NRRC R&D Roadmap

As of March, 2024

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

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

Application

Feedback

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 Implementation Guide 2026 Level 2 MUPRA Method	2023 Revision of WinMACCS Utilization Guide 2025～ Trial Level 3 PRA (Model Area)
Internal Event	Shutdown PRA			
Internal Event	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)		
External Event	Tsunami PRA	2017-2020 Tsunami PRA (Model Plant)		
External Event	Multi-Hazard PRA	2021-2023 MHPRA (Seismic & Seismically-Induced Tsunami PRA, Model Plant)		
External Event	Other External Event PRA (Tornado/High Wind/Volcano)	2022～ High Wind PRA Model Plant 2024～ 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 ⇒ Practical Application ≀ Application of each key method as soon as it becomes available

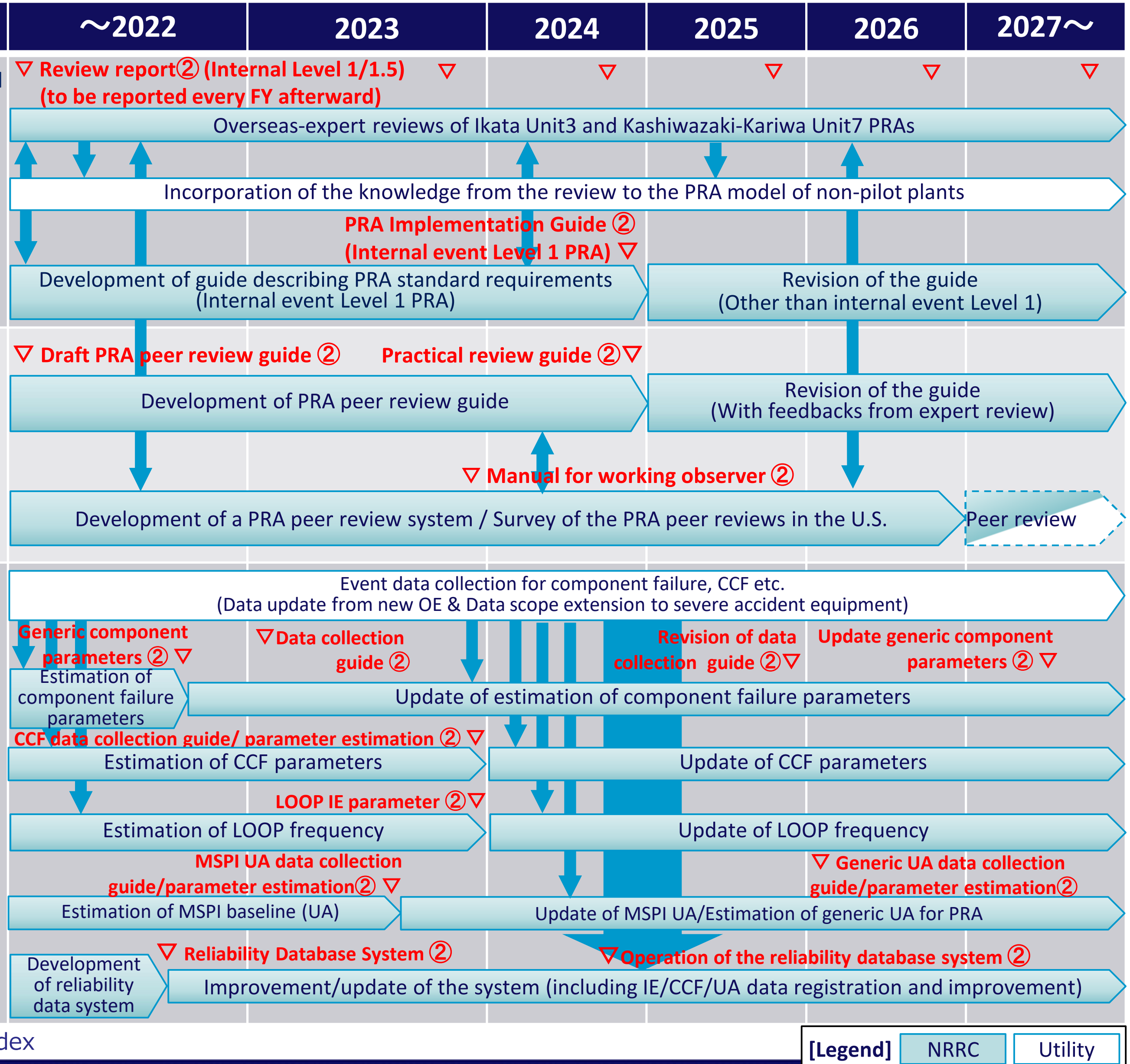
PRA Item	R&D Item \ Fiscal Year	～2022	2023*	2024	2025	2026	2027～
Internal Events	Internal Event Level1 PRA Method Improvement		●				
	Human Reliability Analysis (HRA) Method Improvement		●				
	HRA Method Development for Extreme Condition		●				
	Multi-Unit PRA Method Development						
	Radioactive Material 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 2024, 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)

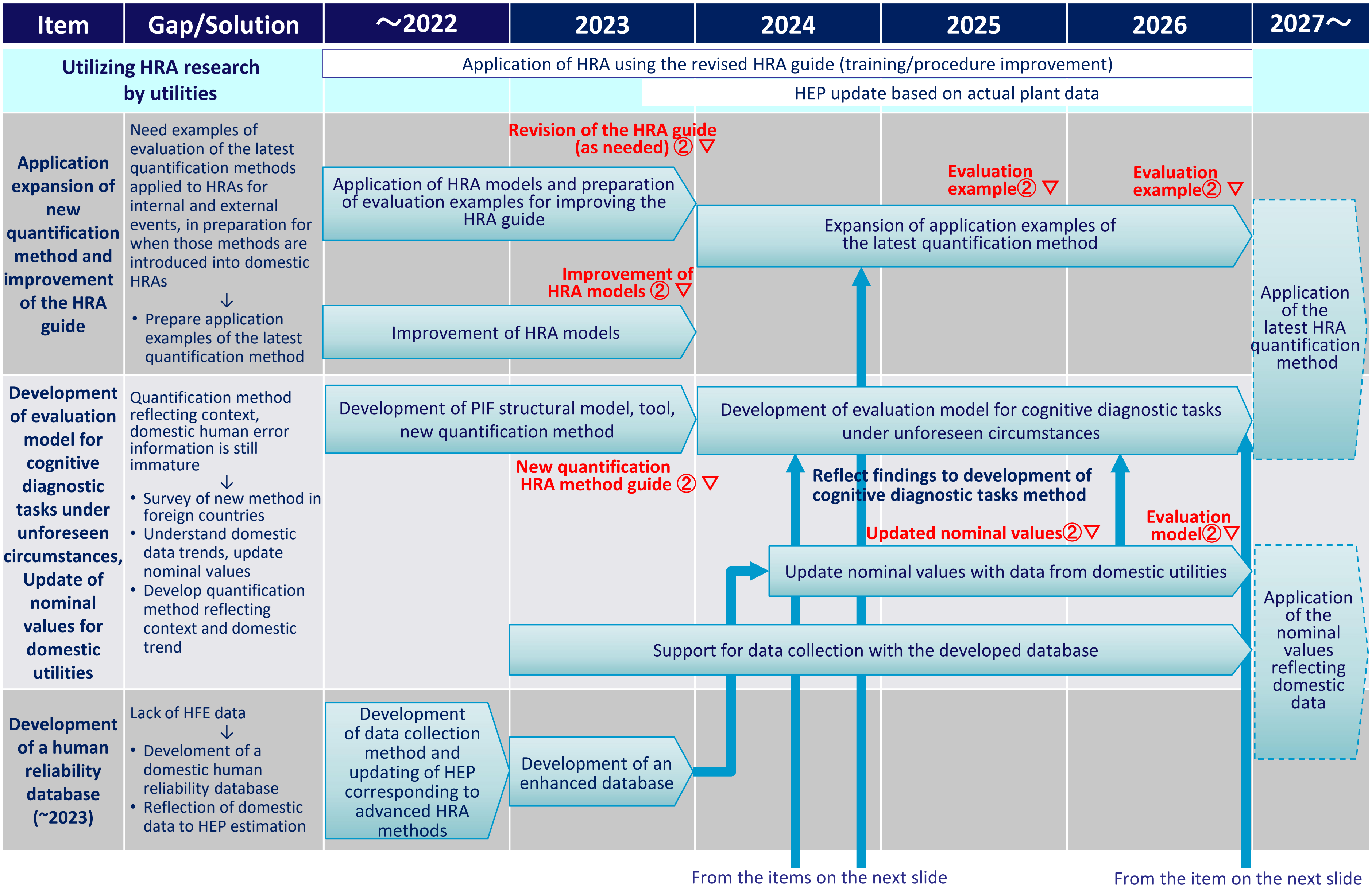
Item	Gap/Solution
Support of pilot projects for Good PRA	Domestic PRA has not reached the state of practice. ↓ • Overseas-expert reviews of pilot plants for PRA model improvement • Develop a guide to support utility's PRA modelling to meet international standard
Development of PRA peer review procedure	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
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.



*MSPI: Mitigating System Performance Index

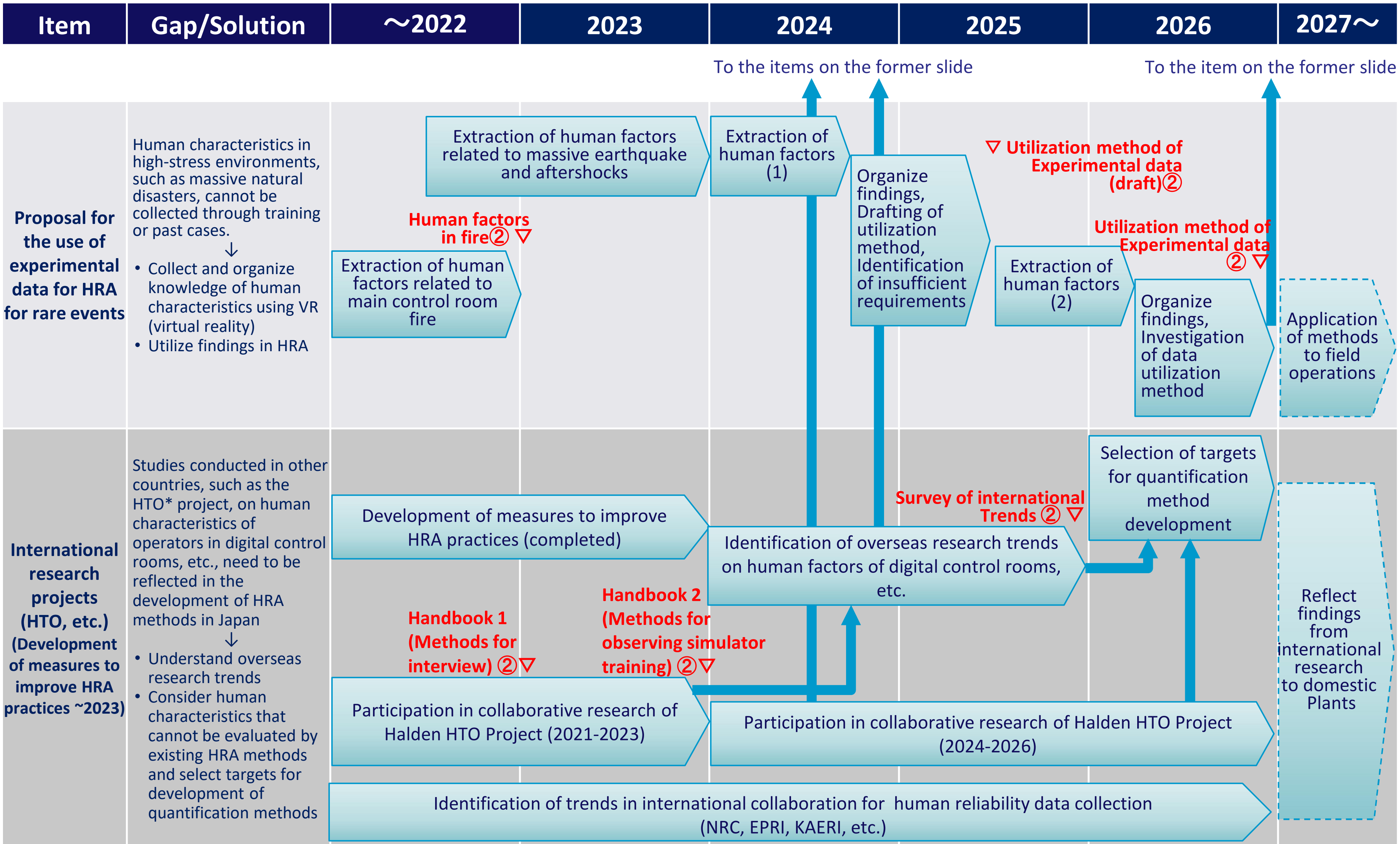
2. Development and Advancement of Human Reliability Analysis Methods (1/2)

▽ : 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)



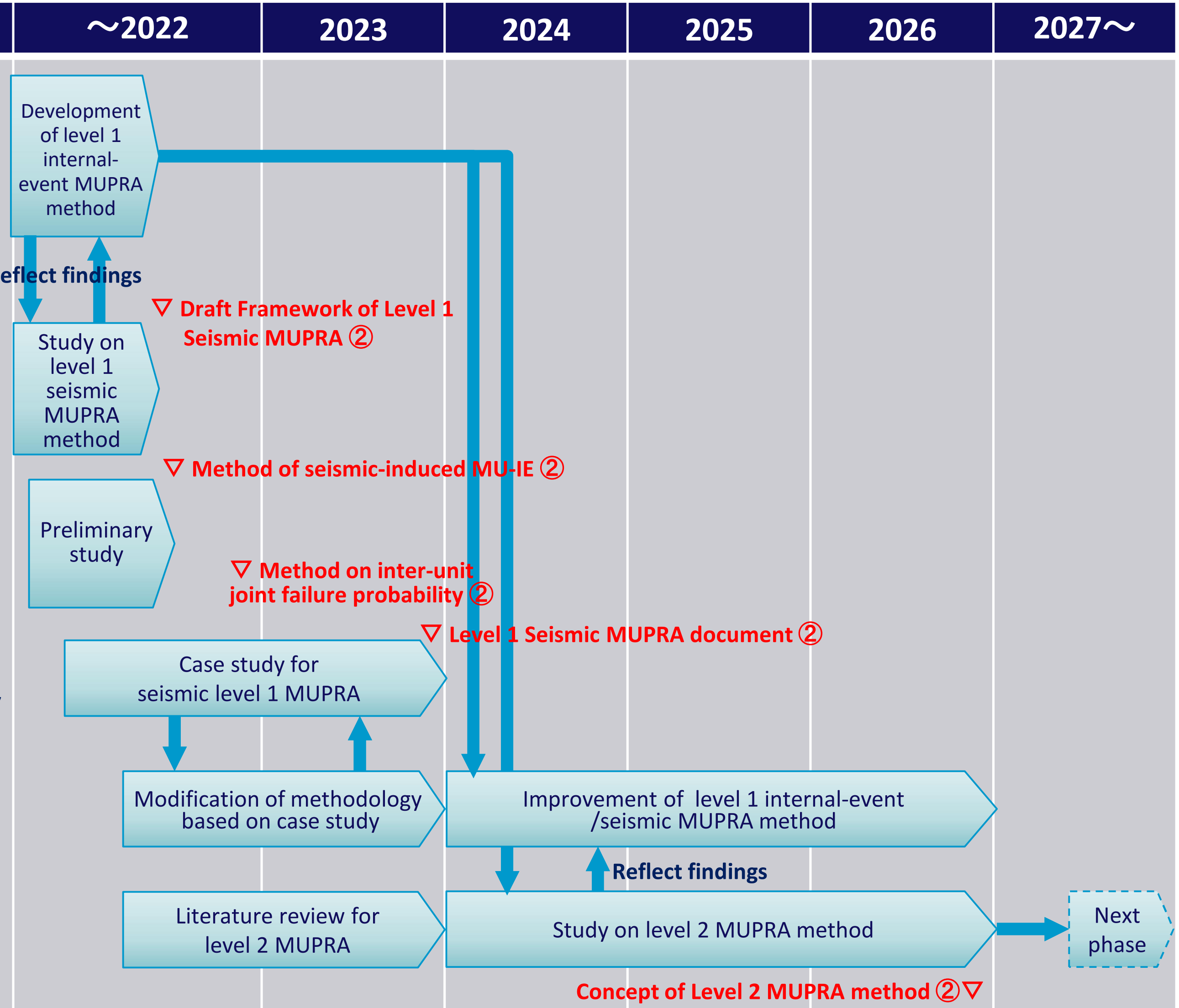
*HTO: Human-Technology-Organisation

[Legend] NRRC Utility

3. Multi-Unit PRA (MUPRA)

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

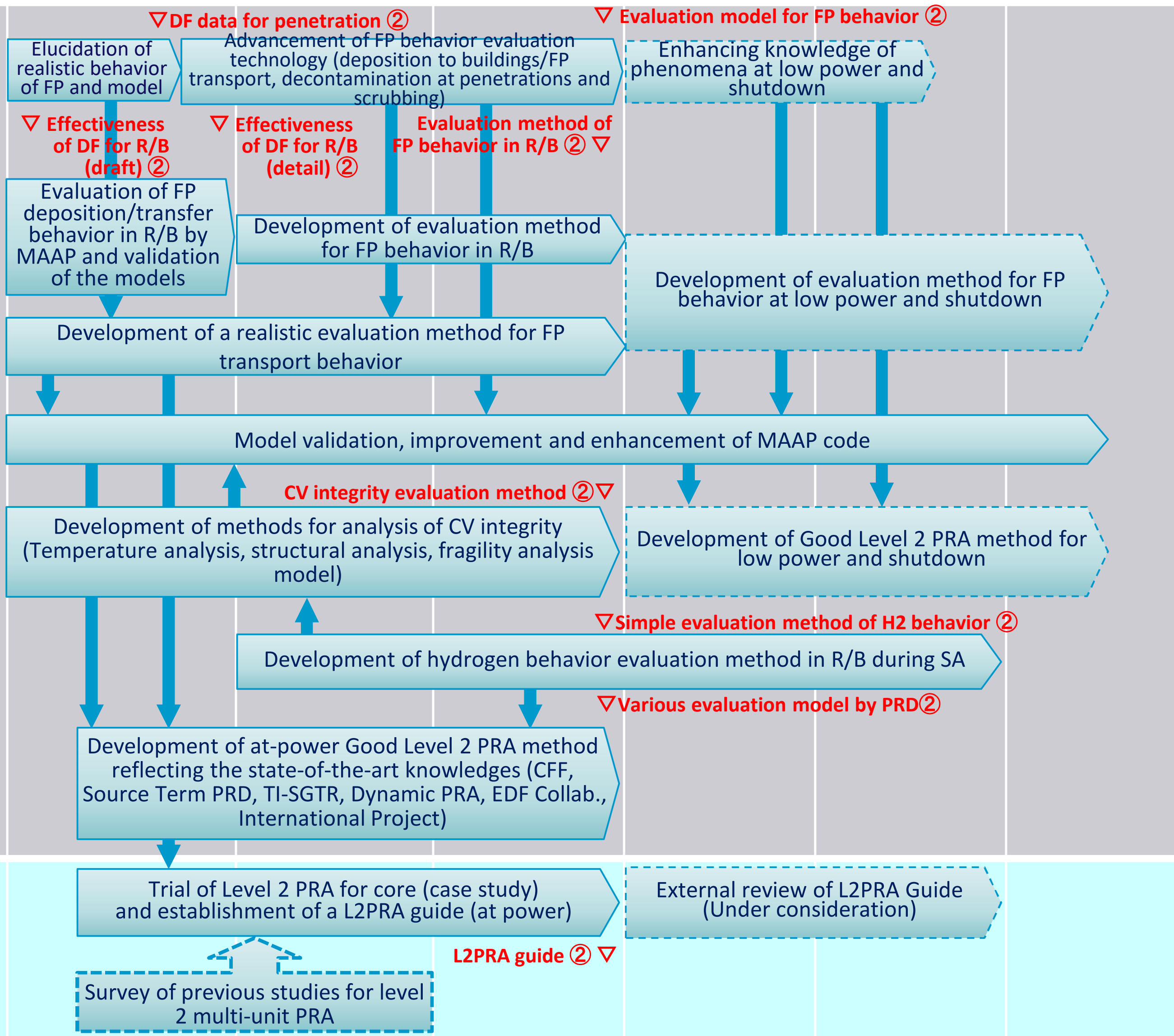
Item	Gap/Solution
Development of multi-unit PRA (MUPRA) methodology	Standard methodology for implementing Good PRA that consider the context of MU accident are not yet developed. ↓ • Development of level 1 internal-event MUPRA method • Development of level 1 external hazard (seismic) MUPRA method • Contribution to level 2 PRA study



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

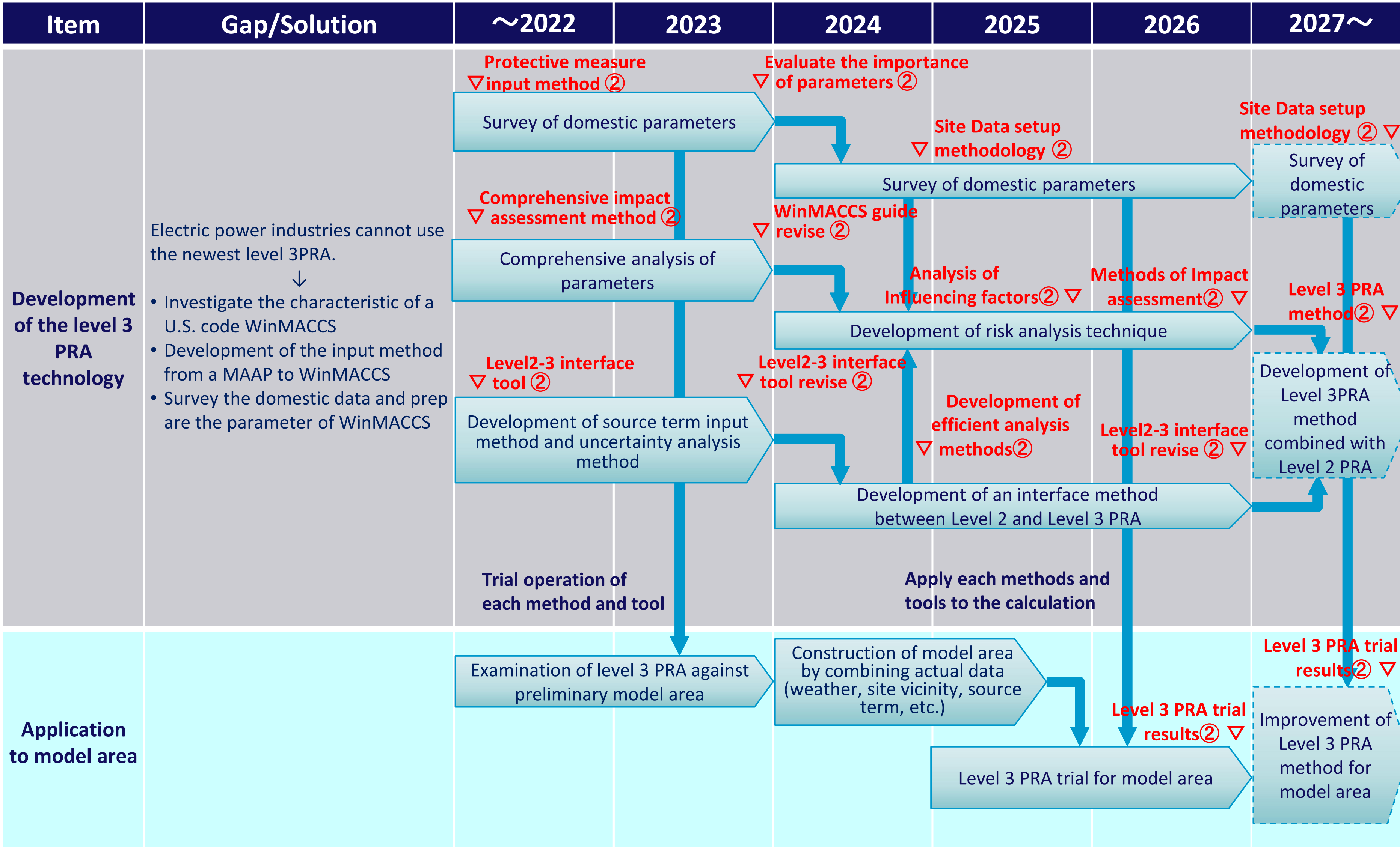
▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2022	2023	2024	2025	2026	2027～
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						
Model plant assessment	Development of Good Level 2 PRA methodology by confirming the applicability of various methods						



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)

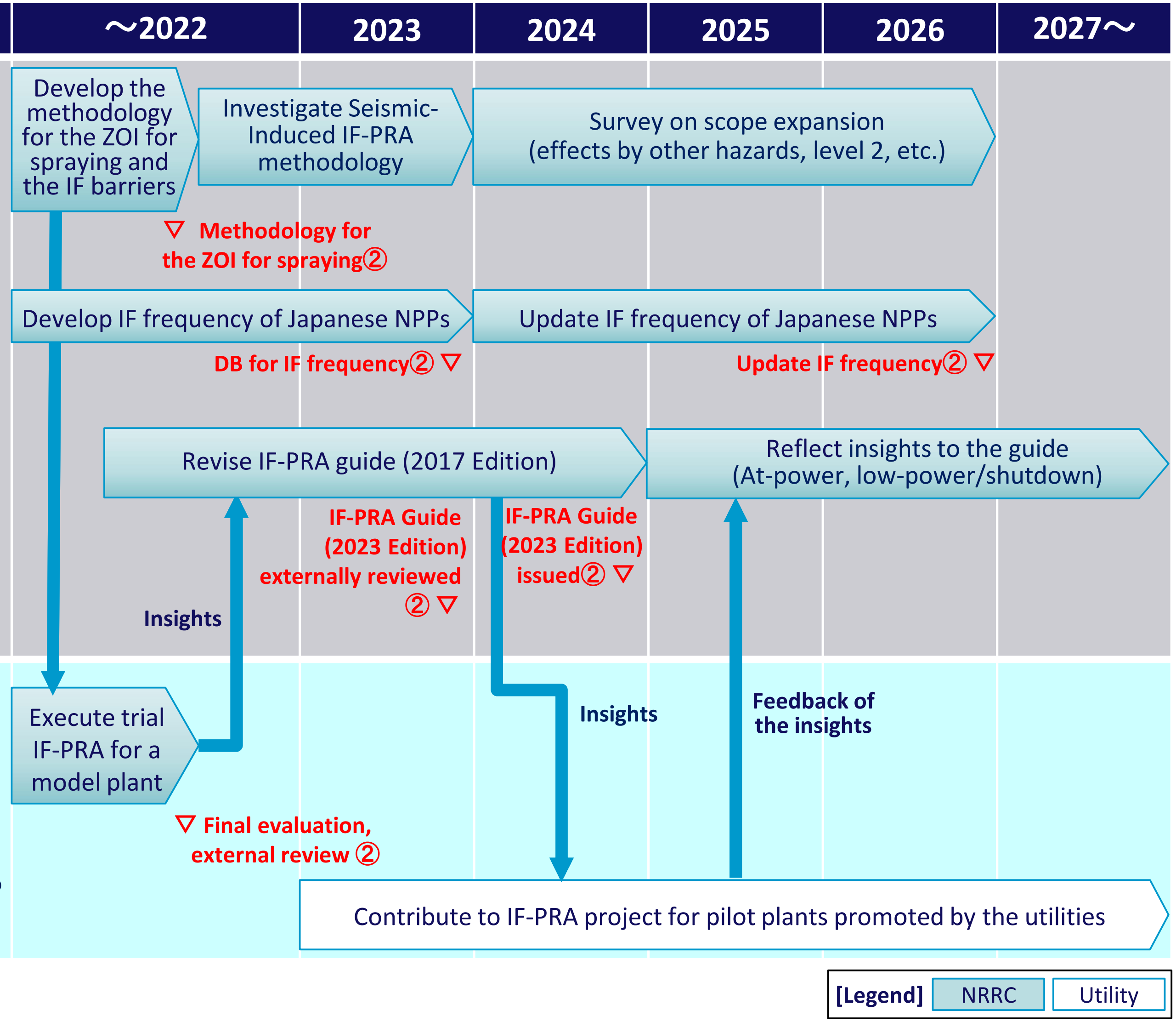
Item	Gap/Solution	～2022	2023	2024	2025	2026	2027～
Establish internal fire PRA (FPRA) methodology	➢ Applicability of FPRA Guide (FPRAG) and Fire Ignition Frequency (FIF) to PRA for actual NPPs, including low-power and shutdown conditions ➢ Accumulate the insights for scope expansion ↓ • Update FPRAG (2019 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 Develop FIF for Japanese NPPs Fire ignition frequency②▽	Accumulate insights to update FPRAG Investigate seismic-Induced FPRA methodology	Revision of FPRAG (At-power) Insights Insights Update FIF for Japanese NPPs, Survey on scope expansion (effects by other hazards, level 2, etc.)	FPRAG (2026 Edition) externally reviewed ②▽	FPRAG (2026 edition) issued ②▽	(Low-power, Shutdown)
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 by NRA due to the regulation amendment related to cabinets and bus-ducts ➢ Damage mechanism on targets (including digital I&C) due to smoke and heat ↓ • Accumulate the knowledge by HEAF fire tests using full-scale electric cabinets and bus ducts • 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) Information exchange with EDF, INL HEAF fire and ZOI tests on electrical cabinets and bus-ducts ▽ Prevention methodology on HEAF fires① International cooperation with OECD/NEA (HEAF ZOI: HEAF2)	Release updated zone model (BRI2-CRIEPI). ② ▽ Participate in “FAIR” project ▽HEAF-ZOI model① Insights	Improve modeling methodology Collaborative fire test with EDF “PRELUDE” Correspond to new insights (digital I&C, etc.)	Develop field model.② ▽	Develop DL model.②▽	

[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)

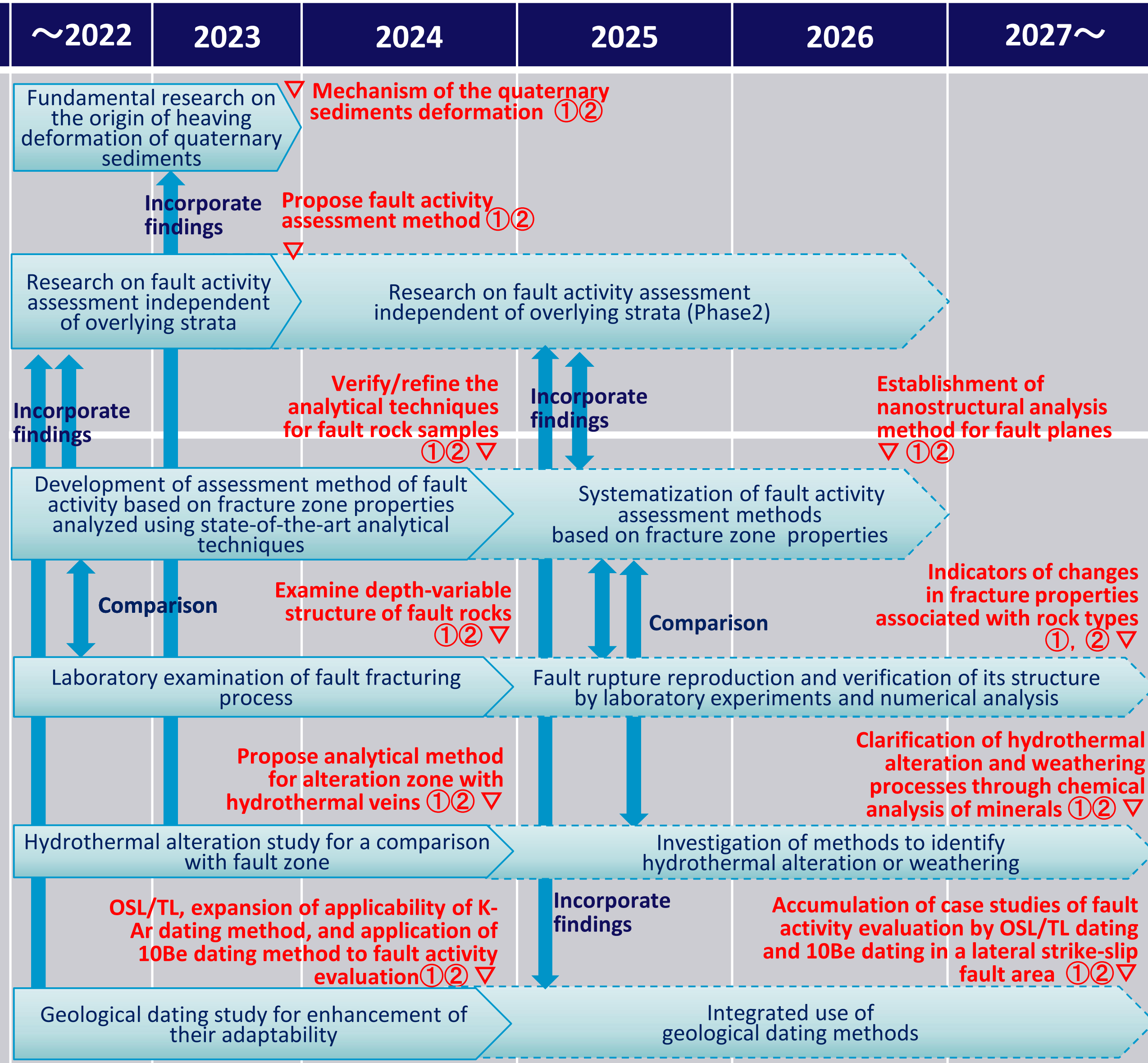
Item	Gap/Solution
Establish internal flooding PRA (IF-PRA) methodology	➢ No published practical IF-PRA guide for Japanese NPPs, including low-power and shutdown conditions ➢ Insufficiently developed IF event database and its frequency in Japan ➢ Accumulate the insights for scope expansion ↓ • Update and publish a practical IF-PRA guide (2017 edition) based on the latest knowledge and lessen 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
Fault activity assessment based on the nature of fault zone	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



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	～2022	2023	2024	2025	2026	2027～
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	Rational assessment method of multi-segment faulting (quantitative analysis) (～2024) **Qualification of the condition of fault rupture termination ② ▽** ↓ Incorporate findings Development of a recognition method for active faults in coastal area (～2024) **Advancement of seismic source characterization in coastal area ①② ▽**			Systematization of source fault assessment methods for earthquake magnitude prediction (2025～) **Advanced method for evaluating seismogenic layer and fault geometry ①② ▽** ↑ Incorporate findings Development of a recognition method for blind active faults (2025～) **Advancement of seismic source characterization for blind faults ①② ▽**		
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	Collection of new findings related to revision of international standards (～2022) **Sort out issues ② ▽** ↓ Incorporate findings Assessment of distributions, characteristics, and displacements of surface ruptures based on remote sensing and field surveys (～2024) **Summarization of basic information on distributions, characteristics, and displacements of subsidiary faults ② ▽** ↕ Comparison Systematization of the development process of active fault systems based on model tests and analyses (～2024) **Organization and analysis of fault model test results, and systematization of assessment techniques ①② ▽**			Incorporate findings (from Development of a recognition method for blind active faults) **Feature extraction of near-surface fault structure ①② ▽** Characterization of recently occurred surface ruptures (2025～) ↕ Comparison / ↑ Incorporate findings Assessment of distributions and displacements of surface ruptures based on remote sensing (2025～) **Establishment of a fault displacement evaluation method ①② ▽** ↕ Comparison Accumulation of data on fault continuity and proposal of a method for its evaluation (2025～) **Feature extraction of continuous and disappearing faults ①② ▽**		

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

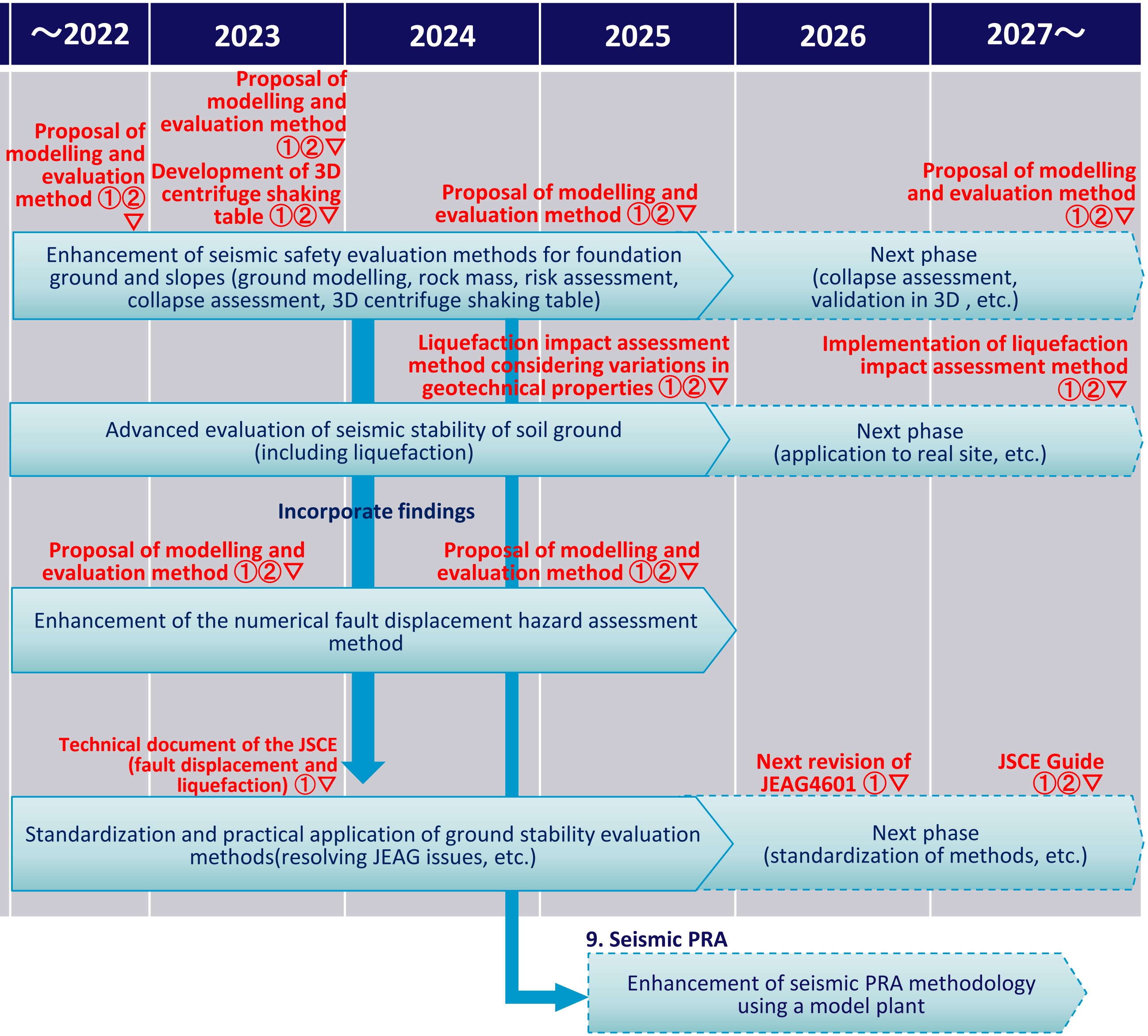
▽ : R&D outcome and specific area of contribution (indicated by number ①-⑤ in page 2)

Item	Gap/Solution	～2022 – 2024	2025 – 2027～
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	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 **Standard level assessment of seismic ground motion with unspecified source ①②▽**	Next phase
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	Next phase
		Flat file database ①②▽ Construction of database on outcrop rock records	Expansion of database
		Applicability of existing GMPE	Development of new generation domestic GMPE for hardrock
		Establishment of GMPE conversion method to site rock conditions ①②▽ Development of site adjustment method for ground motion prediction equation based on subsurface structural model	Subsurface structure modeling and its application to the site adjustment for GMPE
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▽** Construction of a domestic implementation plan for multi-site SSHAC(site response models for Incorporation into PSHA)	Implementation of multi-site SSHAC based on the domestic development plan
		Multi-hazard assessment of earthquake and tsunami superposition, etc.	
		Estimating epistemic uncertainty ②▽ Enhancement of estimating the epistemic uncertainty of ground motion prediction models	Next phase
		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 methodology based on fault model

8-3. Seismic/Earthquake Resistance (Ground)

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

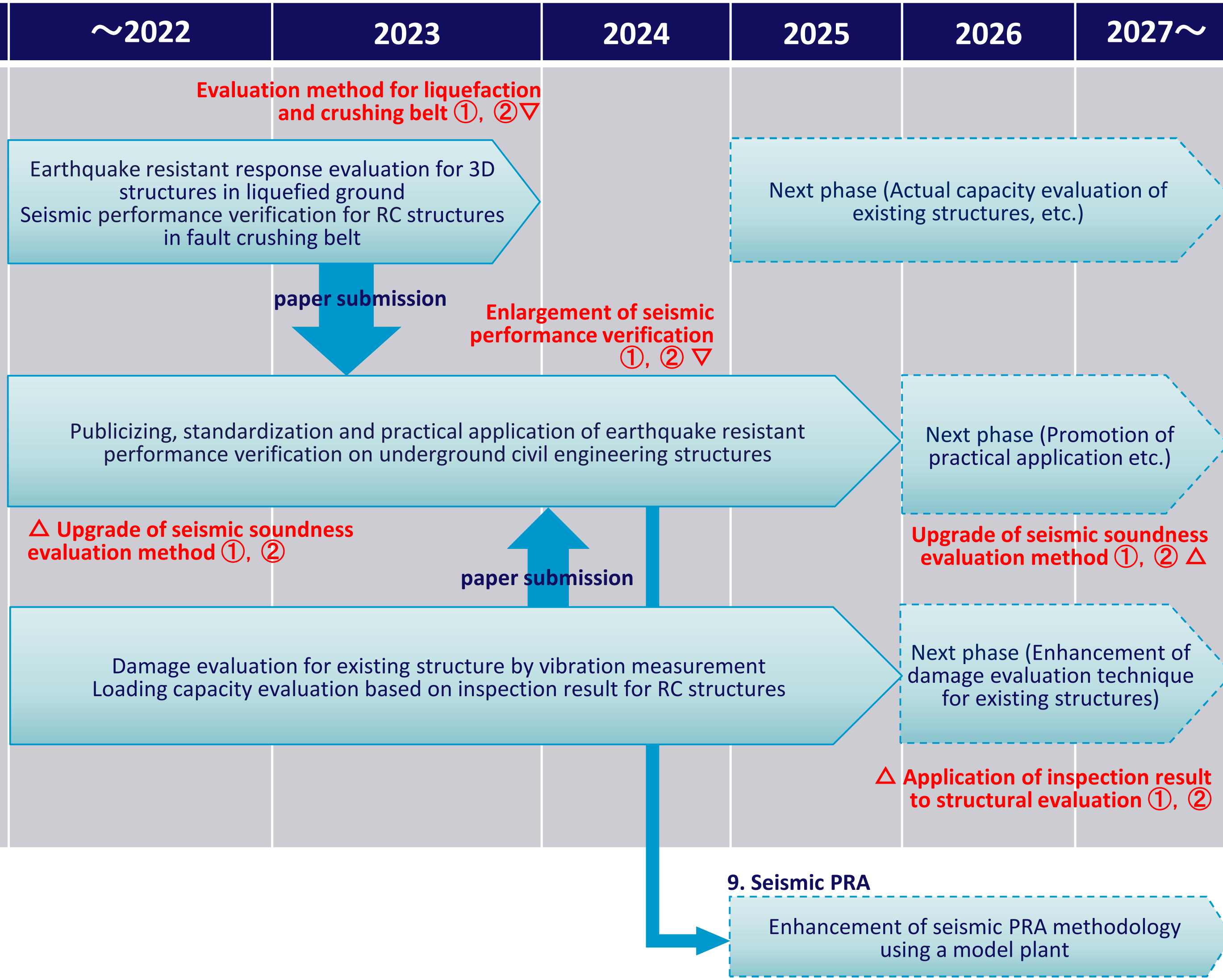
Item	Gap/Solution
Enhancement and systematization of evaluation methods for seismic safety of ground	With the increase of the reference earthquake ground motion, it is necessary to improve the seismic safety evaluation method for foundation ground and slope, and to clarify the uncertainty in seismic PRA. ↓ • Enhancement of seismic safety evaluation methods for foundation ground and slopes (ground modelling, rock mass, risk assessment, collapse assessment, 3D centrifuge shaking table) • Advanced evaluation of seismic stability of soil ground (including liquefaction) Uncertainty of fault parameters and superposition of fault displacement and earthquake motion are not taken into account in fault displacement evaluation. ↓ • Advancement of fault displacement hazard assessment methods using numerical analysis



8-4. Seismic/Earthquake Resistance (Structures)

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

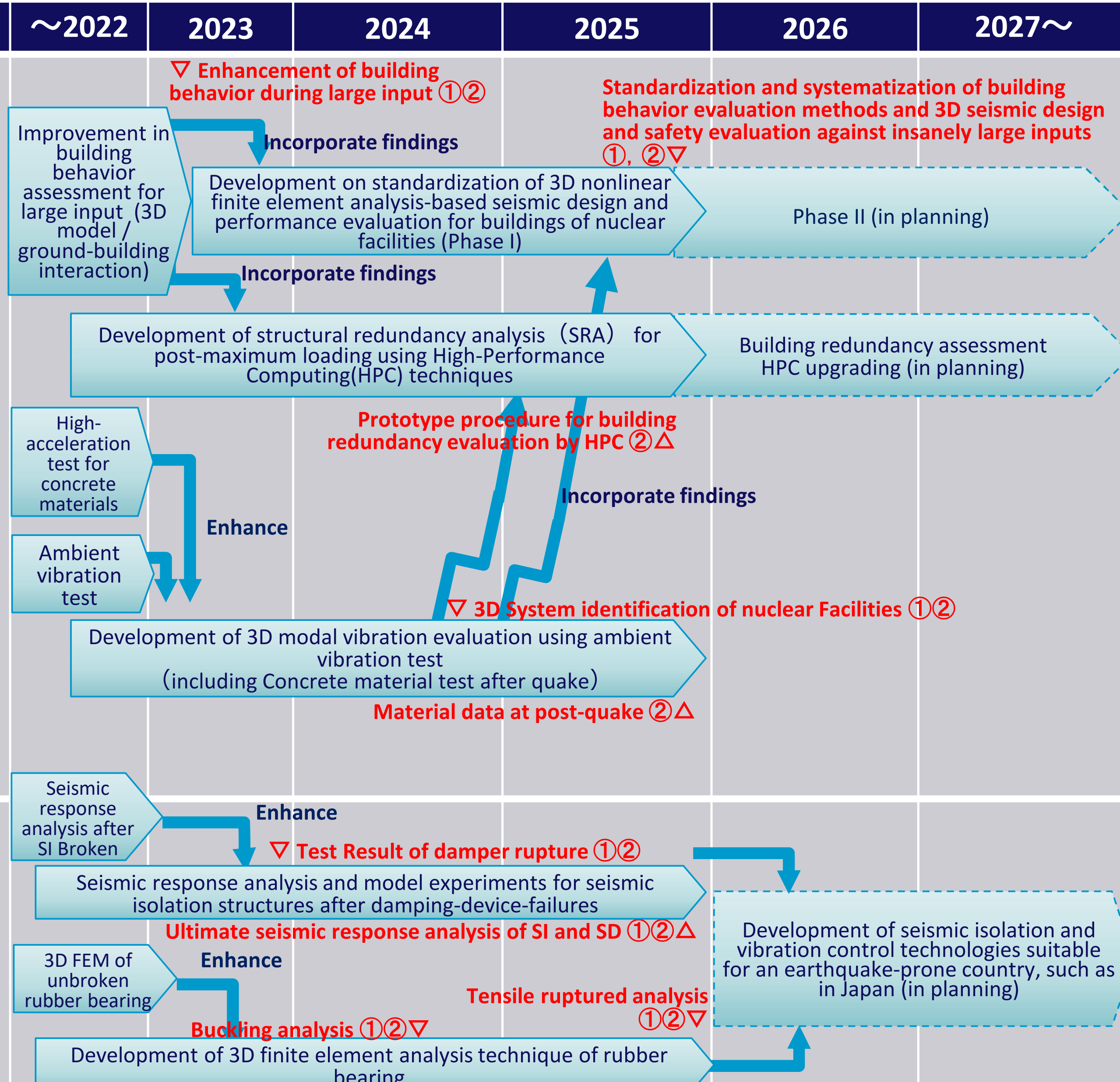
Item	Gap/Solution
Assessment of civil engineering structures	For critical civil engineering structures in liquefied ground and fault crushing belt, seismic evaluation is required. ↓ • Development and standardization of seismic performance verification methods for RC structures in liquefied ground and 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	Insufficient knowledge of three-dimensional (3D) and highly-nonlinear(H-N) seismic behaviors on nuclear power building ↓ • Basic techniques for 3D and H-N seismic response prediction, e.g., 3D modeling with concrete cracks and partial collapses; soil-structure interaction with base uplifting and sliding; modeling for high-performance computing (HPC) A building is 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 Strong earthquake observation can be improved to seismic design, and more observation points are needed for verification of 3D based design. ↓ • Ambient vibration test for nuclear facilities
Ultimate load design for seismic isolation structures	Underdevelopment of seismic analysis after seismic isolation(SI) and damper(SD) devices damaged ↓ • Shake test for damaged dampers • Seismic response analysis after SDs damaged • 3D FEA 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	～2022	2023	2024	2025	2026	2027～
Rationalization of seismic design methods for equipment and piping systems	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	Rationalization of seismic design methods Practical application and standardization of seismic evaluation methods for equipment and piping considering elasto-plasticity	**Practical application of elasto-plastic evaluation methods for piping ①②▽**		Improvement and standardization of methods Reflection on code case of the JSME standard	**Standardization of elasto-plastic evaluation methods ①②▽**	
		Standardization of fragility evaluation methods Development of simplified elasto-plastic evaluation method for fatigue evaluation	**Rationalization of simplified elasto-plastic evaluation method (Ke) ①②▽**		Improvement of evaluation methods	**Improvement of elasto-plastic evaluation methods ①②▽**	
		Rationalization of seismic design methods Individual tank sloshing evaluation		Rationalization of seismic design methods Development of a simple evaluation method for large amplitude sloshing loads		**Simple evaluation method of large-amplitude sloshing load ①②▽**	
Advanced fragility evaluation of equipment and piping systems	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	Improvement of fragility Piping fragility evaluation method using fatigue as an indicator	**Piping fragility evaluation method ②▽**		Improvement and standardization of evaluation methods Reflection on the Atomic Energy Society of Japan standards	**Reflection of piping fragility evaluation methods in standards ②▽**	
		Improvement of fragility Development of Evaluation method of loss of offsite power fragility	**Evaluation method of loss of offsite power fragility ②▽**	Improvement of evaluation methods Public knowledge through papers for standardization		**Reflection of loss of offsite power fragility evaluation methods in standards ②▽**	
		Improvement of fragility Development of Structural and Equipment Coupled Fragility Evaluation Methods	**Structural and equipment coupled fragility evaluation method②▽**	Improvement of evaluation methods Structural and equipment coupled fragility evaluation method development		**Development and improvement of methods for evaluating the fragility of structure-equipment coupling ②▽**	
Utilization of seismic experience data	Experience data on seismic BC-class equipment is not sufficiently reflected in fragility evaluations. ↓ • Utilizing for evaluating the equipment fragility	Study on enhancing scope of application of actual earthquake experience data, etc.					

9. Seismic PRA

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

Item	Gap/Solution	～2022	2023	2024	2025	2026	2027～
Development of seismic PRA methodology	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						

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

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

Enhancement of seismic PRA methodology using a model plant

- Consideration of seismic-induced consequential events
- Implementation of more realistic method regarding seismic correlation evaluation
- Implementation of enhanced/advanced PSHA
- Finalization of NRRC Seismic PRA implementation guideline
- Improvement and enhancement study of system analysis for external event PRA

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

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 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	～2022	2023	2024	2025	2026	2027～

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

Roadmap

- ～2024: Development of methods on Judgement for event deposits including tsunamis
  - ▽ (end of 2024) Analysis technologies on uncertainty in judgement for event deposits ①,②
- 2025～2027～: Upgrade of methods on judgement for event deposits including tsunamis
  - ▽ (end of 2027～) Advanced analysis technologies on uncertainty in judgement for event deposits ①,②
- ～2024: Development of numerical simulation technologies for landslide tsunamis
  - ▽ (2023) Three-dimensional Eulerian approaches ①, ②
- 2025～2027～: Upgrade of numerical simulation technologies for landslide tsunamis
  - ▽ (2025) Three dimensional Lagrangian approaches ①, ②
  - ▽ (end of 2027～) Practical application of 2D/3D numerical simulation technology①,②
- ～2026 (continuing into 2027～): Development of methodology of PTHA including non-seismic tsunamis
  - ▽ (2023) Methodology of PTHA including non-seismic tsunamis ①,②
  - ▽ (2026) Proposal of PTHA methodology including non-seismic tsunamis ①,②

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

Roadmap

- ～2026 (continuing into 2027～): Upgrade of tsunami simulation technologies
  - ▽ (end of 2024) Upgrade of tsunami simulation technologies (intake) ①,②
  - ▽ (2026) Upgrade of tsunami simulation technologies (Hybrid 2D&3D simulation and proper usage)①, ②
- ～2024: Development and systemization of evaluation methods of debris collision effects
  - ▽ (end of 2024) Systemization of evaluation methods of debris collision effects ①, ② (JSCE)
  - △ (end of 2024) Upgrade of collision simulation technologies for small boat①, ②
- 2025～2027～: Systemization of evaluation methods of debris collision effects (Phase 2)
  - ▽ (end of 2027～) Publication of technical reports on evaluation methods of debris collision effects ①, ② (JSCE, JEAC)
- ～2026: Study on secondary influence assessment
  - ▽ (2023) Evaluation method of wave force by tsunami with high sediment concentration ①, ②
  - ▽ (end of 2026) Upgrade of probabilistic risk assessment methodology of secondary influence①, ②

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	～2022	2023	2024	2025	2026	2027～
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 • Develop a methodology of evaluation for tsunami inundation in sites	**Methodology of tsunami PRA ②** ▽ Accumulation and upgrade of methodology of tsunami PRA using BRW model plant (→ 2024)		**Accumulation of knowledge on tsunami PRA and development of related tools ②** ▽	Accumulation and upgrade of methodology of tsunami PRA toward practical application (2025 → 2027～)		**Standardization of methodology of tsunami PRA (AESJ) ②** ▽
Development of PRA methodology against combination of earthquake and seismic – induced tsunami	No PRA method has been developed worldwide considering superposed natural external hazards. ↓ • Development of PRA methodology against combination of earthquake and seismic-induced tsunami	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 (→ 2023)	▽ **Hazard and fragility evaluation method against combination of earthquake and tsunami (Basic method)②** ▽ **Concept of technical elements, evaluation for earthquake and seismic-induced tsunami PRA②**		Next phase (2025 → 2027～)		

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	～2022	2023	2024	2025	2026	2027～
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	**Propose literature-based hazard curve. ②▽** Improve ash-fall database and hazard curve. Study floating pumice phenomena (～2022–2024) Develop hazard assessment method for volcanic ash-fall based on ash-cloud transport analysis (～2022–2024)	**GUI software for hazard curve②▽** **Propose wind distribution application method②▽**	**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 (2025–2027～) **Determine particle size distribution②▽** Develop assessment method for physical properties of volcanic ash particles and floating pumice (2025–2027～) **Propose analysis-based hazard curve.②▽** Develop hazard curve based on ash-cloud transport analysis (2025–2027～) Develop numerical analysis model for ash-cloud dispersion from large-scale eruptions (Include co-ignimbrite ash cloud) (2025–2027～)		**Interpolation and extrapolation method for ash-fall distribution ②▽** **Density of ash particles②▽** **Expand numerical model②▽**
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 (～2022–2024) **Propose long-life pre-filter for volcanic ash ①②▽** Develop long-life pre-filter for volcanic ash particles (～2022–2024)		**Propose assessment method for volcanic ash particles. ①②▽**	**Propose improved particle separator. ①②▽** Improve efficiency of particle separation measures for air intake facilities (2025–2027～)		
Volcanic ash-fall PRA	Yet to be performed. ↓ • Develop preliminary PRA model and its guideline		**Select methods to be improved in the next phase of PRA model development. ②▽** Development and trial of preliminary PRA model for volcanic ash-fall (2023–2024)		**Guideline for ash-fall PRA②▽** Revise volcanic ash-fall PRA model (2025–2027～)		**Revise ash-fall PRA guideline. ②▽**

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	～2022	2023	2024	2025	2026	2027～
Extreme weather hazard assessment	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	Adaptation of tornado and missile hazard estimation method, e.g., TOWLA, TONBOS for JEF		**Tornado hazard estimation method considering state-of art technique ①②▽**			
		Improvement of tornado hazard assessment methods with reflecting new findings (including missile management)			Rationalization and application of tornado hazard assessment		
		Application of missile assessment code TOMAXI and development of simplified method for domestic plants					
				Typhoon hazard assessment tool ①②▽			
		Establishment of typhoon hazard assessment method and design tool			Deployment to superimposed events of high winds and other extreme weather events		
Extreme weather fragility assessment	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	Development of impact test for steel plate		**Damage estimation method ①②▽**			
		Accumulation of missile impact test data Rationalization and generalization of damage estimation method			Expansion of evaluation object, including typhoon debris		
		Establishment of numerical simulation technique for missile structure damage			Generalization of numerical simulation technology		
				Calculation method of fragility curve for missile ②▽			
		Development of fragility curve estimation for missile impact			Application of fragility curve estimation to actual site		

→ 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)

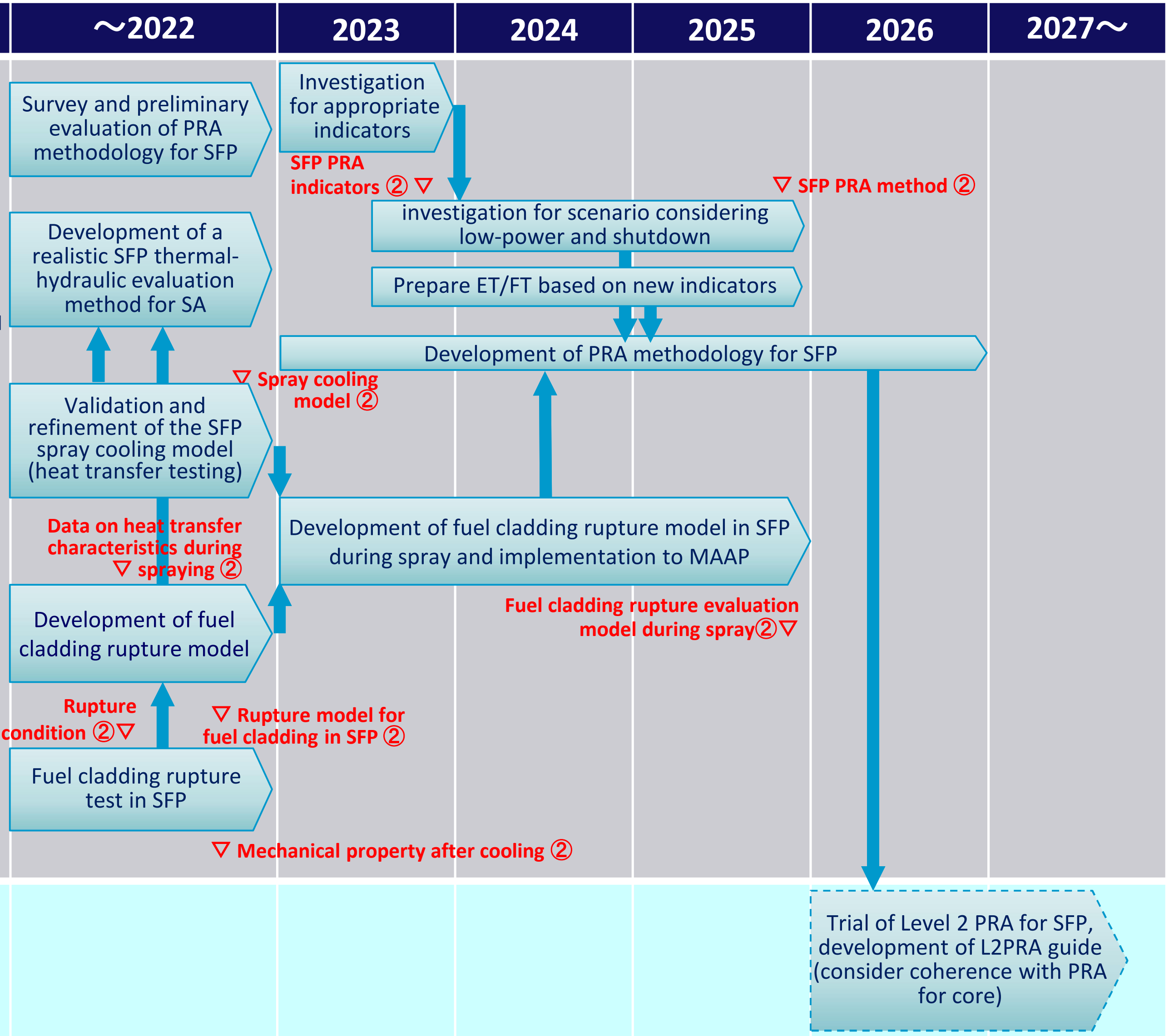
Item	Gap/Solution	～2022	2023	2024	2025	2026	2027～
High wind PRA technique	Undeveloped practical code for high wind PRA for Japanese conditions ↓ • Establishment of tornado PRA technique with application for real site under Japanese conditions • Development of calculation and input tool of hazard information for Japanese tornado PRA • Generalization of Japanese tornado PRA method	Conduct detailed tornado PRAs at representative plant in Japan for generalization (～2024) Development of code for tornado PRA under Japanese condition (～2024)	**Database of tornado missile for Japanese NPPs ②▽**	**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 (2025～) Improved practicality of tools for tornado PRA (2025～)		

Extreme weather hazard and fragility assessment ↑ (feeds into: Improved practicality of tools for tornado PRA)

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 during SA (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 Level 2 PRA for SFP • Develop a 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	～2022	2023	2024	2025	2026	2027～
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	**【Item 4. until 2023】 Creating new community for local communication activity using social media** **The result of trial for providing nuclear information ⑤▽** Creation of experimental communities and identification of issues of them	**Strategies for construction of local SNS community with a sense of trust ⑤▽** Organized operational methods	**Results of analysis of responses to energy security and other content in local communities ⑤▽** Analysis of responses to SNS content	**Interaction strategies and effective content delivery strategies for each SNS ⑤▽** Study of measures to provide SNS content	**Utilization of SNS by utilities ⑤▽** Development of SNS utilization strategies	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)
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	**【Item 3. until 2023】 Development of dialogue techniques for information that the public considers to be risks** **Survey results on risk information required by local residents ⑤▽** RC design/ implementation / analysis at a pilot site	**Proposal of dialogue technique for risk information ⑤▽** Application/ evaluation on other sites	**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	
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	**【Item 2. until 2023】 Development of survey technique for validation of RC strategy** **Survey results on validation of RC strategy of utilities ⑤▽** Development of survey technique by collaboration at a pilot site, analysis of case studies in other countries and other industries	**Survey technique for validation of RC strategy of utilities ⑤▽** Application/ evaluation on other sites	**Findings obtained through research and experiments in response to RC practical issues ⑤▽** Research and experimentation based on RC practical issues (depending on each utility's needs every FY)	**⑤▽** (the same on the left)	**⑤▽** (the same on the left)	

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	～2022	2023	2024	2025	2026	2027～
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.) Establishment of OLM Guide	OLM Guide④▽ Revision of OLM Guide (Case additions and feedbacks from application)	▽Revision of the Guide④ * 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.	Application to actual plants (*)	▽Revision of the Guide④	
Extension of containment vessel leak rate test (CVLRT) interval	The leak rate test (Type A test) 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
Further expansion of the scope of RIDM process application	It is desirable to introduce further measures to promote using risk information in Japan. ↓ • Consider introducing measures based on overseas examples			Examination of the introduction of risk information utilization measures based on overseas case studies (Example: risk-informed inservice inspection (RI-ISI), risk-informed categorization and treatment of SSC (10CFR50.69), etc.)			

[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	～2022	2023	2024	2025	2026	2027～
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		**Practical application cases of IRIDM and risk assessment④** ▽ ▽ ▽ Survey of foreign case studies of integrated risk assessment and RIDM practices		Development of draft guidance on integrated risk assessment	**Draft guidance on integrated risk assessment④**▽	Establishment of guidance on integrated risk assessment Case study of guidance and methodology (trial at a model plant)
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			**Knowledges of existing methods and technologies for risk aggregation②** ▽ ▽ Survey of foreign case studies (methods and technologies) related to risk aggregation	Identification of technical issues on risk aggregation and plans toward their solution measures **Technical issues on risk aggregation and solution measures②**▽		Development of methodology and technology for integrated risk assessment