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PWR Vessel Through Wall Crack Frequency based on Realistic Crack Assessment and its Implications for In-service Inspection

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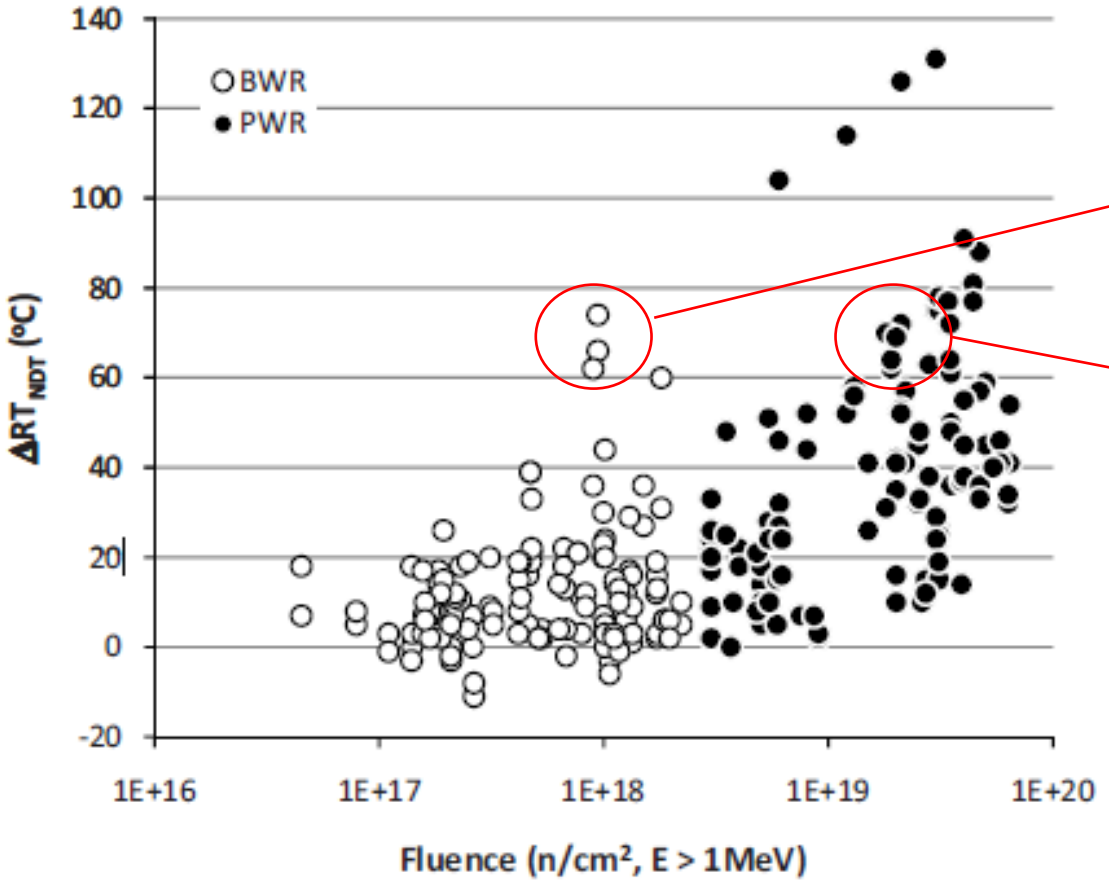
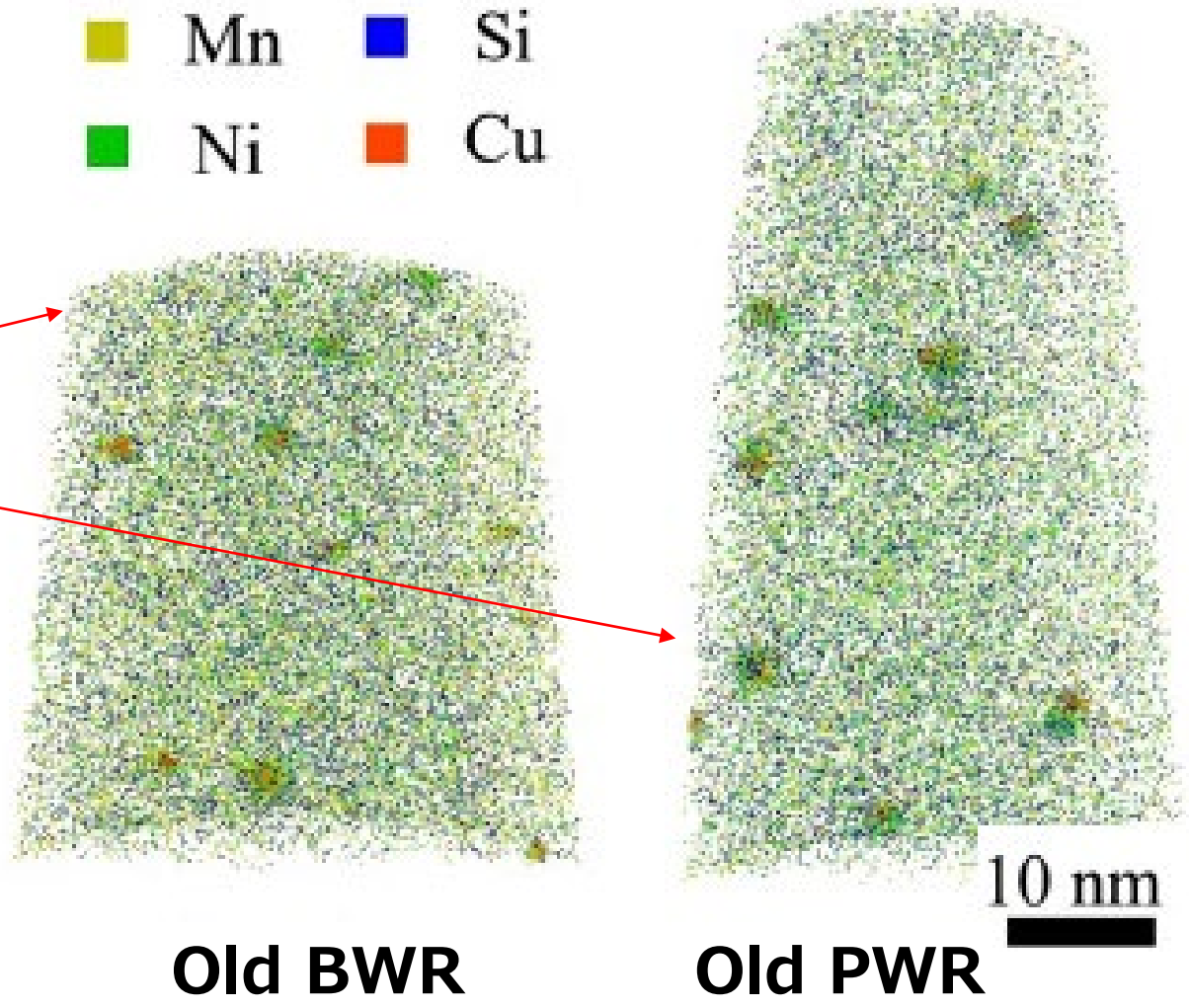
Introduction of the Lab (1)

Material research for safety, especially the safe LTO



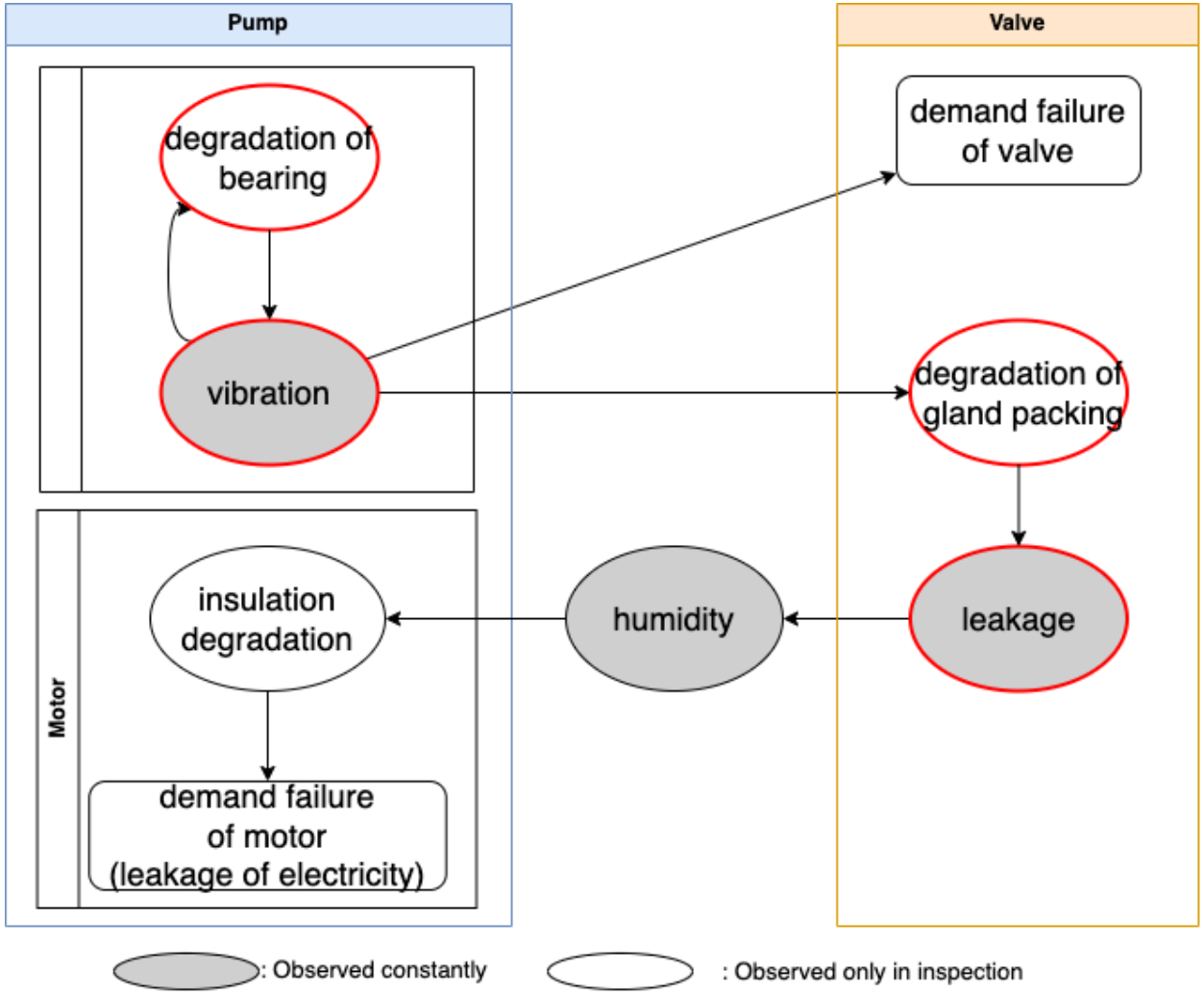
Yamashita, ASME-PVP 2010

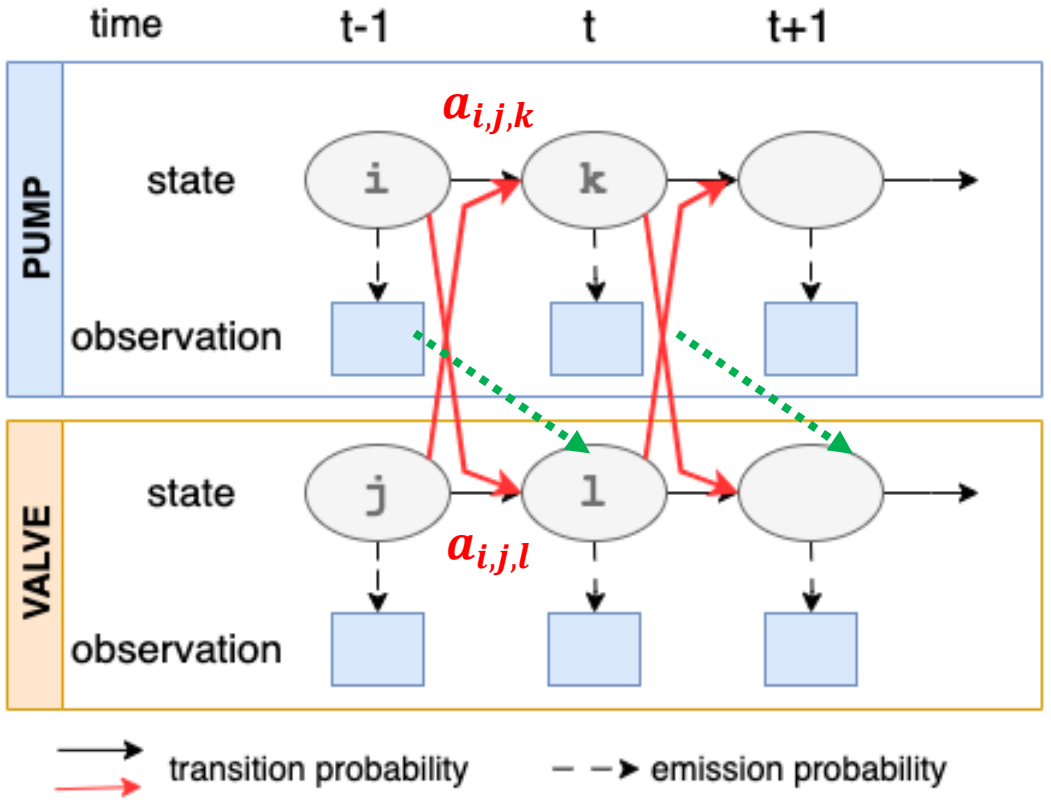


Murakami, J. Nucl. Mater. 2021

Introduction of the Lab (2)

Risk-informed decision making for O&M





Background: Reinforcement of ISI in Japan

- Special Inspection for LTO @ 40y (and 80y)
  - Requires UT for all region (base, weld) in beltline

- Endorsement of JSME S NA1 (ver 2012-14) :
  - The area and frequency of Ultrasonic Testing for RPV welding line were reinforced from 7.5%/T to 100%/T
    - T＝10 year（by 30 years old）、T=7 year（> 30 years old）

Research Questions

- How ISI can be justified theoretically?

    1. Very small crack, overlooked pre-operational inspection, may be **grown by fatigue** and may be found by the ISI

    2. Reduction of fracture toughness by neutron irradiation can be **compensated by ISI, limiting/reducing the crack probability**

- Effect of **crack distribution changes along time** is demonstrated and Rationality of ISI reinforcement may be evaluated.

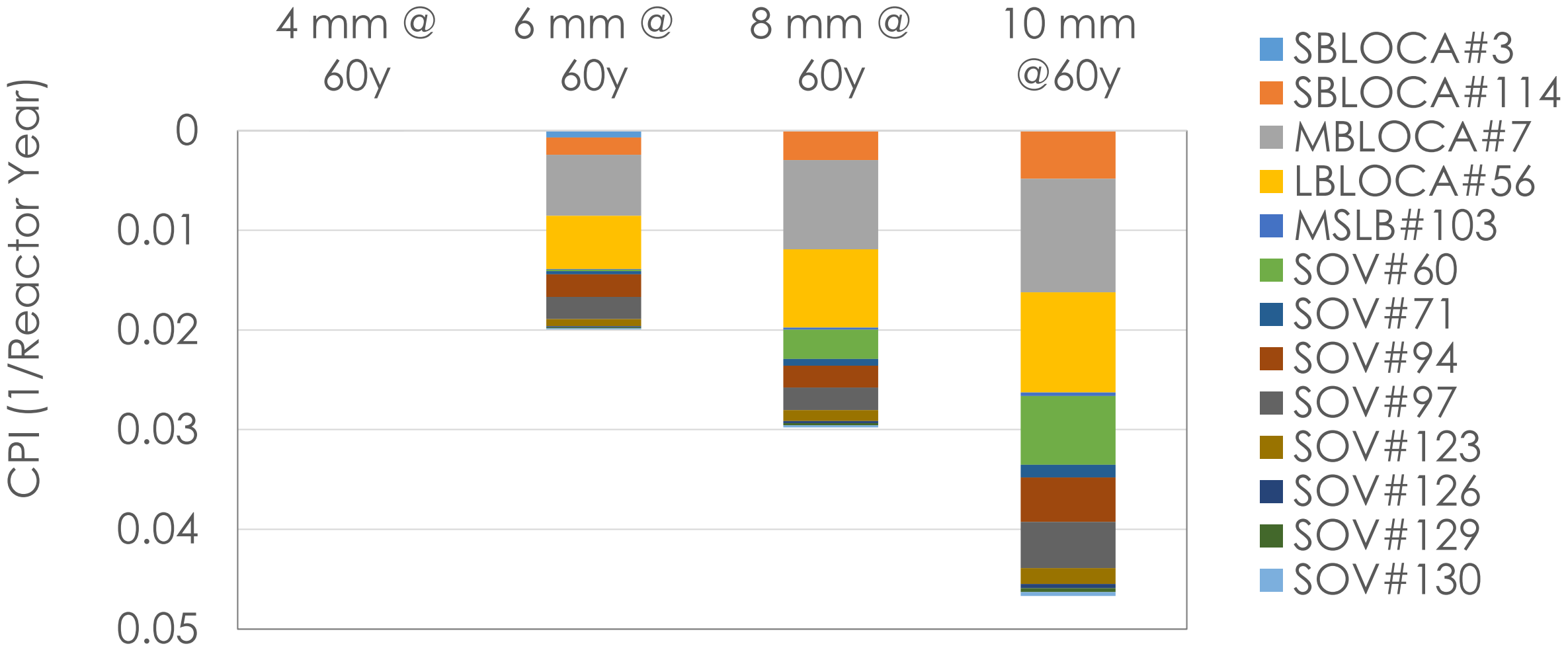
Analysis : PASCAL-5, Referring JAEA-Data/Code 2022-006

- Information of RPV
  - Size: Conventional 3-loop PWR
  - RT_{NDT}: Base: around 90℃,Weld: around 50℃ @ 60y
    - Base : Initial RT_{NDT}=-5℃, 0.16%Cu, 0.61%Ni (median)
    - Weld : Initial RT_{NDT}=-50℃, 0.14%Cu, 0.80%Ni (median)
    - Embrittlement Trend Curve: JEAC4201-2007 (2013 addendum), Fast neutron fluence is $7x10^{19}$ n/cm^2 @ 60y.

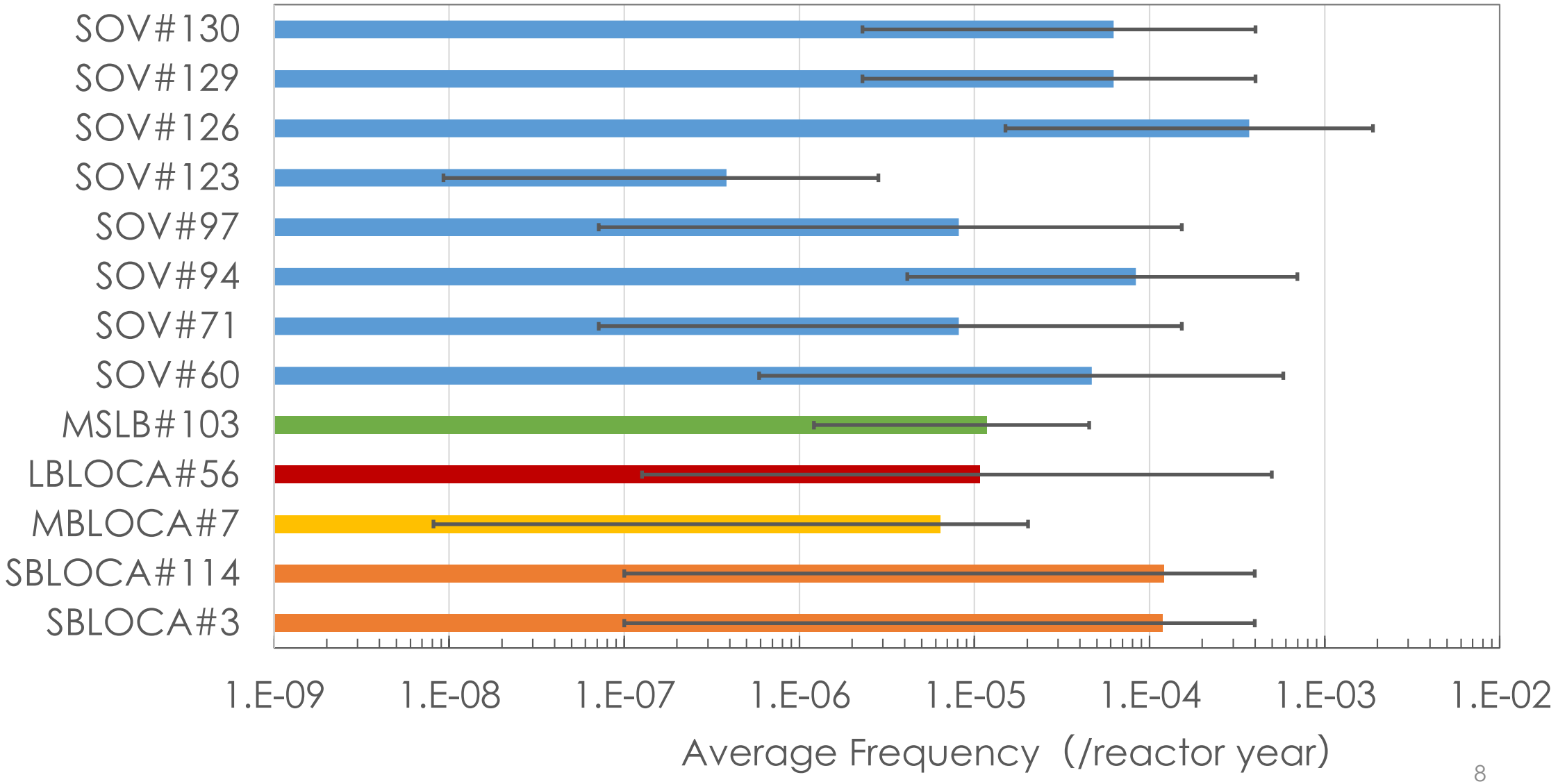
- Crack distribution
  - Initial distribution: VFLAW, considering Japanese PWR welding
  - Stress history and crack growth: JSME S-ND1 + Paris Law
  - Non-distractive testing: Bayesian update, POD H/M/L

Conditional Probability for Crack Initiation for Deterministic Embedded Cracks

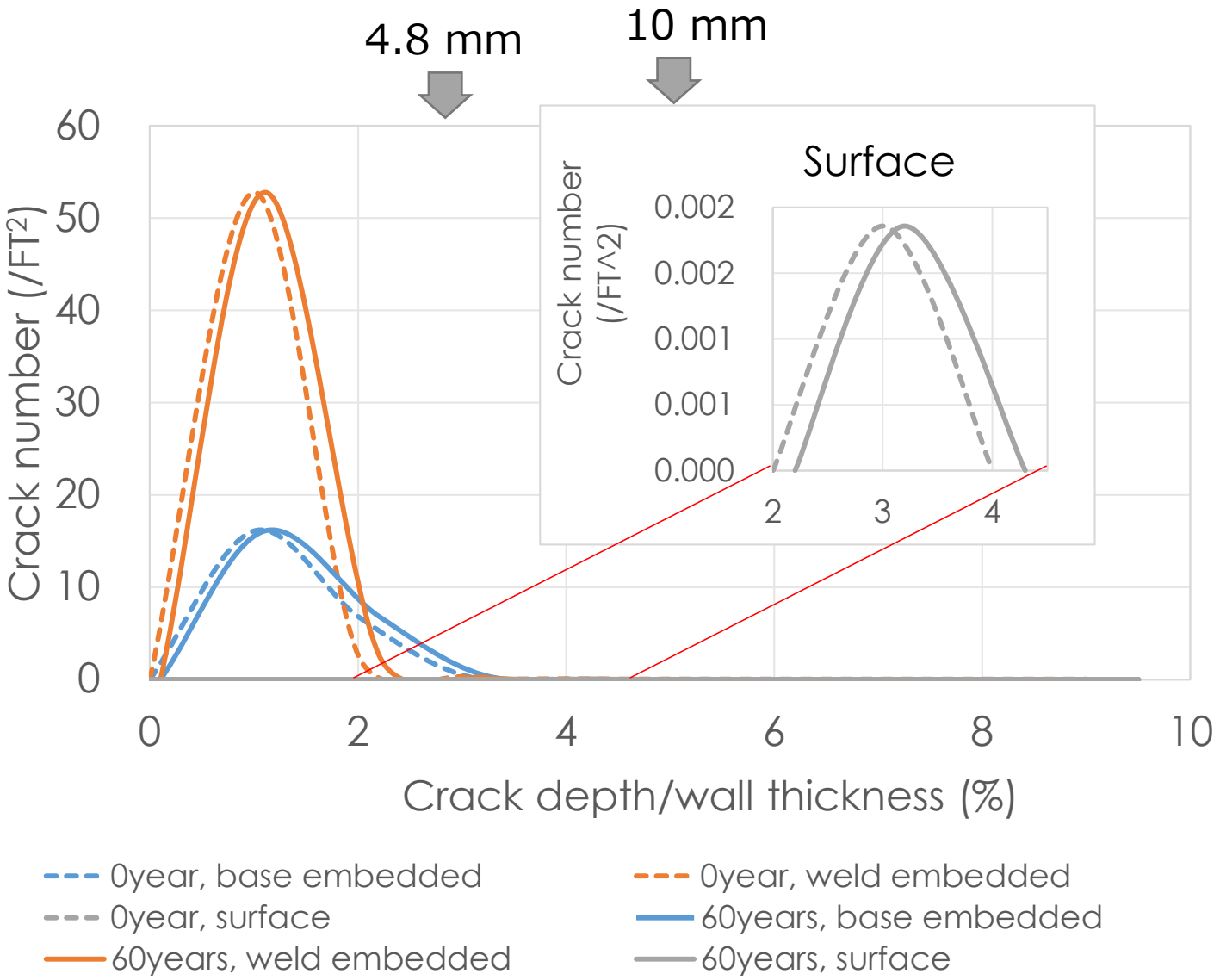
Uncertainty for fracture toughness were taken into account



13 Transients selected based on NUREG-1806



Crack Growth by Fatigue

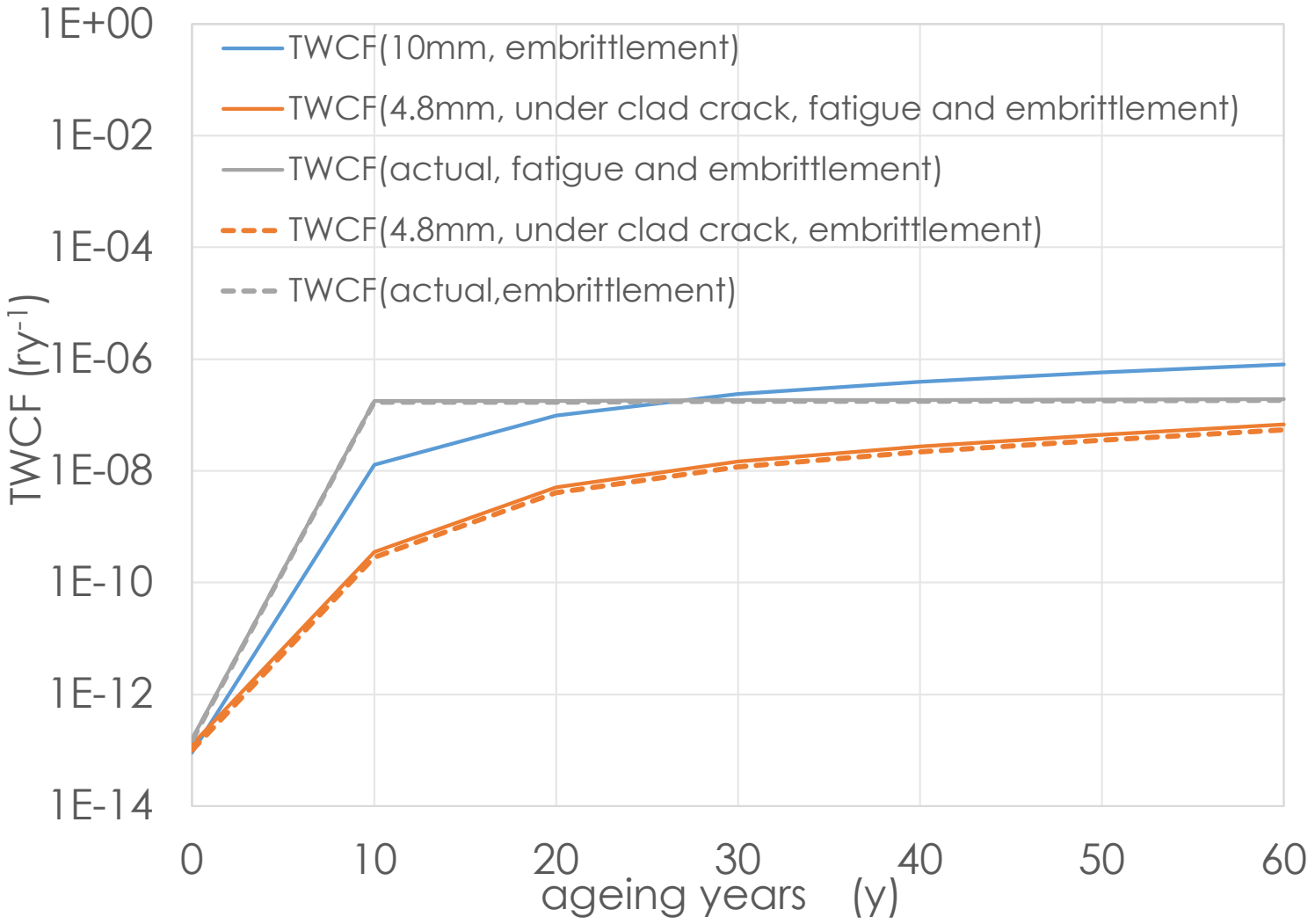


- Surface crack is 3 order smaller than embedded crack
- Crack size change is smaller than 1% (=2mm) of the thickness of wall

→ The change has to be considered by stress intensity factor

- Crack size would be smaller than 6 mm after 60 years of operation.

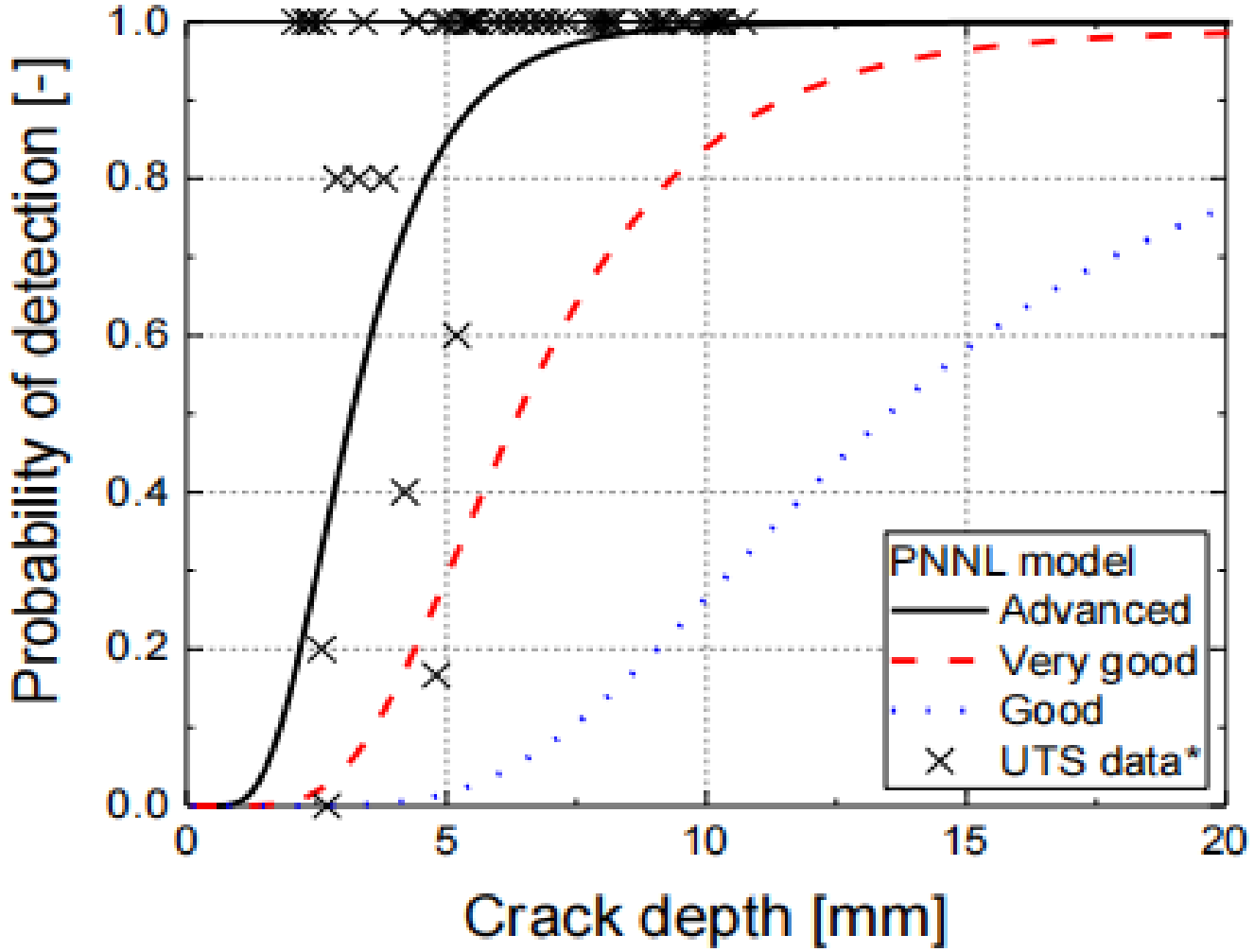
Effect of Fatigue and Embrittlement on Through Wall Crack Frequency (TWCF) without ISI



VFLAL Crack Distribution
Conservative embedded crack (10 mm)
Realistic embedded crack (4.8 mm)

Fatigue (---) does not affect the TWCF
→ "Justification 1" was not valid

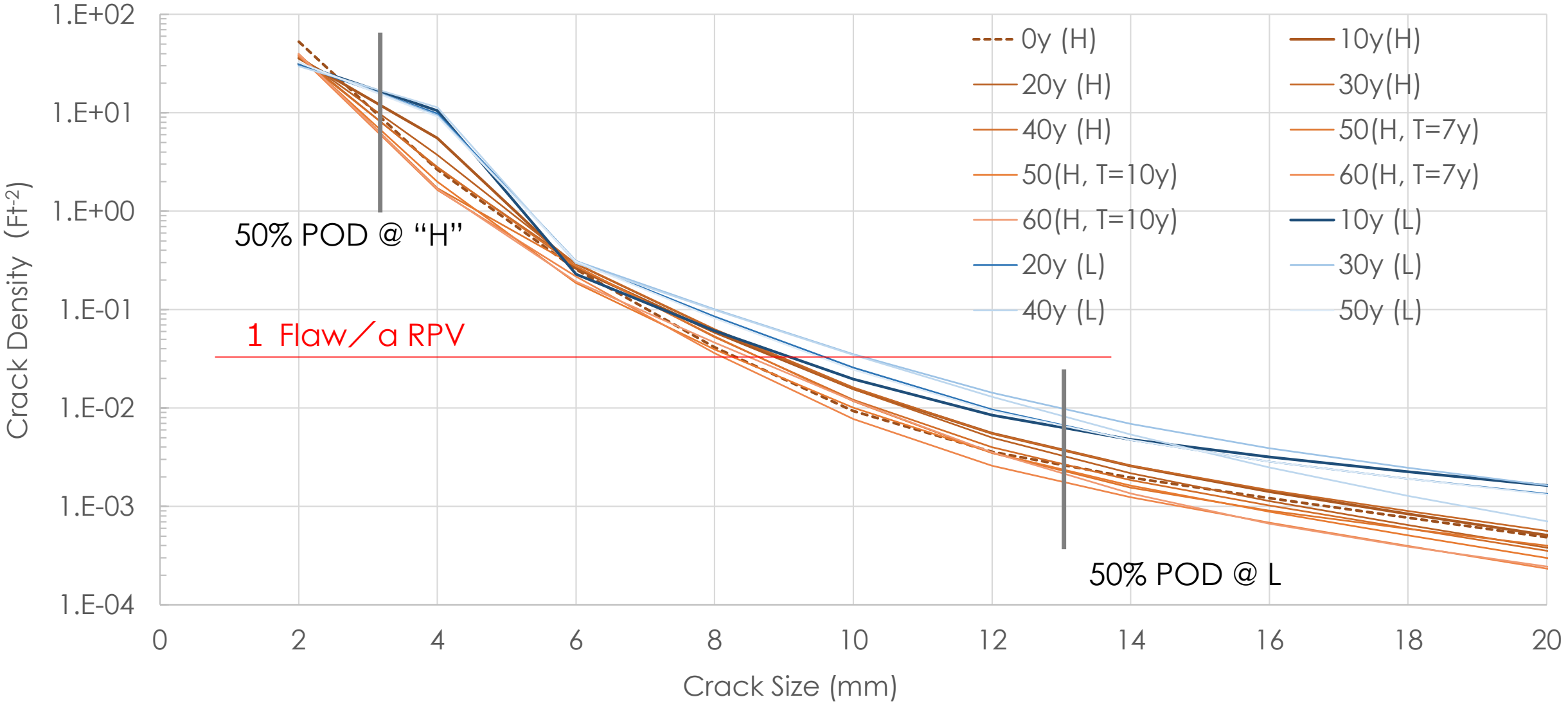
Bayesian Update of Crack Distribution 亀裂分布のベイズ更新の方法



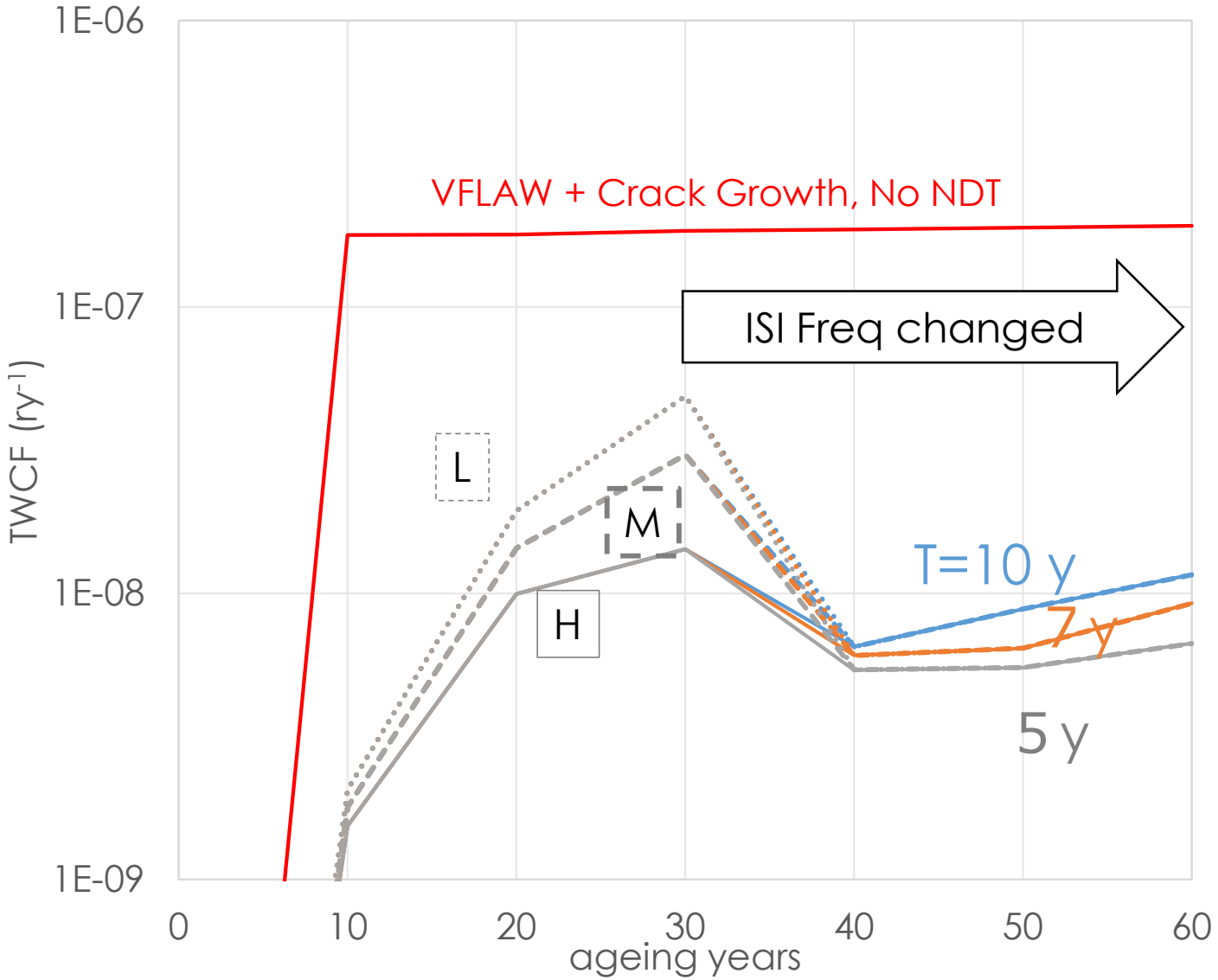
$$L(a|\Phi) = \frac{f(a|\Phi,t_{tr})\cdot \mathrm{POD}(a)}{POD(\Phi,t_{tr})}$$

Katsuyama, Proc. ASME PVP 2020

Change in Crack Distribution at Weld line



Change in TWCF by ISI



ISI reduces TWCF (one order)

→”Justification 2” may be valid

POD does not affect TWCF during LTO?

Conclusion

- ISI reinforcements in Japan would affect the structural integrity of the PWR as follows:

1. On the beltline, **effect of fatigue is ignorable**, and crack distribution will not change significantly by the updating

2. **Slight reduction of TWCF** was recognized by the ISI, but it is the order of **10^{-8} /reactor year**. Reason of this trend is under the estimation.