcanic Ash-Fall Risk Analysis Method Improvement (Level 1-2)						
	Hazard/Fragility Analysis Method Improvement		●				
Spent Fuel Pool (SFP)	SFP Risk Assessment Method Development						
Risk Communication	Internal/External Communication Measures		●				

*●: R&D items with outcomes or elements, as of March 2025, applicable to preliminary study or plant evaluation of PRA by the utilities

1. Internal Event Level 1 PRA Method Improvement

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

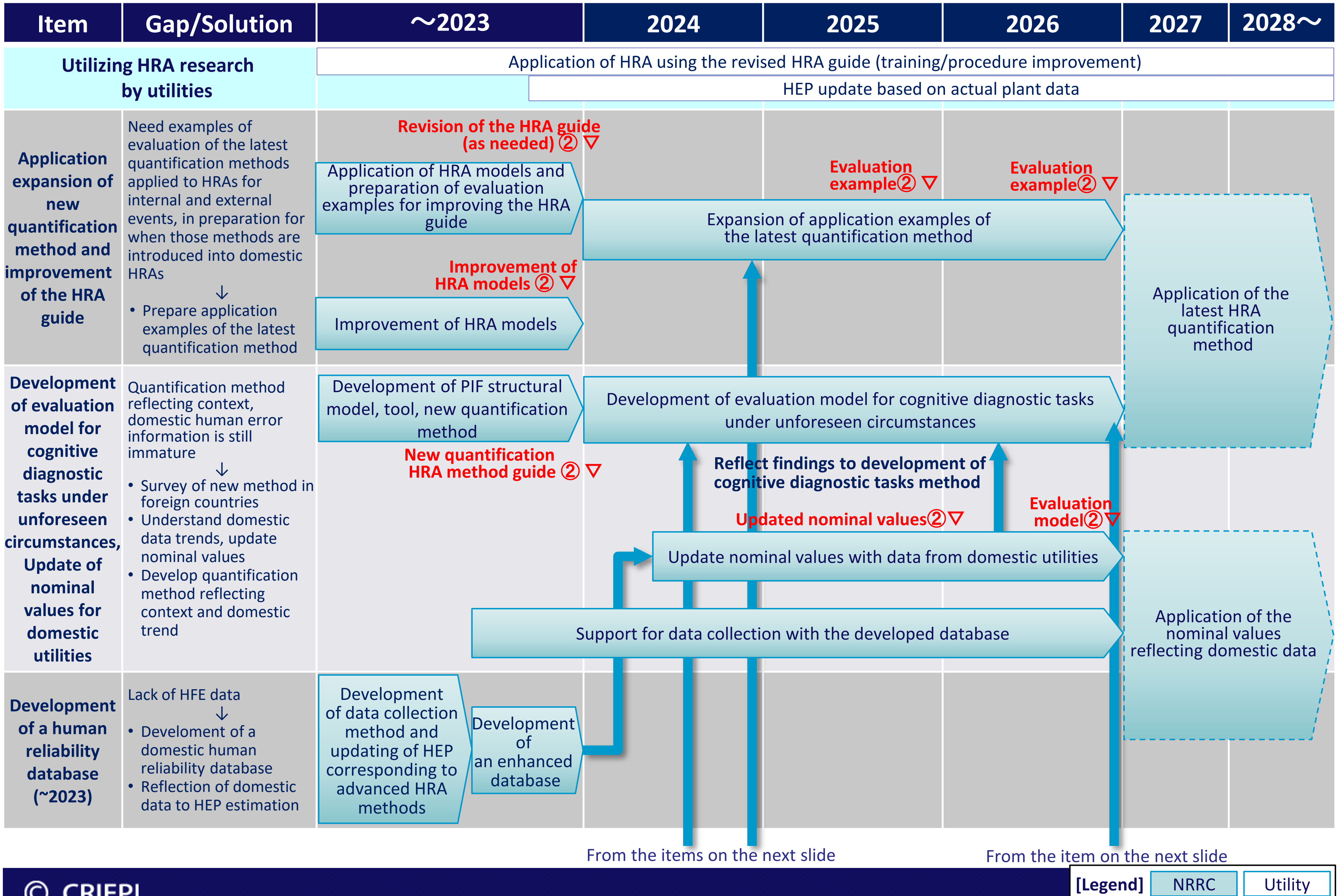
Item	Gap/Solution	～2023 / 2024 / 2025 / 2026 / 2027 / 2028～
Support of pilot projects for Good PRA	Domestic PRA has not reached the state of practice. ↓ • Overseas-expert reviews of pilot plants for PRA model improvement • Develop a guide to support utility's PRA modelling to meet international standard	▽ Review report② (Internal Level 1/1.5) (to be reported every FY afterward) ▽ ▽ ▽ ▽ ▽ Overseas-expert reviews of Ikata Unit3 and Kashiwazaki-Kariwa Unit7 PRAs Incorporation of the knowledge from the review to the PRA model of non-pilot plants PRA Implementation Guide ② (Internal event Level 1 PRA) ▽ Development of guide describing PRA standard requirements (Internal event Level 1 PRA) Revision of the guide (Other than internal event Level 1)
Development of PRA peer review procedure	The domestic system of achieving good quality PRA is not well-developed. ↓ • Develop PRA peer review guide for non-pilot plants • Develop peer review system with domestic engineers	▽ Draft PRA peer review guide ② ▽ Practical review guide ② Development of PRA peer review guide Revision of the guide (With feedbacks from expert review) ▽ Manual for working observer ② ▽ Peer review trial ② Development of a PRA peer review system / Survey of the PRA peer reviews in the U.S. Peer review implementation
Development of PRA reliability database **Development of PRA reliability parameters**	PRA reliability parameters with adequate quality have not been developed. ↓ • Development of a data collection guide • Estimation of generic PRA parameters of equipment reliability, CCF (common cause failure), LOOP (loss of offsite power), UA (unavailability), etc.	Event data collection for component failure, CCF etc. (Data update from new OE & Data scope extension to severe accident equipment) ▽ Generic component parameters ② ▽ Data collection guide ② Revision of data collection guide ② ▽ Update generic component parameters ② ▽ Estimation of component failure parameters Update of estimation of component failure parameters ▽ CCF data collection guide ② ▽ CCF parameter estimation ② Estimation of CCF parameters Update of CCF parameters LOOP IE parameter ② ▽ ▽ Probability of LOOP recovery failure ② Estimation of LOOP frequency Update of LOOP frequency ▽ MSPI UA data collection guide/parameter estimation ② ▽ Generic UA data collection guide/parameter estimation ② Estimation of MSPI baseline (UA) Update of MSPI UA/Estimation of generic UA for PRA ▽ Reliability Database System ② ▽ Operation of the reliability database system ② Development of reliability data system Improvement/update of the system (including IE/CCF/UA data registration and improvement)

*MSPI: Mitigating System Performance Index

[Legend] NRRC Utility

2. Development and Advancement of Human Reliability Analysis Methods (1/2)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)



2. Development and Advancement of Human Reliability Analysis Methods (2/2)

▽ ：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～

To the items on the former slide

To the item on the former slide

Proposal for the use of experimental data for HRA for rare events

Gap/Solution: Human characteristics in high-stress environments, such as massive natural disasters, cannot be collected through training or past cases.

↓

- Collect and organize knowledge of human characteristics using VR (virtual reality)
- Utilize findings in HRA

～2023:
- Extraction of human factors related to massive earthquake and aftershocks
- Extraction of human factors related to main control room fire
- **Human factors in fire② ▽**

2024:
- Extraction of human factors (1)
- Organize findings, Drafting of utilization method, Identification of insufficient requirements

2025:
- Extraction of human factors (2)
- **▽ Utilization method of Experimental data (draft)②**

2026:
- Organize findings, Investigation of data utilization method
- **Utilization method of Experimental data ② ▽**

2027～2028～:
- Application of methods to field operations

International research projects (HTO, etc.) (Development of measures to improve HRA practices ~2023)

Gap/Solution: Studies conducted in other countries, such as the HTO* project, on human characteristics of operators in digital control rooms, etc., need to be reflected in the development of HRA methods in Japan

↓

- Understand overseas research trends
- Consider human characteristics that cannot be evaluated by existing HRA methods and select targets for development of quantification methods

～2023:
- Development of measures to improve HRA practices (completed)
- **Handbook 1 (Methods for interview) ②▽**
- **Handbook 2 (Methods for observing simulator training) ②▽**
- Participation in collaborative research of Halden HTO Project (2021-2023)

2024–2025:
- Identification of overseas research trends on human factors of digital control rooms, etc.
- **Survey of international Trends ② ▽**

2024–2026:
- Participation in collaborative research of Halden HTO Project (2024-2026)

2026:
- Selection of targets for quantification method development

～2023–2026:
- Identification of trends in international collaboration for human reliability data collection (NRC, EPRI, KAERI, etc.)

2027～2028～:
- Reflect findings from International research to domestic plants

***HTO: Human-Technology-Organisation**

[Legend] NRRC | Utility

3. Multi-Unit PRA (MUPRA)

▽ ：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

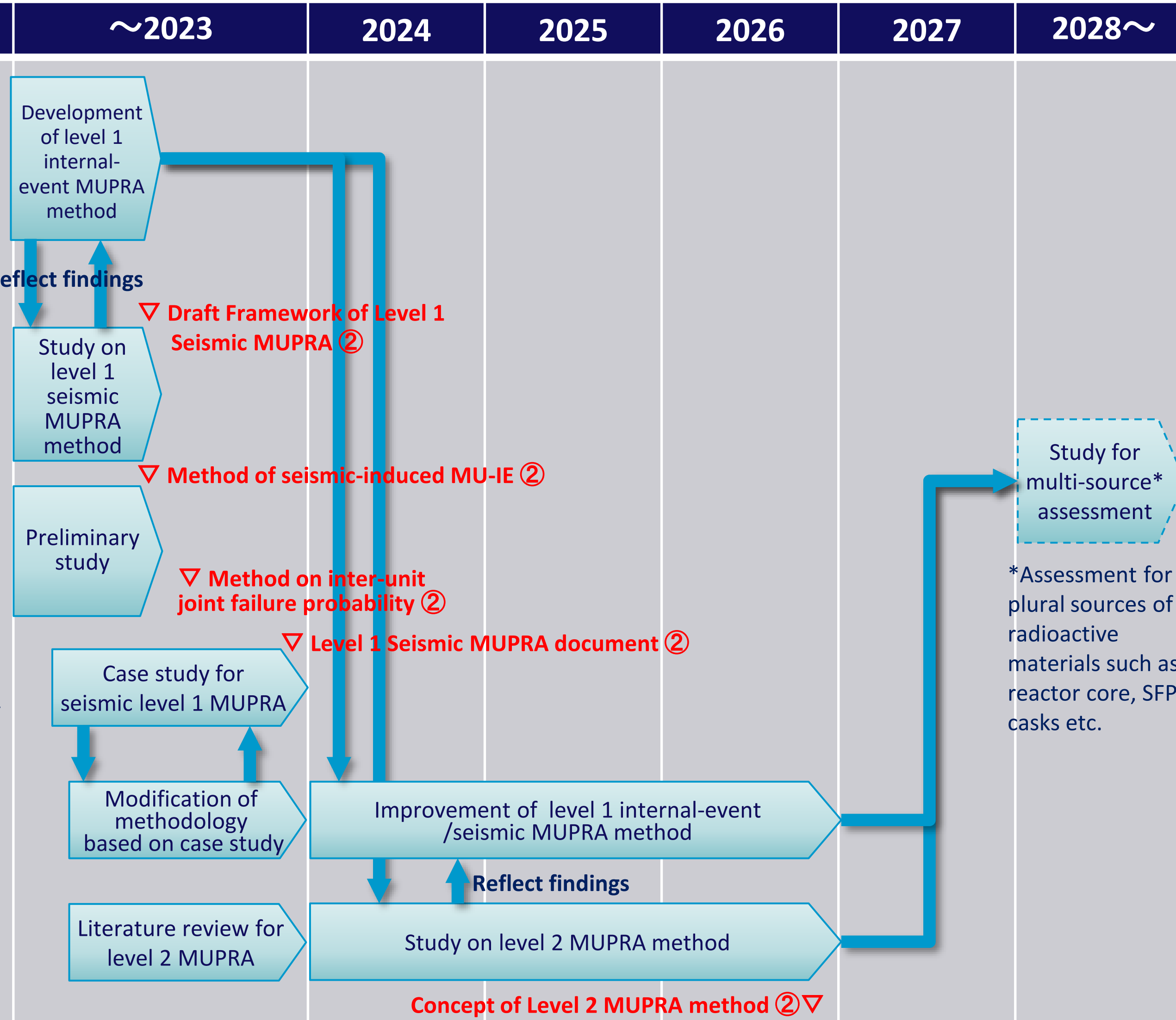
Item: Development of multi-unit PRA (MUPRA) methodology

Gap/Solution:

Standard methodology for implementing Good PRA that consider the context of MU accident are not yet developed.

↓

- Development of level 1 internal-event MUPRA method
- Development of level 1 external hazard (seismic) MUPRA method
- Contribution to level 2 PRA study



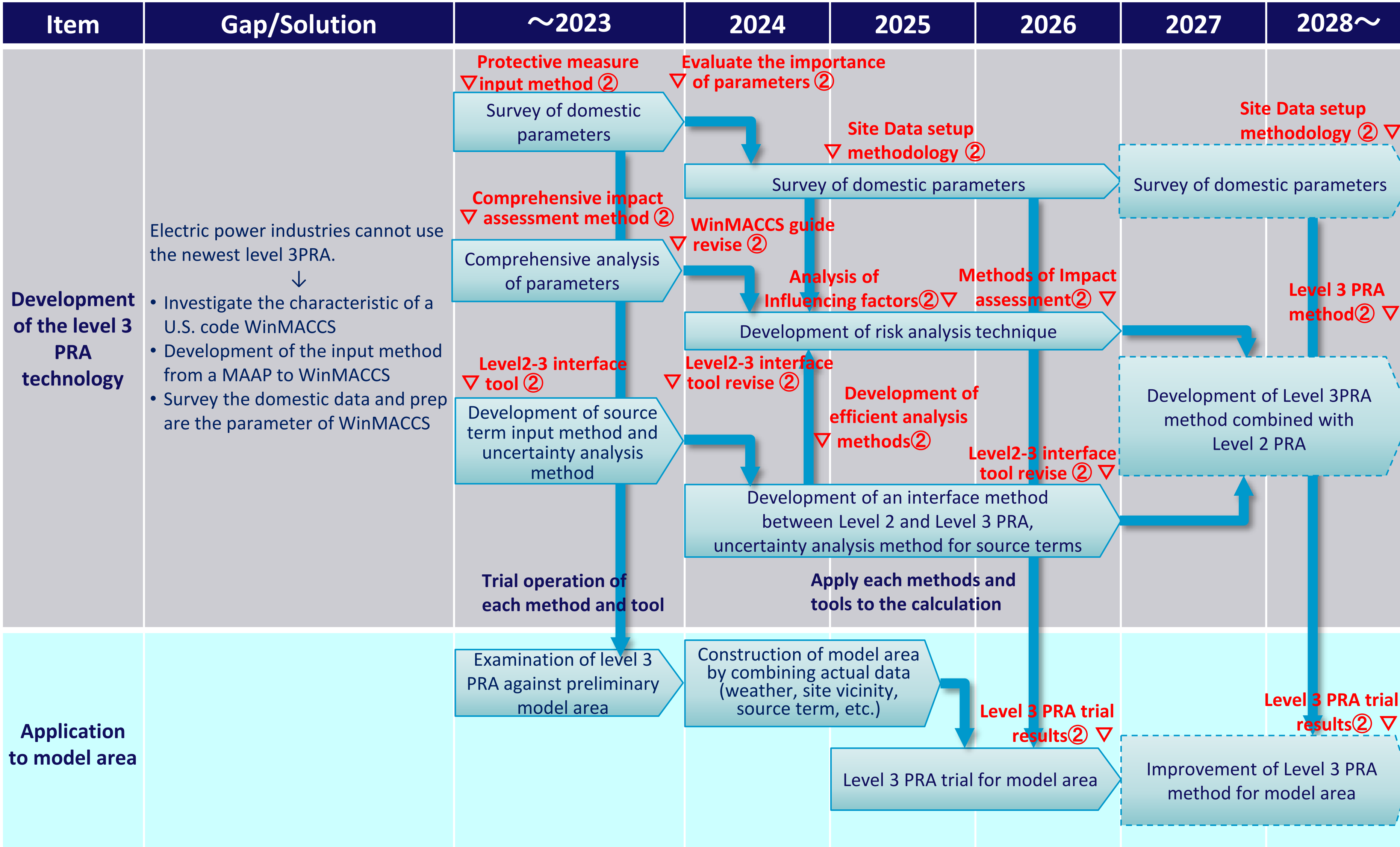
4. Radioactive Material Release Risk Analysis Method Development (Level 2)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～
Accident progress analysis during SA (reactor - containment vessel - reactor building)	Insufficient development of evaluation method for realistic containment failure, its frequency (CFF), and source term ↓ • Elucidation of the behavior of representative nuclides (Cs) • Analysis of FP deposition and transfer behavior in a containment vessel (CV) and a reactor building • Model validation and advancement of MAAP code • Development of methods for estimating realistic FP behavior • Model development for mitigation systems, such as FCVS • Development of analysis methods for the temperature inside a CV and identifying the damaged parts • Development of hydrogen behavior evaluation method in R/B • Establishment of evaluation method on important accident scenario	Elucidation of realistic behavior of FP and model ▽DF data for penetration ② Advancement of FP behavior evaluation technology (deposition to buildings/FP transport, decontamination at penetrations and scrubbing) ▽ Effectiveness of DF for R/B (detail) ② Evaluation of FP deposition/transfer behavior in R/B by MAAP and validation of the models Development of evaluation method for FP behavior in R/B Development of a realistic evaluation method for FP transport behavior CV integrity evaluation method ②▽ Development of methods for analysis of CV integrity (Temperature analysis, structural analysis, fragility analysis model) Simple evaluation method of H2 behavior ②▽ Development of at-power Good Level 2 PRA method reflecting the state-of-the-art knowledges (CFF, Source Term PRD, TI-SGTR, Dynamic PRA, EDF Collab., International Project)		▽ Evaluation model for FP behavior ② Enhancing knowledge of phenomena at low power and shutdown ▽Evaluation method of FP behavior in R/B ② Updated evaluation method for FP behavior and CV integrity ②▽ Extension of evaluation method for FP behavior and CV integrity at low power and shutdown Procedure of shutdown L2PRA② ▽ Development of Good Level 2 PRA method for low power and shutdown Confirm effectiveness of blowout panel and ceiling ventilation ②▽ ▽Various evaluation model by PRD② Streamlining Level 2 PRA through international cooperation (OECD/NEA FACE, ATRIUM, CSARP, IPRESCA etc.), or utilizing AI and machine learning			Study for multi-source* assessment *Assessment for plural sources of radioactive materials such as reactor core, SFP, casks etc.
		Model validation, improvement and enhancement of MAAP code (～2023 – 2027)					
		Development of hydrogen behavior evaluation method in R/B during SA (～2023 – 2027)					
Model plant assessment	Development of Good Level 2 PRA methodology by confirming the applicability of various methods	Trial of Level 2 PRA for core (case study) and establishment of a L2PRA case study collection (at power) L2PRA case study collection** ② ▽ Survey of previous studies for level 2 multi-unit PRA		Update of L2PRA case study collection **② ▽ Extension and update of case study collection ** A case study report was to be published instead of a guide for Level 2 PRA to keep range of users' choice under the current situation that various practical methods internationally exist (as of March 2025).			

5. Environmental Risk Evaluation Method Development (Level 3)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)



6. Development of Fire PRA Methodology and Data

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

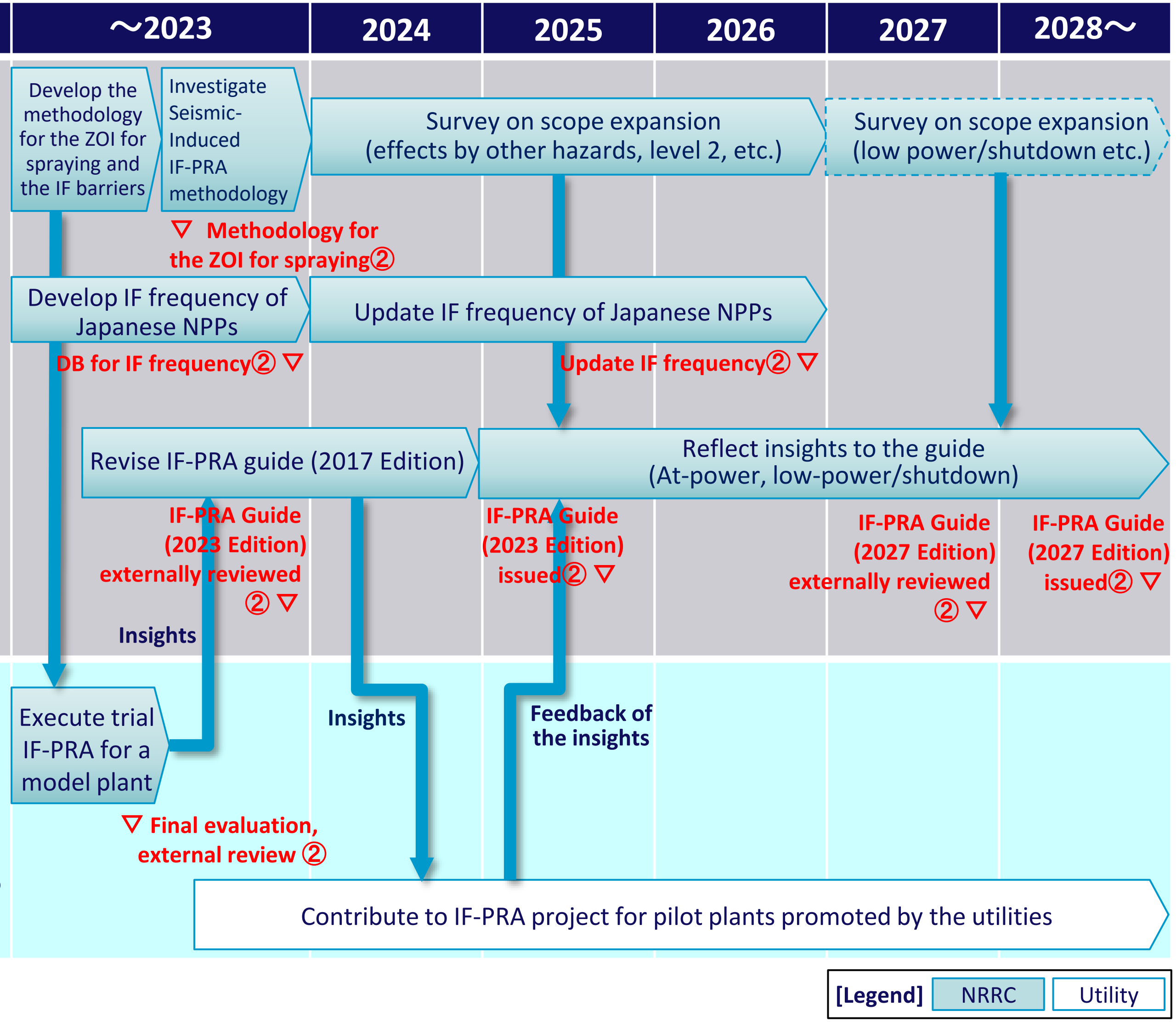
Item	Gap/Solution	~2023	2024	2025	2026	2027	2028~
Establish internal fire PRA (FPRA) methodology	➢ Applicability of FPRA Guide (FPRAG) and Fire Ignition Frequency (FIF) to PRA for actual NPPs, including low-power and shutdown conditions ➢ Accumulate the insights for scope expansion ↓ • Update FPRAG (2019 edition) based on the latest knowledge and lessen learned in Japan and other countries • Develop and update FIF based on OEs in Japanese NPPs • Develop methodology considering effects by other hazards	**▽ FPRAG (2019 edition) issued ②** Develop FPRA methodology → Accumulate insights to update FPRAG Develop FIF for Japanese NPPs → Investigate seismic-Induced FPRA methodology **Fire ignition frequency②▽**	Revision of FPRAG (At-power) Insights / Insights Update FIF for Japanese NPPs, Survey on scope expansion (low-power/shutdown, effects by other hazards, level 2 etc., consider guide revision)		**FPRAG (2026 Edition) externally reviewed ②▽**	**FPRAG (2026 edition) issued ②▽** Reflect new findings to the revised version (At-power, low-power/shutdown) **▽Update fire ignition frequency②**	
FPRA model plant project	➢ Applicability of FPRAG and FIF ↓ • FPRA for a model plant and gain feedbacks to FPRAG	Execute trial IF-PRA for a model plant (Phase 1) **Fire modeling methods** **Risk profile ②▽**	Execute trial IF-PRA for a model plant (Phase 2)		Contribute to FPRA project for pilot plants promoted by the utilities		
Update of fire modeling methods	➢ Potential back-fits considering regulation trends & new findings ➢ Lack of knowledge about electric cabinet fire ignition and propagation ➢ Damage mechanism on targets (including digital I&C) due to smoke and heat ↓ • Accumulate the knowledge by fire tests using full-scale electric cabinets and various combustibles • Develop fire model and deep learning (DL) model necessary for fire propagation analysis • Introduce and utilize the latest knowledge through international joint research and collaboration with overseas organizations	Develop fire modeling methodology **Insights** International cooperation with OECD/NEA (multi room fires: PRISME3) **▽Release updated zone model (BRI2-CRIEPI)②** Information exchange with EDF, INL HEAF fire and ZOI tests on electrical cabinets and bus-ducts **▽ Prevention methodology on HEAF fires①** **▽HEAF-ZOI model①** International cooperation with OECD/NEA (HEAF ZOI: HEAF2)	Improve modeling methodology Collaborative fire test with EDF "PRELUDE" **Insights**	**Develop field model.② ▽** Correspond to new insights (digital I&C, etc.)	**Develop DL model.②▽**	Evaluation tests for target failure condition (digital I&C, etc.)	

[Legend] NRRC | Utility

7. Development of Internal Flooding PRA

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution
Establish internal flooding PRA (IF-PRA) methodology	➢ No published practical IF-PRA guide for Japanese NPPs, including low-power and shutdown conditions ➢ Insufficiently developed IF event database and its frequency in Japan ➢ Accumulate the insights for scope expansion ↓ • Update and publish a practical IF-PRA guide (2017 edition) based on the latest knowledge and lesson learned in Japan and other countries • Develop and update IF frequency based on OEs in Japanese NPPs • Develop methodology considering effects by other hazards
IFPRA model plant project	➢ Confirm technical and practical adequacy of the IF-PRA guide ↓ • Execute trial IF-PRA for a model plant • Feedback the insights obtained trough the model plant project to the IF-PRA guide



8-1. Seismic/Earthquake Resistance (Fault Activity) (1/2)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	~2023	2024	2025	2026	2027	2028~

Item: Fault activity assessment based on the nature of fault zone

Gap/Solution:

It is difficult to assess the activity of faults without overlying strata of known age.

↓

- Development of assessment method of fault activity based on fracture zone properties
- Development of a new dating method which can be applied to a strata undated by traditional methods

Roadmap:

Fundamental research on the origin of heaving deformation of quaternary sediments

▽ Mechanism of the quaternary sediments deformation ①②

Incorporate findings

Research on fault activity assessment independent of overlying strata → Research on fault activity assessment independent of overlying strata (Phase2)

▽ Propose fault activity assessment method ①②

Incorporate findings

Verify/refine the analytical techniques for fault rock samples ①② ▽

Development of assessment method of fault activity based on fracture zone properties analyzed using state-of-the-art analytical techniques → Systematization of fault activity assessment methods based on nano-structure analysis of fracture zone

Establishment of nanostructural analysis method for fault planes ▽ ①②

Comparison

Examine depth-variable structure of fault rocks ①② ▽

Comparison

Indicators of changes in fracture properties associated with rock types ①②▽

Laboratory examination of fault fracturing process → Fault rupture reproduction and verification of its structure by laboratory experiments and numerical analysis

Propose analytical method for alteration zone with hydrothermal veins ①②▽

Clarification of hydrothermal alteration and weathering processes through chemical analysis of minerals ①② ▽

Hydrothermal alteration study for a comparison with fault zone → Investigation of methods to identify hydrothermal alteration or weathering

OSL/TL, expansion of applicability of K-Ar dating method, and application of 10Be dating method to fault activity evaluation ①②▽

Incorporate findings

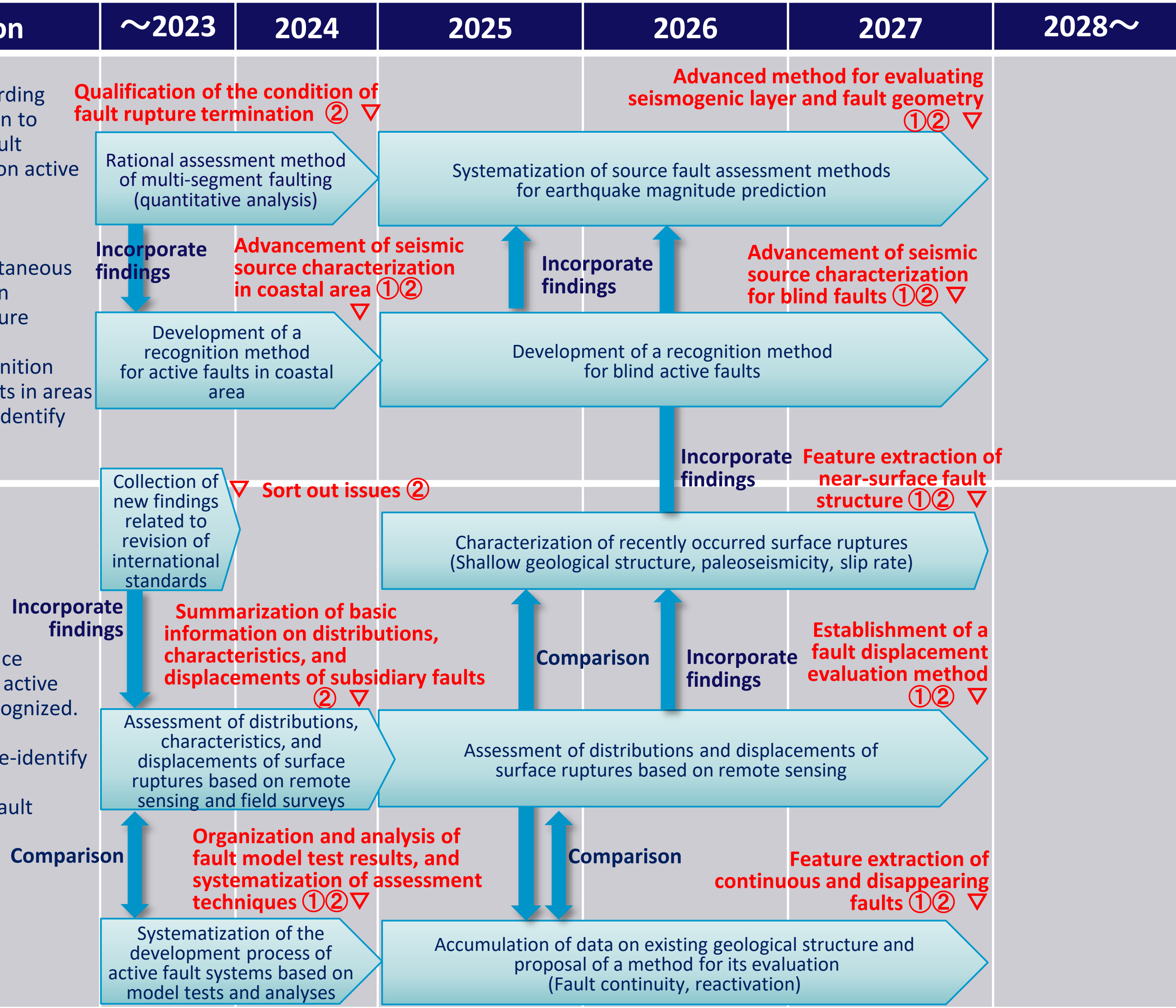
Accumulation of case studies of fault activity evaluation by OSL/TL dating, 10Be dating and aeolian dust over a wide area ①② ▽

Geological dating study for enhancement of their adaptability → Integrated use of geological dating methods

8-1. Seismic/Earthquake Resistance (Fault Activity) (2/2)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution
Assessment of seismic source through active fault	Insufficient criteria regarding active fault segmentation to assess seismic source fault Uncertainty in recognition active faults due to regional characteristics ↓ • Development of simultaneous rupture index based on examples of fault rupture termination • Development of recognition method for active faults in areas where it is difficult to identify seismic source
Investigation of distribution patterns and characteristics of surface ruptures	Increasing cases of surface ruptures in areas where active faults have not been recognized. ↓ • Clarify possibility to pre-identify active faults based on investigation of their fault properties



8-2. Seismic/Earthquake Resistance (Seismic Motion)

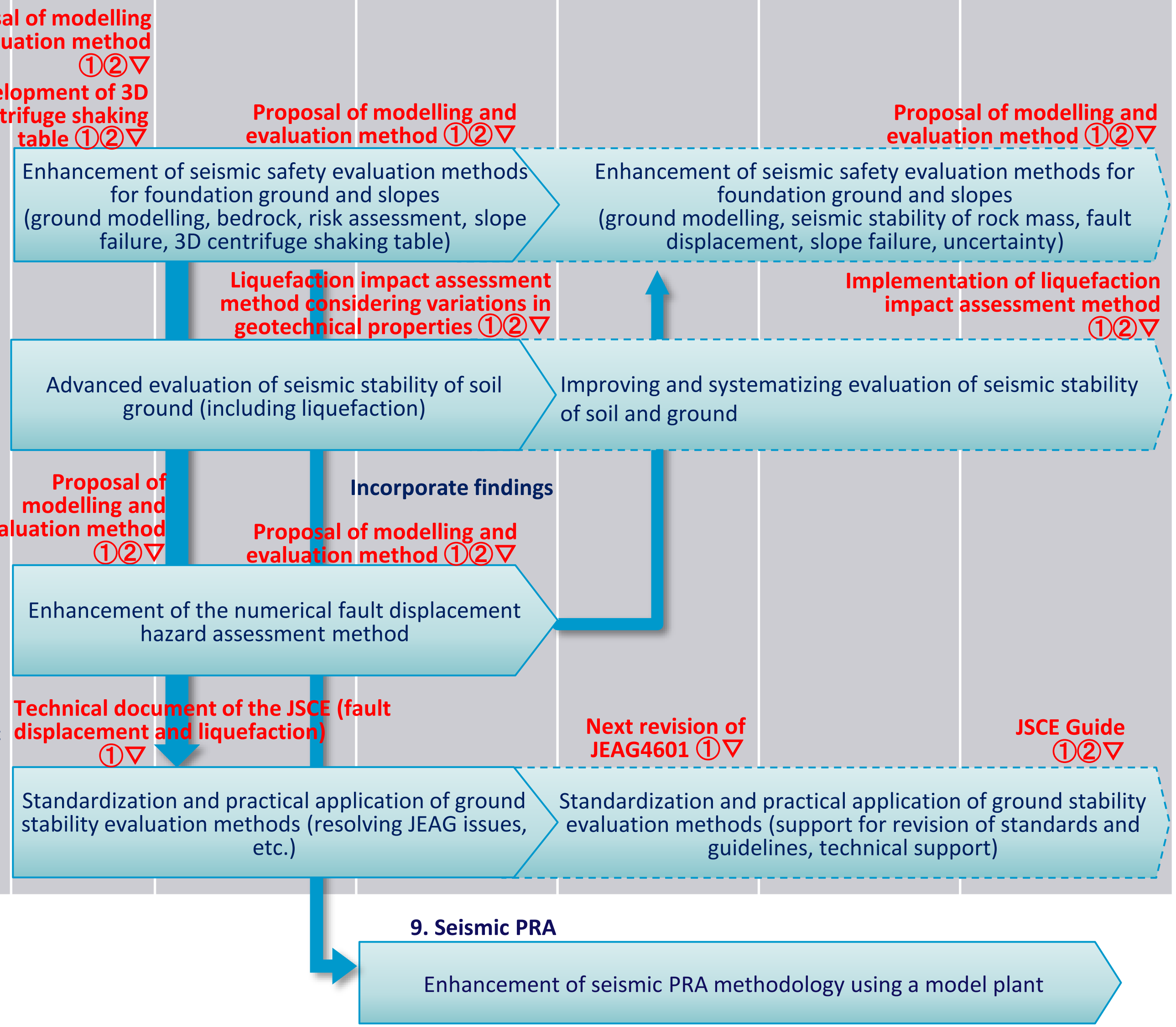
▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023 – 2024 – 2025 – 2026 – 2027 – 2028～
Evaluation of seismic ground motion with unspecified source	The causes of high-acceleration ground motions exceptionally observed at middle scale M6-class earthquakes are not fully understood. ↓ • Understanding the causes of the strong-motion records based on detailed investigations of the sites • Estimation of outcrop ground motions at the bedrock	**Standard level assessment of seismic ground motion with unspecified source ①②▽** **Standard level assessment of seismic ground motion with unspecified source ①②▽** Understanding the causes of strong ground motion based on the in-situ survey and its application to site characterization and evaluation of outcrop rock motions Development of new generation domestic GMPE for hardrock
Evaluation of seismic ground motion by identifying the seismic source	Enhancement of methodology for evaluating near-source seismic motions, updating of ground motion prediction equation and adjusting the equation to a local bedrock are necessary. ↓ • Enhancement of evaluating near-source seismic motions • Construction of flat file database of outcrop rock records and updating ground motion prediction equation based on nationwide high quality outcrop rock records • Developing site adjustment of ground motion prediction equation based on subsurface structural model	**Source modeling and evaluation of near-source ground motions using dynamic models ①②▽** **Assessment techniques for velocity structure (incl. seismogenic layer) ①②▽** Modeling of deep subsurface structure and seismic soevaluationurce and enhancement of near-source seismic motion method Modeling of deep seismic soevaluationurce and enhancement of near-source seismic motion method **Flat file database ①②▽** **Flat file database ①②▽** Construction of database on outcrop rock records Expansion of database Development of new generation domestic GMPE for hardrock (Non-ergodic) **Establishment of GMPE conversion method to site rock conditions ①②▽** Advancement of subsurface structure modeling and attenuating modeling methods and site characterization methods
Probabilistic seismic hazard analysis (PSHA)	The domestic implementation method of SSHAC has not been established yet. ↓ • Establishment of domestic SSHAC applications considering epistemic uncertainty in PSHA and introduction of site characterization • Enhancement of underlying techniques for PSHA	**Plan for domestic implementation of multi-site SSHAC ②▽** **Reflection to AESJ standard ①▽** **Plan for domestic implementation of multi-site SSHAC ②▽** Construction of a domestic implementation plan for multi-site SSHAC (East Japan area) Construction of a domestic implementation plan for multi-site SSHAC (West Japan area) Plan application Multi-hazard assessment of earthquake and tsunami superposition, etc. **Estimating epistemic uncertainty ②▽** **Estimating epistemic uncertainty ②▽** Enhancement of estimating the epistemic uncertainty of ground motion prediction models **Estimating epistemic uncertainty for fault-rupture model of ground motion prediction model ②▽** Development of seismic PRA method introducing fault-rupture model Application of seismic PRA method

8-3. Seismic/Earthquake Resistance (Ground)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

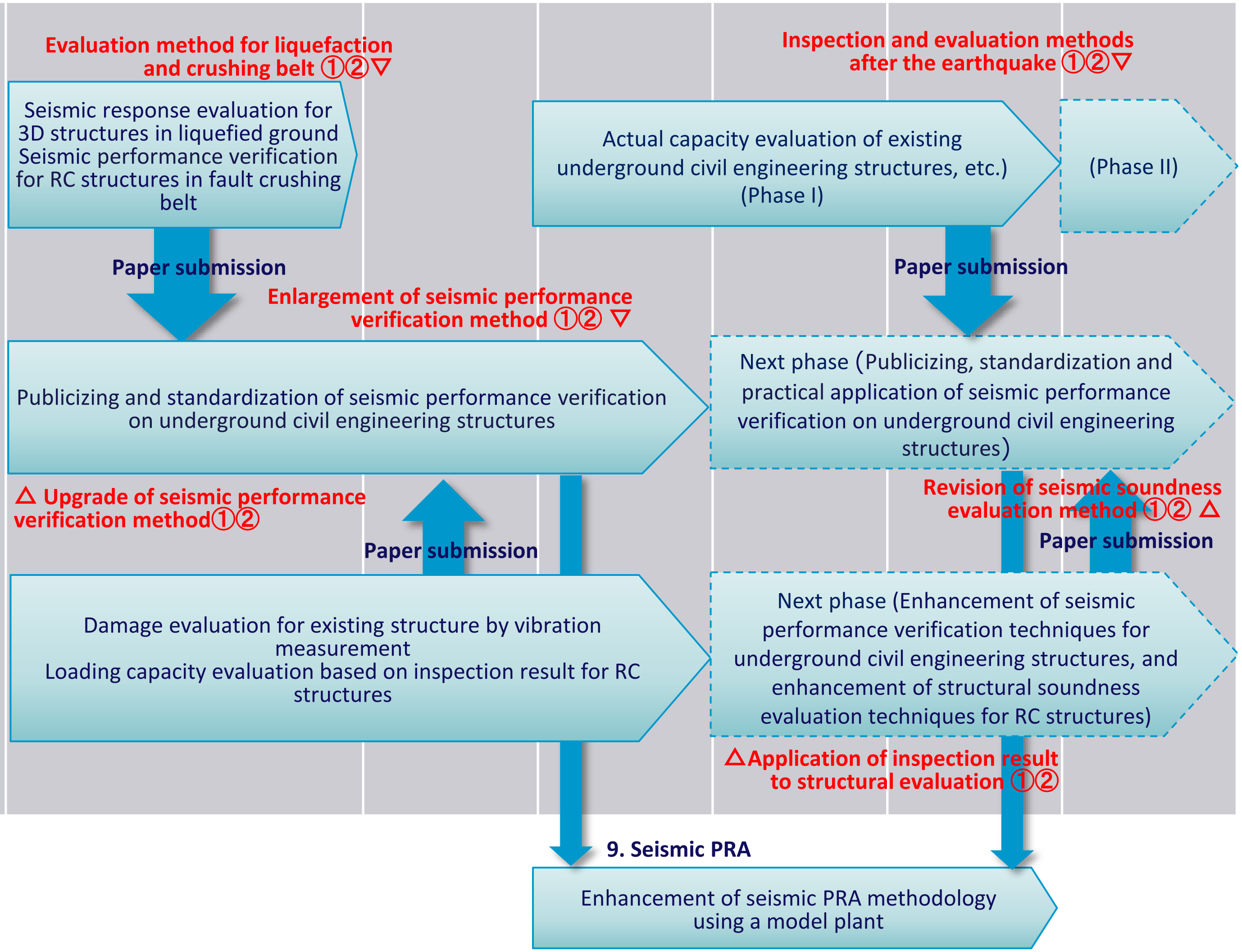
Item	Gap/Solution	~2023	2024	2025	2026	2027	2028~
Enhancement and systematization of evaluation methods for seismic safety of ground	With the increase of the reference earthquake ground motion, it is necessary to improve the seismic safety evaluation method for foundation ground and slope, and to clarify the uncertainty in seismic PRA. Possibility of introducing next-generation innovative reactors. ↓ • Enhancement of seismic safety evaluation methods for foundation ground and slopes (ground modelling, seismic stability of rock mass, fault displacement, slope failure, uncertainty) • Improving and systematizing the evaluation of the stability of soil and ground during earthquakes • Formulation of standards and guidelines for advanced seismic safety assessment methods	(see roadmap below)					



8-4. Seismic/Earthquake Resistance (Structures)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

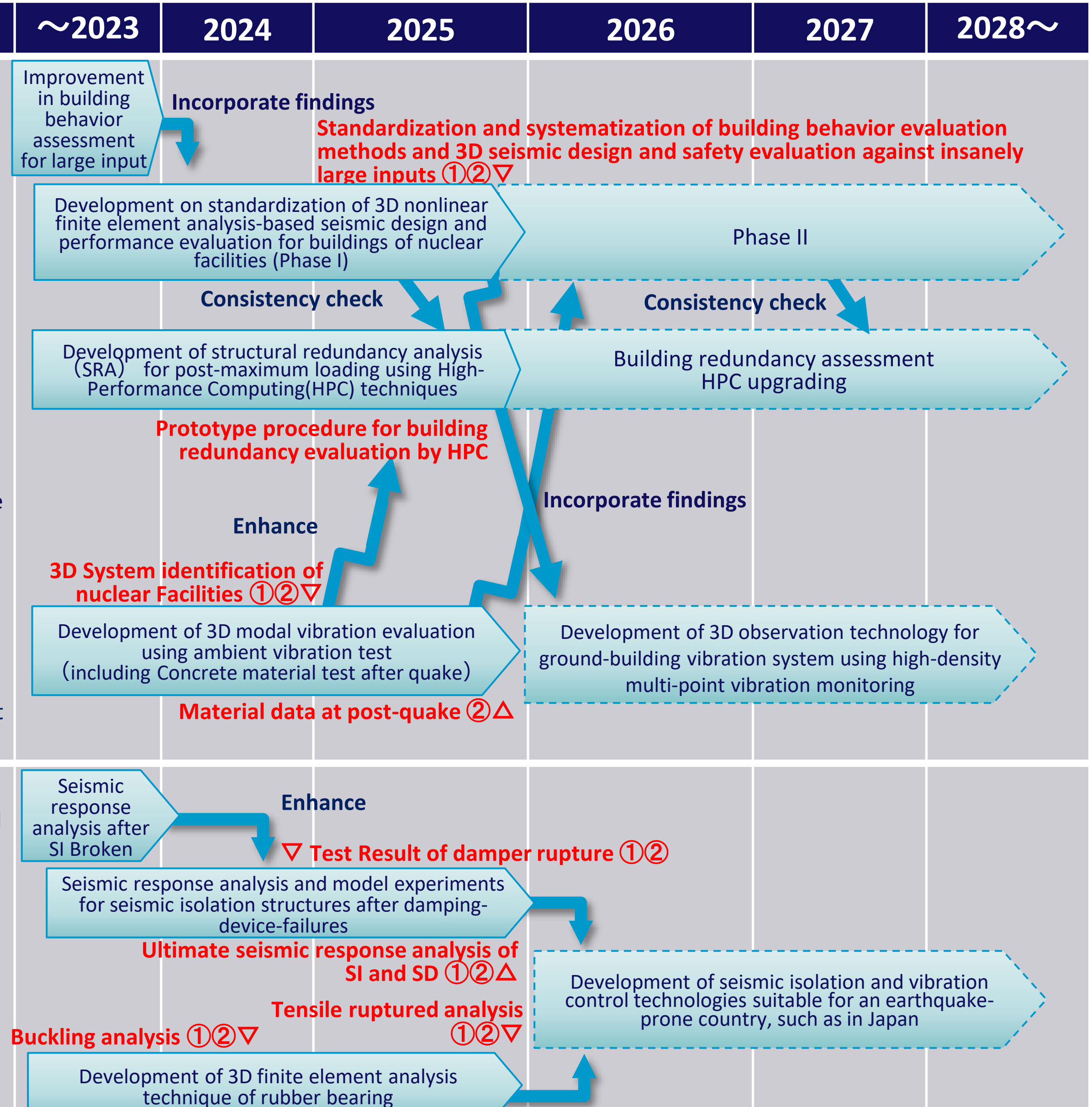
Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～
Assessment of civil engineering structures	For critical civil engineering structures in liquefied ground and fault crushing belt, seismic evaluation is required. ↓ • Development and standardization of seismic performance verification methods for RC structures in liquefied ground and fault crushing belt Considering earthquake damage, seismic retrofitting and aging deterioration, standardization and practical application of rational structural soundness evaluation is required ↓ • Proposal and publicizing of structural soundness evaluation methods by non-destructive measurement and inspection result						



8-5. Seismic/Earthquake Resistance (Buildings)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution
Rational seismic design technique and safety assessment technique	Knowledge needs to be accumulated to develop a building seismic design system for large inputs that includes nonlinear 3D finite element analysis (3D-FEM). ↓ • Gradually developing the elemental technologies (nonlinear model setting, ground-building interaction, high-performance computing (HPC)) needed to utilize 3D-FEM In PRA evaluation, a building is conservatively considered to be a total loss when one of seismic walls reaches at maximum load, and that is likely to leads to severe core damage. ↓ • Computational evaluation for partial-damage and structural-redundancy analysis Technology development for multi-point observation is necessary for verifying the 3D behavior of buildings. ↓ • Development of ambient vibration test for nuclear facilities and high-density multi-point vibration monitoring technology
Ultimate load design for seismic isolation structures	Development of analysis method for fragility evaluation after damper devices (SD) damaged is needed. ↓ • Development of seismic response analysis after SDs damaged Analysis methods are needed for evaluating the fragility of seismic isolation (SI) at the ultimate state and after rupture. ↓ • Development of 3D-FEM technology of SI rubber bearing



8-6. Seismic/Earthquake Resistance (Equipment)

▽ ：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～

Rationalization of seismic design methods for equipment and piping systems

Gap/Solution: Due to the increase in base earthquake ground motions, it has become necessary to develop more sophisticated methods for evaluating the seismic safety of equipment and piping systems.

↓

- Development, practical application, and standardization of evaluation methods that take elasto-plasticity into account
- Development of a rational evaluation method for large amplitude sloshing loads

Roadmap:

- ～2024: Research on the advancement and standardization of methods for evaluating the elasto-plasticity of equipment and piping systems Phase3 → **Practical application of elasto-plastic evaluation methods for piping ①②▽**
- 2024–2027: Research on the advancement and standardization of methods for evaluating the elasto-plasticity of equipment and piping systems Phase4 → **Standardization of elasto-plastic evaluation methods for piping ①②▽**
- 2028～: Studies towards standardization and criteria
- ～2023: Development of a fatigue evaluation method for welded joints → **Fatigue curve for welded joints ①②▽**
- 2025: Equipment vibration test → **Function-verified acceleration①②▽**
- 2026: Advancement of fatigue evaluation methods for welded joints → **Fatigue curve for welded joints ①②▽**
- ～2024: Practical application of the piping elasto-plastic evaluation method → **Practical application of the piping elasto-plastic evaluation method①②▽**
- 2025: Nonlinear spring upgrade for piping support structures
- 2026–2027: Advanced and standardized evaluation methods Inclusion in JSME case standards → **Standardization of elasto-plastic evaluation methods ①②▽**
- ～2023: Individual tank sloshing evaluation
- 2024–2026: Development of a simple evaluation method for large amplitude sloshing loads → **Simple evaluation method of large-amplitude sloshing load ①②▽**
- 2027: Studies towards standardization and criteria
- ～2024: Development of simplified elasto-plastic evaluation method for fatigue evaluation → **Rationalization of simplified elasto-plastic evaluation method (Ke) ①②▽**
- 2025–2027: Advanced and standardized simplified elasto-plastic evaluation methods → **Improvement of elasto-plastic evaluation methods ①②▽**

Advanced fragility evaluation of equipment and piping systems

Gap/Solution: Due to the increase in base earthquake ground motions, it has become necessary to develop more sophisticated methods for evaluating fragility in seismic PRA.

↓

- Development and standardization of fragility evaluation method based on detailed analysis
- Development and standardization of Evaluation method of loss of offsite power fragility
- Development of fragility evaluation method considering coupling of structures and components

Roadmap:

- ～2024: Piping fragility evaluation method using fatigue as an indicator → **Piping fragility evaluation method ②▽**
- 2025–2027: Development of simplified methods for evaluating piping system fragility → **Reflection of piping fragility evaluation methods in standards ②▽**
- 2028～: Studies towards standardization and criteria
- ～2023: Development of Evaluation method of loss of offsite power fragility → **Evaluation method of loss of offsite power fragility ②▽**
- 2024–2026: Public knowledge through papers for standardization → **Reflection of loss of offsite power fragility evaluation methods in standards ②▽**
- ～2023: Structural and equipment coupled fragility evaluation methods → **Structural and equipment coupled fragility evaluation method ②▽**
- 2024–2026: Development of structural and equipment coupled fragility evaluation methods → **Development and improvement of methods for evaluating the fragility of structure-equipment coupling ②▽**
- 2027: Studies towards standardization and criteria

9. Seismic PRA

▽ ：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～

Item: Development of seismic PRA methodology

Gap/Solution:

PRA precision as a whole is determined by the elements (PRA models) with the lowest precision.

↓

- Using a model plant, conduct seismic risk quantification based on enhanced/ developed hazard and fragility evaluation results. Then, analyze the effect by those enhanced/improved models to risk quantification. Provide implementation methods and procedures.

Uncertainties of SPRA models are not sufficiently optimized.

↓

- Develop a method to optimize SPRA-specific risk profile
- Develop an optimized size o system model (e.g., SEL, seismic correlation) in SPRA

～2023:

Development of SPRA methodology using a model plant (Phase 1)
- Implementation of developed foundation ground fragility evaluation
- Implementation of developed seismic hazard evaluation
- Implementation of developed piping fragility evaluation

2024:

Development of SPRA implementation methods and procedures where the latest seismic hazard and fragility evaluations methods are utilized. ②▽

- Sensitivity analyses to measure/analyze how developed/improved fragility and hazard evaluations results affect to system's seismic risk
- Study an optimized SPRA system model size against earthquakes.

Develop a methodology to reduce effects by dominating multi-factors commonly in seismic risk quantification. ②③▽

Study on risk profile optimization against earthquakes

Advancement of fragility assessment of electrical cable trays

2025–2027:

Reflection in domestic and international standards related to seismic PRA ②③▽

Enhancement of seismic PRA methodology using a model plant
- Implementation of more realistic method regarding seismic correlation evaluation
- Implementation of enhanced/advanced PSHA methodology
- Finalization of NRRC Seismic PRA implementation guideline (Technical supplement and support document for the AESJ Seismic PRA Standard 2024)
- Improvement and enhancement study of system analysis for external event PRA

Development of risk assessment methodology for earthquake-induced multi-hazards.
- Consideration of earthquake-induced multi-hazards: Development of a fragility assessment method (prototype) for earthquake-induced multi-hazards.

2028～:

Development of a risk assessment methodology for earthquake-induced multi-hazards

8-4. Seismic/Earthquake Resistance 【Structures】

Enhancement of fragility evaluation methods for civil engineering structures

8-3. Seismic/Earthquake Resistance 【Ground】

Enhancement of fragility evaluation of ground subsurface and fragility evaluation methods for slopes

10. Tsunami (Hazard and Fragility)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～

Tsunami hazard assessment

Gap/Solution

Organization on uncertainty in judgements of event deposits is insufficient.

↓

- Increase knowledge on field survey on event depots, and organization of uncertainty of the results

Knowledge on numerical simulation technologies for non-seismic tsunamis and methodologies of Probabilistic Tsunami Hazard Analysis (PTHA) for them are insufficient.

↓

- Development of numerical simulation technologies for non-seismic tsunami
- Development methodology for PTHA including non-seismic tsunami

Schedule

- ～2024: Development of methods on Judgement for event deposits including tsunamis
  - ▽ **Analysis technologies on uncertainty in judgement for event deposits ①②**
- 2025–2027: Upgrade of methods on judgement for event deposits including tsunamis
  - ▽ **Advanced analysis technologies on uncertainty in judgement for event deposits ①②**
- 2028～: Systemization of methods on judgement for event deposits including tsunamis
- ～2024: Development of numerical simulation technologies for landslide tsunamis
  - ▽ **Three-dimensional Eulerian approaches ①②**
- 2025–2027: Practical application of numerical simulation technologies for landslide tsunamis
  - ▽ **Three dimensional Lagrangian approaches ①②**
  - ▽ **Practical application of 2D/3D numerical simulation technology ①②**
- 2028～: Upgrade of numerical simulation technologies for landslide tsunamis
- ～2026: Development of methodology of PTHA including non-seismic tsunamis
  - ▽ **Methodology of PTHA including non-seismic tsunamis ①②**
  - ▽ **Proposal of PTHA methodology including non-seismic tsunamis ①②**
- 2027～: Systemization of methodology of PTHA including non-seismic tsunamis

Tsunami fragility assessment

Gap/Solution

Knowledge for fragility evaluation method considering various tsunami effects is insufficient.

Novel technologies on tsunami impact assessment needs to be verified.

↓

- Upgrade of tsunami simulation technologies by considering novel knowledge
- Upgrade of evaluation technologies for tsunami debris impact
- Accumulation of novel knowledge and verification of them

Schedule

- ～2026: Upgrade of tsunami simulation technologies
  - **Upgrade of tsunami simulation technologies (intake) ①②▽**
  - **Upgrade of tsunami simulation technologies (Hybrid 2D&3D simulation and proper usage) ①②▽**
- 2027～: Gathering the latest knowledge and advancing of tsunami simulation technologies
- ～2024: Development and systemization of evaluation methods of debris collision effects
  - **Systemization of evaluation methods of debris collision effects ①② (JSCE) ▽**
  - △ **Upgrade of collision simulation technologies for small boat ①②**
- 2025–2027: Systemization of evaluation methods of debris collision effects (Phase 2)
  - **Publication of technical reports on evaluation methods of debris collision effects ①② (JSCE, JEAC) ▽**
- 2028～: Upgrade of evaluation methods of debris collision effects
- ～2026: Study on secondary influence assessment
  - ▽ **Evaluation method of wave force by tsunami with high sediment concentration ①②**
  - **Upgrade of probabilistic risk assessment methodology of secondary influence ①②▽**

11. Tsunami PRA, and Seismic and Seismically-Induced Tsunami PRA

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～
Development of methodologies of tsunami PRA	Accumulation knowledge and upgrade of methodology on tsunami PRA are necessary. ↓ • Trial of tsunami PRA using a model plant • Accumulation of knowledge through application to actual plants and reflection in standards	**Accumulation of knowledge on tsunami PRA and development of related tools ②** ▽ Accumulation and upgrade of methodology of tsunami PRA using BRW model plant		Accumulation of knowledge on tsunami PRA methodology and examination of applicability to actual plants		**Standardization of methodology of tsunami PRA (AESJ)** ▽	Improvements through application of tsunami PRA methodology to actual plants
Development of PRA methodology against combination of earthquake and seismic – induced tsunami	No PRA method has been developed worldwide considering combination of earthquake and seismic-induced tsunami. ↓ • Development of PRA methodology against combination of earthquake and seismic-induced tsunami • Reflection in standards	**Hazard and fragility evaluation method against combination of earthquake and tsunami (Basic method) ②**▽ PRA front-end process, elemental technology development • Overall scenario building, model analysis • Development of basic evaluation method for hazard, fragility, accident sequence, and relevant technical elements considering superposed external hazards	▽ **Concept of technical elements, evaluation for earthquake and seismic-induced tsunami PRA ②**		Development and practical application of a consistent level 1 to level 2 PRA against combination of seismic and seismically-induced tsunami		

12. Volcanic Ash-Fall Risk Analysis

▽ ：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～
Hazard analysis of volcanic ash-fall	Need to improve hazard curve, to develop hazard curve based on numerical analysis of ash-cloud dispersion, and to assess hazard from floating and suspended volcanic ash particles ↓ • Update volcanic ash-fall data-base and analytical software • Develop hazard curve based on ash-cloud transport analysis • Develop hazard assessment method from floating and suspended volcanic ash particles	**GUI software for hazard curve②▽** Improve ash-fall database and hazard curve. Study floating pumice phenomena **Propose wind distribution application method②▽** Develop hazard assessment method for volcanic ash-fall based on ash-cloud transport analysis	**Long-term floating mechanism ②▽** **Propose vertical distribution of ash particles②▽**	**Tracking method for floating pumice ②▽** Develop assessment method for eruption magnitude and transport distance of volcanic ash particles Develop assessment method for physical properties of volcanic ash particles and floating pumice Develop hazard curve based on ash-cloud transport analysis Develop numerical analysis model for ash-cloud dispersion from large-scale eruptions (Include co-ignimbrite ash cloud)	**Propose new ash-fall database to include revised interpolation and extrpolation methods ②▽** **Density of ash particles②▽** **Expand numerical model②▽**	**Propose analysis-based hazard curve.②▽**	Develop eruption intensity and particle transport assessment based on magmatic properties. Develop assessment method for deposit load and settling in water. Develop hazard curve by ash-cloud transport analysis that include co-ignimbrite ash
Vulnerability assessment to volcanic ash-fall	Need to assess particle ingestion to air intake system, and to reduce the frequency of filter exchange. ↓ • Develop assessment method for particle ingestion and develop long-life pre-filter	**Propose assessment method for spherical particles. ①②▽** Experiment and numerical analysis on the amount of ash to enter the air intake system of DG Design long-life pre-filter for volcanic ash particles	**Propose assessment method for volcanic ash particles. ①②▽**	Develop simple numerical analysis method for air intake facility. Develop long-life pre-filter for volcanic ash particles	**Propose simple analysis method ①②▽** **Propose particle separator ①②▽**		Improve efficiency of particle separation measures for air intake facilities
Volcanic eruption and ash-fall PRA	Yet to be performed. ↓ • Develop preliminary PRA model and its guideline		Extract gaps on sub-models for volcano PRA	Develop volcanic ash-fall PRA model		**Guideline for volcanic ash-fall PRA ②▽**	Develop volcanic eruption PRA model

13. Extreme Weather such as Tornadoes (Hazard and Fragility)

▽：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～

Extreme weather hazard assessment

Gap/Solution:

Need for rational missile management, state-of art hazard estimation and those application under Japanese conditions

↓

- Development of tornado hazard estimation and missile management
- Application of probabilistic tornado missile strike assessment code, TOMAXI for Japanese conditions
- Establishment of typhoon hazard estimation and calculation design wind speed at real site

Roadmap:

- ～2023: Adaptation of tornado and missile hazard estimation method, e.g., TOWLA, TONBOS for JEF
- ～2023–2024: Improvement of tornado hazard assessment methods with reflecting new findings (including missile management)
  - ▽ Tornado hazard estimation method considering state-of art technique ①②
- 2025–2027: Rationalization and application of tornado hazard assessment
  - Refinement of technology for managing missiles①②▽
  - Tornado hazard estimation method considering state-of art technique ①②▽
- ～2023–2024: Application of missile assessment code TOMAXI and development of simplified method for domestic plants
- 2025–2027: Development of a probabilistic tornado missile evaluation method based on graded approach
- ～2023–2024: Establishment of typhoon hazard assessment method and design tool
  - Typhoon hazard assessment tool ①②▽
- 2025–2027: Application to probabilistic evaluation of typhoon hazards and deployment to superimposed events of high winds and other extreme weather events
  - High wind and superimposed hazard evaluation method①②▽
- 2028～: Practical application of probabilistic hazard evaluation technology

Extreme weather fragility assessment

Gap/Solution:

Lack of detailed estimation method for countermeasures for missile and fragility curve estimation method

↓

- Accumulation of missile impact test data and rationalization of damage estimation method
- Establishment of numerical simulation technique for missile structure damage
- Proposal for fragility curve estimation

Roadmap:

- ～2023: Development of impact test for steel plate
- ～2023–2024: Accumulation of missile impact test data and rationalization and generalization of damage estimation method
  - Damage estimation method ①②▽
- 2025–2027: Expansion of evaluation object, including typhoon debris
  - Damage estimation method ①②▽
- ～2023–2024: Establishment of numerical simulation technique for missile structure damage
- 2025–2027: Generalization of numerical simulation technology
- ～2023–2024: Development of fragility curve estimation for missile impact
  - Calculation method of fragility curve for missile ②▽
- 2025–2027: Application of fragility curve estimation to actual site
  - Calculation method of fragility curve for missile ②▽
- 2028～: Development of fragility estimation methods for probabilistic risk assessment

High wind PRA technique

13. Extreme Weather such as Tornadoes (PRA)

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	~2023	2024	2025	2026	2027	2028~
High wind PRA technique	Undeveloped practical code for high wind PRA for Japanese conditions ↓ • Establishment of tornado PRA technique with application for real site under Japanese conditions • Development of calculation and input tool of hazard information for Japanese tornado PRA • Generalization of Japanese tornado PRA method	Conduct detailed tornado PRAs at representative plant in Japan for generalization Development of code and technical report for tornado PRA	**Methodology of tornado PRA for Japanese NPPs ②▽** **Hazard and fragility estimation tool for tornado PRA ②▽**	Support and systematization of application of tornado PRA method to actual equipment with extension for typhoon event Improved practicality of tools for tornado PRA		**Instructions of tornado PRA for Japanese NPPs ②▽** **Improving the convenience of the hazard and fragility estimation tool for tornado PRA②▽**	Integration of probabilistic high wind risk assessment techniques

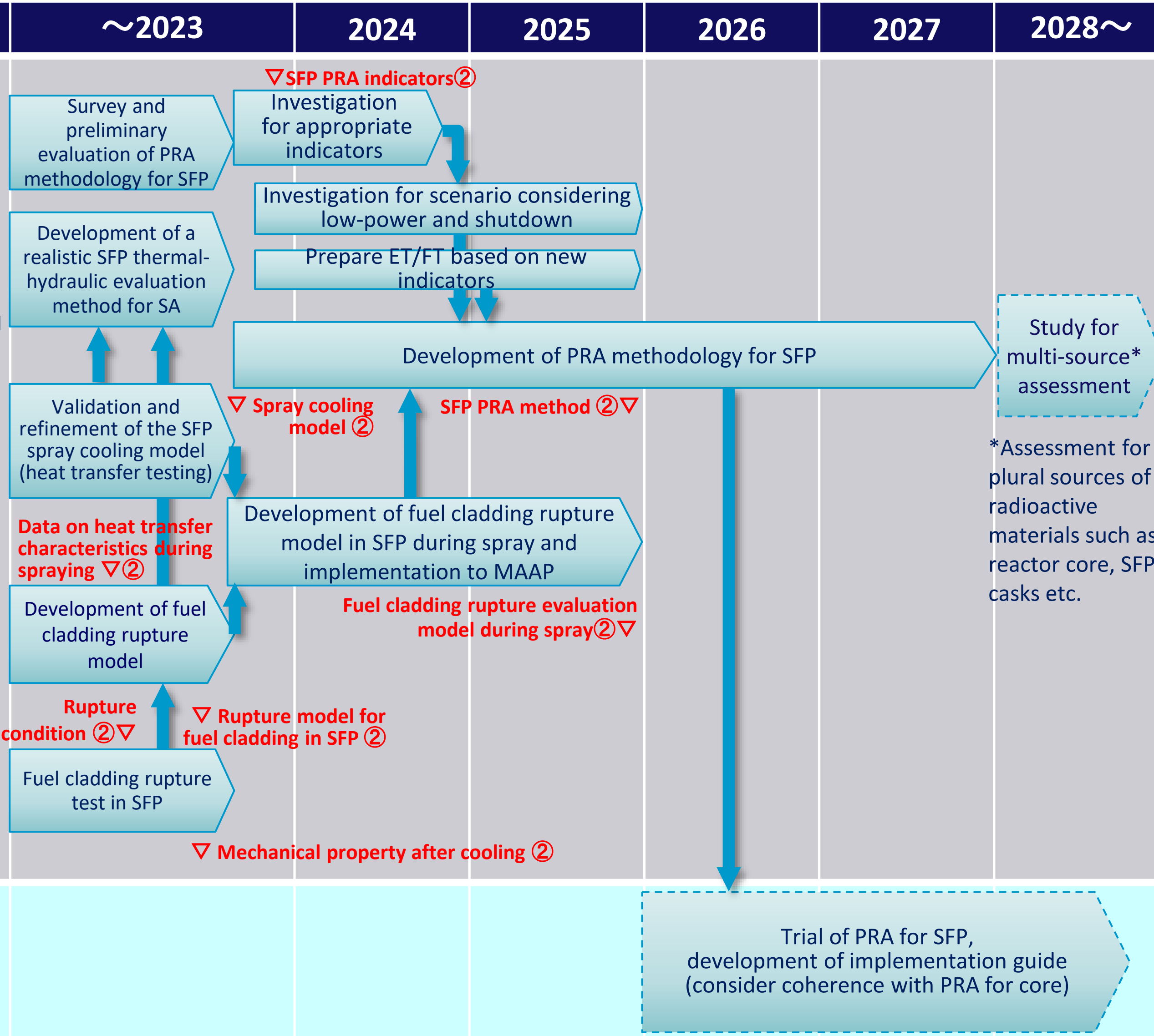
↑

Extreme weather hazard and fragility assessment

14. Spent Fuel Pool Risk Analysis Method Development

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution
Accident progress analysis of spent fuel pool (SFP)	Insufficient knowledge necessary to validate models for thermal behavior, fuel failure, and criticality in SFPs during SA, and PRA methods for SFPs. Investigation of appropriate indicators for SFP needed based on model plant study. ↓ • Clarification of natural circulation of gas phase in SFP, spray cooling effect, and rupture behavior of fuel cladding during SA and validation and improvement of MAAP model • Development of evaluation method for criticality in SFP during SA • Development of PRA method for SFP
Model plant assessment	Applicability of the developed method needs to be confirmed. ↓ • Trial of PRA for SFP • Develop implementation guide



15. Development of RC Method Considering Energy Security and Radiation Risk

▽：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～
Development of SNS utilization measures in RC practice	Utilities see SNS as a promising tool for communicating about nuclear power to the younger generation and child-rasing population but have yet to find a way to make use of it in RC. ↓ • Development of SNS utilization strategies in RC practice	**Strategies for construction of local SNS community with a sense of trust ⑤▽** Investigation of the construction and operation process through the trial of an experimental SNS community	**Results of analysis of responses to energy security and other content in local communities ⑤▽** Analysis of responses to SNS content including nuclear power	**Interaction strategies and effective content delivery strategies for each SNS ⑤▽** Study of measures to provide contents for SNS types	**Utilization of SNS by utilities ⑤▽** Development of SNS utilization strategies in regional dialogue		
Development of measures to provide information on radiation risks	Need to build trust in the protective measures and safety improvements to bridge the gap in knowledge between senders and receivers of information on radiation risk, which is a growing concern for local residents before and after the restart ↓ • Development of measures to provide information on radiation risks	**Risk communication guide for trust and regional dialogue on nuclear power ⑤▽** Development of dialogue technique for risk information	**Survey results of public perception of radiation risk ⑤▽** Survey of public perceptions of radiation risk	**Survey results of evacuation behavior, Analysis results of sender and receiver discrepancies ⑤▽** Survey of behavior regarding radiation risk, analysis of sender and receiver discrepancies	**Strategies for providing information on radiation risks ⑤▽** Development of information provision measures using Level 3 PRA	Development of RC methods that incorporate the concept of risk for building public confidence in nuclear energy (Items to be implemented based on the results of the research needs survey)	
Creation of knowledge that contributes to solving practical issues in regional dialogue	Need knowledge of risk messages related to risk management of nuclear power plants, etc., that are timely and responsive to changing social conditions associated with nuclear energy policy and restart of nuclear power plants ↓ • Timely provision of knowledge on risk messages that respond to practical issues related to RC	**Survey technique for validation of RC strategy of utilities ⑤▽** Development of survey technique for validation of utilities' RC strategy by collaboration at a pilot site	**Findings obtained through research and experiments in response to RC practical issues of utilities' ⑤▽** Qualitative/quantitative research and dialogue experiments on risk messages based on the identification of the needs and RC practical issues of utilities' (depending on each utility's needs every FY)	**⑤▽**	**⑤▽**		

RC：Risk Communication　SNS：Social Networking Service

16. Expansion of the Scope of RIDM Process Application

▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2023	2024	2025	2026	2027	2028～
Online Maintenance (OLM)	OLM has not yet been introduced in Japan. ↓ • Examination of specific cases base on domestic and international situations • Development of OLM Guide for domestic plants	International trend survey Case study of OLM (EDG, filling pumps, etc.) **OLM Guide④▽** Establishment of OLM Guide	**▽Revision of the Guide④** Revision of OLM Guide (Case additions and feedbacks from application)	Application to actual plants (*)	**▽Revision of the Guide④**		
Extension of containment vessel leak rate test (CVLRT) interval	The leak rate test (Type A) for the entire CV is conducted once per outage or every three outage. In US, test interval can be extended to 15 years maximum, based on risk information. ↓ • Based on domestic test data, confirm feasibility through risk impact. assessment when the test interval is extended. • Support for actual application	International trend survey, study of domestic application measures Trial risk evaluation based on domestic test data assuming extended CVLRT intervals, etc.	**Report on trial risk evaluation ④▽**	Support for application to actual plants			Application to actual plants
Risk-informed inservice inspection (RI-ISI)	The impact of introducing RI-ISI to Japanese NPPs need to be known. Domestic codes and guides are not established yet. ↓ • Evaluate the impact of introducing RI-ISI. • Support the establishment of domestic codes.		Evaluate the impact of introducing RI-ISI, identify issues for application Support the establishment of domestic codes		Pilot plant trial evaluation, proposal of methods for solving issues for application Support the revision of domestic codes		Application to actual plants

*** Among the actions for application to actual plants, OLM Guide is developed by the NRRC. The Nuclear Energy Association (ATENA) is considering the application of OLM to actual plants, including other efforts.**

[Legend] NRRC | Utility

17. Development of Integrated Risk Assessment Technology

▽：R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution
Development of practical guidance for integrated risk assessment	In Japan, RIDM implementation strategy has not been established based on a full-scope assessment of overall plant risk and its contributing factors. ↓ • Organize the concept of integrated RIDM, integrated risk assessment, and risk aggregation (including interpretation of and response to uncertainty), and develop practical guidance for integrated risk assessment to realize it
Development of a method for integrated risk assessment	There is no methodology or technique to embody integrated risk assessment and risk aggregation from the domestic business model. ↓ • Collection of existing knowledge (methods and technologies) to embody integrated risk assessment • Methodology development through identification of issues in embodiment of integrated risk assessment