



Development of PFM analysis code FERMAT based on Japanese PFM guideline JEAG 4640-2018

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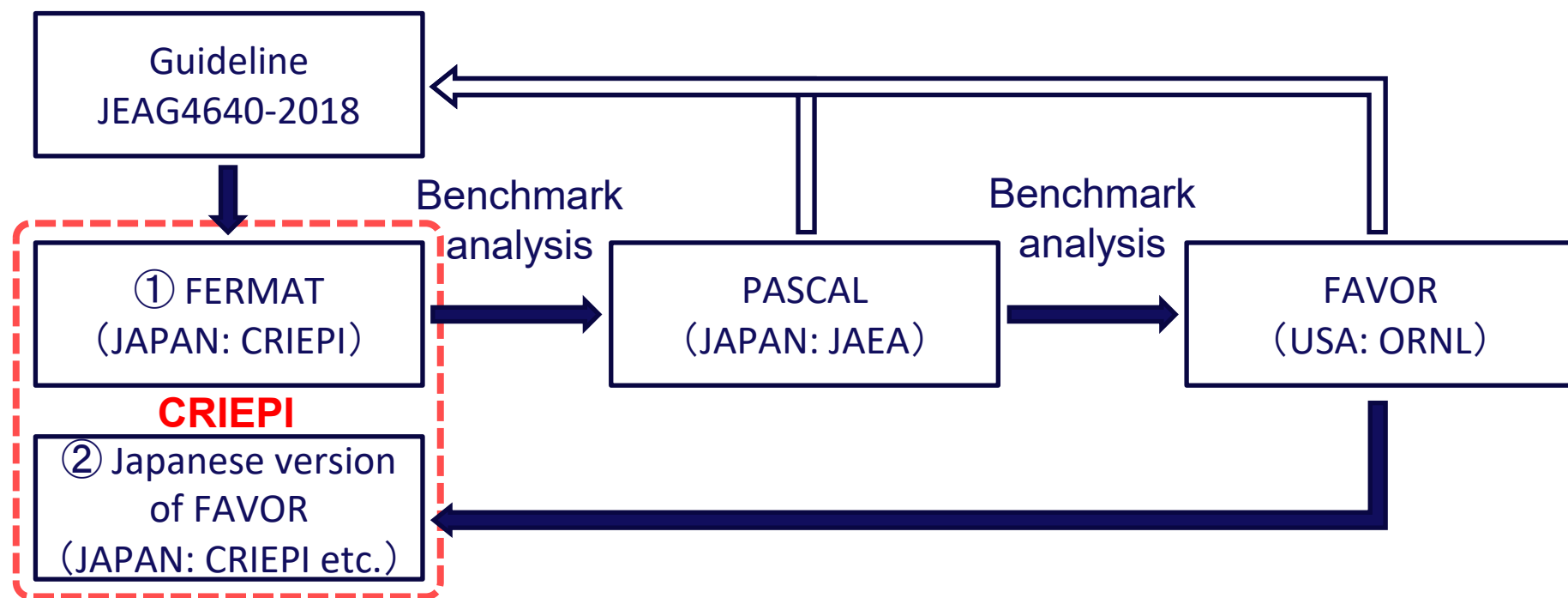
October 7th-9th, 2024

Background

- ◆ The implementation of probabilistic fracture mechanics (PFM) on integrity assessment standards of reactor pressure vessels (RPVs) is not yet actualized in Japan.
- ◆ Guideline JEAG 4640-2018 was established in 2018.
 - JEAG 4640-2018 describes framework and preferred specifications for assessing frequency of crack initiation (FCI) and through-wall crack frequency (TWCF) in Japan.
 - JEAG 4640-2018 is established in conformity with Japanese structural integrity standards. Various part of standards are different from other countries.
 - Equations for predicting radiation embrittlement
 - Fracture toughness curve
 - etc.

PFM analysis approaches in CRIEPI

- ◆ CRIEPI takes following 2 approaches to develop PFM analysis basis for RPVs.
 - ① New development of JEAG 4640-2018 consistent code, FERMAT (Fracture mechanics Evaluation of RPV MATerials)
 - ② Localization of US code FAVOR16.1 to JEAG 4640-2018

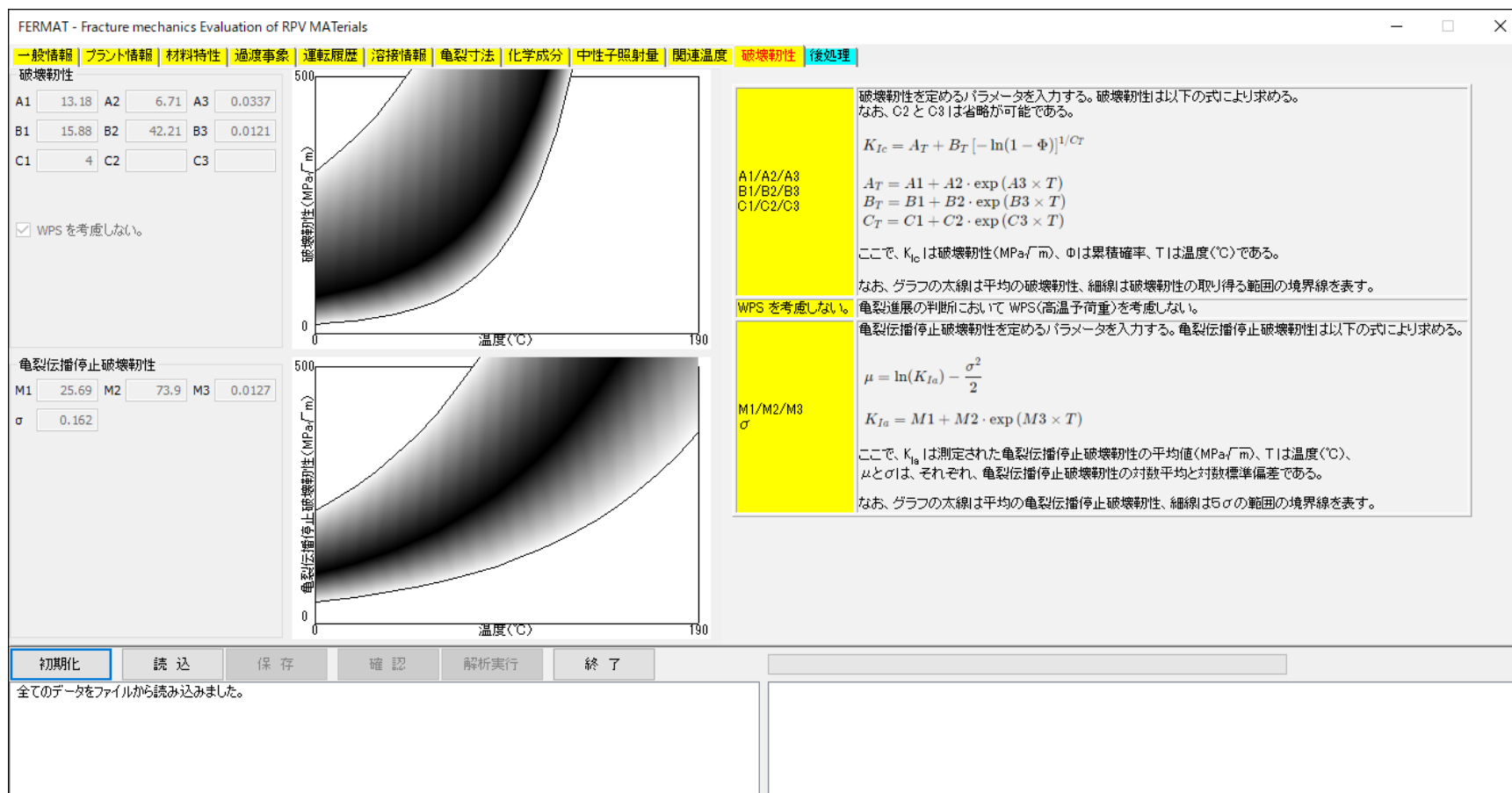


Concept of FERMAT

- ◆ PASCAL has already been developed for Japanese RPV by JAEA.
- ◆ There is difference in concept between PASCAL and FERMAT.
 - PASCAL has various options. That feature makes PASCAL one of the best codes for comparable research.
 - FERMAT is developed as a simple code for practical application. This feature is achieved by referring JEAG 4640-2018.
- ◆ FERMAT can assess FCI and TWCF based on JEAG 4640-2018.

Graphical user interface of FERMAT

- ◆ All processes (including pre-processes and post-processes) can be finished in one code with graphical user interface.

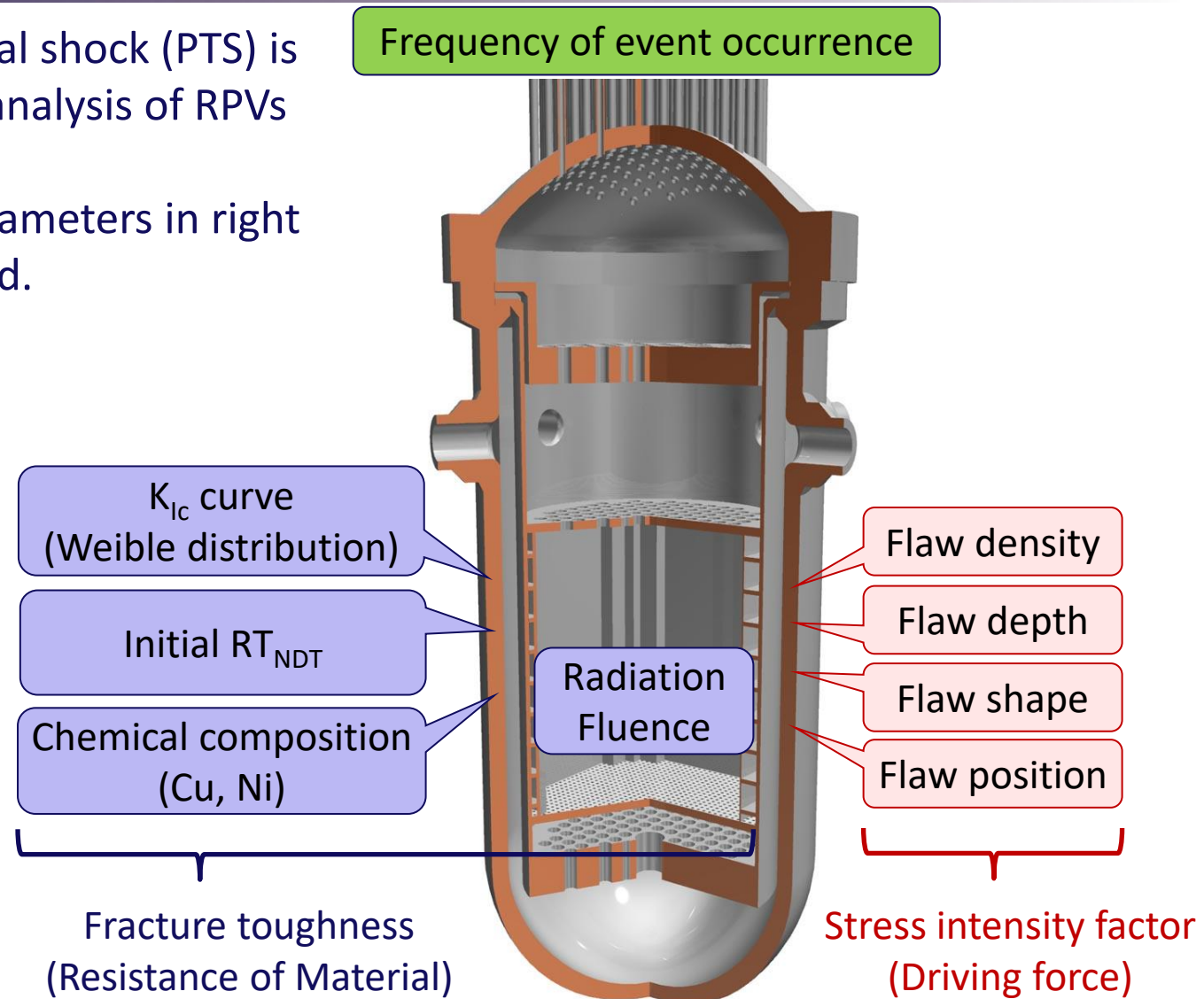


Objective

- ◆ The outcomes for crack initiation and failure assessed by FERMAT were compared with those of PASCAL5 with Japanese model case.
- ◆ In this presentation, the following was compared.
 - Stress intensity factor for deterministic part of analysis
 - Failure probability and frequency for probabilistic part of analysis

Input parameters for PFM analysis for RPVs

- ◆ Pressurized thermal shock (PTS) is targeted for PFM analysis of RPVs for PWR plants.
- ◆ Uncertainty of parameters in right figure is considered.

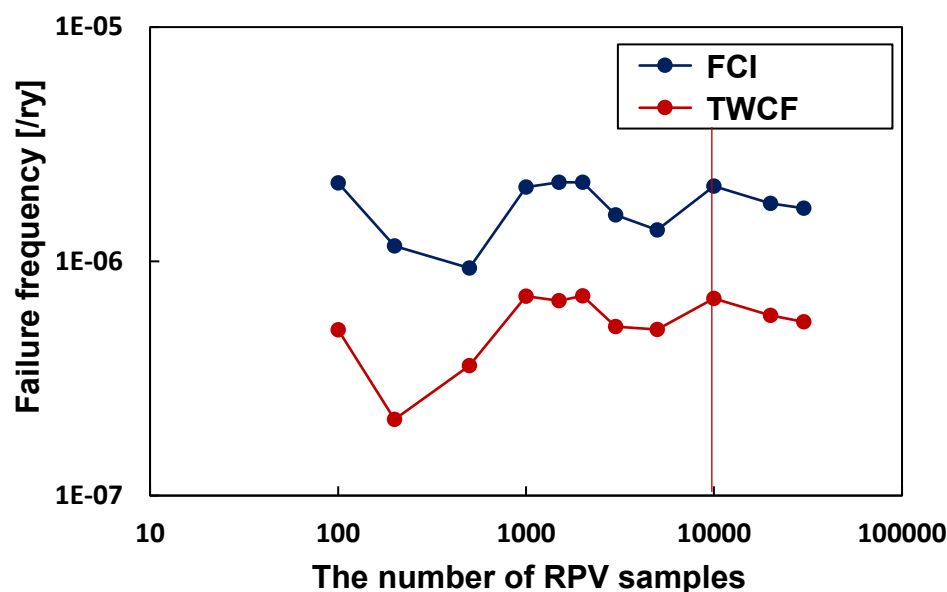


Analysis conditions

	items		Analysis conditions
Transients	Determine transients		Dominant 13 transients selected from transients of Beaver Valley [2]
Flaws	Surface flaw	Crack direction	Circumference flaws [1]
		Crack depth [mm]	6.5 [2]
	Embedded flaw	Crack direction	Circumference and axial flaws
		Crack depth [mm]	Determined by VFLAW [1]
WPS	Model of Warm prestress (WPS)		Basic model of JEAG 4640-2018
Irradiation conditions	Neutron fluence [n/cm ²] (E>1MeV)	Spatial distribution	Maanshan Unit 1 (Taiwan)
		Mean value	7×10^{19} (48EFPY)
		Standard deviation	13.1% of mean value [1]
	Neutron flux [n/cm ² /s](E>1MeV)		4.62×10^{10} [1]
	Irradiation temperature [°C]		288 [1]
Chemical composition	Cu [wt%]	Mean value	Base metal: 0.16, Weld: 0.14 [1]
		Standard deviation	0.01 [1]
	Ni [wt%]	Mean value	Base metal: 0.61, Weld: 0.80 [1]
		Standard deviation	0.02 [1]
Initial RT_{NDT}	Mean value		Base metal: -5.0 , Weld: -50.0 [1]
	Standard deviation		9.40 [1]

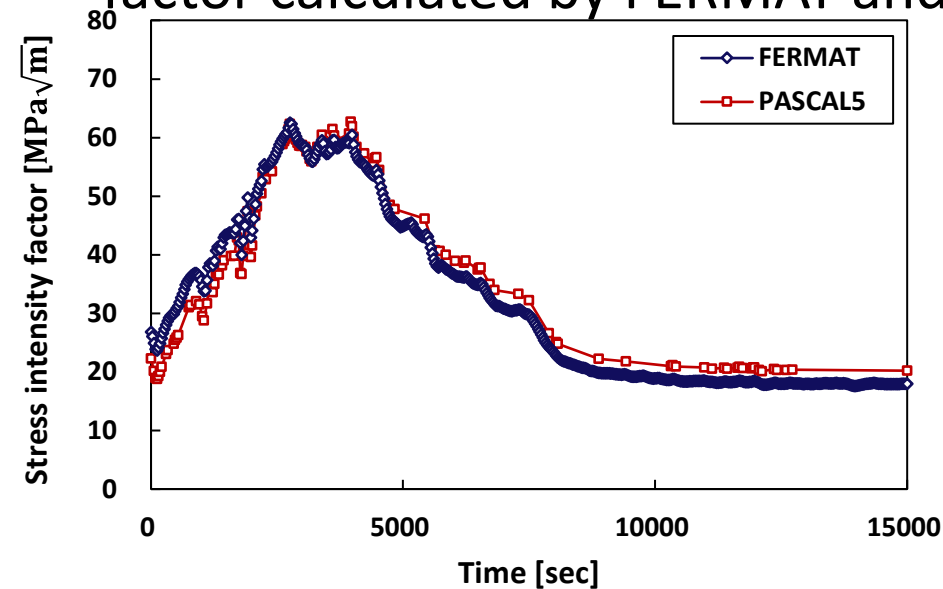
Sensitivity analysis for the number of RPV samples

- ◆ 1000 was chosen as the number of RPV samples for PASCAL by JAEA [3].
- ◆ For FERMAT, FCI and TWCF were assessed with various number of RPV samples.
 - 10000 was chosen as the number of samples for analysis in this study.

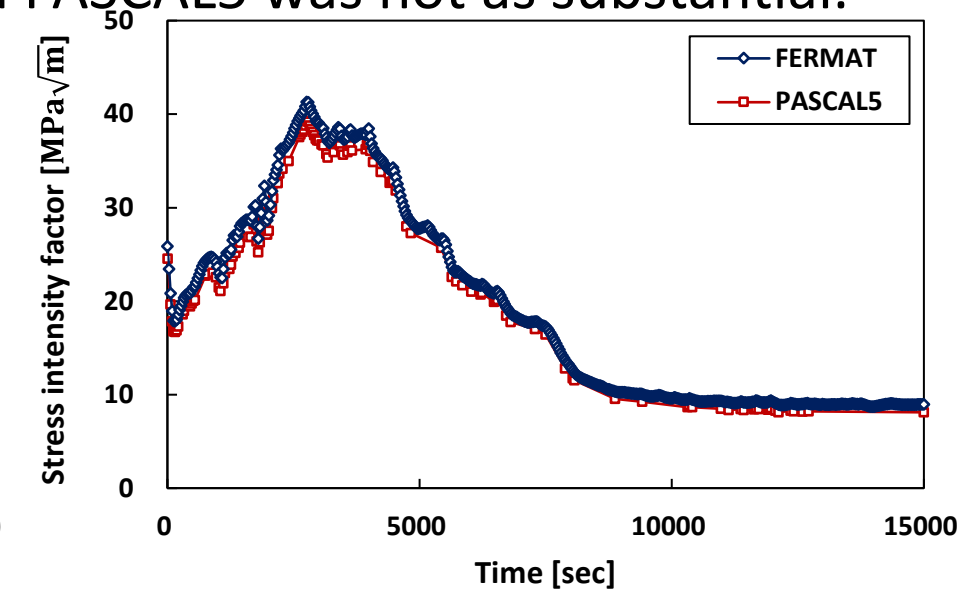


Results of deterministic part of analysis (Stress intensity factor)

- ◆ Stress intensity factor for small breaking loss of coolant accident (SBLOCA) calculated by FERMAT and PASCAL5 were compared.
- ◆ Although there are some differences in model used to calculate stress intensity factor for surface crack, difference in stress intensity factor calculated by FERMAT and PASCAL5 was not as substantial.



(a) surface crack



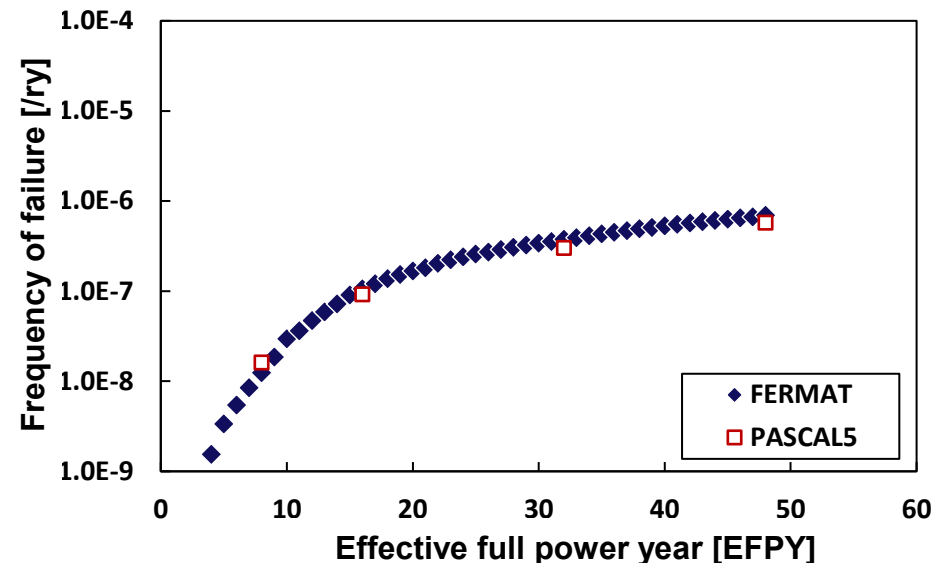
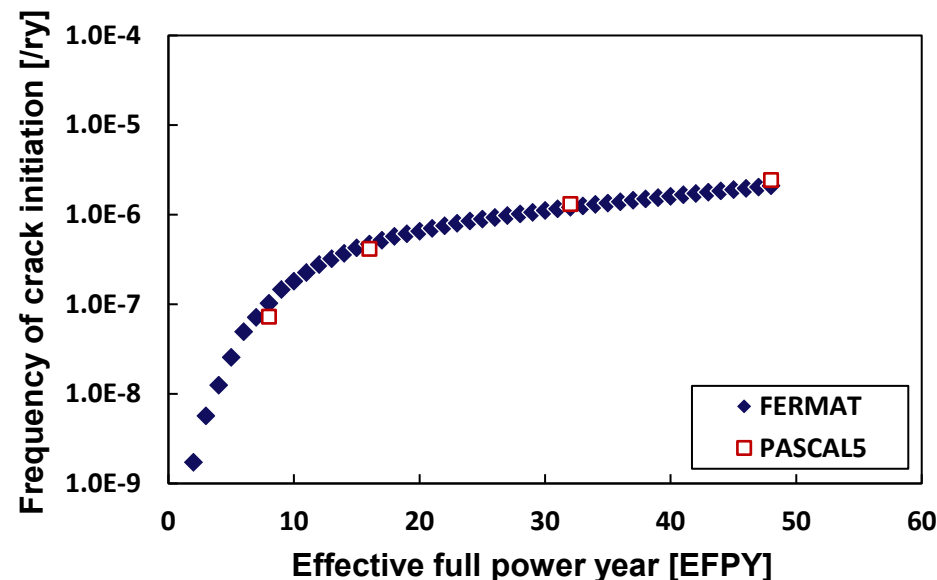
(b) Embedded crack

(Depth=6.5mm, aspect ratio $2c/a = 6$) (Depth=5% of thickness, aspect ratio $c/a=2.5$)
Time dependence of stress intensity factor

Results of PFM analysis

(The frequency of crack initiation and failure)

- ◆ The frequency of crack initiation (FCI) and failure (TWCF) assessed by FERMAT and PASCAL5 were compared.
 - Outcomes were well corresponding each other regardless of used code.



Conclusion

- ◆ A new PFM analysis code FERMAT has been developed.
- ◆ Outcomes of FERMAT were compared with those of PASCAL5.
 - Stress intensity factors calculated by FERMAT and PASCAL5 were well corresponding each other.
 - The frequency of crack initiation and failure assessed by those two codes were compared. They were well corresponding each other regardless of used code.

Those results indicate that FERMAT and PASCAL5 provide equivalent results for assessment of failure frequency of RPV.

Future work

- ◆ Public release of FERMAT is planned right now.

[Post-presentation update]

FERMAT is now publicly available:

<https://criepi.denken.or.jp/en/fermat/index.html>

- ◆ Modification of FERMAT for analyze failure frequency of RPVs in BWR plants is ongoing.