PFMのBWR機器への適用事例

PFM Application to BWR Components

Effect of Crack Detection Performance and Sizing Accuracy on Reliability of Piping Having Stress Corrosion Cracks

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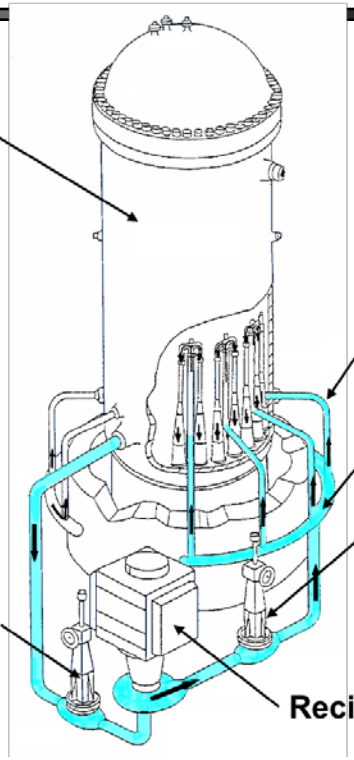
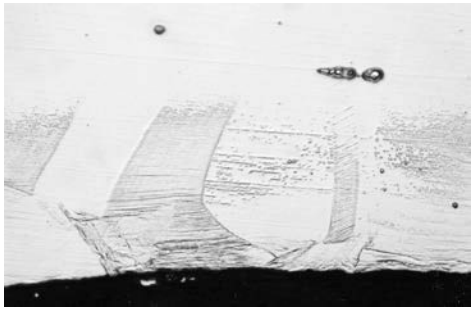
Background

- Many stress corrosion cracks (SCCs) have been observed in wild joints of PLR piping of Japanese BWRs since around 2000.
- When SCCs are detected in the weld joint, structural integrity of a cracked pipe is evaluated according to the JSME Fitness-for-Service Codes (FFS Codes).
- The inspection frequency and an evaluation period to piping which is not carried out preventive maintenance are as follows;
  - Inspection frequency: 100% / five years
  - Evaluation period: Max. five years
  - Successive inspection: Every year

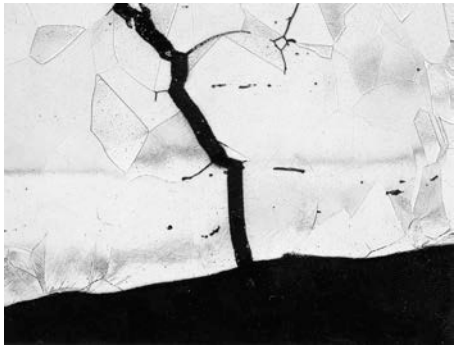
SCC in Kashiwazaki-Kariwa-1



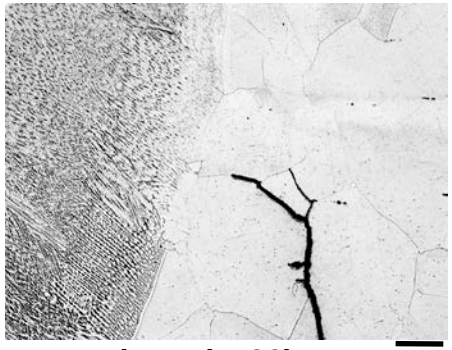
Crack (×400) 1mm



Inner Surface (×400) 50μm



Point-F (×100) 0.1mm



Point-D (×100) 0.1mm

Contents

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- Relation between inspection performance with reliability of piping
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Relation of structural integrity evaluation and non-destructive tests

Maintenance of a nuclear power plant

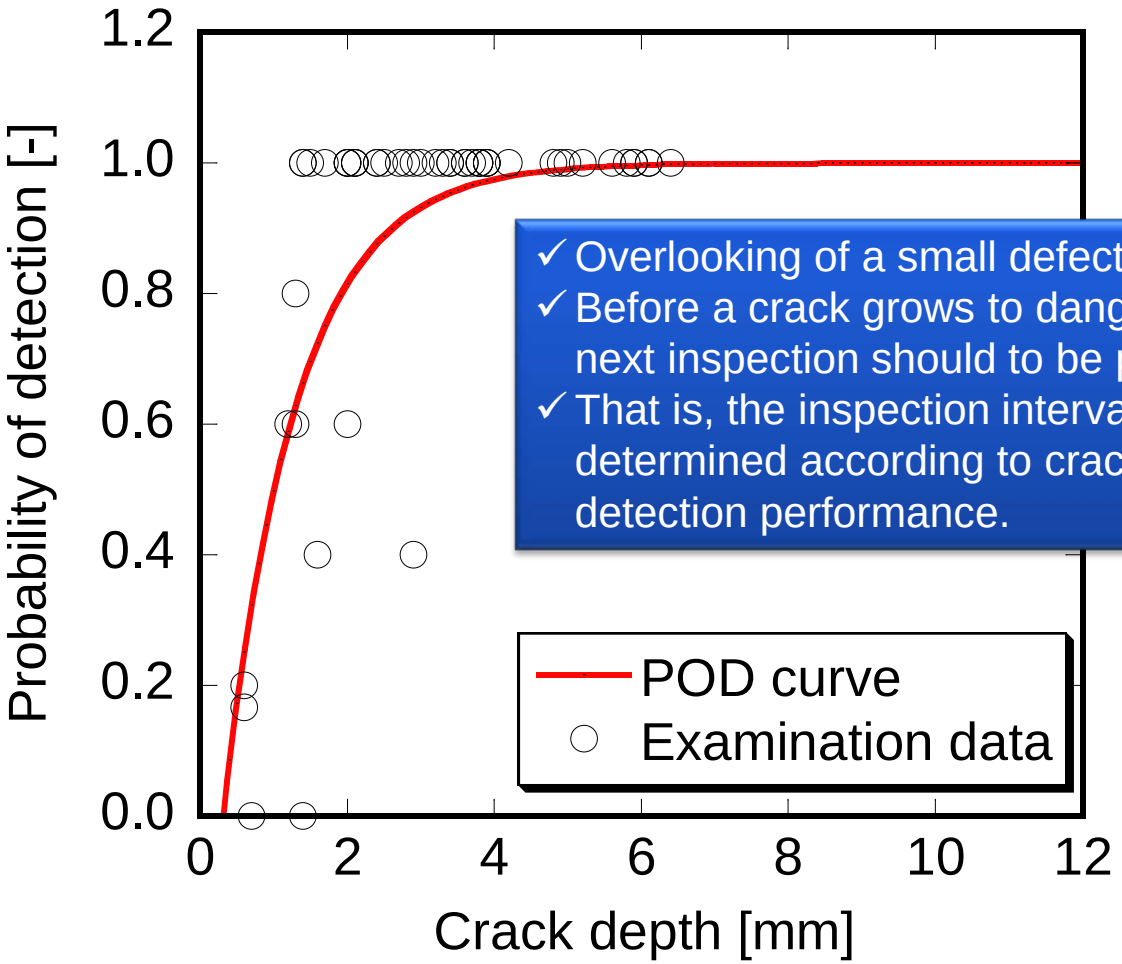
- The structural integrity of the component in nuclear power plants and maintenance of their function are attained by inspection, evaluation and repair/replace.
  - The JSME Fitness-for-Service Codes
- However, improvement in such technology (inspection and evaluation) is advanced independently and these do not harmonize well.
- Thereby, too much conservativeness or omission may exist.
- For SCCs in the PLR piping, the inspection performance and accuracy of flaw evaluation were examined from a viewpoint of reliability using a PFM analysis code.

Uncertainty in flaw evaluations

- In flaw evaluations, the following variations exist.
  - An oversight of flaws in NDT (inspection)
  - Sizing error (inspection)
  - Crack growth estimation error (evaluation)
- The performance of inspection is an important factor for the FFS Codes.
  - An inspection interval
  - An inspection method
  - Safety factor (structural factor) considered in flaw evaluations

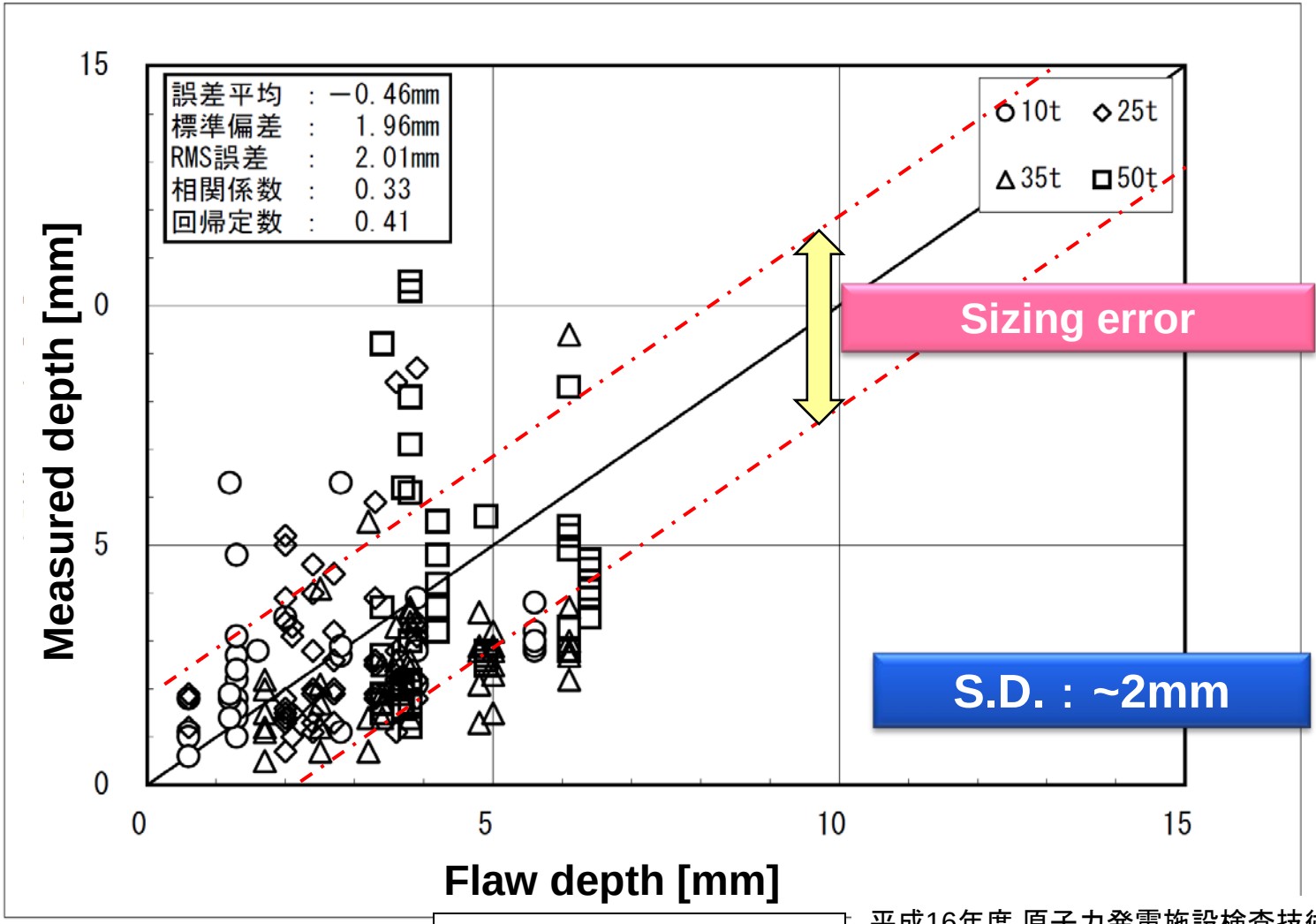
Performance of NDT related to structural integrity evaluation

Flaw detection performance



- ✓ Overlooking of a small defect is not avoidable.
- ✓ Before a crack grows to dangerous size, the next inspection should to be performed.
- ✓ That is, the inspection interval should be determined according to crack growth rate and detection performance.

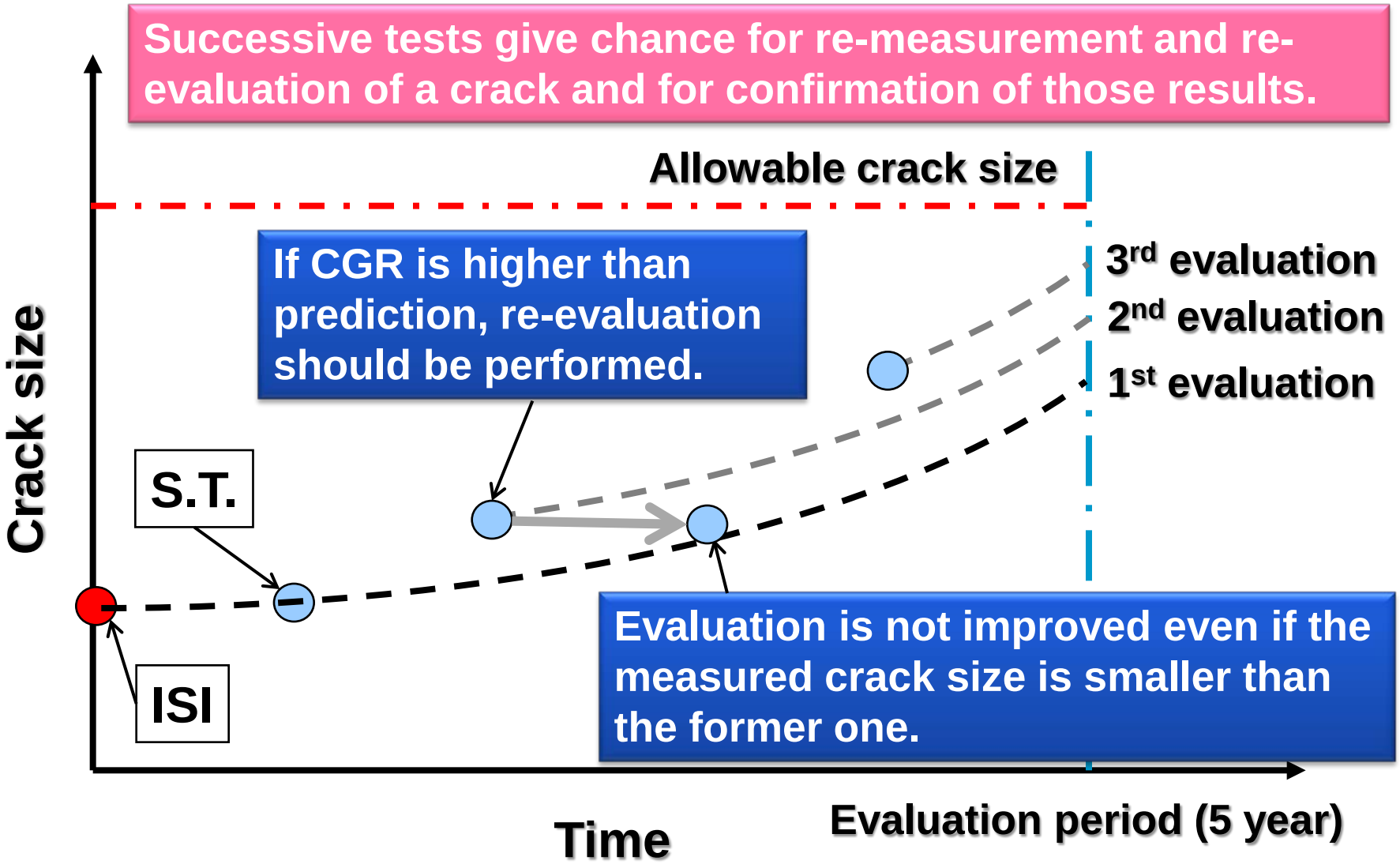
Flaw depth sizing error



Part echo method

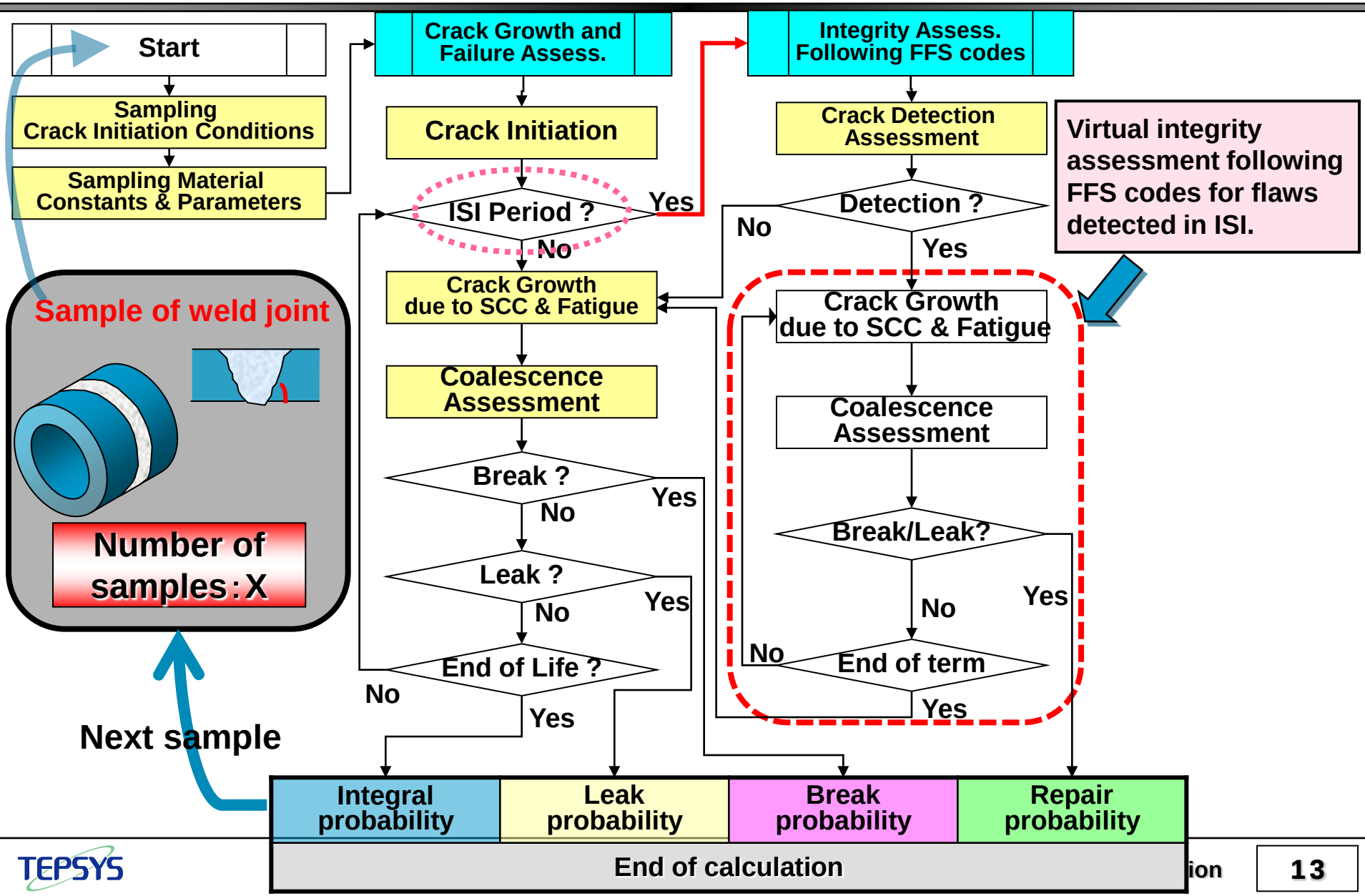
平成16年度 原子力発電施設検査技術実証事業に関する報告書, JNES

Evaluation in a successive tests

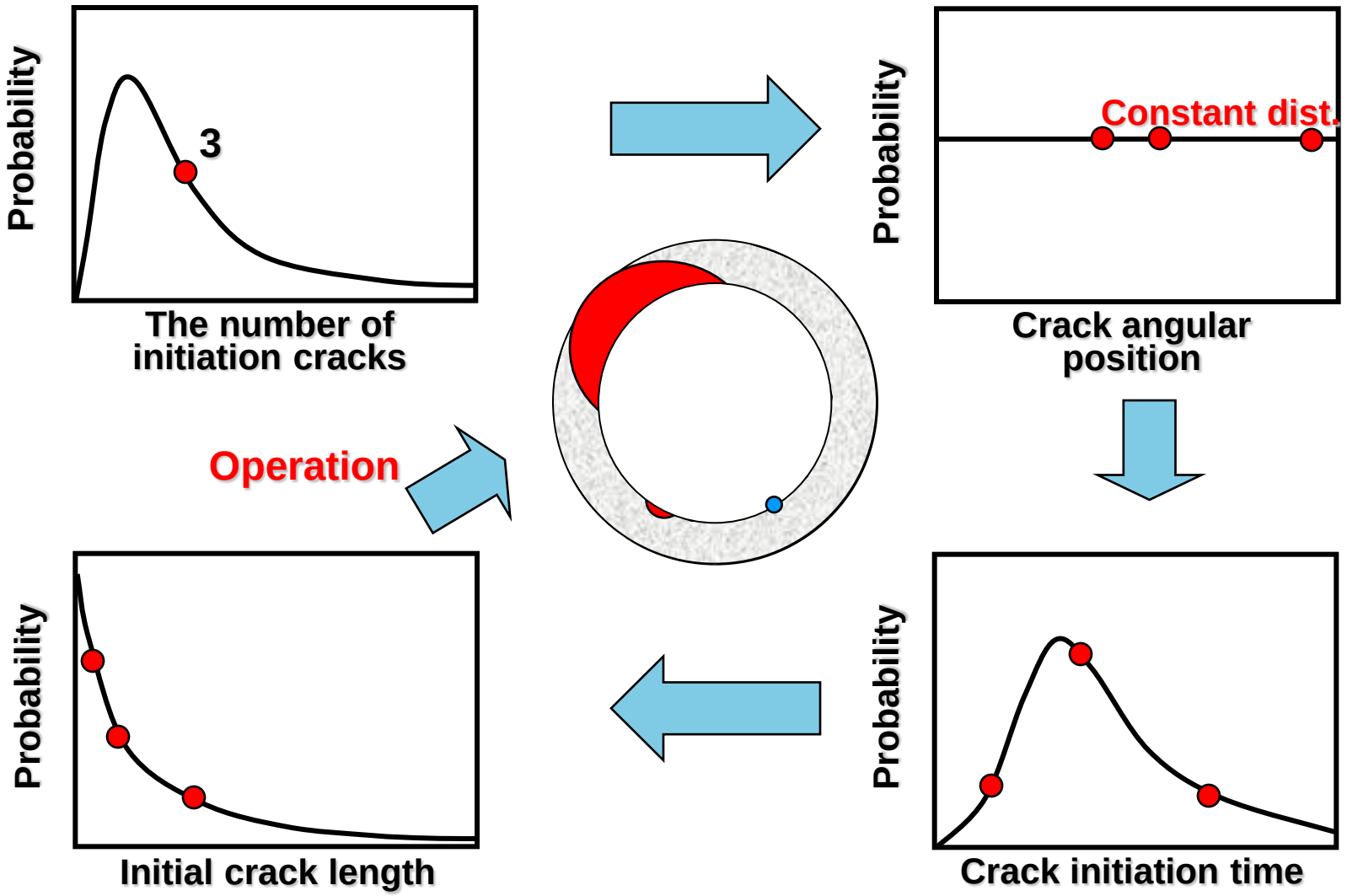


PFM Code (PEPPER-M)

Evaluation flowchart of PEPPER-M



Flow of calculation

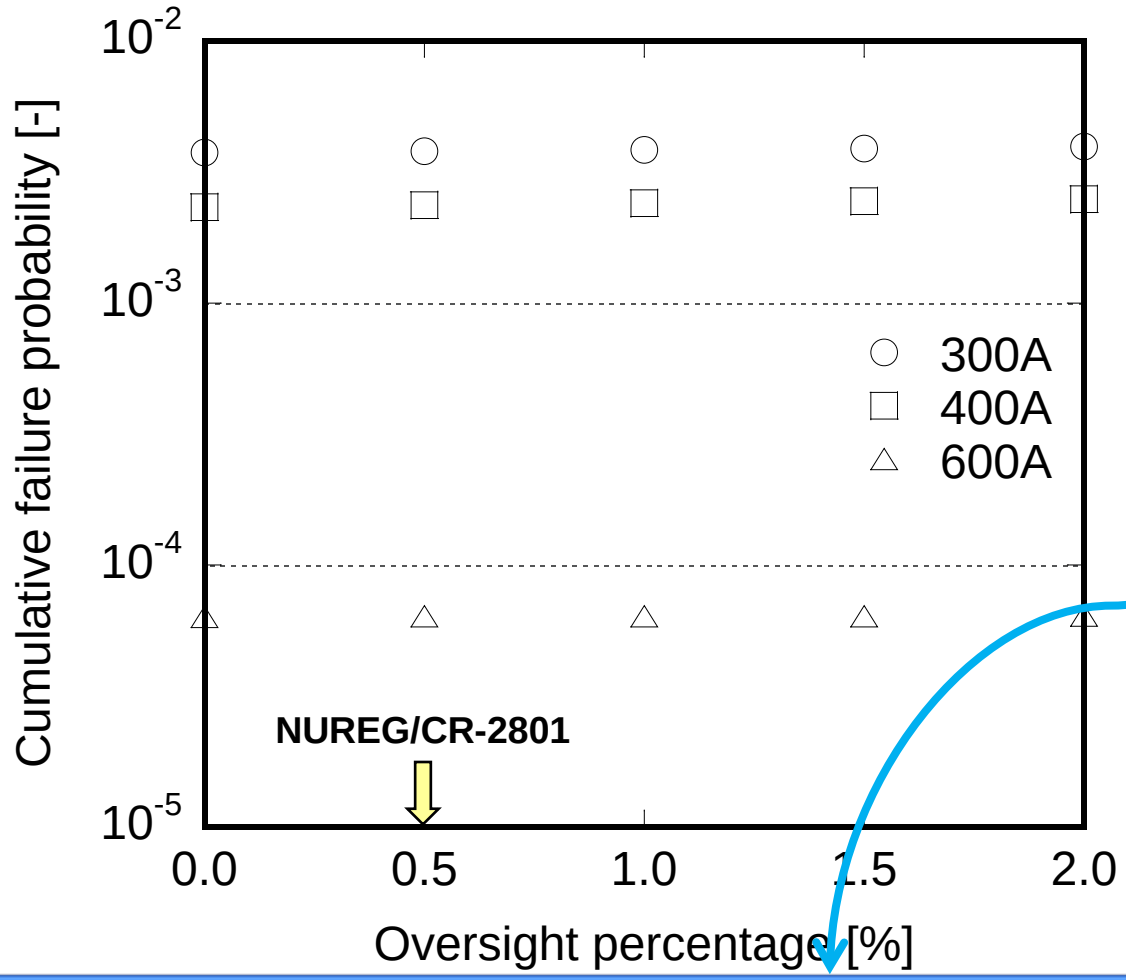


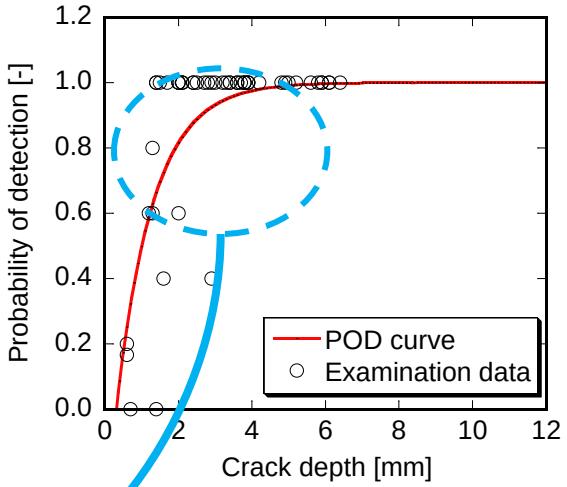
Relation between inspection performance with reliability of piping

Oversight of a flaw

- The NDT of piping system may be carried out on in radiation environment or bad accessibility.
- A possibility of oversight of a flaw is assumed from these influences.
- PFM analysis can estimate the influence of oversight using very simple way.
- Failure probability was calculated based on the following assumptions;
  - Oversight is irrespective of the flaw size,
  - An accidental oversight arises.

Effect of oversight of a flaw



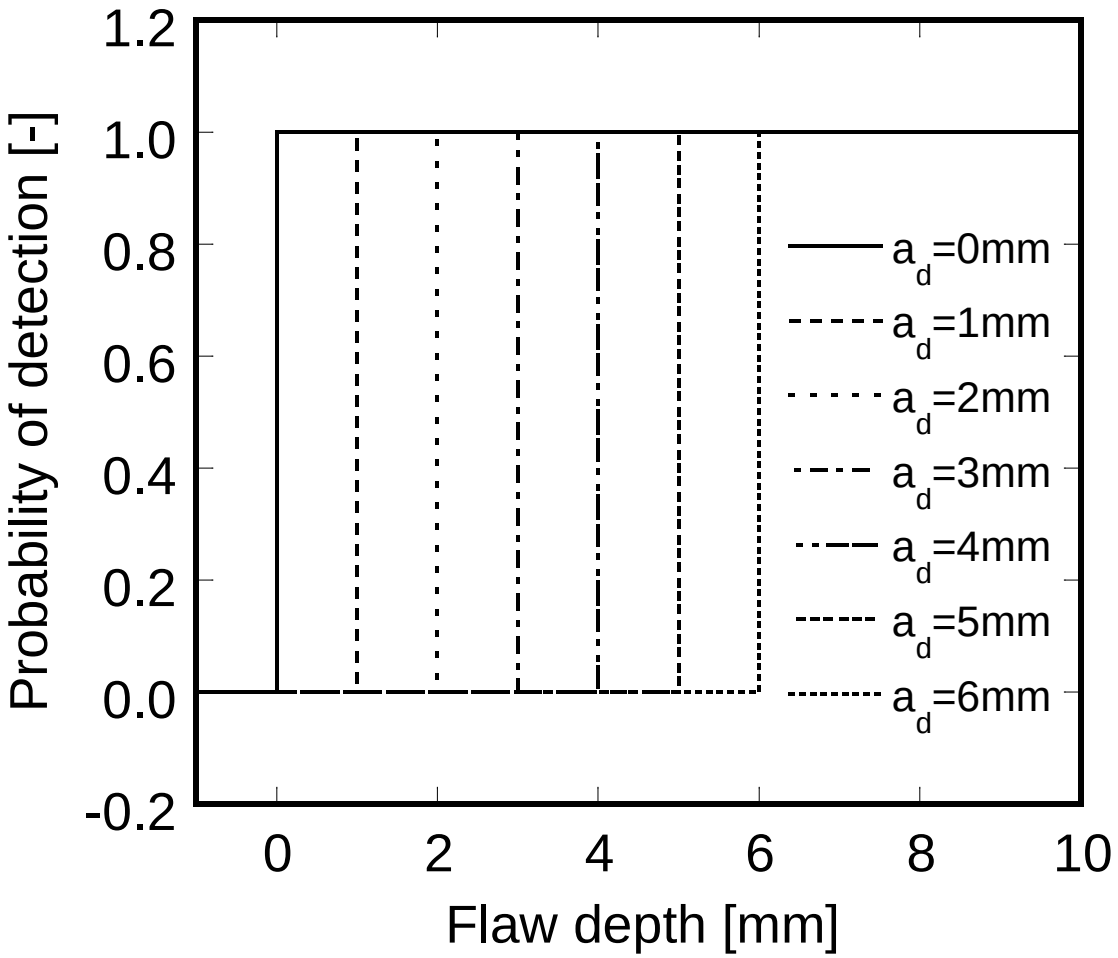


Since the percentage of an undetectable crack is larger than oversight, the influence of oversight hardly appears. Then, influence of oversight of 2% or less is negligible.

Flaw detection performance

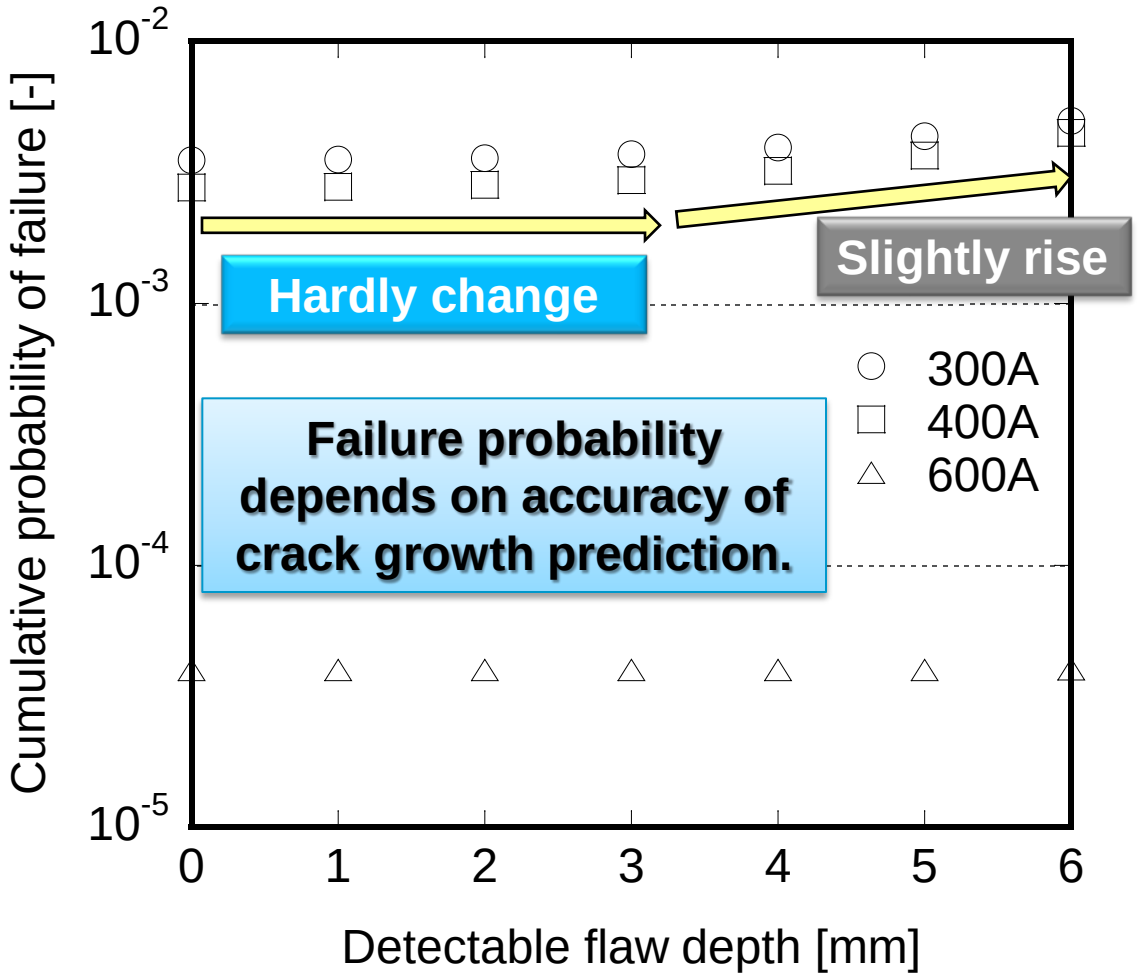
- The minimum detectable flaw size is one of the performances of NDT.
- Efforts to detect a smaller flaw have been performed.
- On the other hand, since growth rate of a small flaw is very low, it does not cause failure of piping if it cannot be detected.
- The flaw size which should be detected is evaluated from a viewpoint of failure probability.

Flaw detectability (Virtual POD curve)



Note: Oversight is not taken into consideration.

Effect of a flaw detection performance

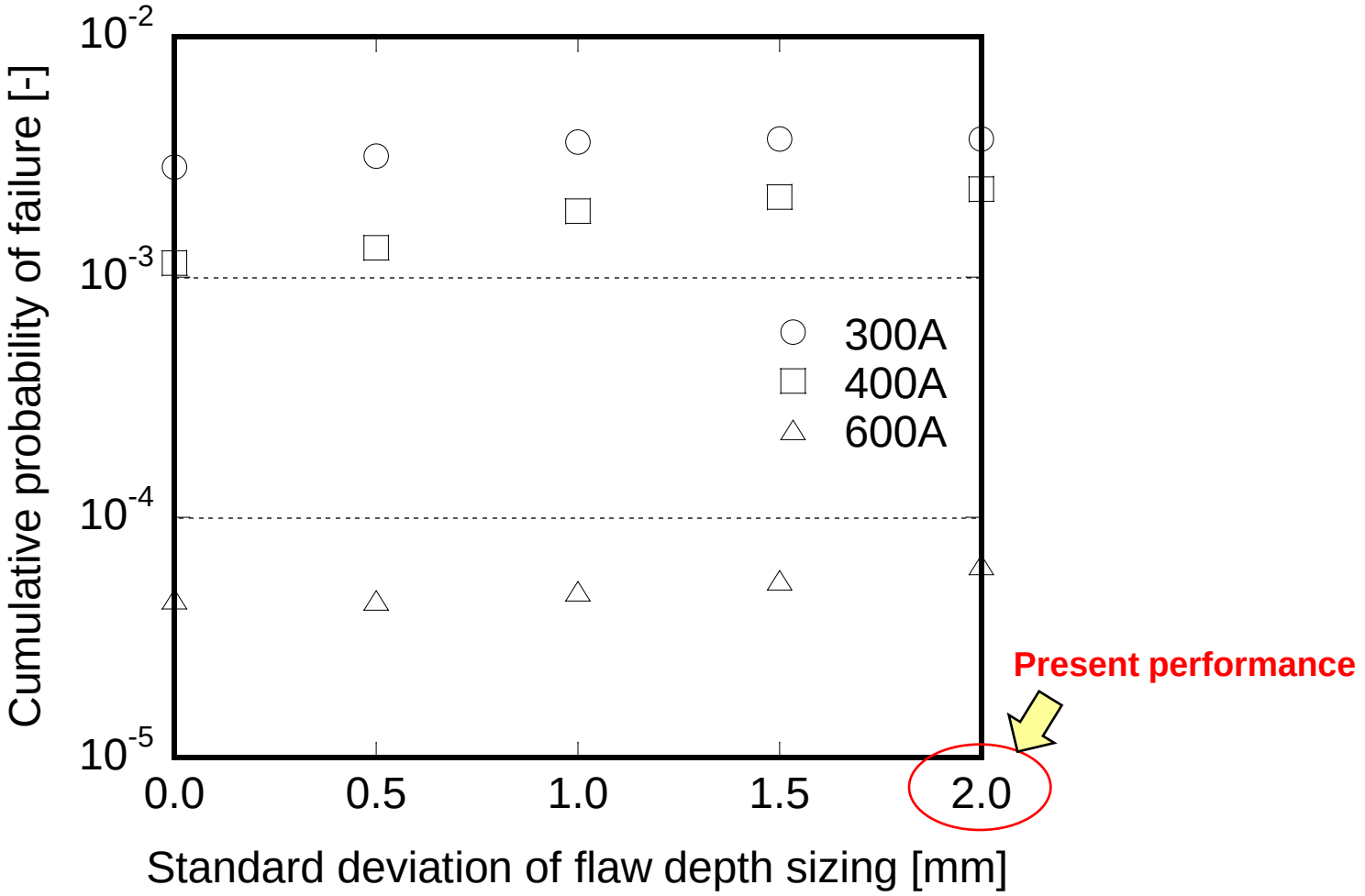


If the flaw depth is 3mm or less, failure probability will hardly change.
⇨ It is important to detect a flaw around 3mm depth certainly.

Flaw depth sizing error

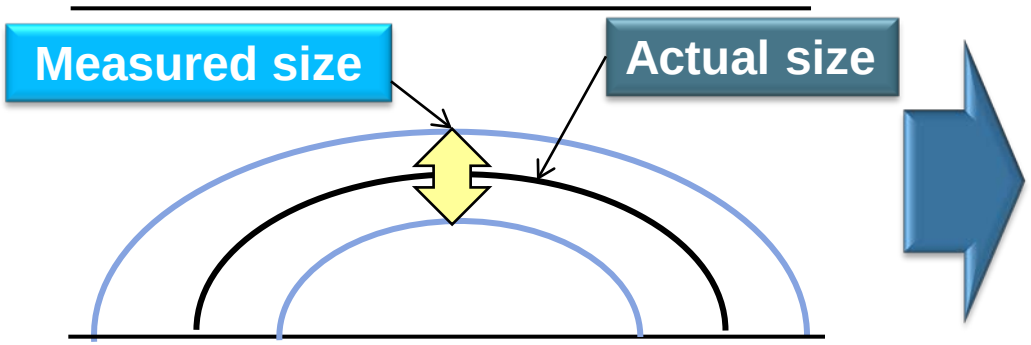
- The variation in measurement of the flaw depth is 2.0 mm (standard deviation) by qualified inspectors by PD system.
- However, it is expected that this value will improve by development of measuring device or improvement of an inspection method.
- Then, the influence of standard deviation of crack depth sizing error on failure probability was evaluated.

Effect of flaw depth sizing error



Even if a flaw depth sizing error decreases, failure probability does not improve extremely.

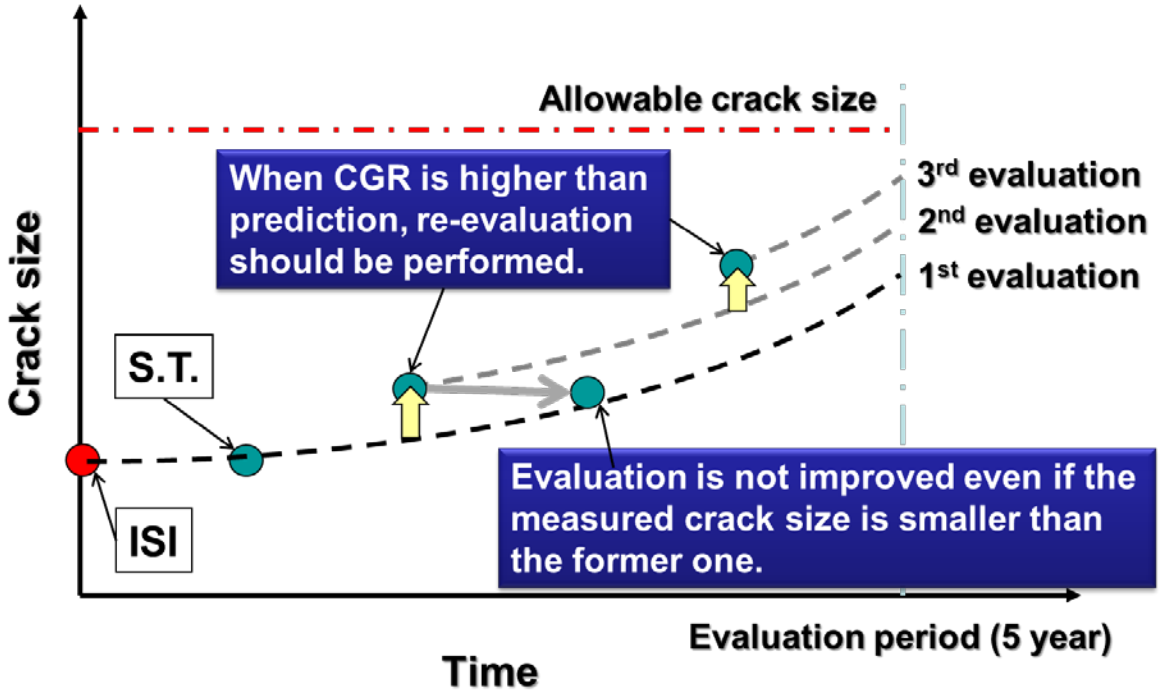
The reason flaw depth sizing error does not influence on failure probability



- Flaw depth is not only measured small, but may be measured large.
- If measured several times, an average of measured size will approach an actual size.

Moreover

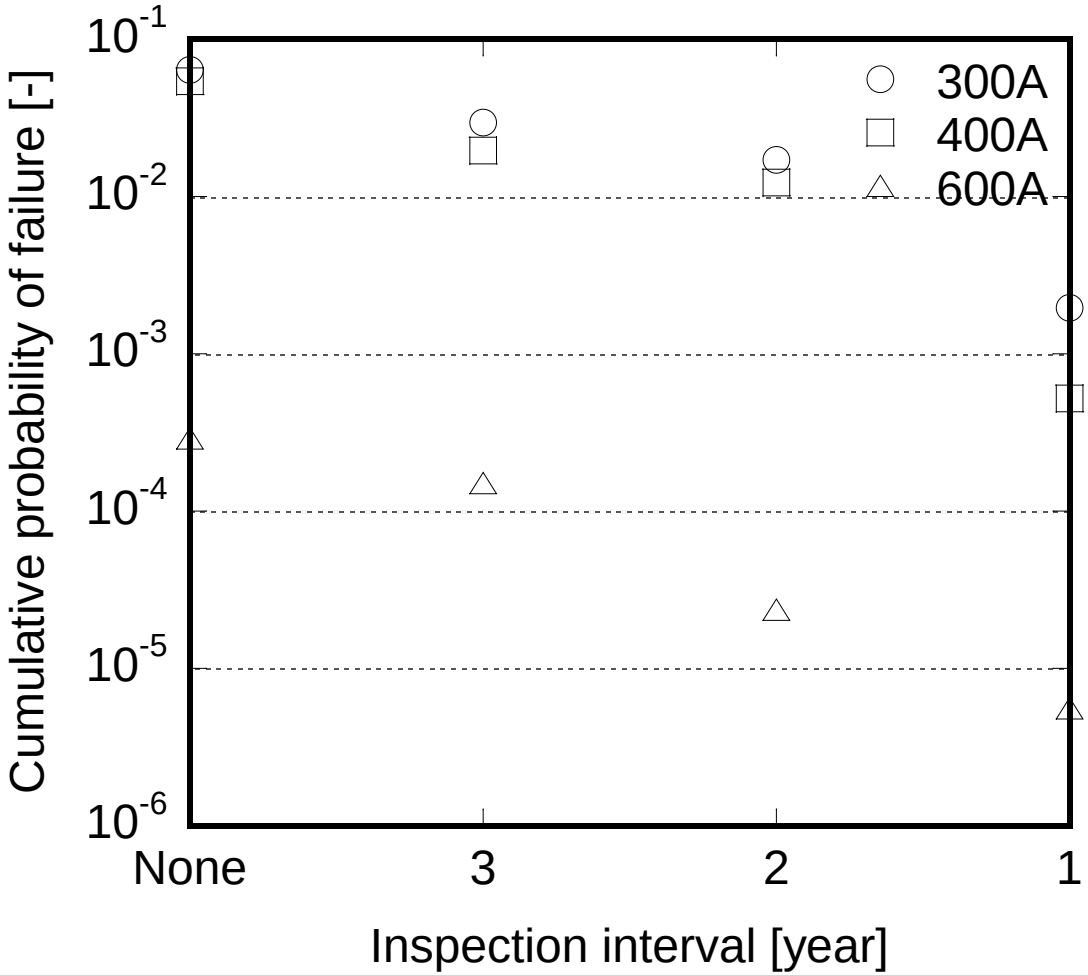
The successive tests are also effective, in order to decrease failure probability due to flaw sizing error.



Effect of successive test

- When SCCs are detected, 3 times of successive tests (it is 4 times when SCCs grow) are carried out during an evaluation period (5 years).
- Failure probability is evaluated when successive tests are carried out every year, every two years, every three years and not carrying out.
  - When carrying out every year, 4 times (1, 2, 3 and 4th year)
  - When carrying out every tow year, 2 times (2 and 4th year)
  - When carrying out every three year, 1 times (3rd year)

Effect of successive test

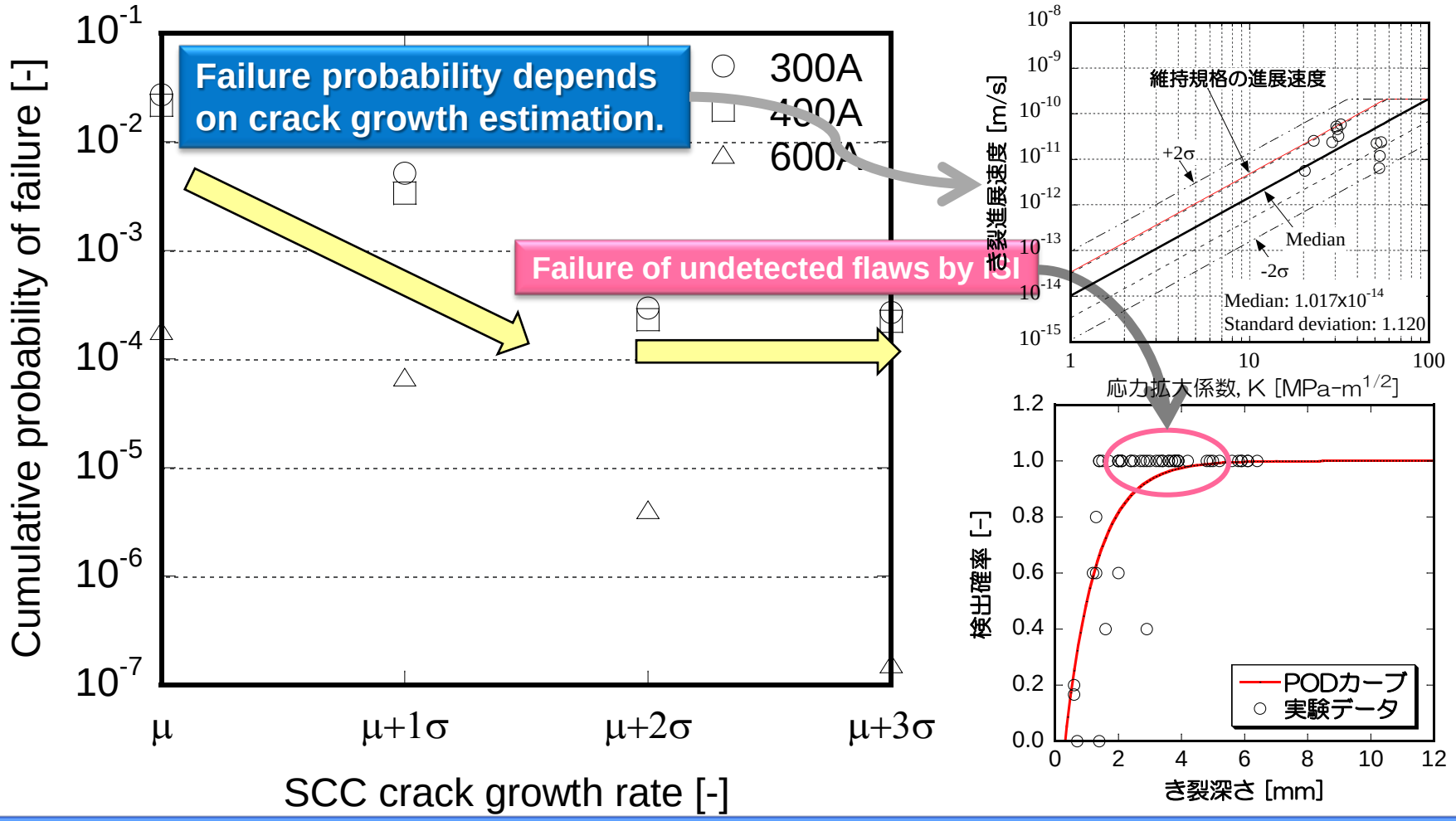


Failure probability drops clearly by performing frequent successive tests. ⇨ **A frequent inspection leads to low efficiency.**

Effect of crack growth rate

- If an actual flaw size exceeds predicted size based on the FFS codes, re-evaluation should be performed based on the results of the successive tests.
- The effect of successive tests on failure probability was evaluated when crack growth rate applied in an integrity assessment changes from the mean (μ) to μ +3σ (σ is standard deviation) .

Influence of crack growth rate



Reliability of flaw evaluation should be improved with well combined inspection and evaluation considering those performance.

Proposals for the inspection (Conclusions)

Proposals (1)

- **Since failure probability depends on the failure of an undetectable crack, influence of oversight of 2% or less is negligible.**
  - **Oversight of a flaw of this level (~2%) is permitted from the judgment based on reliability.**
- **Very small flaw does not lead to failure, if it is not detected.**
  - **The new NDT equipment aiming at detecting an extremely small flaw is not required from a viewpoint of reliability.**
  - **Rather, it is very important to detect certainly a big flaw with a possibility of leading to failure.**

Proposals (2)

- Flaw sizing accuracy appears as a tendency of the both sides in the case of measuring small and large.
  - As a result, failure probability is almost equal to the no-error case.
  - The further improvement in sizing accuracy does not lead to improvement of reliability.
- In order to improve reliability, it is important to grasp the crack growth estimation accuracy and NDT performance, and to make up for each week point.

Demands

- PFM analysis codes or analytical technics have been established.
- Unfortunately, discussion on application of PFM analysis or judgment base on risk/reliability is missing in Japan.
- In order to extend practical use of PFM, performance requirement (target reliability) should be proposed.
- JSME, JEA and AESJ which publish industrial standards should promote examinations concerning application of probabilistic methods or acceptance criterion.