# *DRAFT*
# *Use of PE Pipe in Safety-Related Nuclear Power Plant Piping*

by

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# Presentation Outline

- **Background**
- **ASME Code Case CC N-755**
- **US Nuclear Regulatory Commission (US NRC) – Status on PE Piping**
- **Technical Issues**
  1. **Effect of Elevated Temperature**
  2. **Allowable Flaw Size and Shape**
  3. **Design (Safety) Factor for Safety-Related piping**
  4. **Service Life Prediction Models**
  5. **Butt-Joint Inspection**
- **Summary Discussion**

# Background - Industry Activities

- **HDPE Pipe has been used in non-safety-related nuclear power plant applications for over 10 years in the US**
- **Nuclear Power Industry intends to use HDPE in Class 3 *safety-related* service-water piping applications**
- **ASME-Boiler and Pressure Vessel (BPV) Committee has developed a Code Case CC N-755 under Section III-Design, Special Working Group – PE Piping titled *"Use of Polyethylene (PE) Plastic Pipe, Sections III, Division 1, and XI," March 22, 2007***
- **Draft of CC N-755, Rev. 1 is being reviewed to address the use of newer grade HDPE resins with cell classification 445574C (per 2008 ASME-BPV meetings)**
- **Code Case for "Above Ground PE Piping" is being drafted by ASME SWG-PP**
- **Proposal to include electro-fusion joining of PE piping in Code Cases for repairs**

# CC N-755 – Design Allowable Limits

## Allowable Stress Values per Table 3021-1

| Table 3021-1 | Allowable Stress S for PE, MPa (psi) | | | | |
|---|---|---|---|---|---|
| Temp °C (°F) | Duration (years) at temperature | | | | |
| | 10 | 20 | 30 | 40 | 50 |
| < 21.1 (70) | 5.79 (840) | 5.79 (840) | 5.65 (820) | 5.65 (820) | 5.52 (800) |
| 40.0 (104) | 4.27 (620) | 4.27 (620) | 4.27 (620) | 4.27 (620) | **4.27 (620)** |
| 48.9 (120) | 3.59 (520) | - | - | - | - |
| 60.0 (140) | **2.96 (430)** | - | - | - | - |

**Any surface flaw up to 10% of wall thickness is acceptable [Section 2310 a)] for all diameter and DR piping**

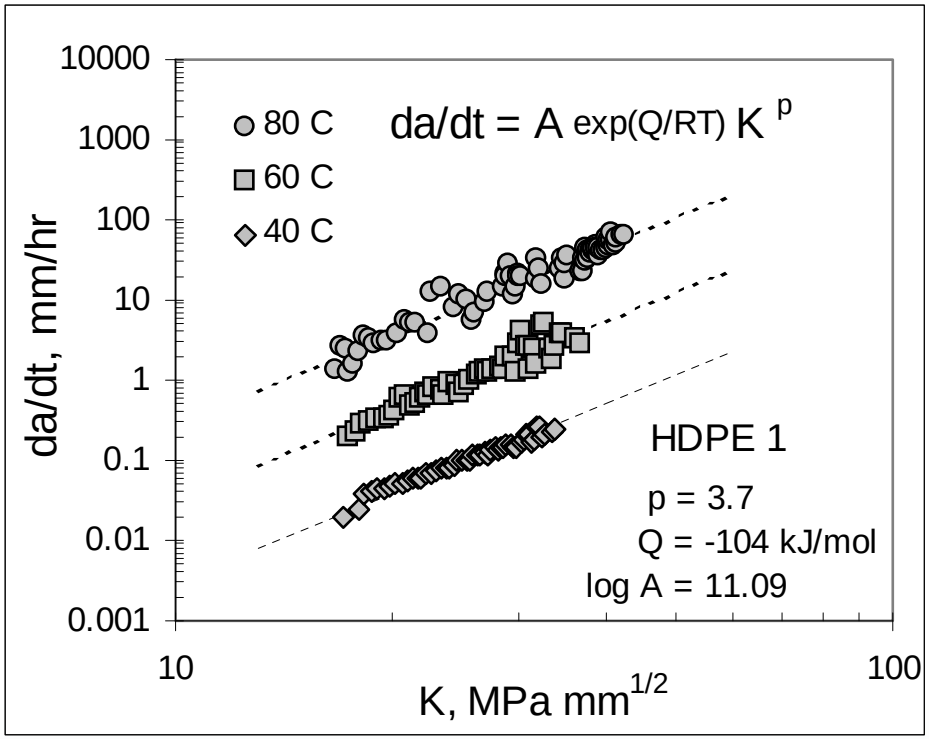
**Materials Grades – HDPE Resin with Cell Classification 445474C or higher per ASTM D 3350**

# US Nuclear Regulatory Commission - Status of PE Piping

- **All safety-related piping in US nuclear power plants is under US NRC purview**
- **Service water piping is a *safety-critical system* in nuclear plants**
- **US Nuclear Power Plants need to have "Relief Requests" approved by the US NRC prior to installing PE Piping in safety-related applications**
- **US NRC *does not necessarily* have to accept Code Cases passed by ASME-BVP**
- **CC N-755 Rev 0, *has not been accepted by the USNRC* to date based on –**
  - **Lack of volumetric (or non-destructive) inspection requirements of butt joints after installation**
  - **Lack of experimental data to support the proposed allowable flaw (defect) sizes in piping (especially for large diameters and wall thicknesses)**
- **US NRC is currently reviewing at least two "Relief Requests" by industry for use of safety-related PE Piping in service-water applications**
- **Confirmatory research undertaken in support of the evaluation of ASME activities and industry proposals**

# Technical Issue 1 – Effect of Elevated Temperature

## Typical Slow Crack Growth (PENT) Data*



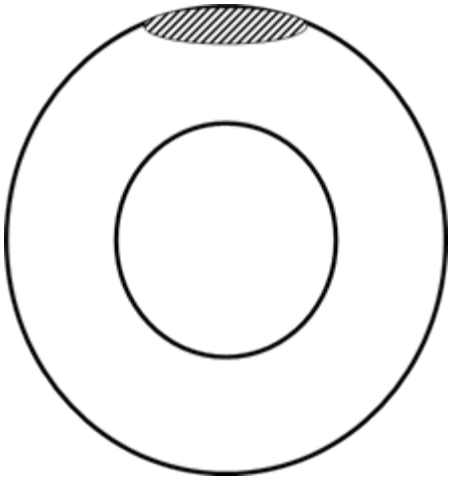

**Effect of Temperature on Crack Growth Rates is Exponential**

*** - Reference: PP XIII – Session 5B, October '06 and other referenced work**

# Technical Issue 1 - Effect of Elevated Temperature (Cont'd)

## Analysis of Circumferential Flaw in Pipe Under Uniform Axial Load

**(depth, a/t ; length, c/a = 5)**



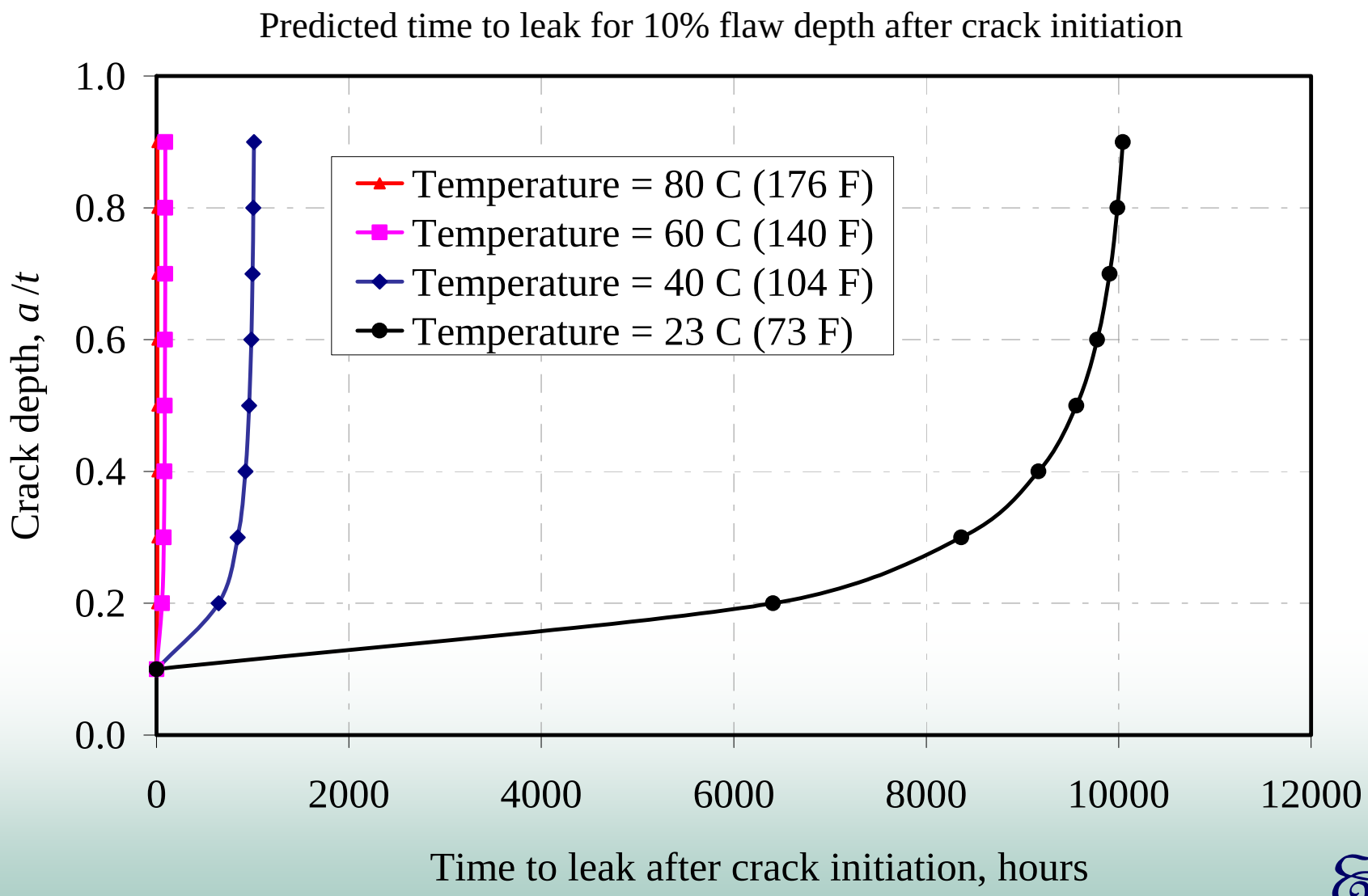
**Semi-elliptical flaw**

**Axial Loading**

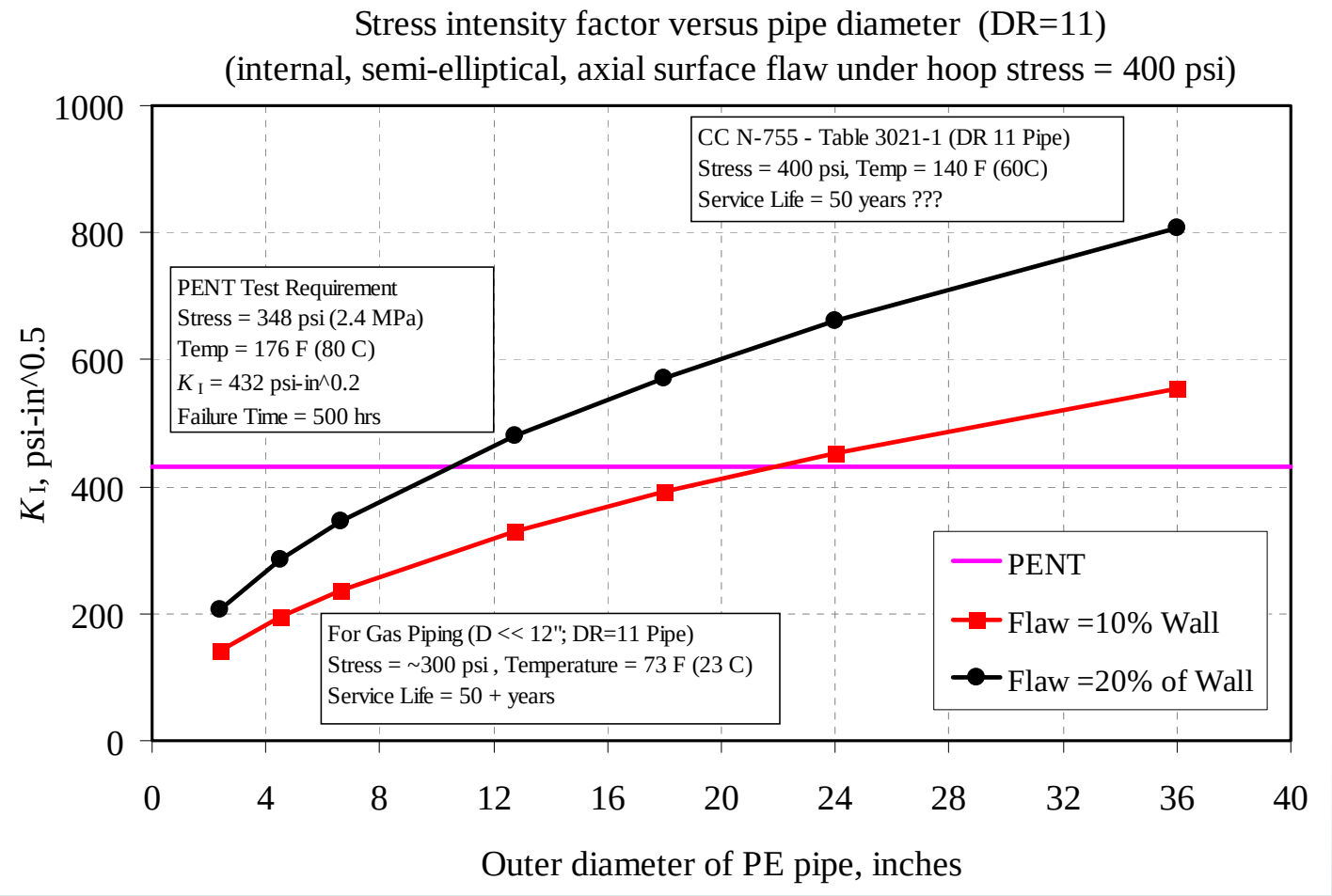
$$K_I = \text{Stress} * (\pi a)^{0.5} * f\,(\text{geometry})$$

$$da/dt = F(K_I, T)$$

# Technical Issue 1 – Effect of Elevated Temperature (Cont'd)

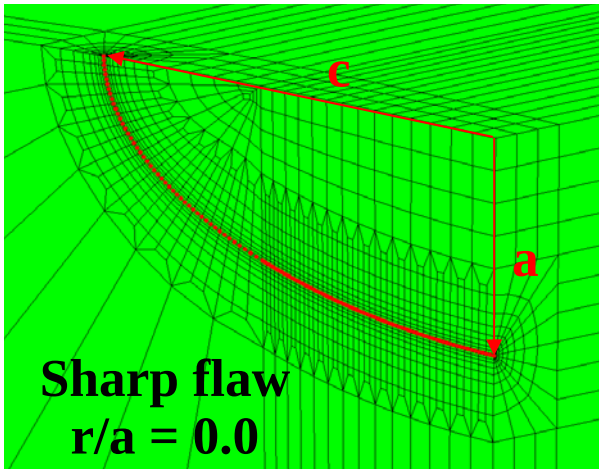


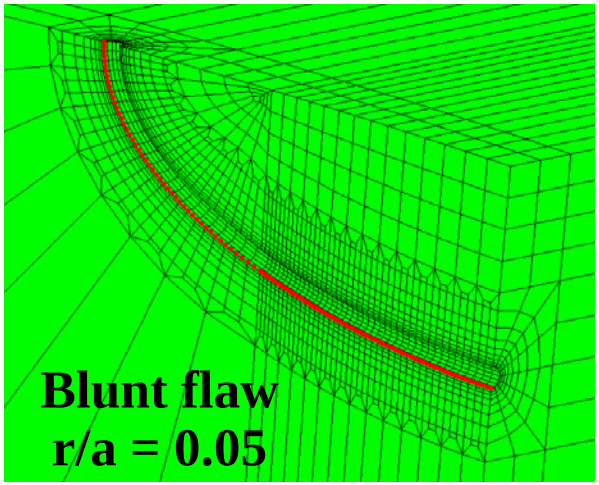
# Technical Issue 2 – Allowable Flaws Size and Shape

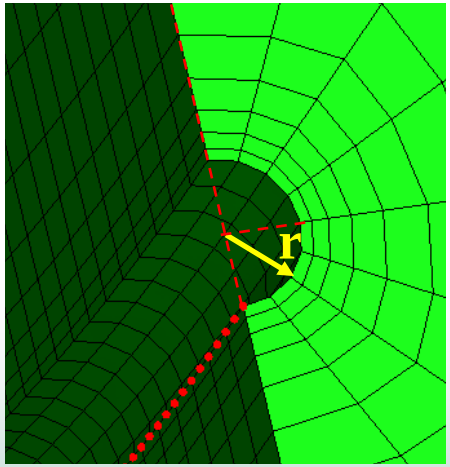



**Allowable Flaw Depth of 10% of pipe wall is non-conservative for large diameter piping at elevated temperatures**

# Technical Issue 2 – Allowable Flaw Size and Shape



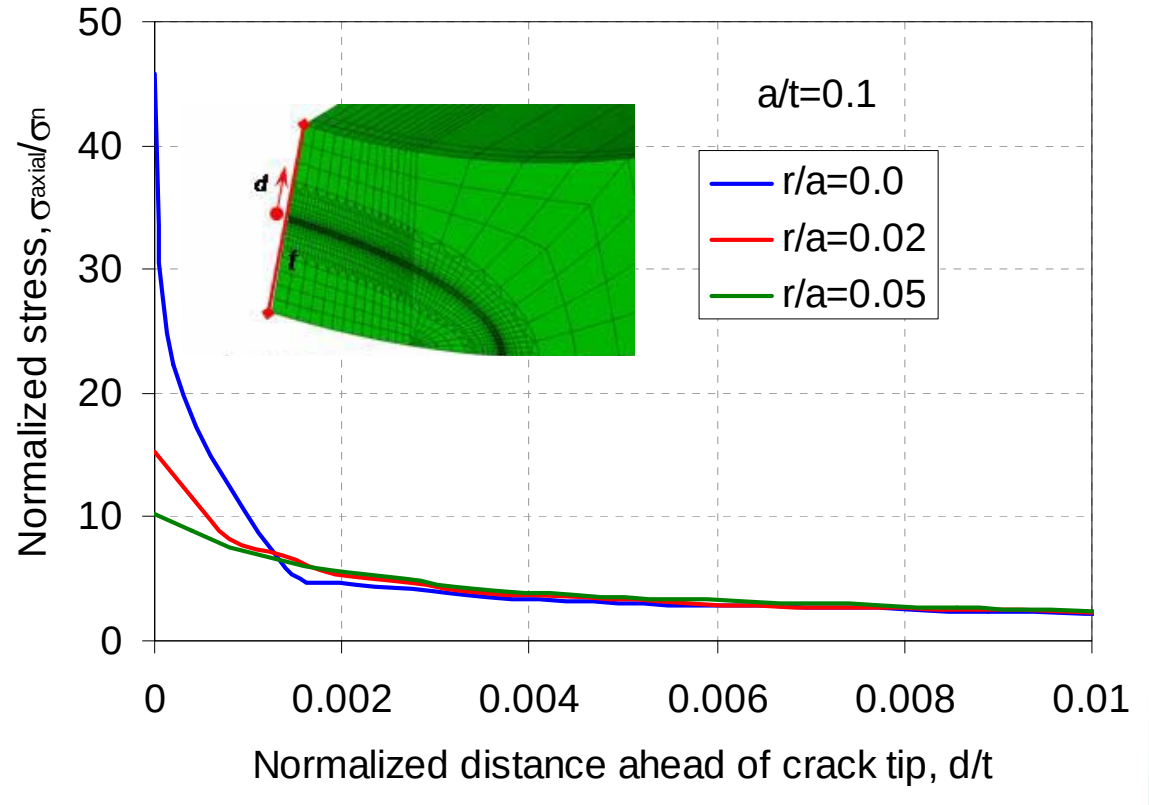




**Analysis of sharp and blunt flaws in 24-inch, DR=11 pipe with semi-elliptical, external, circumferential flaws - a/t = 0.1 ; 2c/a = 5**

# Technical Issue 2 – Allowable Flaw Size and Shape

## Circumferential Blunt and Sharp Flaw Analyses (24 in, DR 11 Pipe)




**Stress intensity decreases significantly with notch root radius**

# Technical Issue 3 – Design Factor (Safety Factor)

- **Per Plastic Pipe Institute Documents TR-9 and TN-28**
  - **Design Factor for *PE Water Piping* is 0.5 (Safety Factor = 2.0); same value used in ASME CC N-755**
  - **Design Factor for *PE Natural Gas Piping* (safety-related) piping is 0.32 (Safety Factor = 3.13)**

- **Only recently the US Dept. of Transportation (PHMSA) is considering raising the DF from 0.32 to 0.4 for newer PE resins with higher HDB rating for gas piping**

- **ASME is considering a higher Design Factor of 0.56 (Safety Factor = 1.79) being considered for newer grades of HDPE (Cell Class 445574C per ASTM D3350)**

- **Need to substantiate the use of higher DF with additional experimental data especially for allowable flaws under sustained stresses and elevated temperatures**

# Technical Issue 4 - Models for Service Life Prediction

- **Rate Process Method (conventional approach)**
  - **Uses stress rupture data from testing of *unflawed pipe***
- **Bi-Directional Shift Method**
  - **Material constants for model based on PE gas grade resins from late 1980s and early 1990s ; may need to be modified for newer resins**
- **Correlation between PENT failure times to service life**
  - **Number of uncertainties in material constants in correlation**
- **Time to failure using measured crack growth rates**
  - **Need to have experimental data and model for each PE material**

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- **Models need modification to address use accelerated testing data to predict service life at elevated (and varying) temperatures, sustained stresses, with an allowable flaw**

# Technical Issue 5 – Butt Joint Integrity and Inspection

- **CC N-755 only allows butt joints in PE Piping with *no requirements for volumetric inspection***

- **Significant work done over last two decades to develop reliable non-destructive inspection methods for PE joints to identify defects including - flaws, lack of fusion, material inhomogenieties/ inclusions, and "heat affected zone"**

- **No reliable technique established to date to predict the smallest defect that can be found (or largest defect that can be missed)**

- **Limited data on older PE resins indicate that butt joints may be more susceptible to slow crack growth than parent materials**
  - **Confirmatory research underway under NRC contract for resins grades in CC N-755**

## Summary and Conclusions

- **Extensive review of PE piping data and literature conducted for safety-related service water application in nuclear power plants**

- **Specific technical issues that need to be addressed have been identified – especially in relation to CC N-755 requirements**

- **Additional data and information and feedback sought from plastic pipe industry and participants at PP XIV to resolve issues**