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Power Cycle Chemistry WG

Determination of Wall Thinning Rates and High-Risk Zones for Local Wall Thinning due to Flow-Accelerated Corrosion

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Background

- Thousands of FAC-possible zones cause
  long and costly inspection procedures for plants.

- Suitable prediction or estimation procedures for FAC occurrence
  should be applied to narrow down the number of inspection zones.

- The computer programs tuned with as many inspection data as possible.

- Fusion of the estimation and inspection procedures should lead to
  effective and reliable preparation against FAC occurrence and propagation.

- A six-step procedure based on 3D CFD codes and a coupled model of
  electrochemistry and oxide layer growth was proposed.

- As a result of a V&V evaluation, it was confirmed that wall thinning rate
  could be predicted with an accuracy within a factor of 2.

- One of the disadvantage of the 3D FAC code was
  large amount of computational time for its application for whole plant analysis.

Objectives

- In order to improve large amount of computational time of 3D FAC code, a 1D code is developed by applying 1D CFD code and geometry factors.
  The locally maximum thinning rate can be predicted with an accuracy within a factor of 2.

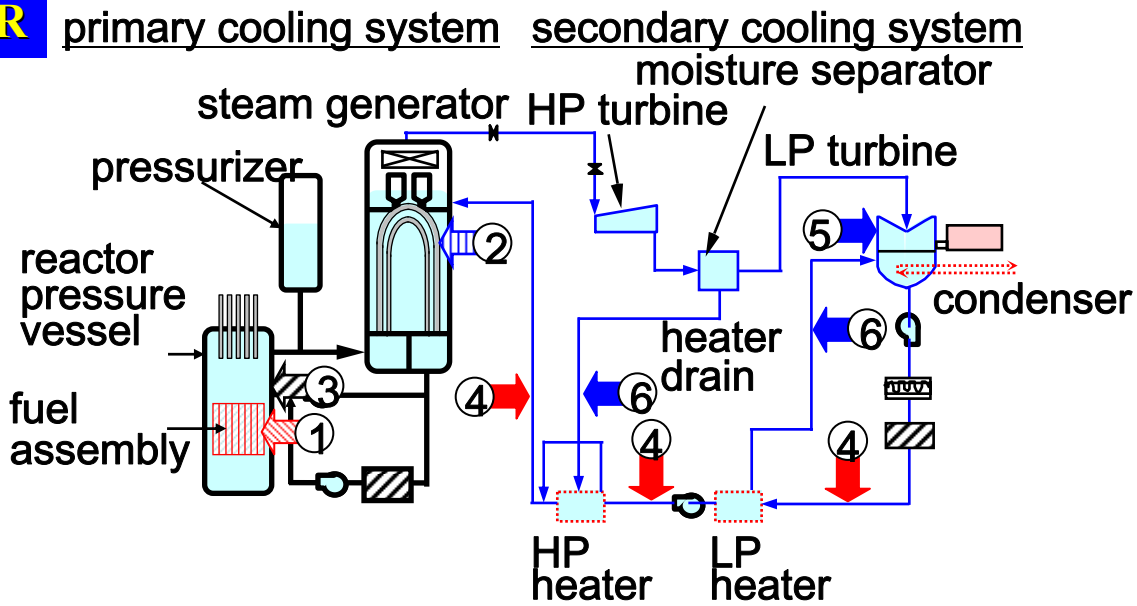
- Hazard scale of pipe rupture as well as serious wall thinning occurrence can be analyzed.

- FAC risks defined as a mathematical product of wall thinning occurrence probability and its hazard scale are evaluated.

- High FAC risk zones in whole cooling systems as well as effects of countermeasures on mitigating the risks can be evaluated in small amount of computer time. At the same the procedures to evaluate the risks are traceable.

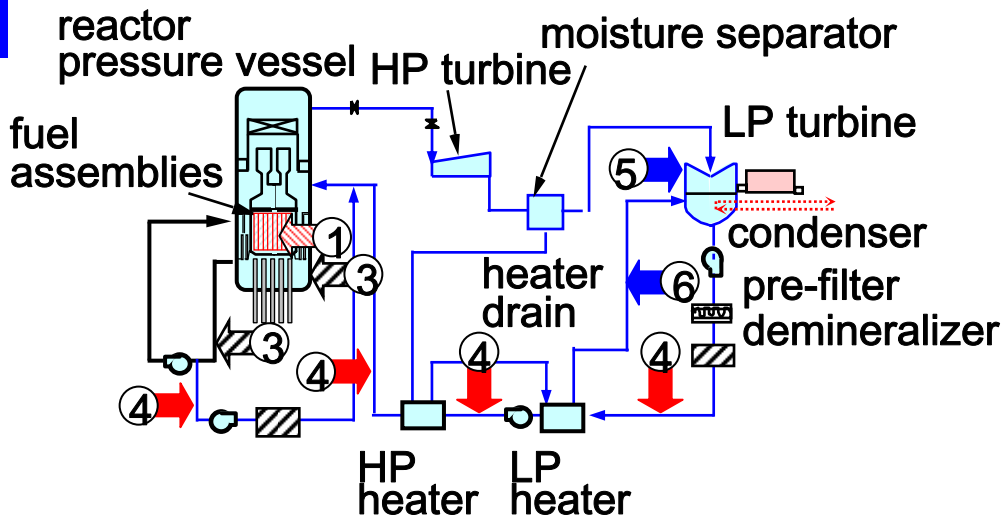
Material atlases in PWR and BWR power plants

PWR



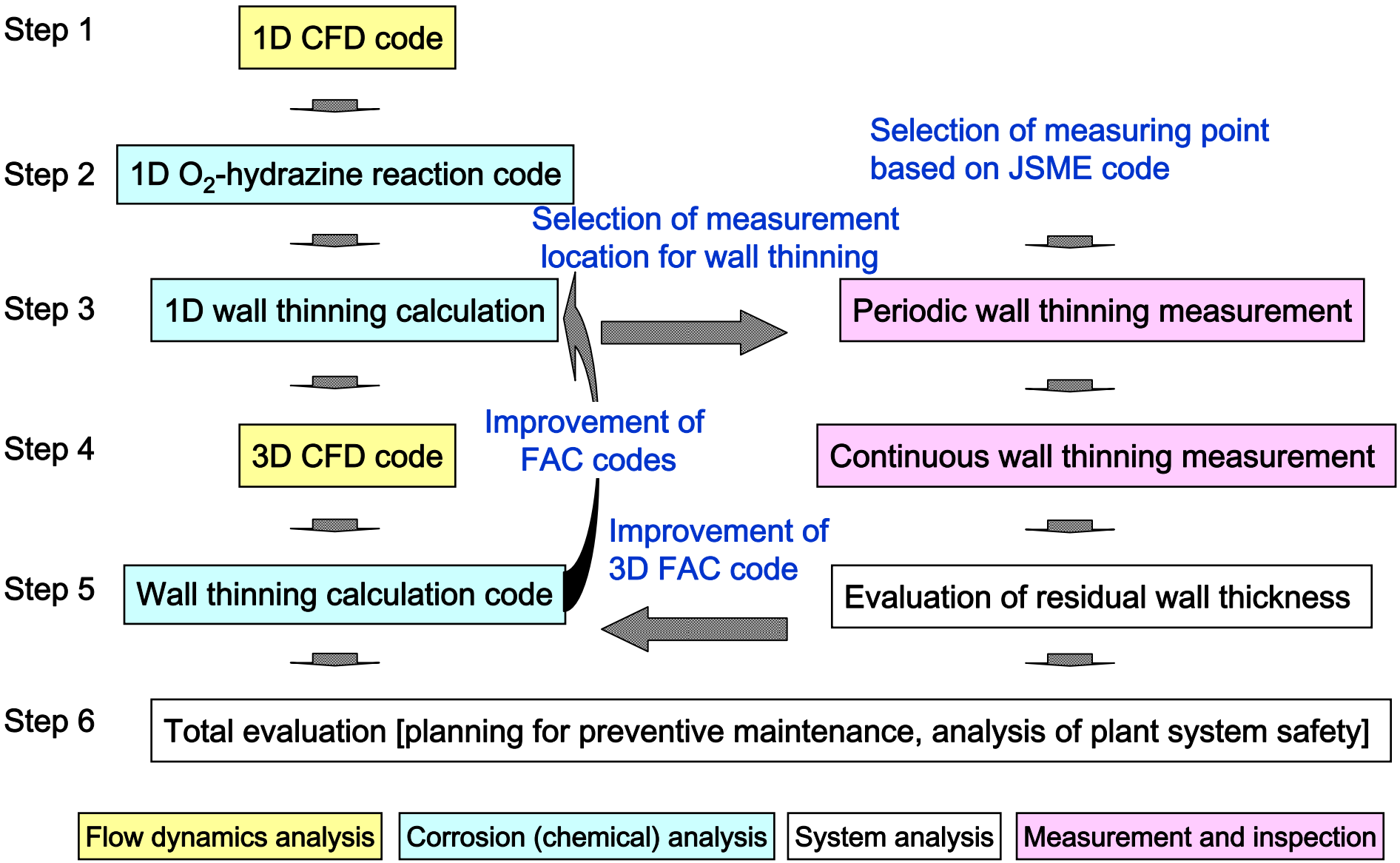
Major materials
- stainless steel
- carbon steel
- nickel base alloy
- zirconium alloy
- copper alloy/ titanium

BWR



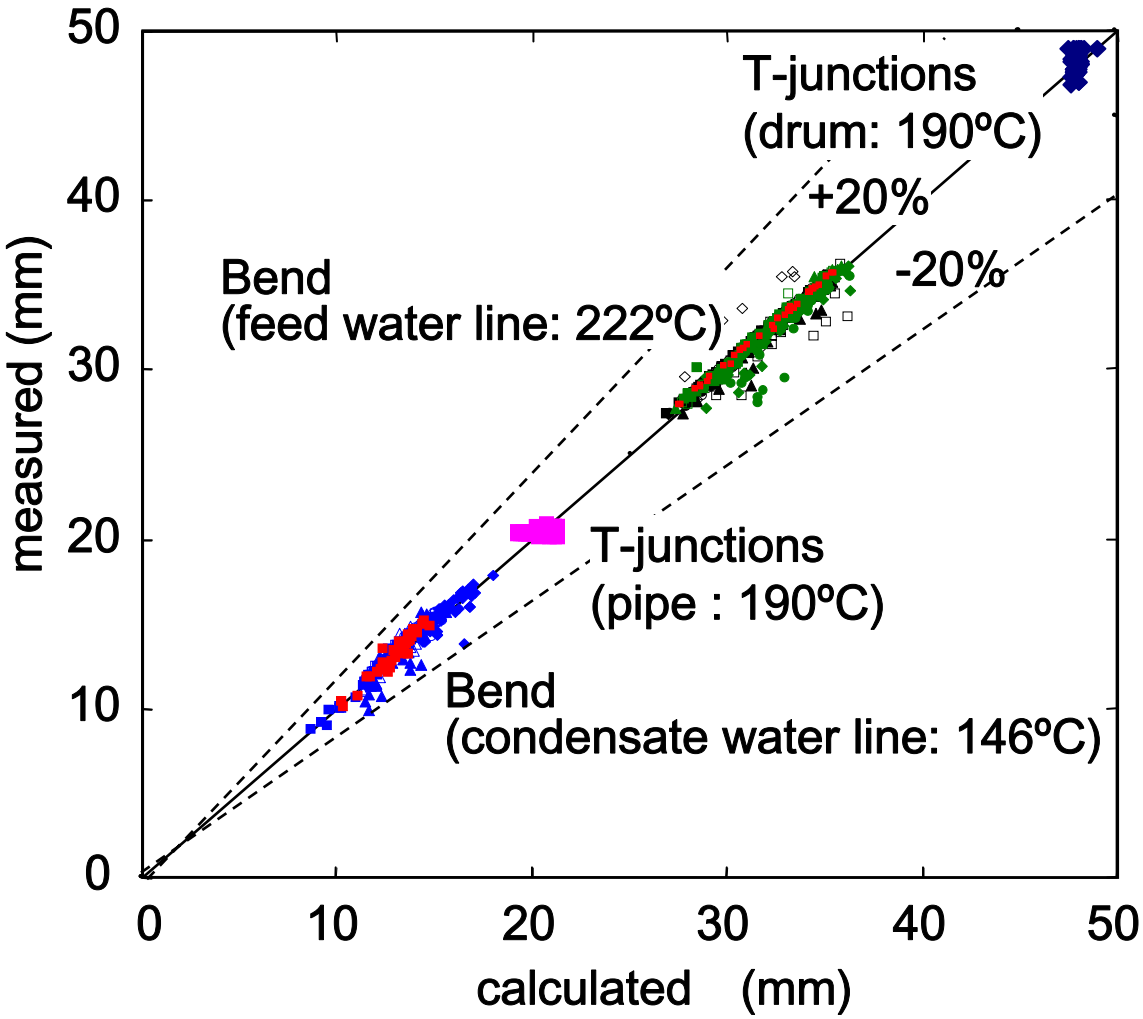
Problems related to corrosion
- ① : zirconium corrosion
- ② : SG tube defects
- ③ : IGSCC/PWSCC
- ④ : FAC
- ⑤ : LDI (erosion)
- ⑥ : LDI (corrosion)

Evaluation inspection steps for wall thinning due to FAC



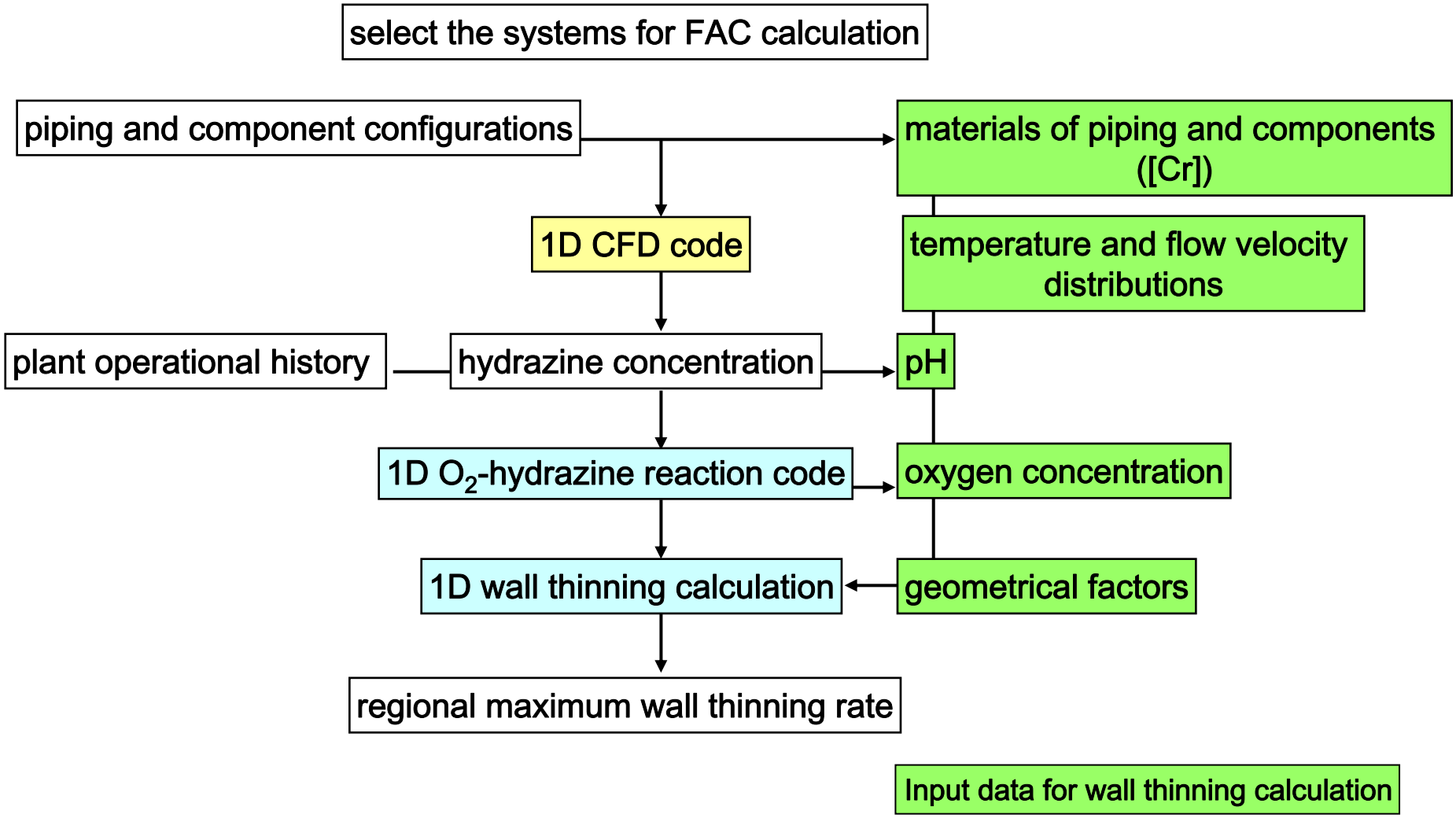
Comparison of the calculated results with the measured

Residual thickness

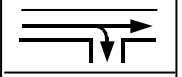
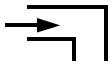
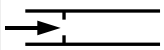
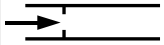


Calculation procedures and major input data

of 1D FAC code (DREAM-FAC)

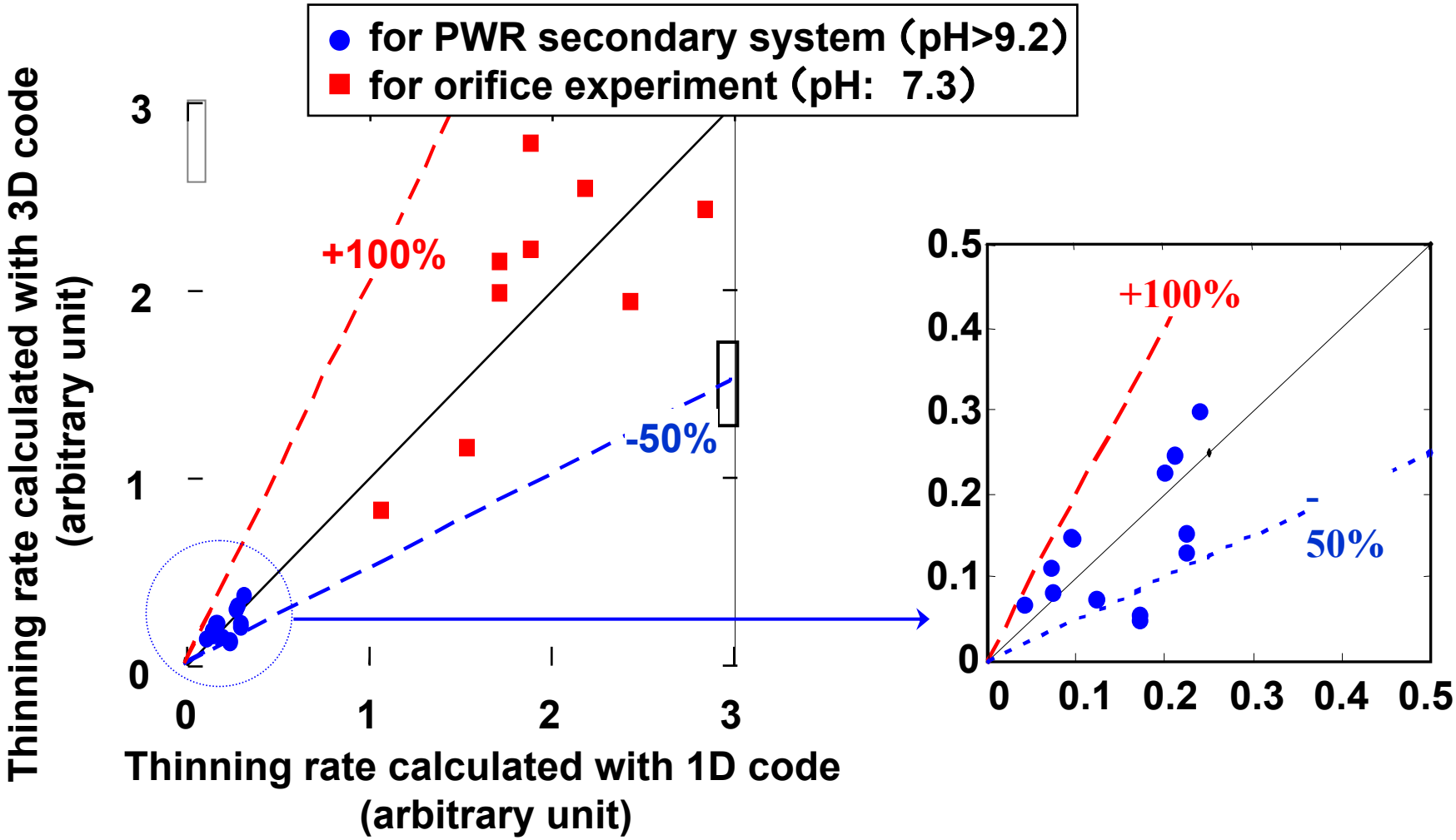


Geometrical factors for FAC

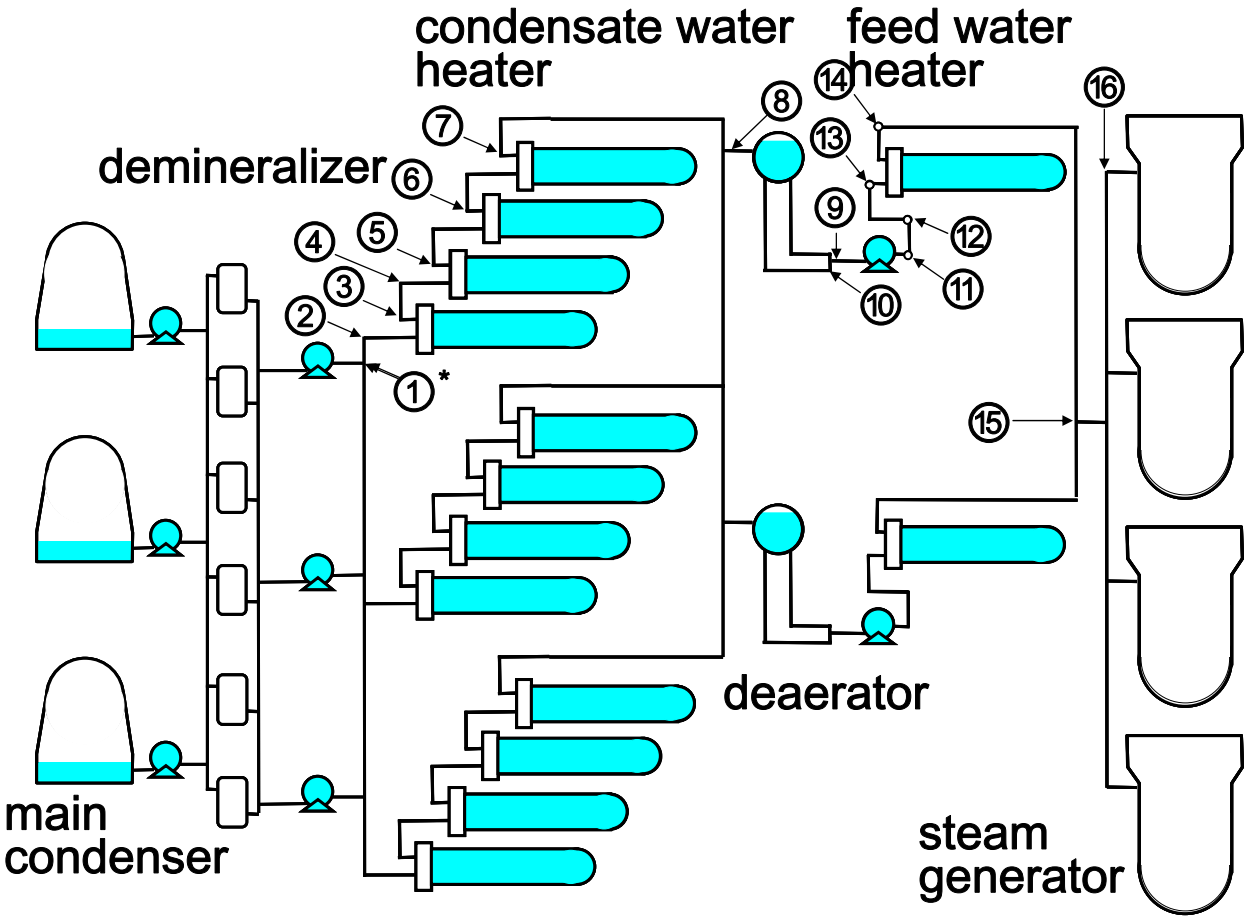
Type of exposure				Reference velocity	k_C *3
Stagnation points of primary flow		at distributor and behind orifices		Impact velocity	0.75
					0.6
Stagnation points of secondary flow		r/d_I *1=0.5	in bends and outlet diffusers	Flow velocity	0.3
		r/d_I=1.5			0.23
		r/d_I=2.5			0.15
		behind junctions			0.15
Stagnation points after separation vortices		at and behind Obstructions		Flow velocity	0.16
		d_O/d_I *1=0.41	behind orifices		0.5
		d_O/d_I=0.5			0.4
		d_O/d_I=0.61			0.3
Without stagnant point		in straight pipes		Flow velocity	0.04

*1 d_I: pipe inner diameter (m), r: radius of curvature (m)
*2 Geometrical factor (GF) for orifice has been redefined as a function of orifice geometry
d_I: pipe inner diameter (m), d_O: orifice diameter (m)
*3 GF for straight pipe: 0.04

Wall thinning rate calculated with 1D and 3D FAC codes



Schematic diagram of PWR secondary cooling system

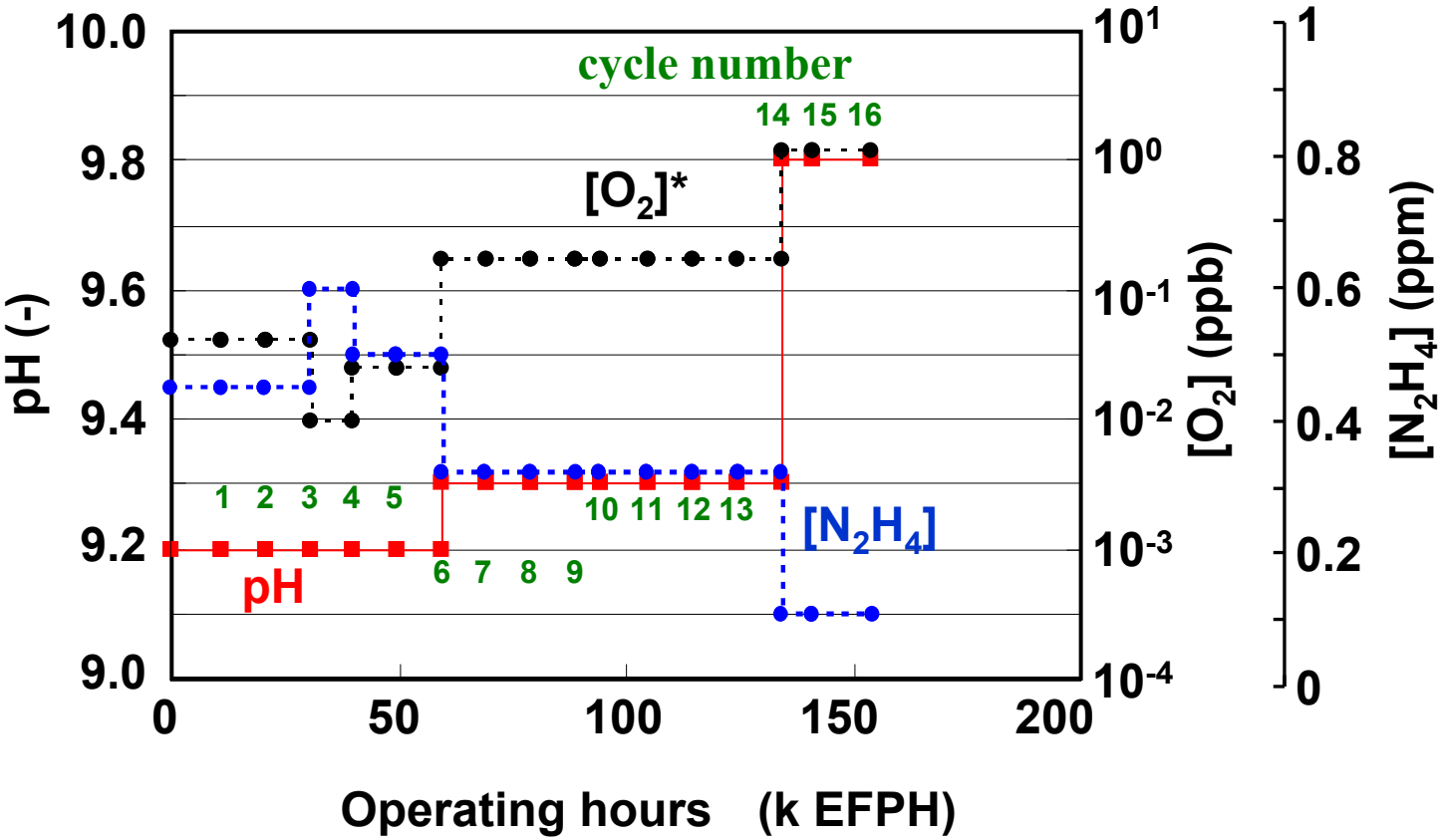


*The numbers correspond to the location numbers

Major input data for 1D FAC code

location	[Cr] (%)	inner diameter d_I (m)	wall thickness T_w (mm)	flow velocity v (m/s)	pressure P (MPa)	tempe-rature T (℃)	enthalpy H (kJ/kg)	hazard scale enthalpy x d_I^2 (a.u)	geometry	geometrical factor K_c
①	0.001	0.620	20.0	3.58	2.64	33.0	140	0.19	T-junction	0.16
②	0.001	0.381	12.7	3.16	2.62	33.0	140	0.07	bend	0.23
③	0.001	0.381	12.7	3.23	2.35	74.0	312	0.16	bend	0.23
④	0.001	0.425	16.0	2.59	2.38	74.0	312	0.19	bend	0.23
⑤	0.001	0.425	16.0	2.63	2.04	98.0	412	0.26	bend	0.23
⑥	0.001	0.425	16.0	2.70	1.71	129.0	543	0.34	bend	0.15
⑦	0.001	0.425	16.0	2.75	1.41	146.0	616	0.38	bend	0.15
⑧	0.001	0.687	12.0	3.15	1.39	146.0	616	1.00	bend+orifice	0.5
⑨	0.001	0.437	10.0	3.68	0.97	178.9	754	0.50	T-junction	0.16
⑩	0.001	0.381	12.7	4.17	3.22	186.0	793	0.40	bend	0.15
⑪	0.001	0.519	20.0	4.49	3.19	186.0	793	0.73	bend	0.3
⑫	0.001	0.483	38.0	5.19	7.21	188.0	801	0.64	bend	0.3
⑬	0.001	0.483	38.0	5.19	7.12	188.0	801	0.64	bend	0.3
⑭	0.001	0.483	38.0	5.44	7.01	222.0	954	0.76	bend	0.3
⑮	0.001	0.701	56.0	5.16	7.01	222.0	954	1.61	T-junction	0.6
⑯	0.001	0.354	26.2	5.06	7.04	222.0	954	0.41	bend	0.3

History of water chemistry control at Plant A

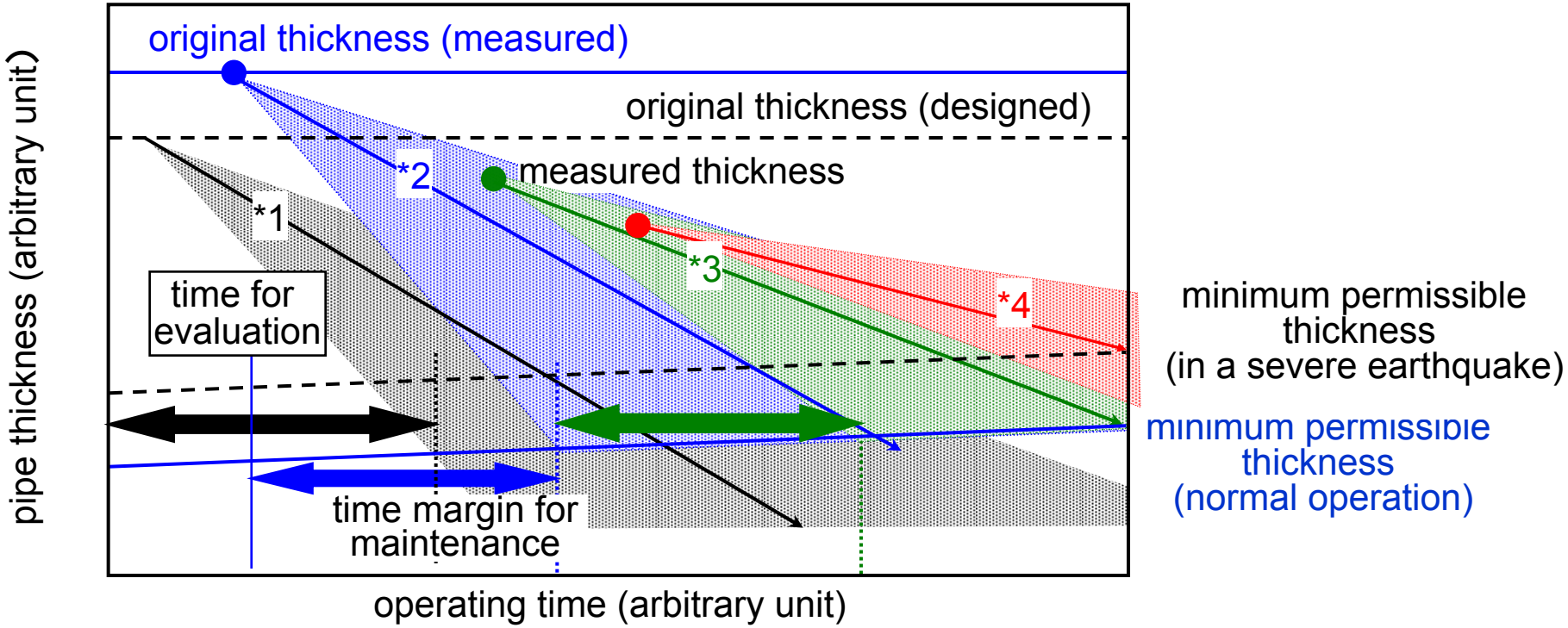


Wall thinning rate calculated with the 1D FAC code

location	inner diameter d_i (m)	flow velocity v (m/s)	temperature T (℃)	mass transfer coefficient h_m (m/s)	geometry	GF K_c	maximum h_m (m/s)	pH (-)	$[O_2]$ (ppb)	$[Fe^{2+}]$ (ppb)	H-factor	T&pH-factors	Cr-factor	O-factor	Fe-factor	da/dt (a.u)
①	0.620	3.58	33.0	1.50E-04	T-junction	0.16	6.02E-04	9.2	0	0	0.07	0.65	0.99	1	1	**0.05**
②	0.381	3.16	33.0	1.50E-04	bend	0.23	8.64E-04	9.2	0	0	0.10	0.65	0.99	1	1	**0.07**
③	0.381	3.23	74.0	3.18E-04	bend	0.23	1.83E-03	9.2	0	0	0.22	1.16	0.99	1	1	**0.25**
④	0.425	2.59	74.0	2.61E-04	bend	0.23	1.50E-03	9.2	0	0	0.18	1.16	0.99	1	1	**0.21**
⑤	0.425	2.63	98.0	3.57E-04	bend	0.23	2.05E-03	9.2	0	0	0.25	1.31	0.99	1	1	**0.32**
⑥	0.425	2.70	129.0	5.00E-04	bend	0.15	1.87E-03	9.2	0	0	0.22	1.22	0.99	1	1	**0.27**
⑦	0.425	2.75	146.0	5.87E-04	bend	0.15	2.20E-03	9.2	0	0	0.26	1.05	0.99	1	1	**0.27**
⑧	0.687	3.15	146.0	5.96E-04	bend+orifice	0.5	7.45E-03	9.2	0	0	0.89	1.05	0.99	1	1	**0.93**
⑨	0.437	3.68	178.9	9.45E-04	T-junction	0.16	3.78E-03	9.2	0	0	0.45	0.62	0.99	1	1	**0.28**
⑩	0.381	4.17	186.0	1.13E-03	bend	0.15	4.22E-03	9.2	0	0	0.51	0.53	0.99	1	1	**0.27**
⑪	0.519	4.49	186.0	1.12E-03	bend	0.3	8.44E-03	9.2	0	0	1.01	0.53	0.99	1	1	**0.53**
⑫	0.483	5.19	188.0	1.30E-03	bend	0.3	9.73E-03	9.2	0	0	1.17	0.51	0.99	1	1	**0.59**
⑬	0.483	5.19	188.0	1.30E-03	bend	0.3	9.73E-03	9.2	0	0	1.17	0.51	0.99	1	1	**0.59**
⑭	0.483	5.44	222.0	1.66E-03	bend	0.3	1.24E-02	9.2	0	0	1.49	0.20	0.99	1	1	**0.29**
⑮	0.701	5.16	222.0	1.47E-03	T-junction	0.6	2.21E-02	9.2	0	0	2.65	0.20	0.99	1	1	**0.52**
⑯	0.354	5.06	222.0	1.66E-03	bend	0.3	1.25E-02	9.2	0	0	1.50	0.20	0.99	1	1	**0.30**

Schematic picture

for predicting pipe wall thickness and their uncertainty



*1 calculation based on design data

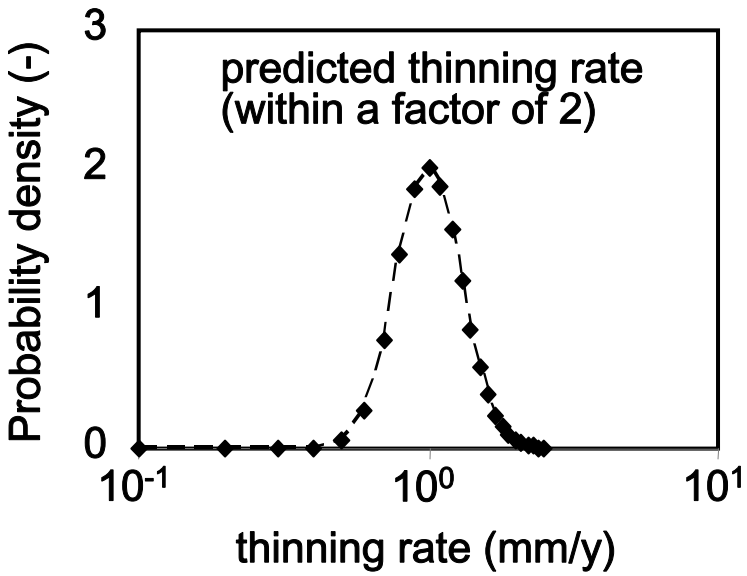
*2 calculation based on measured original thickness

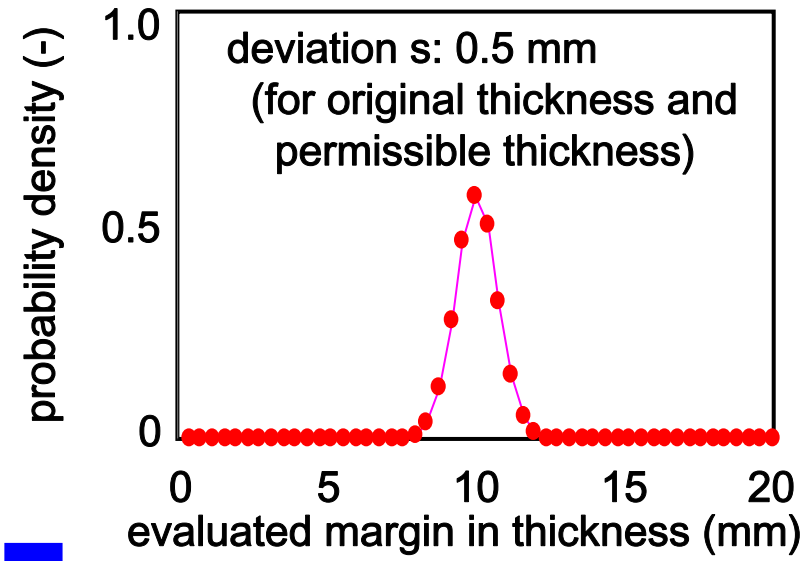
*3 calculation based on measured thickness

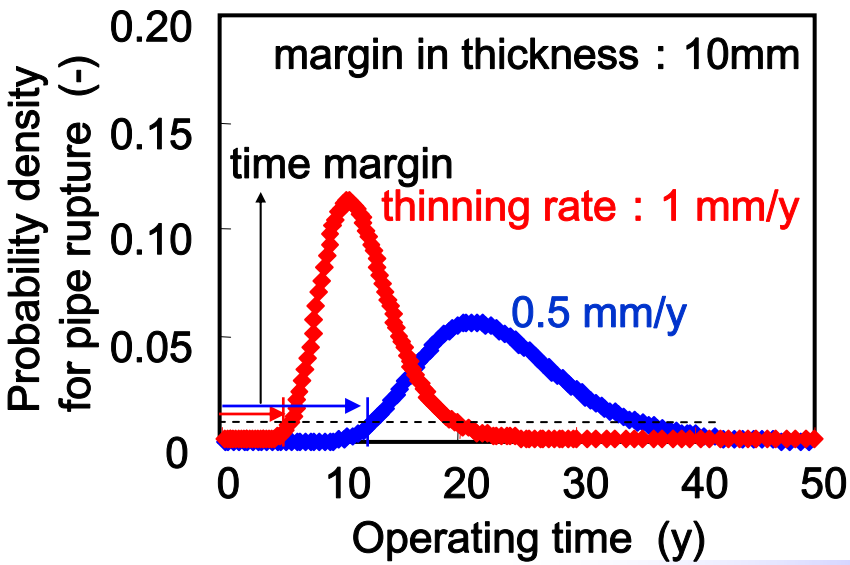
*4 prediction of the effects of water chemistry improvement

Probability distributions of thinning rate

margin in thickness and rupture time

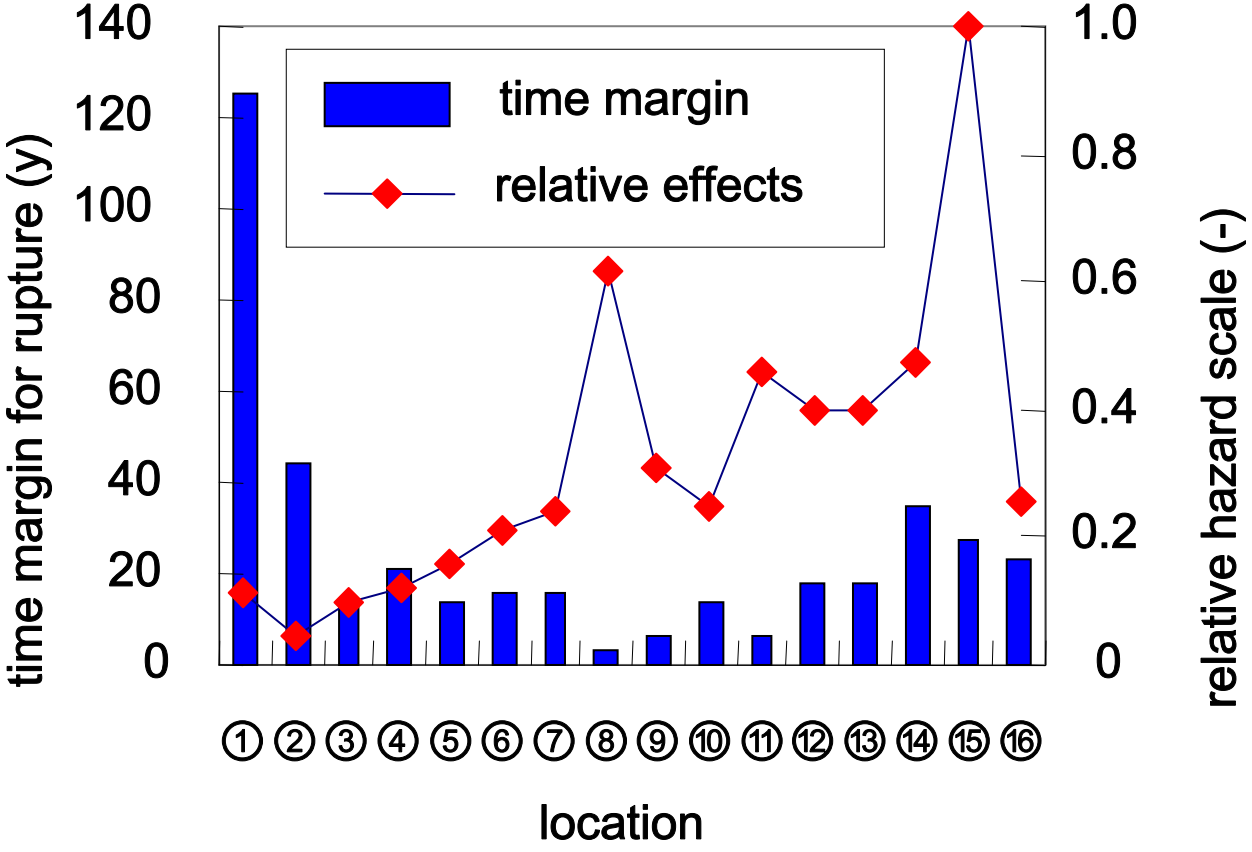






Probability distributions of thinning rate

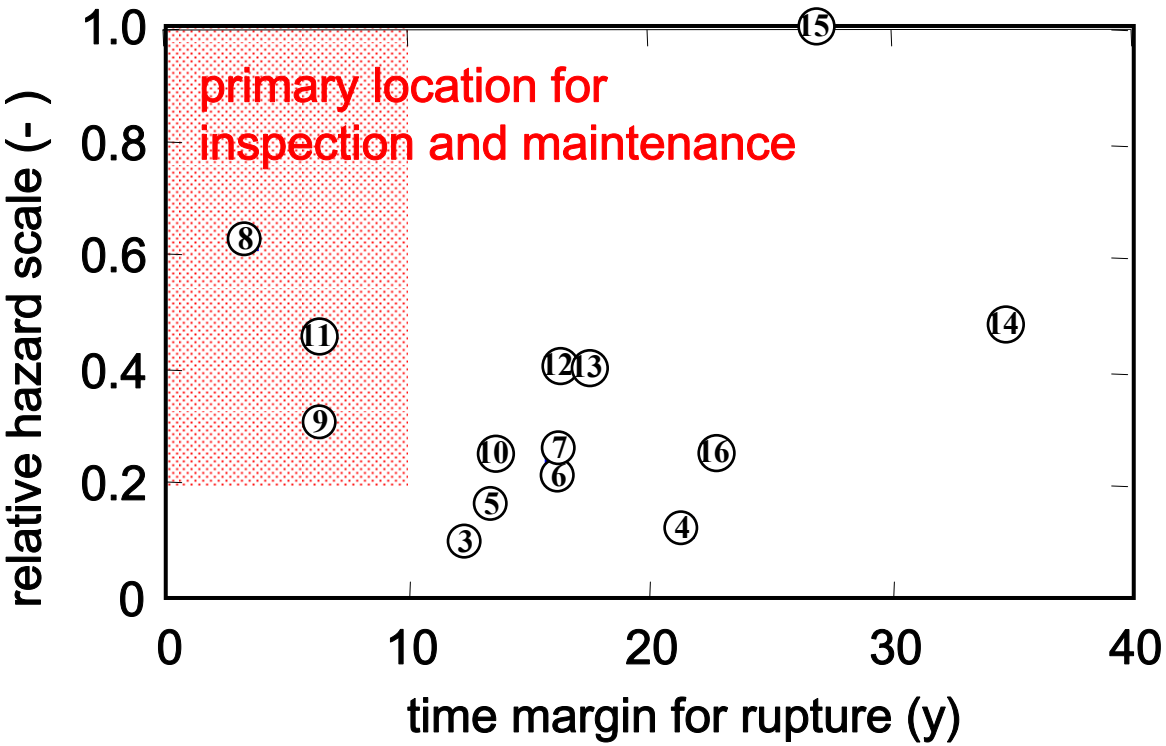
margin in thickness and rupture time



Probability distributions of wall thinning rate

margin in thickness and rupture time

Hazard scale of pipe rupture: "pipe diameter x enthalpy of the water"



Conclusions

1. 1D FAC code has been developed based on 3D FAC code.
   Estimation accuracy of wall thinning rate was within a factor of 2.
   Speedy and easy-to -handle tool for FAC occurrence can be easily applied for evaluation of FAC occurrence probability for entire plant systems.
2. FAC risk designated as the mathematical product of the possibility of serious wall thinning occurrence determined from time margin for pipe rupture and hazard scale of pipe rupture could be applied for selection of thinning detection location and suitable FAC mitigation application.
3. Computer code packages of determination procedures for high FAC risk zones were introduced and determination processes were demonstrated.
4. The fusion of prediction and monitoring could go well to improve plant performance.

Acknowledgement

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The authors express their sincere thanks to METI and NISA for the chance to develop the models and to confirm their accuracy.