2015 Revision of the FAVOR* Probabilistic Fracture Mechanics Computer Program (v15.1)

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Presentation Overview

- Background on FAVOR

- Current work to address
  - bug
  - deficiencies in treatment of $\infty$ flaws

- Plans for release of FAVOR v15.1
The NRC-sponsored FAVOR code performs deterministic and risk-informed probabilistic fracture analyses of nuclear reactor pressure vessels (RPVs) based on linear-elastic fracture mechanics (LEFM).

FAVOR addresses

- normal operational transients (e.g., start-up/shutdown/leak tests)
- upset conditions (e.g., pressurized thermal shock events),
- Inner-surface, embedded, and outer-surface flaws, and
- Cladding effects
BACKGROUND: Range of conditions addressed by FAVOR SIFICs (stress intensity factor influence coefficients) for surface-breaking flaws

- semi-elliptical flaws with $0.01 \leq a/t \leq 0.5$ normalized flaw depths and $2 \leq L/a \leq 10$ aspect ratios
- infinite axial and circumferential 360-degree continuous flaws with $0.01 \leq a/t \leq 0.95$
- inner and outer surfaces of RPV wall
- $R_i/t \approx 10$ (PWR) and $R_i/t \approx 20$ (BWR)
- inside surface cladding layer included (embedded flaws not discussed here)

$a =$ flaw depth; $t =$ wall thickness; $L =$ flaw length; $R_i =$ inner radius of RPV
CURRENT WORK: Overview of revisions to FAVOR

Motivated by results from studies in 2014 (EPRI and ORNL)

1. Coding error - or “bug” - identified by EPRI work (requiring a fix)
   - Bug affects calculation of applied $K_f$ factors for inner surface-breaking flaws by interpolation between $R/t = 10$ & $20$
     - Only an issue for surface breaking flaws
     - Only an issue for interpolation
   - Bug does not alter previous results that did not use interpolation
     - PTS re-evaluation studies
     - Recent shallow-flaw report for Appendix G

2. Improve code by addressing deficiencies identified while investigating bug
   - Calculation of $K_f$ factors for $\infty$ flaws (requiring code enhancements and new SIFICs)
CURRENT WORK [1]: Error in a pointer was identified & fixed

For calculations involving the interpolation of SIFICs, the FAVLOAD module did not correctly account for the different relative flaw depths in the second position of the flaw depth vectors for \( R_i/t = 10 \) and \( R_i/t = 20 \) in the SIFIC databases.

<table>
<thead>
<tr>
<th>Fraction of wall thickness ((a/t))</th>
<th>Crack depth (inches)*</th>
<th>Applied KI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>for ( (R_i/t) = 10 )</td>
<td>for ( (R_i/t) = 20 )</td>
<td>for ( (R_i/t) = 10 )</td>
</tr>
<tr>
<td>.010</td>
<td>.010</td>
<td>0.073</td>
</tr>
<tr>
<td>.0184</td>
<td>.0255</td>
<td>0.134</td>
</tr>
<tr>
<td>.050</td>
<td>.050</td>
<td>0.365</td>
</tr>
<tr>
<td>.075</td>
<td>.075</td>
<td>0.548</td>
</tr>
<tr>
<td>.10</td>
<td>.10</td>
<td>0.731</td>
</tr>
<tr>
<td>.20</td>
<td>.20</td>
<td>1.461</td>
</tr>
<tr>
<td>.30</td>
<td>.30</td>
<td>2.192</td>
</tr>
<tr>
<td>.50</td>
<td>.50</td>
<td>3.652</td>
</tr>
</tbody>
</table>

*Values specific to problem illustrated in figure 23 in draft EPRI report

Existing FAVOR calculations of \( K_i \) for shallow flaws in vessels which require interpolation on \( R_i/t \) did not correctly position the flaw in the vessel wall.

For \( (R_i/t) = 20 \), instead of selecting \((a/t) = 0.0255\), the code incorrectly selected \((a/t) = 0.0184\), i.e., the value for \( (R_i/t) = 10 \).
CURRENT WORK [1]: Revised SIFICs to provide consistency in the relative flaw depths used in the SIFIC databases for finite-length flaws at both R/t = 10 & 20

- The pointer bug affects the interpolation scheme for computing $K_I$ factors for those cases $10 < (R / t) < 20$

- The fix involves calculation of SIFICs using the same relative flaw depths for both R/t values

<table>
<thead>
<tr>
<th>Relative Flaw Depths in SIFIC Database for Finite Surface-Breaking Flaws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old (a/t)</td>
</tr>
</tbody>
</table>
|\begin{tabular}{llll}
  \hline
  $(R_j / t)$ & \hline
  0.010 & 0.010 & 0.010 & 0.010 \\
  0.0164 & 0.0255 & 0.035 & 0.035 \\
  0.050 & 0.050 & 0.050 & 0.050 \\
  0.075 & 0.075 & 0.075 & 0.075 \\
  0.100 & 0.100 & 0.100 & 0.100 \\
  0.200 & 0.200 & 0.200 & 0.200 \\
  0.300 & 0.300 & 0.300 & 0.300 \\
  0.500 & 0.500 & 0.500 & 0.500 \\
  \hline
\end{tabular} |
CURRENT WORK [2]: Developed a new SIFIC database for $\infty$ circ. & axial inner surface-breaking flaws

- Deficiencies identified in the original FAVOR methodology for calculating $K_I$ factors for $\infty$ flaws
  - Old SIFIC solutions selected for comparison were as much as 10% below ABAQUS solutions
  - Old SIFICs did not adequately account for cladding

- SIFICs for $\infty$ flaws now include cladding effects consistent with technique used for finite-length flaws

- 240 ABAQUS models/analyses performed to generate the new SIFIC database
**PLANS:** A few steps remain before issuing FAVOR v15.1

- Complete verification studies
  - installation of the new SIFIC databases,
  - new scheme for processing SIFICs for continuous/infinite-length flaws,
  - interpolation schemes for vessel geometries ($R_i/t$) between 10 and 20; and clad thicknesses between 0.156 inches and 0.25 inches.

- Revised Theory Manual that reflects the changes in the code.

**FAVOR v15.1 release anticipated in Spring 2015**