Primary Water Stress Corrosion Crack Growth Analysis ID flaw;
Developed by Central Engineering Programs, Entergy Operations Inc.

Developed by: J. S. Brihmadesam ***Verified by: B. C. Gray***

References :
1) "Stress Intensity factors for Part-through Surface Cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"7.8" Degree Nozzle, "90" Degree Azimuth, 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr.

ID Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessary to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represents the reference point elevation measured upward from the nozzle end.

$Ref_{Point} = 1.544$

To place the flaw with respect to the reference point, the flaw tips and center can be located as follows:
1) The Upper "c- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "c- tip" located at the reference point (Enter 3).

$Val = 2$

The Input Below is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} = 2.873$ Upper axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

The highlighted region below remians constant for WSES-3 and should not be changed

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.04627$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg F

$$R_o := \frac{od}{2} \qquad R_{id} := \frac{id}{2} \qquad t := R_o - R_{id} \qquad R_m := R_{id} + \frac{t}{2} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$CF_{inhr} := 1.417 \cdot 10^5 \qquad C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right| \qquad c_0 := \frac{L}{2} \qquad R_t := \frac{R_m}{t}$$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67} \right) \right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 [th] percentile MRP-55 Revision 1

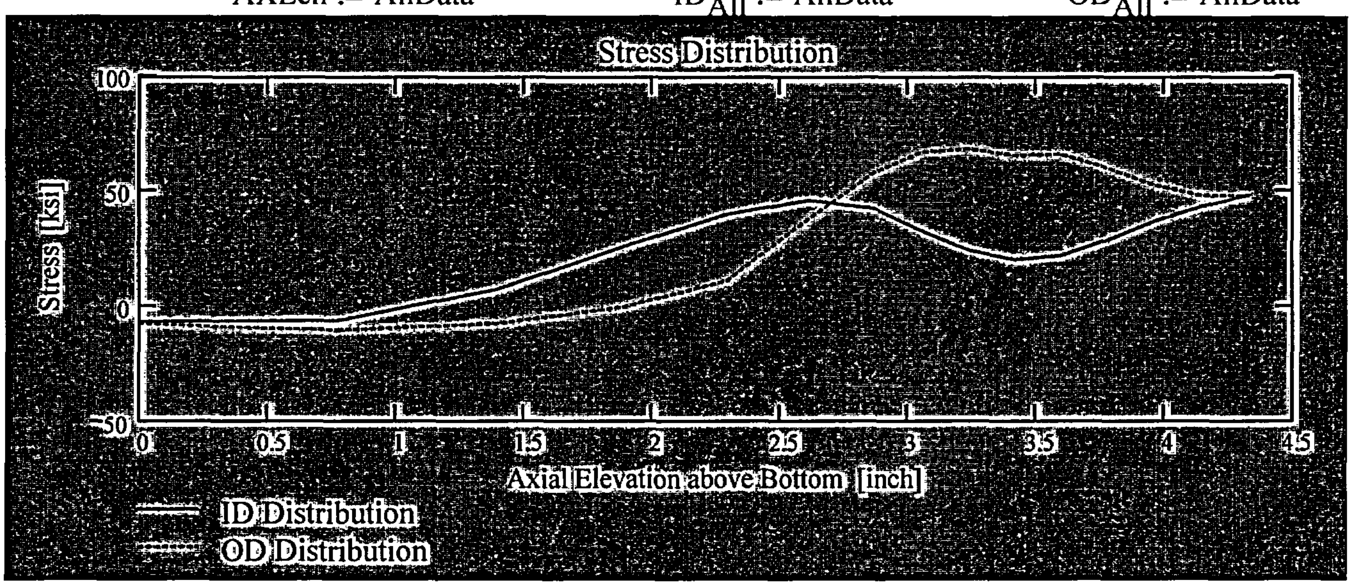
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minimum to maximum recorded on data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-6.55	-6.46	-6.9	-7.26	-7.48
1	0.78	-5.99	-7.03	-8.21	-9.34	-10.21
2	1.4	7.51	2.45	-2.97	-5.77	-7.28
3	1.9	26.16	22.72	15.76	8.38	0.04
4	2.3	40.1	35.77	28.93	20.4	11.34
5	2.62	46.14	38.48	32.97	32.39	38.23
6	2.87	42.48	39.1	37.9	47.33	58.41
7	3.06	32.81	34.63	39.4	53.17	67.33
8	3.24	24.58	30.97	39.99	55.65	68.71
9	3.42	20.31	28.18	39.86	54.12	66.02

$AXLen := AllData^{\langle 0 \rangle}$ $ID_{All} := AllData^{\langle 1 \rangle}$ $OD_{All} := AllData^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Highlight the region in the above table representing the region to be selected (click on the first cell for selection and drag the mouse whilst holding the left mouse button down. Once this is done click the right mouse button and select "Copy Selection"; this will copy the selected area on to the clipboard. Then click on the "Matrix" below (to the right of the data statement) to highlight the entire matrix and delete it from the edit menu. When the Mathcad input symbol appears, use the paste function in the tool bar to paste the selection.

$$Data := \begin{pmatrix} 0.777 & -5.985 & -7.029 & -8.206 & -9.34 & -10.214 \\ 1.399 & 7.507 & 2.446 & -2.972 & -5.766 & -7.284 \\ 1.898 & 26.16 & 22.721 & 15.759 & 8.375 & 0.041 \\ 2.297 & 40.097 & 35.774 & 28.929 & 20.399 & 11.338 \\ 2.617 & 46.142 & 38.476 & 32.974 & 32.389 & 38.226 \\ 2.873 & 42.475 & 39.105 & 37.898 & 47.325 & 58.408 \\ 3.056 & 32.813 & 34.635 & 39.401 & 53.167 & 67.334 \\ 3.238 & 24.577 & 30.972 & 39.991 & 55.653 & 68.712 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $MD := Data^{\langle 3 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $TQ := Data^{\langle 4 \rangle}$ $QT := Data^{\langle 2 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{cases} Ref_{Point} - c_0 & \text{if } Val = 1 \\ Ref_{Point} & \text{if } Val = 2 \\ Ref_{Point} + c_0 & \text{otherwise} \end{cases}$$

Flaw center Location above Nozzle Bottom

$$U_{Tip} := FL_{Cntr} + c_0$$

$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

No User Input is required beyond this Point

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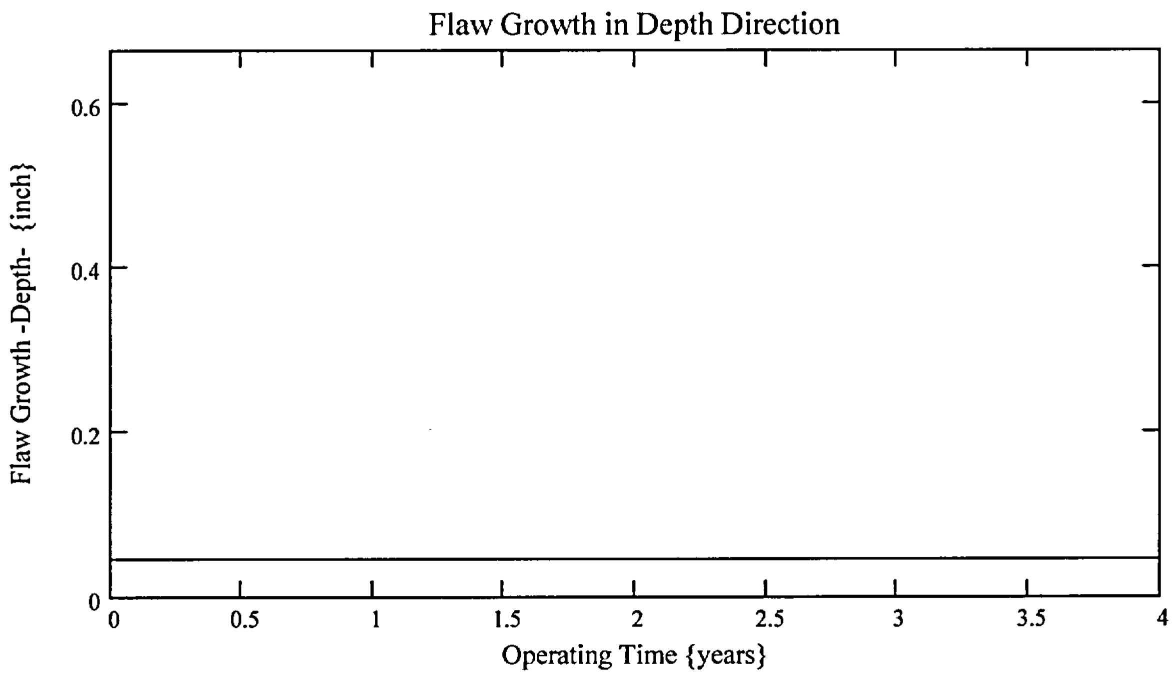
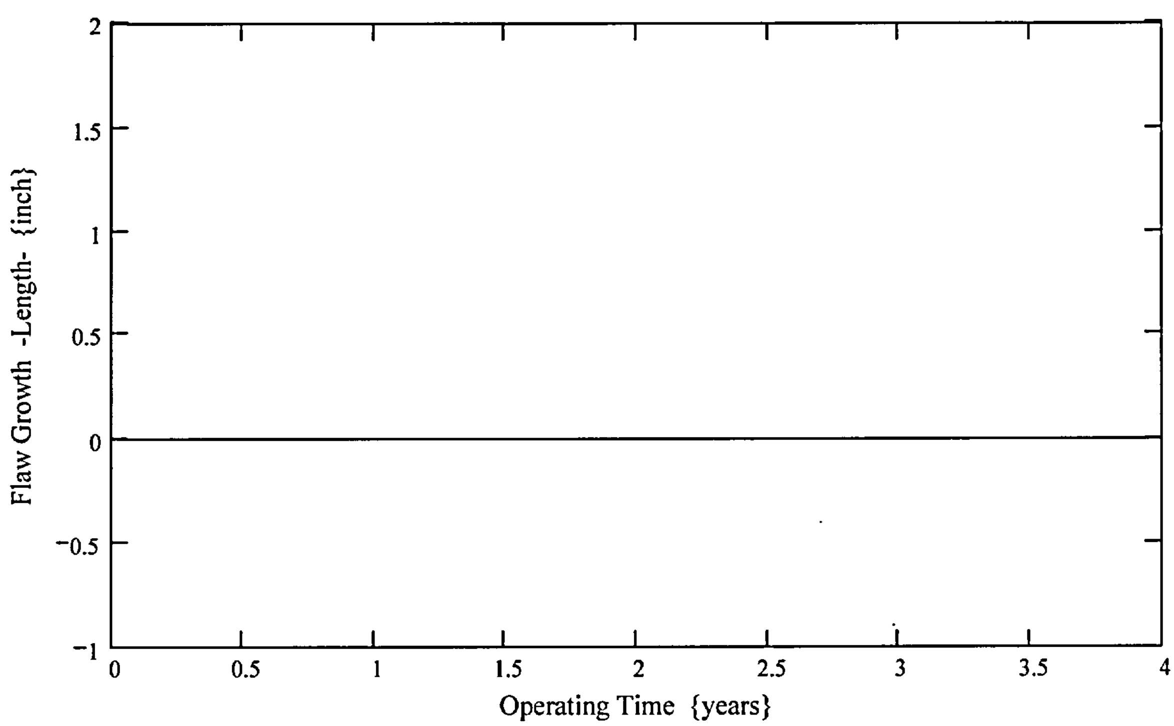
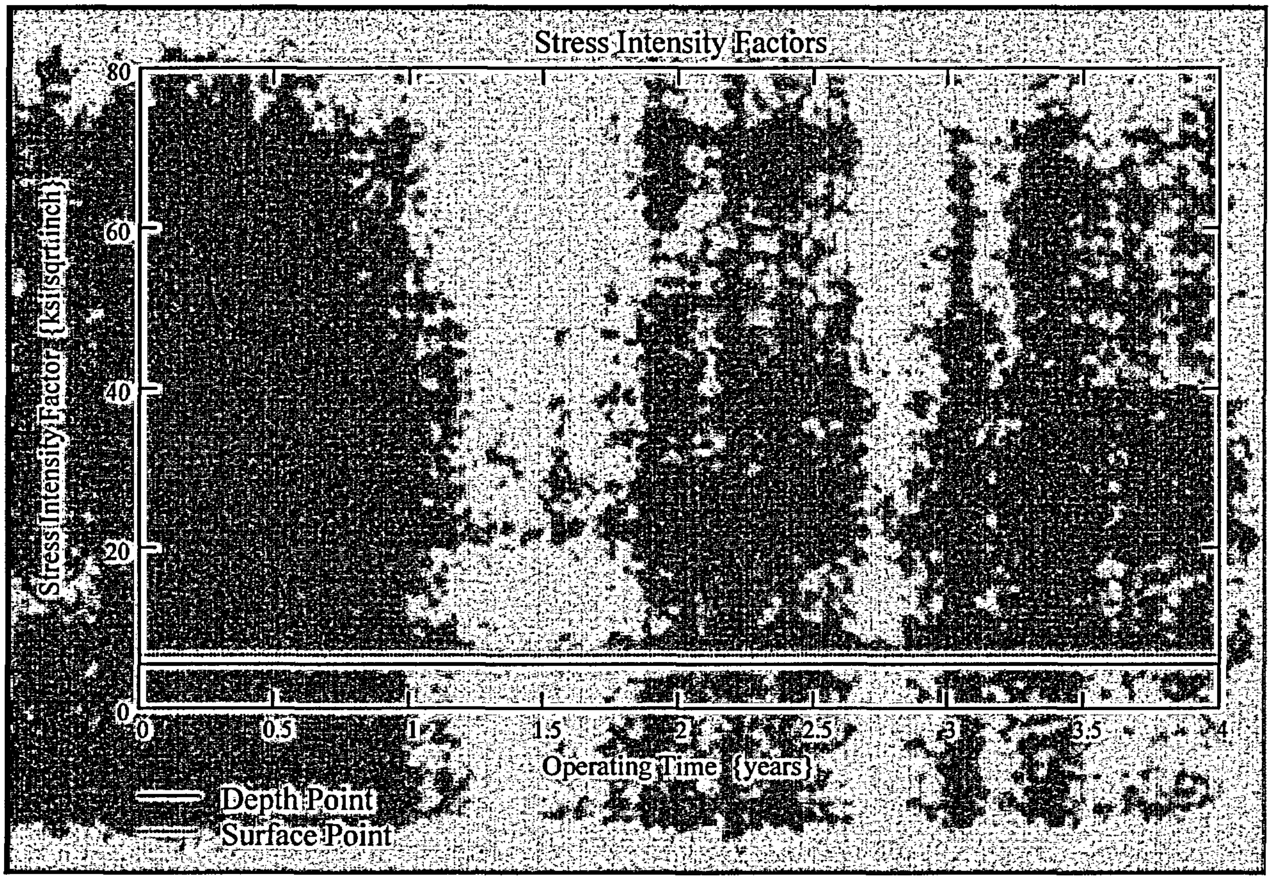
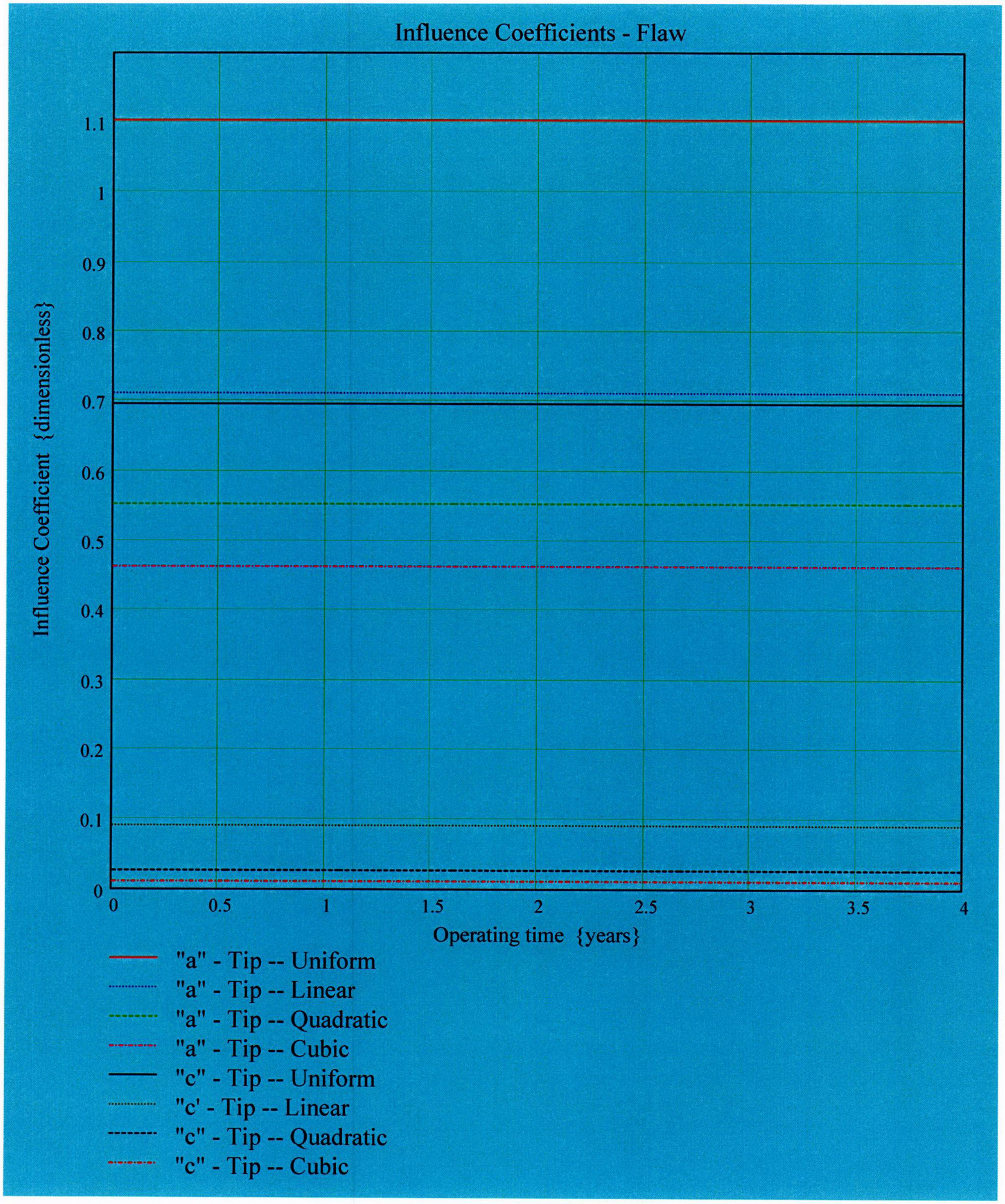
$Prop_{Length} = 1.169$






Stress Intensity Factors
Stress Intensity Factor {ksi*sqrt(inch)}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point
Surface Point


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

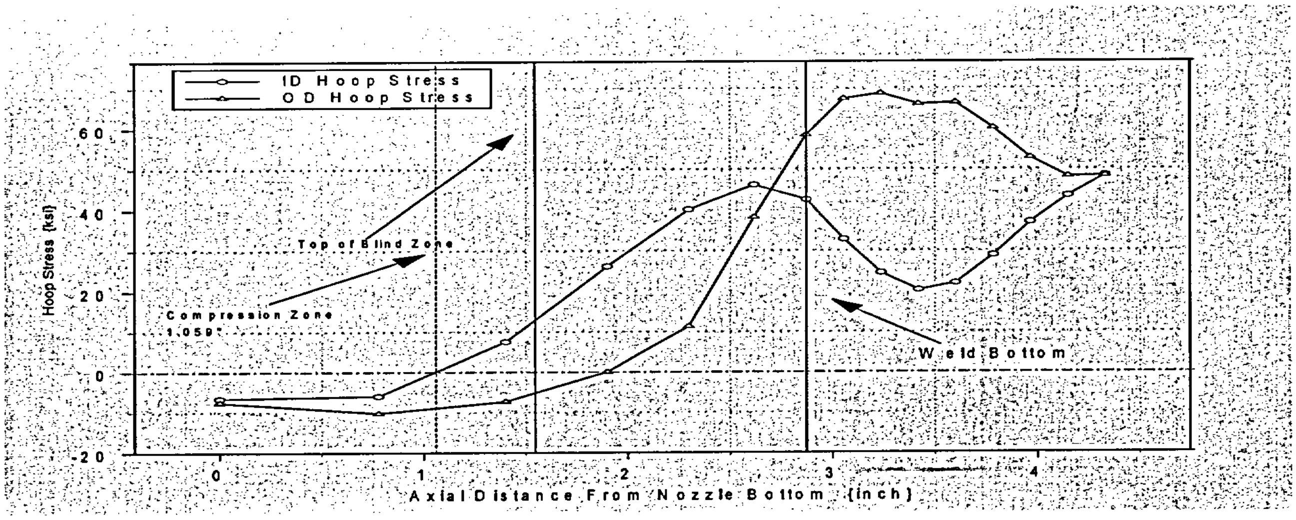
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103

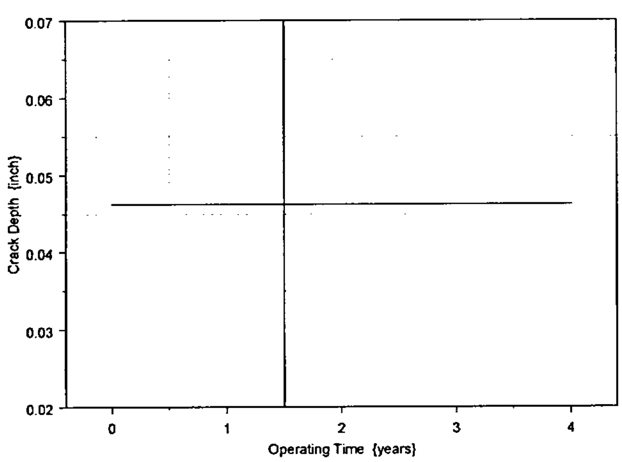
$CGR_{sambi_{(k,6)}} =$

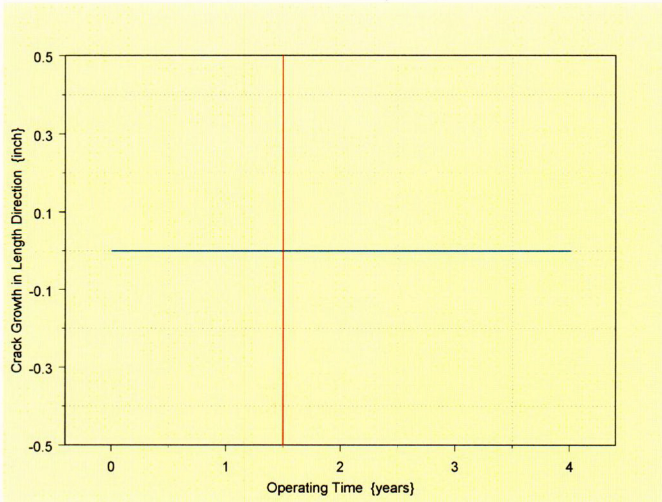
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688
6.688

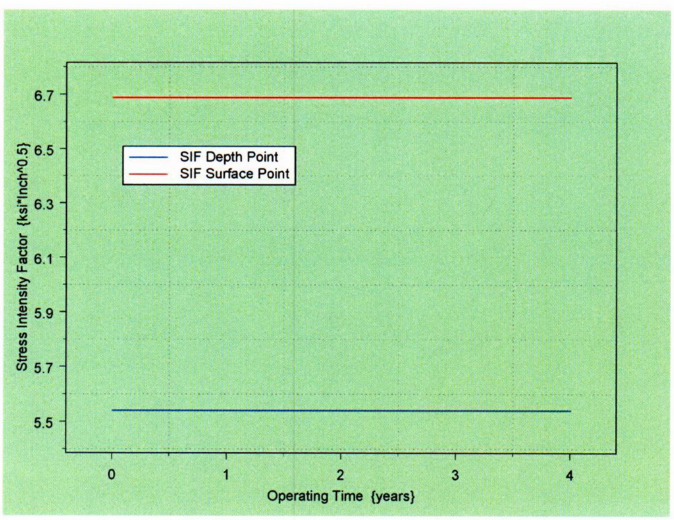
$CGR_{sambi_{(k,5)}} =$

5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54
5.54


ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Compression Zone
1.059"
Weld Bottom
Hoop Stress (ksi)
Axial Distance From Nozzle Bottom (inch)


Crack Depth (inch)
Operating Time (years)


0.5
0.3
0.1
-0.1
-0.3
-0.5
Crack Growth in Length Direction {inch}
0
1
2
3
4
Operating Time {years}


6.7
6.5
6.3
6.1
5.9
5.7
5.5
Stress Intensity Factor {ksi*inch^0.5}
SIF Depth Point
SIF Surface Point
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD Surface Flaw

Developed by Central Engineering Programs, Entergy Operations Inc.

Developed by: J. S. Brihmadesam **Verified by: B. C. Gray**

References :

1) "Stress Intensity factors for Part-through Surface Cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"7.8" Degree Nozzle, "90" Degree Azimuth, 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr.

OD Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessary to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represents the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.544$

To place the flaw with respect to the reference point, the flaw tips and center can be located as follows:
1) The Upper "C- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "C- tip" located at the reference point (Enter 3).

$Val := 2$

Enter the Upper Extent of the Stress Distribution used for the analysis

$UL_{Strs.Dist} := 2.873$

Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

The regions highlighted below remain constant for WSES-3 analysis and should not be changed

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.07932$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg F

$R_o := \frac{od}{2}$ $\quad R_{id} := \frac{id}{2}$ $\quad t := R_o - R_{id}$ $\quad R_m := R_{id} + \frac{t}{2}$ $\quad Tim_{opr} := Years \cdot 365 \cdot 24$

$CF_{inhr} := 1.417 \cdot 10^5$ $\quad C_{blk} := \frac{Tim_{opr}}{I_{lim}}$ $\quad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right|$ $\quad c_0 := \frac{L}{2}$ $\quad R_t := \frac{R_m}{t}$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

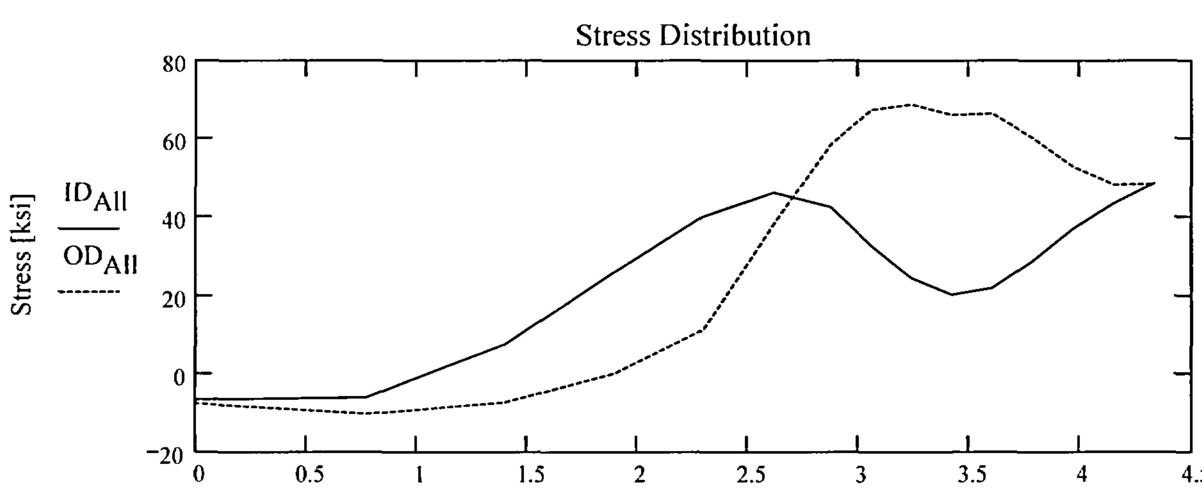
Stress Input Data

mport all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minimum to maximum recorded on data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-6.55	-6.46	-6.9	-7.26	-7.48
1	0.78	-5.99	-7.03	-8.21	-9.34	-10.21
2	1.4	7.51	2.45	-2.97	-5.77	-7.28
3	1.9	26.16	22.72	15.76	8.38	0.04
4	2.3	40.1	35.77	28.93	20.4	11.34
5	2.62	46.14	38.48	32.97	32.39	38.23
6	2.87	42.48	39.1	37.9	47.33	58.41
7	3.06	32.81	34.63	39.4	53.17	67.33
8	3.24	24.58	30.97	39.99	55.65	68.71
9	3.42	20.31	28.18	39.86	54.12	66.02

$AXLen := AllData^{\langle 0 \rangle}$ $ID_{All} := AllData^{\langle 1 \rangle}$ $OD_{All} := AllData^{\langle 5 \rangle}$



AXLen
Axial Elevation above Bottom [inch]

Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table, click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0.777 & -5.985 & -7.029 & -8.206 & -9.34 & -10.214 \\ 1.399 & 7.507 & 2.446 & -2.972 & -5.766 & -7.284 \\ 1.898 & 26.16 & 22.721 & 15.759 & 8.375 & 0.041 \\ 2.297 & 40.097 & 35.774 & 28.929 & 20.399 & 11.338 \\ 2.617 & 46.142 & 38.476 & 32.974 & 32.389 & 38.226 \\ 2.873 & 42.475 & 39.105 & 37.898 & 47.325 & 58.408 \\ 3.056 & 32.813 & 34.635 & 39.401 & 53.167 & 67.334 \\ 3.238 & 24.577 & 30.972 & 39.991 & 55.653 & 68.712 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $MD := Data^{\langle 3 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $TQ := Data^{\langle 4 \rangle}$ $QT := Data^{\langle 2 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{cases} Ref_{Point} - c_0 & \text{if } Val = 1 \\ Ref_{Point} & \text{if } Val = 2 \\ Ref_{Point} + c_0 & \text{otherwise} \end{cases}$$

Flaw center Location Location above Nozzle Bottom

$U_{Tip} := FL_{Cntr} + c_0$

$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

No User Input is required beyond this Point

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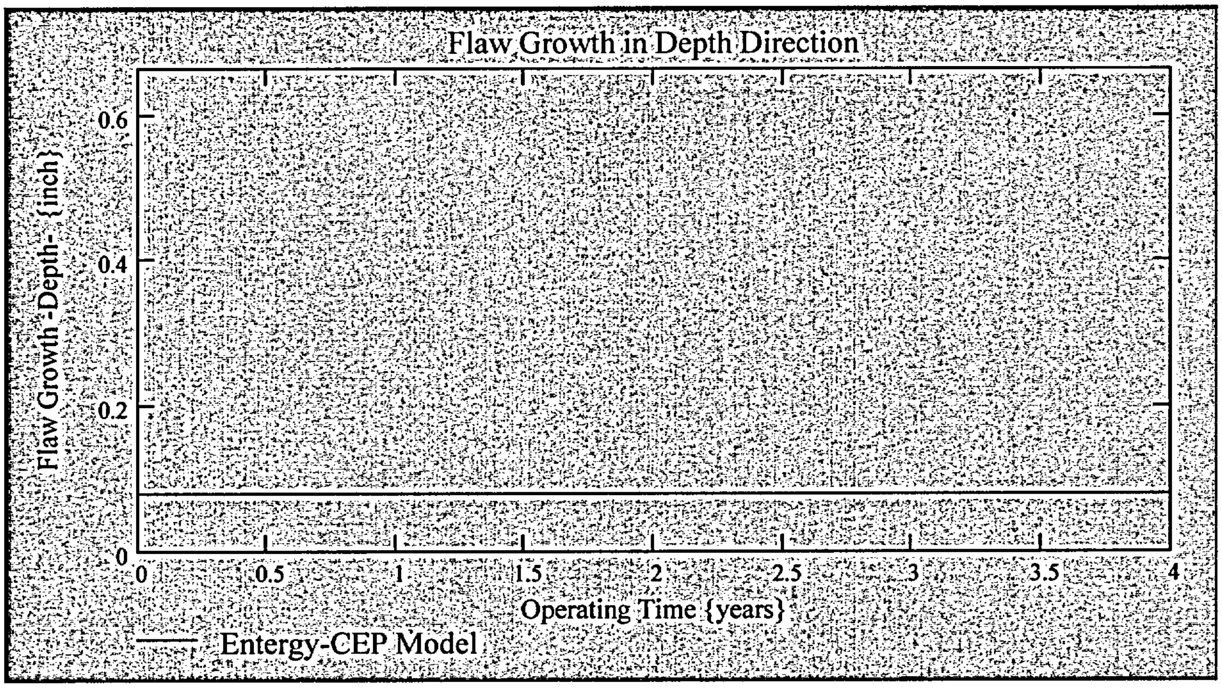
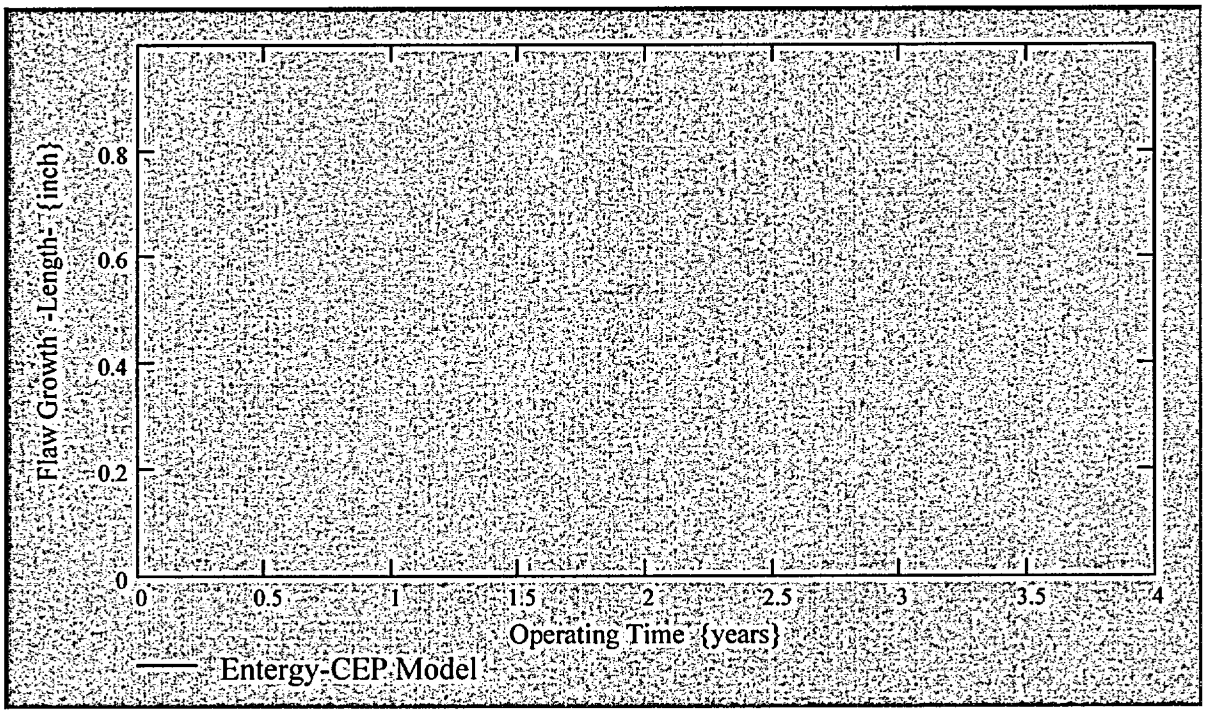
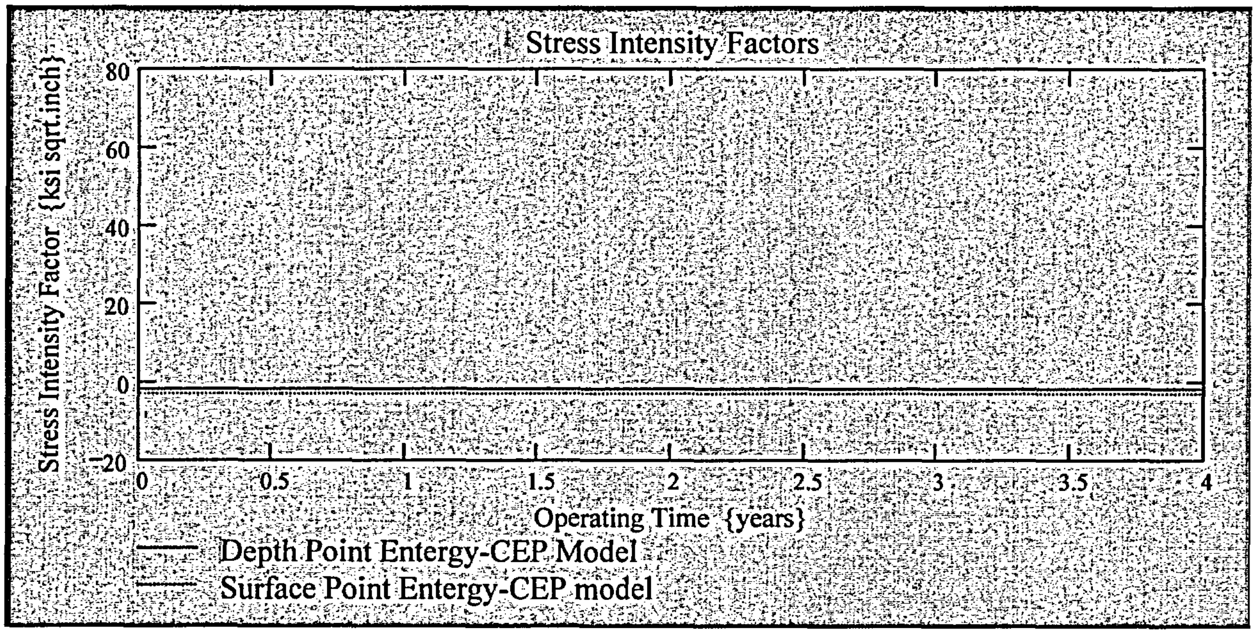
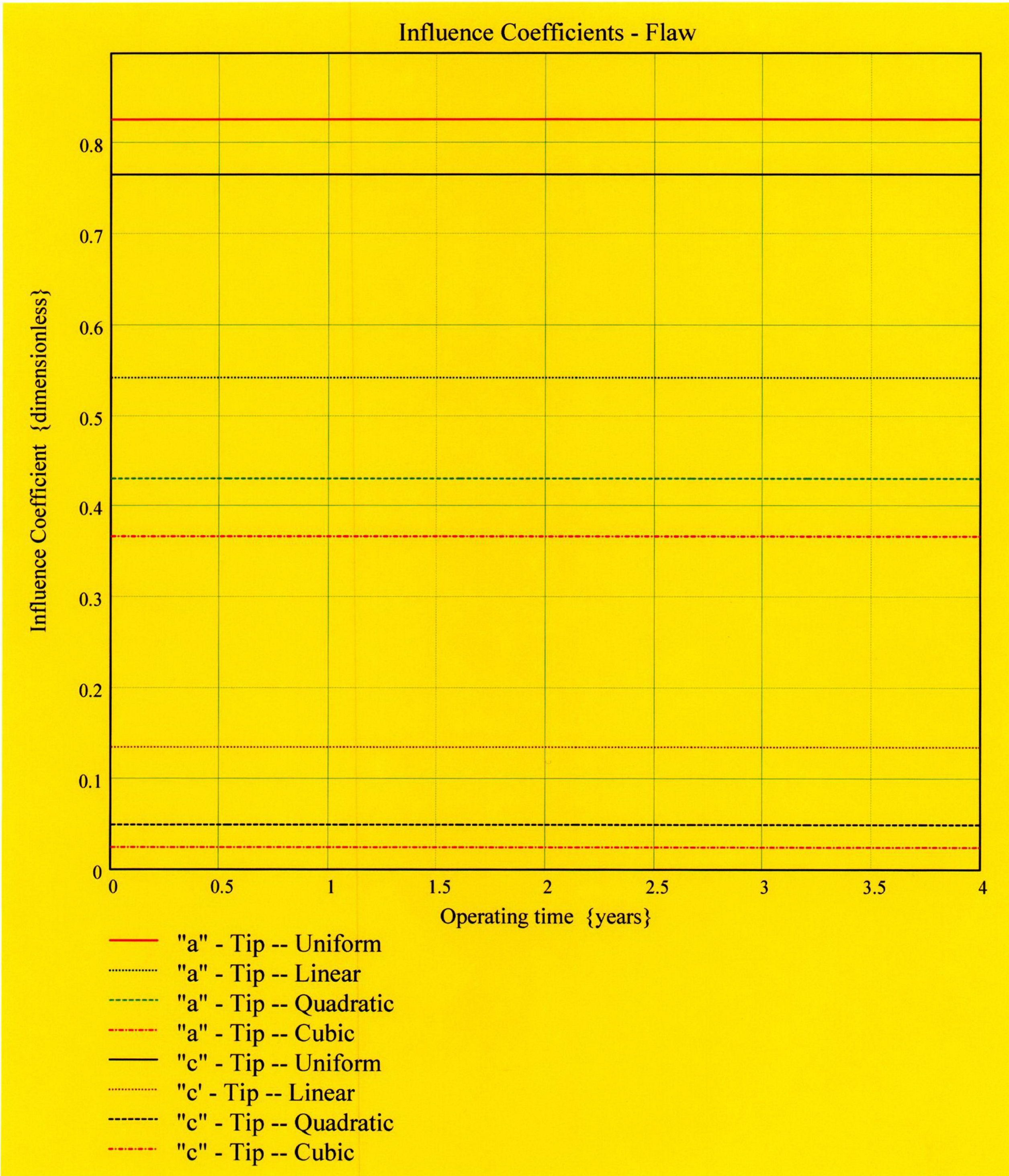
$Prop_{Length} = 1.169$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
-20
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

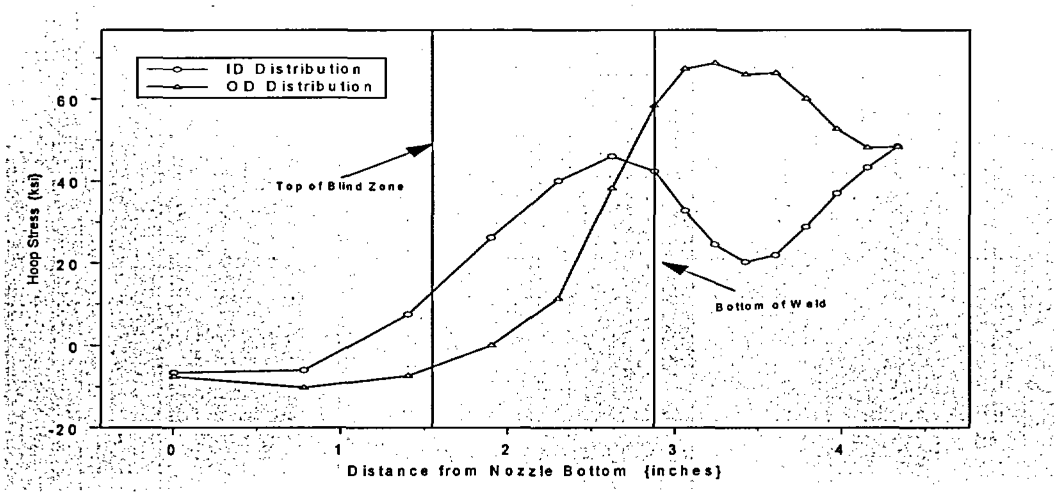
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

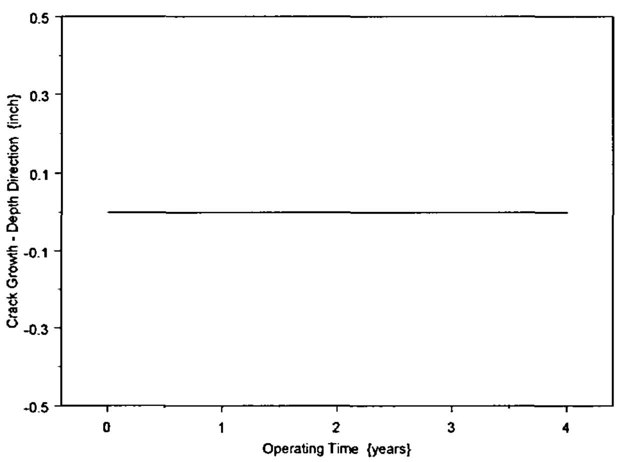
$CGR_{sambi_{(k,6)}} =$

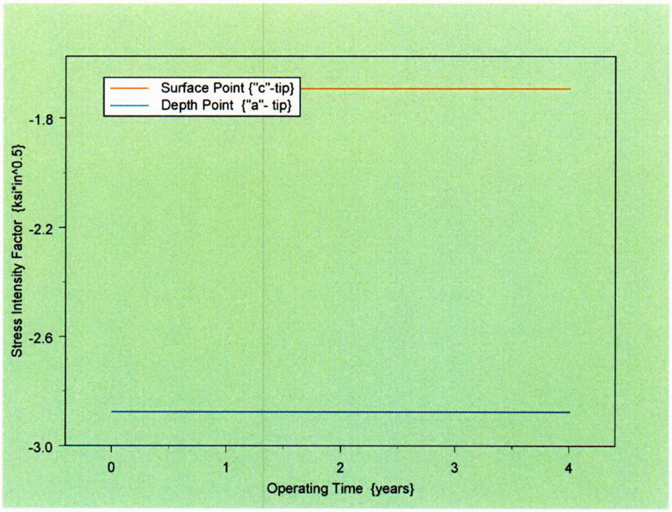
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876
-2.876

$CGR_{sambi_{(k,5)}} =$

-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693
-1.693


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress (ksi)
60
40
20
0
-20
0
1
2
3
4
Distance from Nozzle Bottom (inches)


0.5
0.3
0.1
-0.1
-0.3
-0.5
Crack Growth - Depth Direction (inch)
0
1
2
3
4
Operating Time (years)


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
-1.8
-2.2
-2.6
-3.0
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Through-wall flaw

Developed by Central Engineering Programs, Entergy Operations Inc.
Developed by: J. S. Brihmadesam Verified by: B. C. Gray

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thick-wall Cylinder)

References :
1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"7.8"degree Nozzle, "90" Degree Azimuth 1.544 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1**.*
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The through-wall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg. Blind Zone) above the nozzle bottom in inches.

BZ = 1.544 Location of Blind Zone above nozzle bottom (inch)

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{StrsDist}$ = 2.87 Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

The Highlighted Entries below remains constant for WSES-3 and should not be changed

Input Data :-

$L := 0.25$ — Initial Crack Length TW axial Based on Stress Distribution. Bottom end of Crack to be set @ approximately 10ksi.

$od := 4.05$ — Tube OD

$id := 2.728$ — Tube ID

$P_{int} := 2.235$ — Design Operating Pressure (internal)

$Years := 4$ — Number of Operating Years

$I_{lim} := 1500$ — Iteration limit for Crack Growth loop

$T := 604$ — Estimate of Operating Temperature

$v := 0.307$ — Poissons ratio @ 600 F

$\alpha_{0c} := 2.67 \cdot 10^{-12}$ — Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg F

$Q_g := 31.0$ — Thermal activation Energy for Crack Growth (MRP)

$T_{ref} := 617$ — Reference Temperature for normalizing Data deg F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$

$$Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^{5}$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Developed by: Verified by:

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

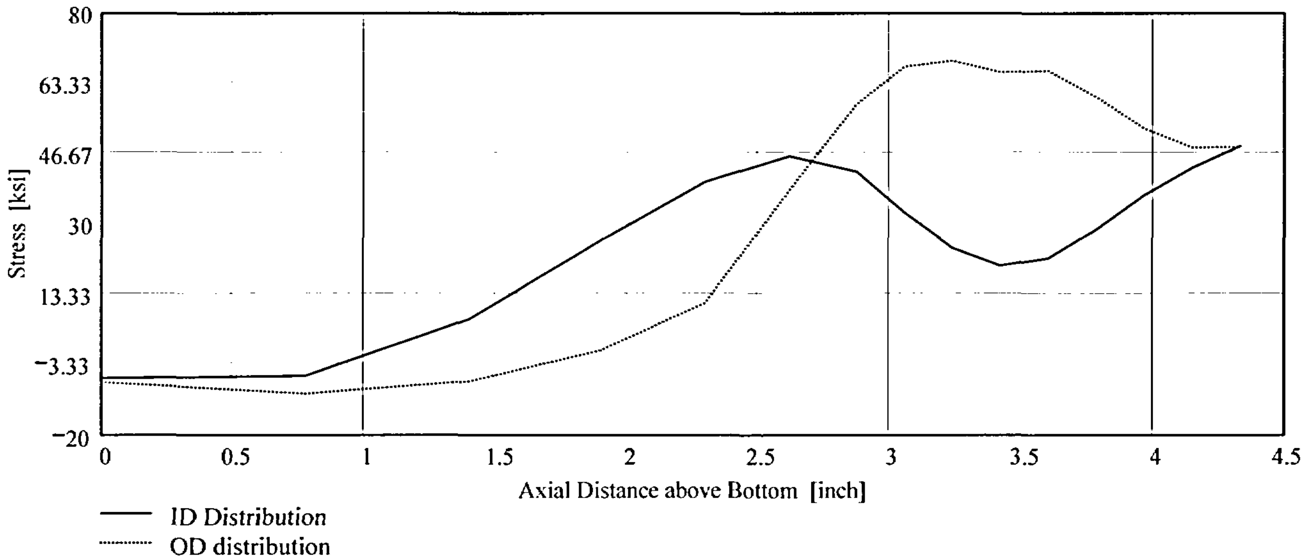
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Column "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-6.55	-6.46	-6.9	-7.26	-7.48
1	0.78	-5.99	-7.03	-8.21	-9.34	-10.21
2	1.4	7.51	2.45	-2.97	-5.77	-7.28
3	1.9	26.16	22.72	15.76	8.38	0.04
4	2.3	40.1	35.77	28.93	20.4	11.34
5	2.62	46.14	38.48	32.97	32.39	38.23
6	2.87	42.48	39.1	37.9	47.33	58.41
7	3.06	32.81	34.63	39.4	53.17	67.33
8	3.24	24.58	30.97	39.99	55.65	68.71
9	3.42	20.31	28.18	39.86	54.12	66.02

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $\quad$ $AllID := Data_{All}^{\langle 1 \rangle}$ $\quad$ $AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table , click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0.777 & -5.985 & -7.029 & -8.206 & -9.34 & -10.214 \\ 1.399 & 7.507 & 2.446 & -2.972 & -5.766 & -7.284 \\ 1.898 & 26.16 & 22.721 & 15.759 & 8.375 & 0.041 \\ 2.297 & 40.097 & 35.774 & 28.929 & 20.399 & 11.338 \\ 2.617 & 46.142 & 38.476 & 32.974 & 32.389 & 38.226 \\ 2.873 & 42.475 & 39.105 & 37.898 & 47.325 & 58.408 \\ 3.056 & 32.813 & 34.635 & 39.401 & 53.167 & 67.334 \\ 3.238 & 24.577 & 30.972 & 39.991 & 55.653 & 68.712 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $\quad ID := Data^{\langle 1 \rangle}$ $\quad OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $\quad R_{OD} := regress(Axl, OD, 3)$

$FL_{Cntr} := BZ - 1$ Flaw Center above Nozzle Bottom

$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

No User Input required beyond this Point

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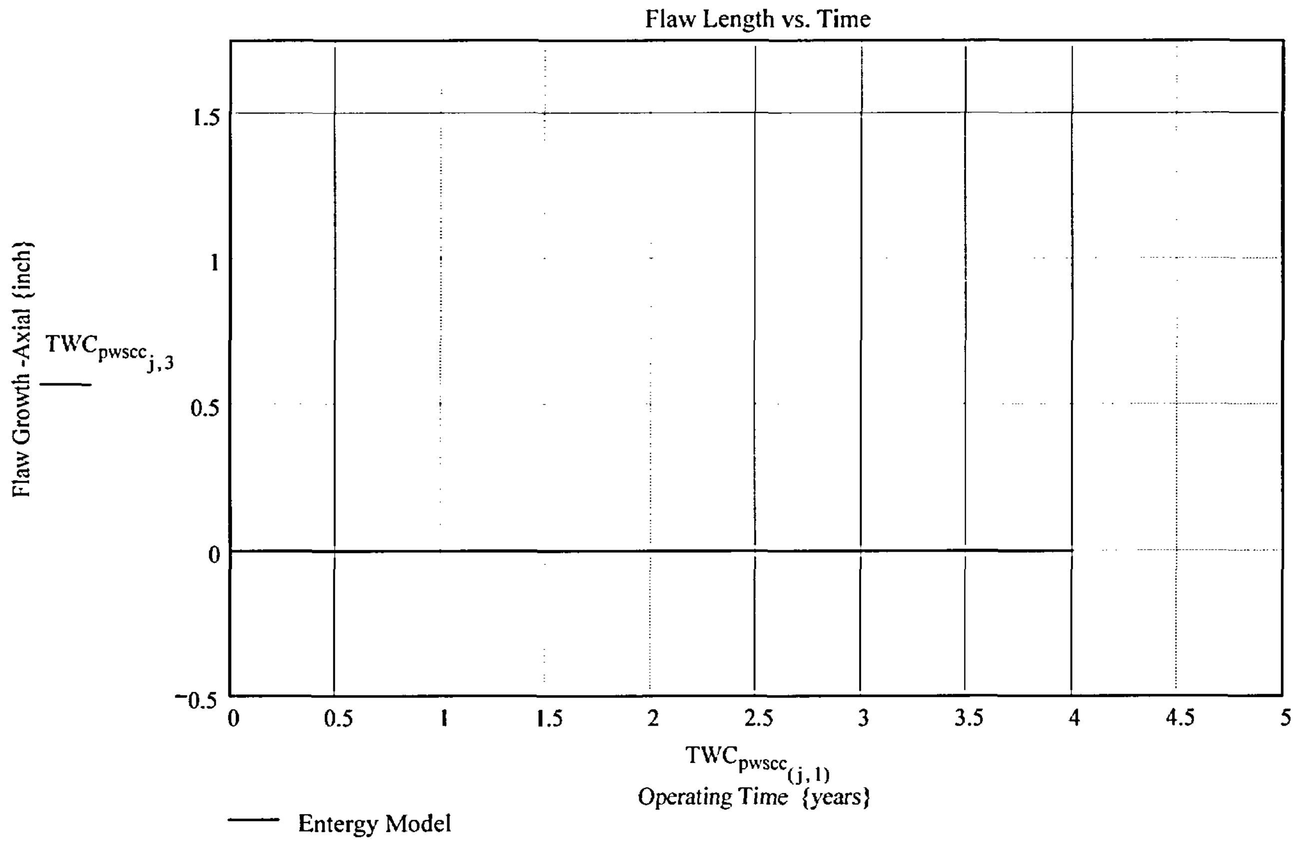
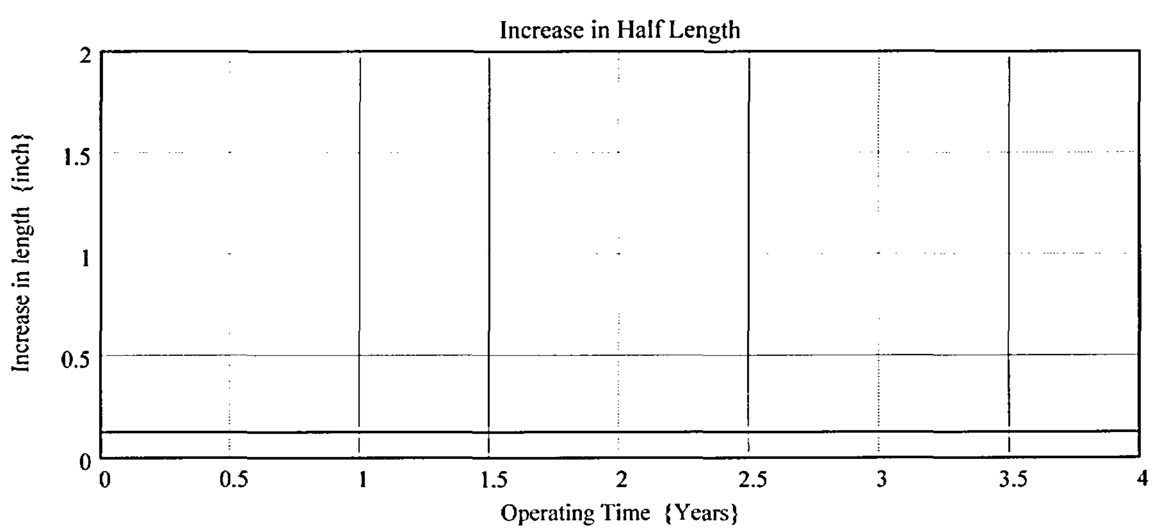
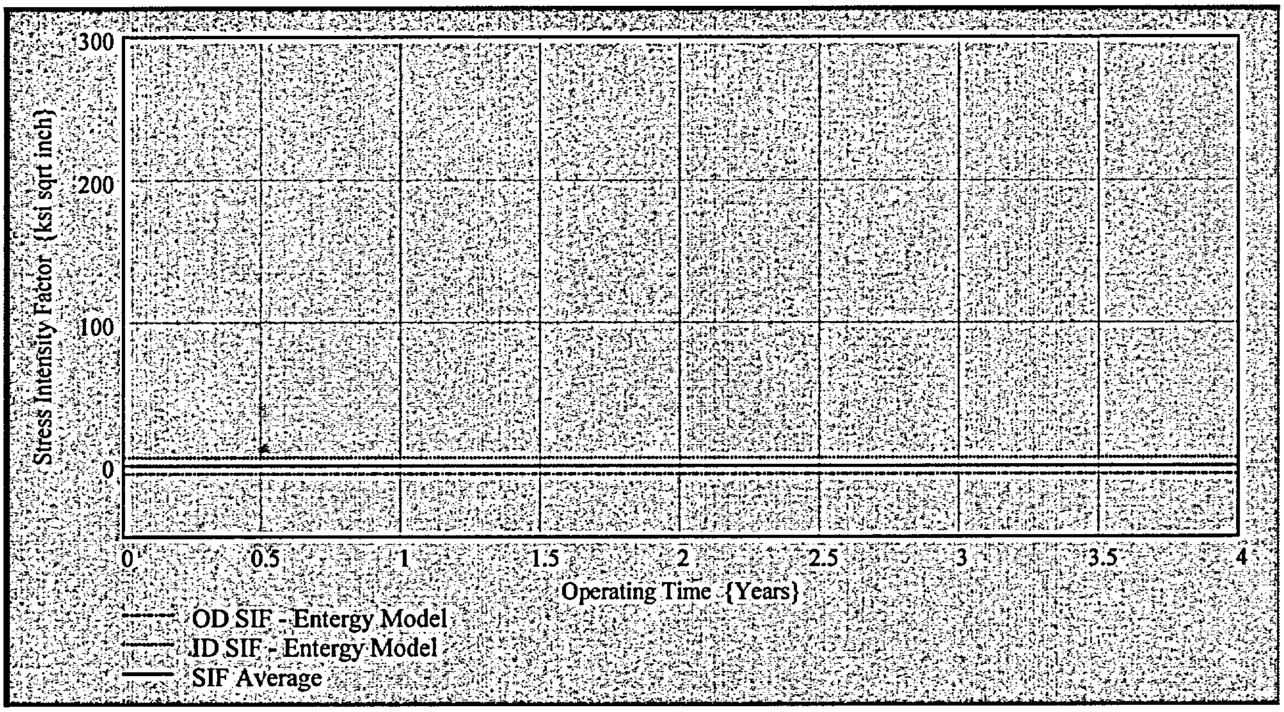
$Prop_{Length} = 1.329$







300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$

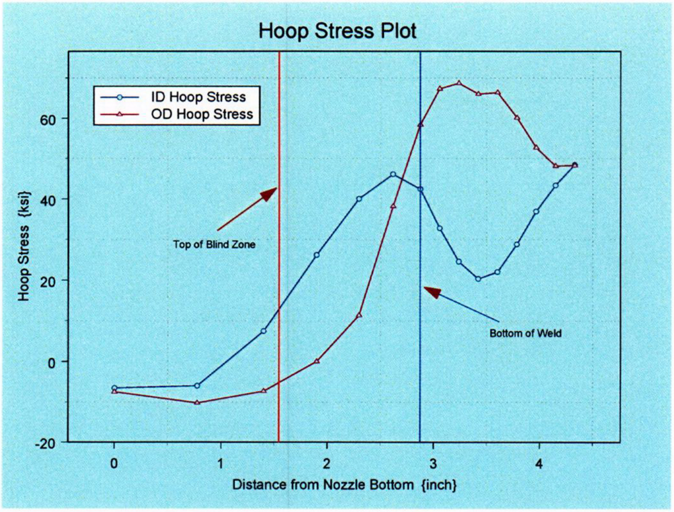
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54
-5.54

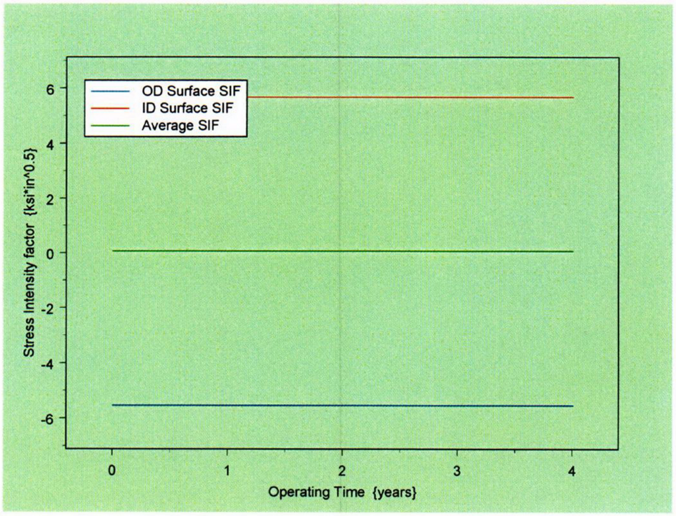
$TWC_{pwscc_{(j,7)}} =$

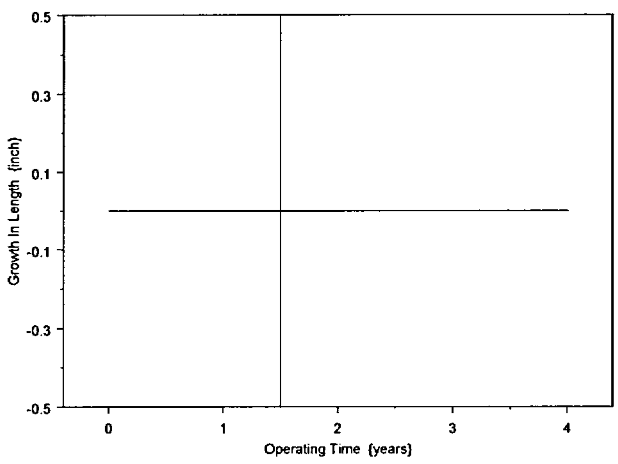
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676
5.676

$TWC_{pwscc_{(j,8)}} =$

0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175
0.175


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Bottom of Weld
Hoop Stress {ksi}
Distance from Nozzle Bottom {inch}


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
Operating Time {years}


0.5
0.3
0.1
-0.1
-0.3
-0.5
Growth In Length (inch)
0
1
2
3
4
Operating Time (years)

Primary Water Stress Corrosion Crack Growth Analysis ID flaw;
Developed by Central Engineering Programs, Entergy Operations Inc.

Developed by: J. S. Brihmadesam ***Verified by: B. C. Gray***

References :

1) "Stress Intensity factors for Part-through Surface Cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"29.1" Degree Nozzle, "0" Degree Azimuth, 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr.

ID Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessary to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represents the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.544$

To place the flaw with respect to the reference point, the flaw tips and center can be located as follows:
1) The Upper "c- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "c- tip" located at the reference point (Enter 3).

$Val := 2$

The Input Below is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 2.181$ Upper axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom).

The highlighted region below remians constant for WSES-3 and should not be changed

Input Data :

$L := 0.32$	Initial Flaw Length
$a_0 := 0.04627$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg F

$R_o := \frac{od}{2}$ $\quad R_{id} := \frac{id}{2}$ $\quad t := R_o - R_{id}$ $\quad R_m := R_{id} + \frac{t}{2}$ $\quad Tim_{opr} := Years \cdot 365 \cdot 24$

$CF_{inhr} := 1.417 \cdot 10^5$ $\quad C_{blk} := \frac{Tim_{opr}}{I_{lim}}$ $\quad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right|$ $\quad c_0 := \frac{L}{2}$ $\quad R_t := \frac{R_m}{t}$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

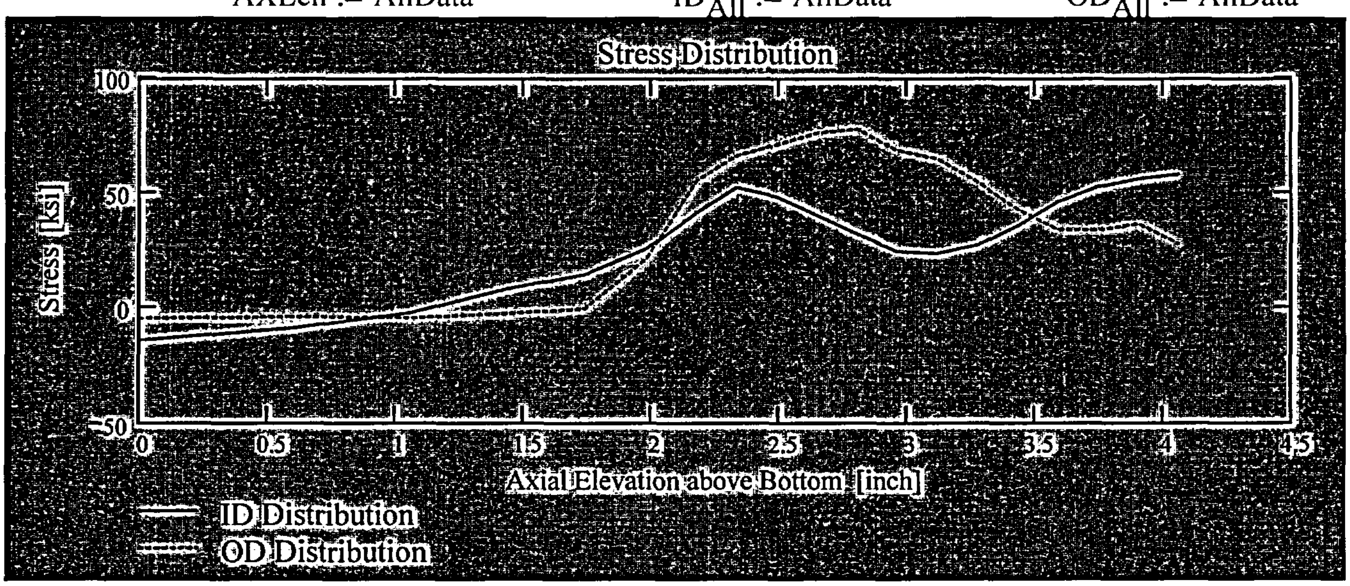
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minimum to maximum recorded on data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-14.12	-10.61	-8.6	-6.67	-4.57
1	0.59	-9	-7.12	-5.97	-4.98	-3.96
2	1.06	-2.28	-2.81	-3.53	-4.07	-4.39
3	1.44	8.13	5.39	2.03	-0.49	-2.55
4	1.74	14.35	12.4	8.32	4.62	-0.62
5	1.99	25.68	22.47	16.06	14.29	21.33
6	2.18	41.45	35.84	33.39	49.7	55.56
7	2.34	52.64	44.8	43.23	62.87	66.64
8	2.49	48.49	45.8	49.07	69.13	71.44
9	2.65	40.38	42.43	49.87	69.01	76.54
10	2.81	32.13	38.24	49.3	66.99	78.11
11	2.96	24.6	34.87	46.68	60.59	69.07

$AXLen := AllData^{\langle 0 \rangle}$ $ID_{All} := AllData^{\langle 1 \rangle}$ $OD_{All} := AllData^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Highlight the region in the above table representing the region to be selected (click on the first cell for selection and drag the mouse whilst holding the left mouse button down. Once this is done click the right mouse button and select "Copy Selection", this will copy the selected area on to the clipboard. Then click on the "Matrix" below (to the right of the data statement) to highlight the entire matrix and delete it from the edit menu. When the Mathcad input symbol appears, use the paste function in the tool bar to paste the selection.

$$Data := \begin{pmatrix} 0 & -14.124 & -10.614 & -8.602 & -6.672 & -4.573 \\ 0.59 & -9.002 & -7.115 & -5.966 & -4.979 & -3.958 \\ 1.062 & -2.278 & -2.811 & -3.527 & -4.069 & -4.39 \\ 1.44 & 8.127 & 5.389 & 2.032 & -0.491 & -2.546 \\ 1.744 & 14.353 & 12.404 & 8.325 & 4.616 & -0.624 \\ 1.987 & 25.675 & 22.473 & 16.062 & 14.285 & 21.33 \\ 2.181 & 41.453 & 35.841 & 33.389 & 49.701 & 55.565 \\ 2.338 & 52.639 & 44.805 & 43.227 & 62.866 & 66.642 \\ 2.495 & 48.491 & 45.796 & 49.068 & 69.125 & 71.441 \\ 2.651 & 40.376 & 42.428 & 49.872 & 69.009 & 76.543 \\ 2.808 & 32.134 & 38.242 & 49.303 & 66.994 & 78.115 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $MD := Data^{\langle 3 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $TQ := Data^{\langle 4 \rangle}$ $QT := Data^{\langle 2 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{cases} Ref_{Point} - c_0 & \text{if } Val = 1 \\ Ref_{Point} & \text{if } Val = 2 \\ Ref_{Point} + c_0 & \text{otherwise} \end{cases}$$

Flaw center Location above Nozzle Bottom

$$U_{Tip} := FL_{Cntr} + c_0$$

$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

No User Input is required beyond this Point

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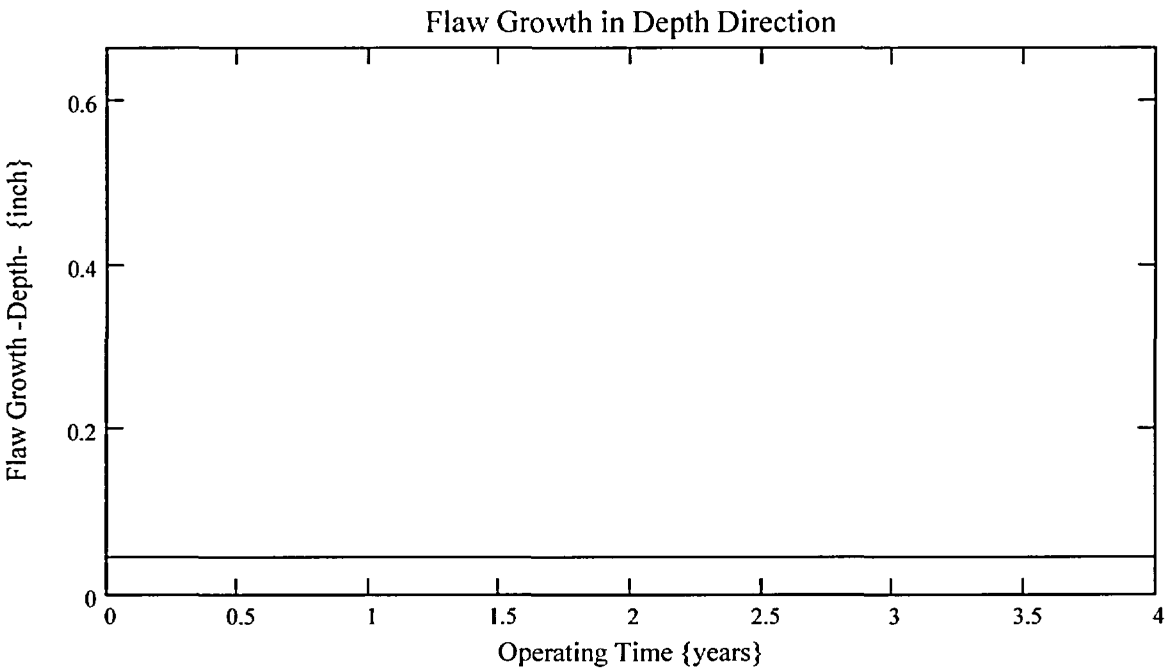
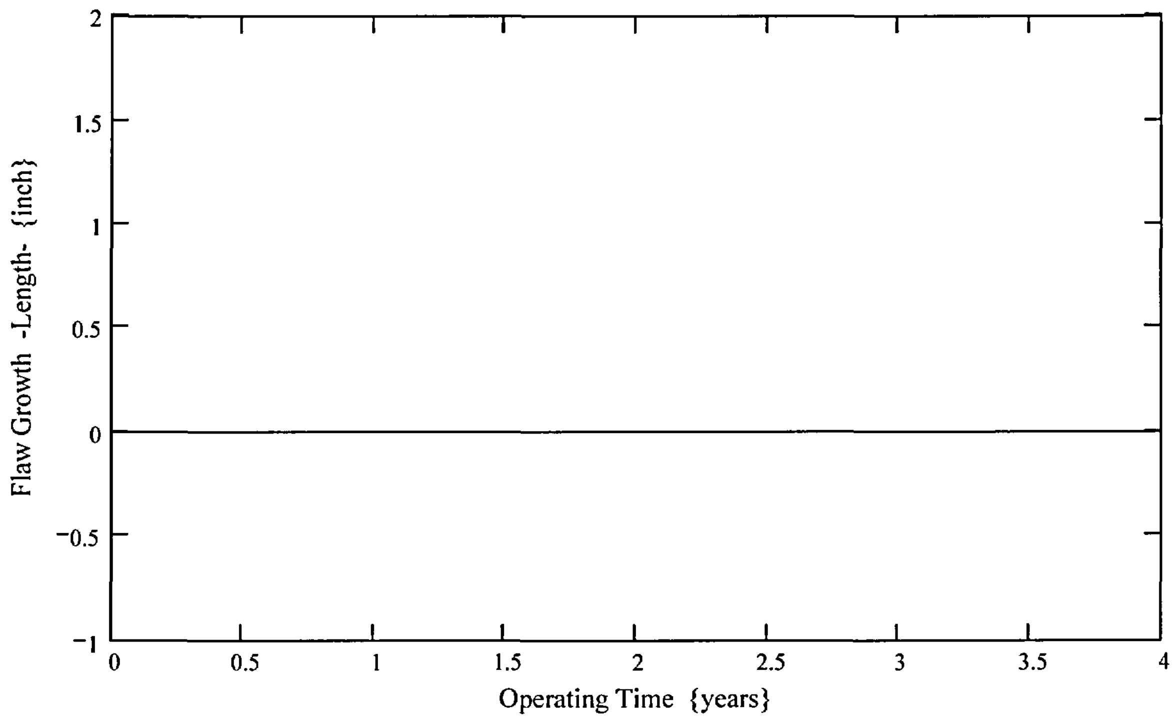
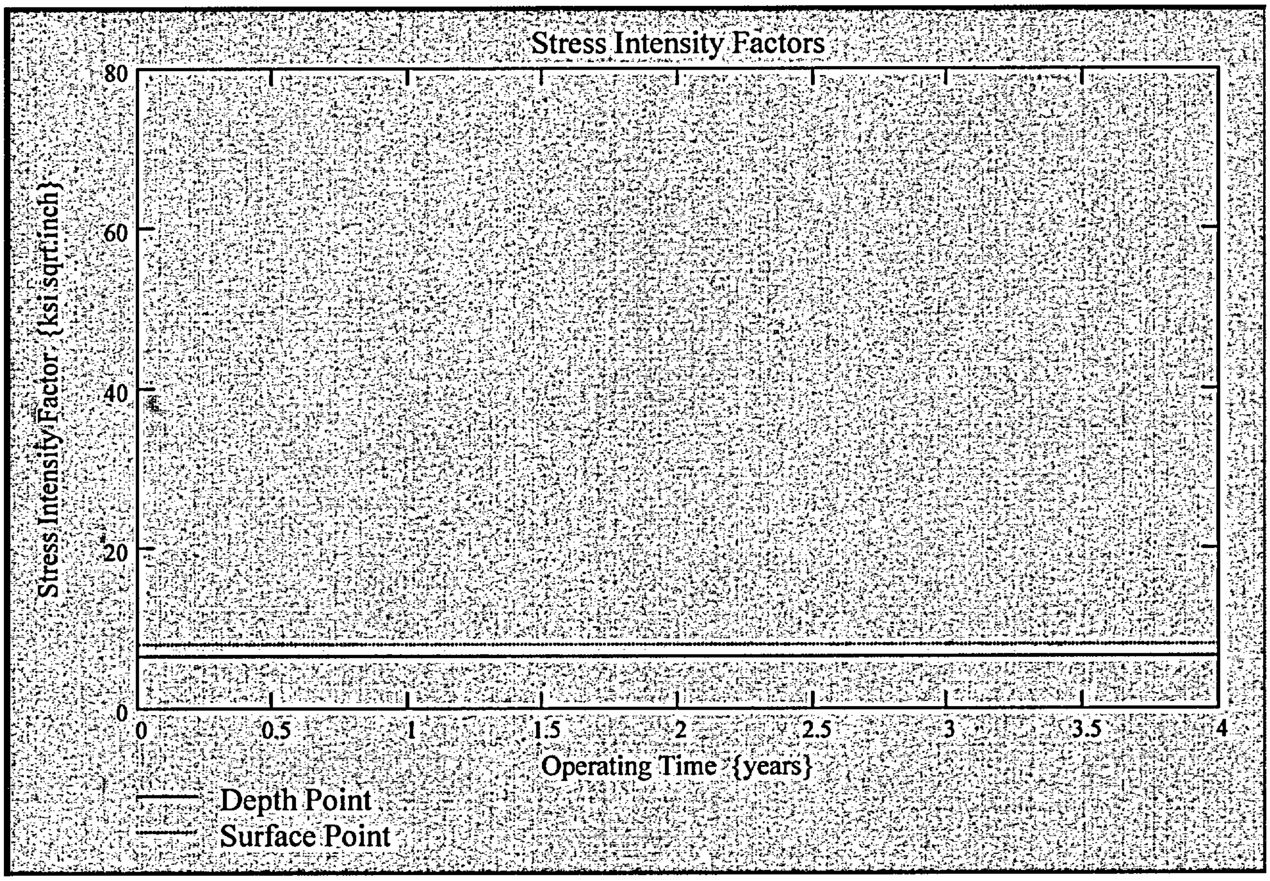
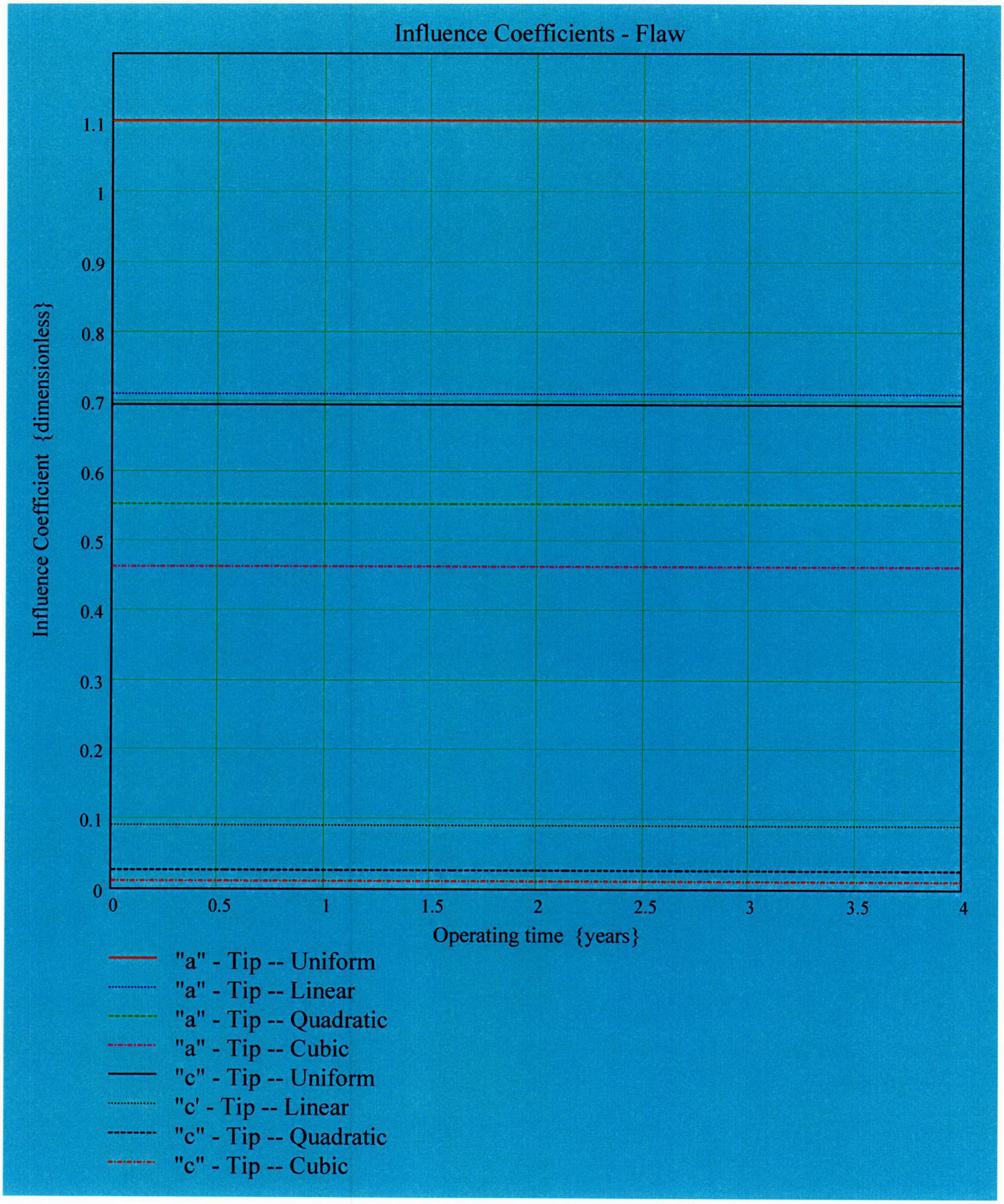
$Prop_{Length} = 0.477$






Stress Intensity Factors
Stress Intensity Factor {ksi.sqrt.inch}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point
Surface Point


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

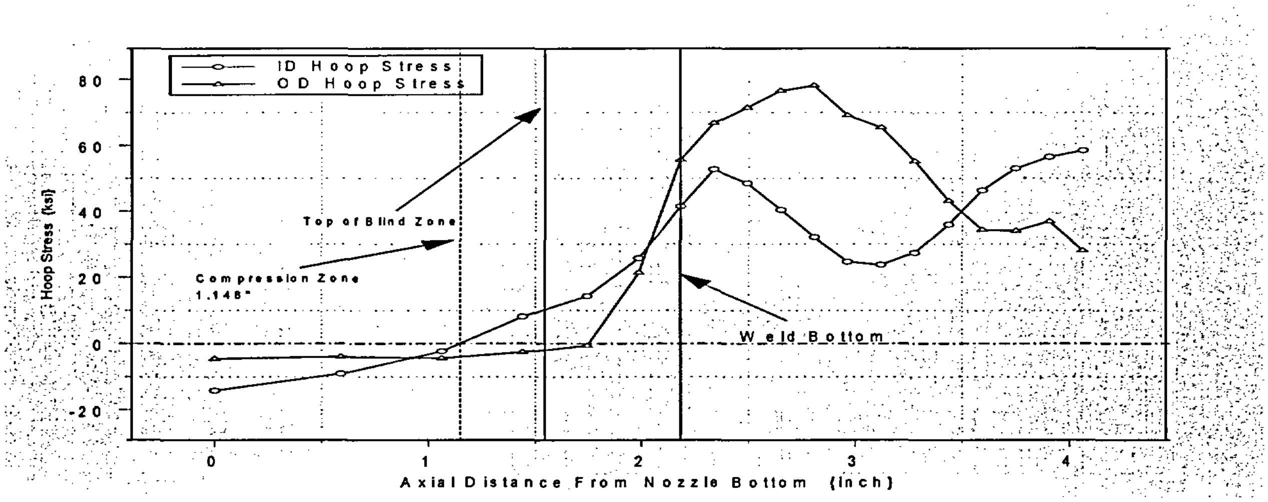
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103

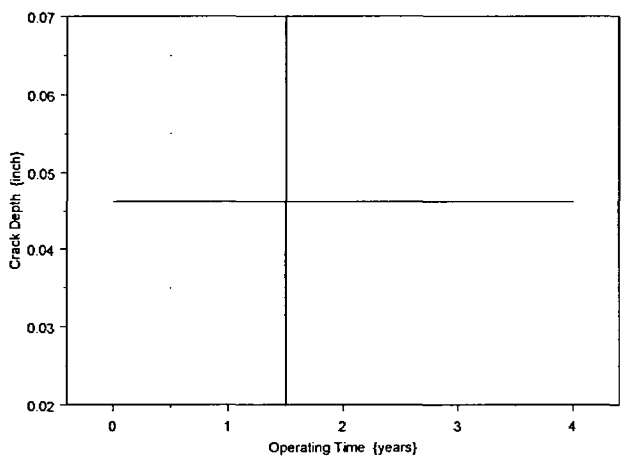
$CGR_{sambi_{(k,6)}} =$

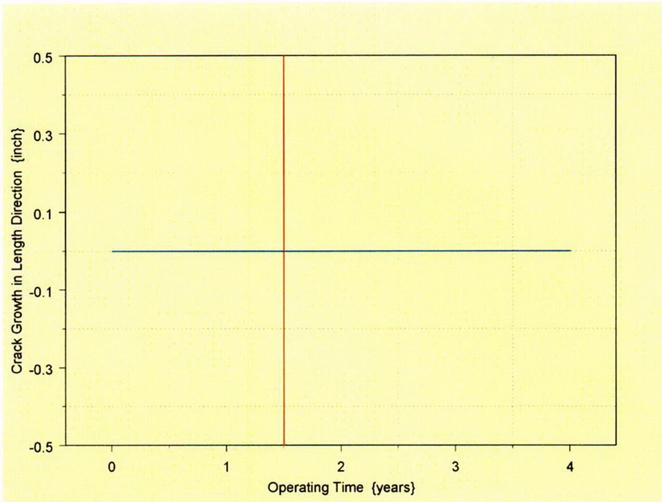
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041
8.041

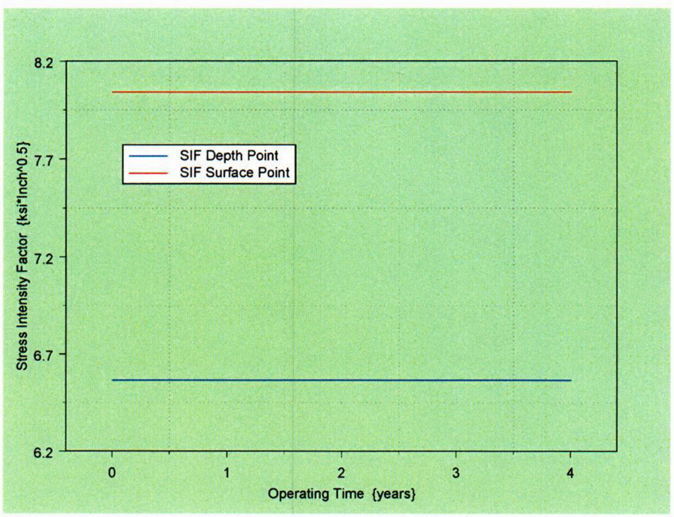
$CGR_{sambi_{(k,5)}} =$

6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566
6.566


ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Compression Zone
1.148"
Weld Bottom
Hoop Stress (ksi)
Axial Distance From Nozzle Bottom (inch)


Crack Depth (inch)
Operating Time (years)


0.5
0.3
0.1
-0.1
-0.3
-0.5
Crack Growth in Length Direction {inch}
0
1
2
3
4
Operating Time {years}


8.2
7.7
7.2
6.7
6.2
Stress Intensity Factor {ksi*inch^0.5}
SIF Depth Point
SIF Surface Point
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD Surface Flaw

Developed by Central Engineering Programs, Entergy Operations Inc.

Developed by: J. S. Brihmadesam   Verified by: B. C. Gray

References :

1) "Stress Intensity factors for Part-through Surface Cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"29.1" Degree Nozzle, "0" Degree Azimuth, 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

OD Surface Flaw

Note : *Used the Metric form of the equation from EPRI MRP 55-Rev. 1.*
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessary to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represents the reference point elevation measured upward from the nozzle end.

$Ref_{Point} = 1.544$

To place the flaw with respect to the reference point, the flaw tips and center can be located as follows:

1) The Upper "C- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "C- tip" located at the reference point (Enter 3).

$Val = 2$

Enter the Upper Extent of the Stress Distribution used for the analysis

$UL_{StrsDist} = 2.181$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

The regions highlighted below remain constant for WSES-3 analysis and should not be changed.

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.07932$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg. F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg. F

$R_o := \frac{od}{2}$ $\quad R_{id} := \frac{id}{2}$ $\quad t := R_o - R_{id}$ $\quad R_m := R_{id} + \frac{t}{2}$ $\quad Tim_{opr} := Years \cdot 365 \cdot 24$

$CF_{inhr} := 1.417 \cdot 10^5$ $\quad C_{blk} := \frac{Tim_{opr}}{I_{lim}}$ $\quad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right|$ $\quad c_0 := \frac{L}{2}$ $\quad R_t := \frac{R_m}{t}$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

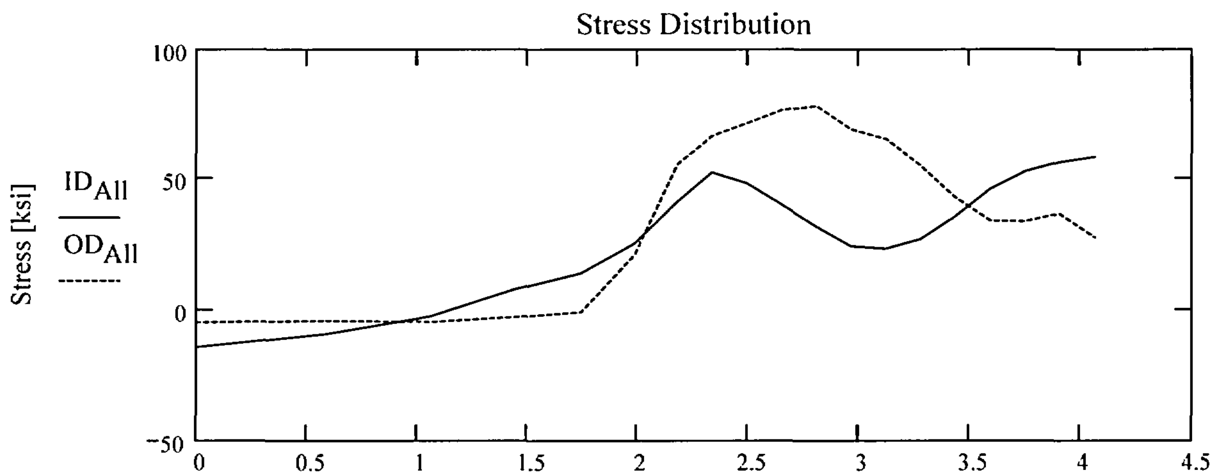
Stress Input Data

Import all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minimum to maximum recorded on data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-14.12	-10.61	-8.6	-6.67	-4.57
1	0.59	-9	-7.12	-5.97	-4.98	-3.96
2	1.06	-2.28	-2.81	-3.53	-4.07	-4.39
3	1.44	8.13	5.39	2.03	-0.49	-2.55
4	1.74	14.35	12.4	8.32	4.62	-0.62
5	1.99	25.68	22.47	16.06	14.29	21.33
6	2.18	41.45	35.84	33.39	49.7	55.56
7	2.34	52.64	44.8	43.23	62.87	66.64
8	2.49	48.49	45.8	49.07	69.13	71.44
9	2.65	40.38	42.43	49.87	69.01	76.54
10	2.81	32.13	38.24	49.3	66.99	78.11
11	2.96	24.6	34.87	46.68	60.59	69.07

$AXLen := AllData^{\langle 0 \rangle}$ $ID_{All} := AllData^{\langle 1 \rangle}$ $OD_{All} := AllData^{\langle 5 \rangle}$



AXLen
Axial Elevation above Bottom [inch]

Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table, click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0.59 & -9.002 & -7.115 & -5.966 & -4.979 & -3.958 \\ 1.062 & -2.278 & -2.811 & -3.527 & -4.069 & -4.39 \\ 1.44 & 8.127 & 5.389 & 2.032 & -0.491 & -2.546 \\ 1.744 & 14.353 & 12.404 & 8.325 & 4.616 & -0.624 \\ 1.987 & 25.675 & 22.473 & 16.062 & 14.285 & 21.33 \\ 2.181 & 41.453 & 35.841 & 33.389 & 49.701 & 55.565 \\ 2.338 & 52.639 & 44.805 & 43.227 & 62.866 & 66.642 \\ 2.495 & 48.491 & 45.796 & 49.068 & 69.125 & 71.441 \\ 2.651 & 40.376 & 42.428 & 49.872 & 69.009 & 76.543 \\ 2.808 & 32.134 & 38.242 & 49.303 & 66.994 & 78.115 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $\quad MD := Data^{\langle 3 \rangle}$ $\quad ID := Data^{\langle 1 \rangle}$ $\quad TQ := Data^{\langle 4 \rangle}$ $\quad QT := Data^{\langle 2 \rangle}$ $\quad OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $\quad R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $\quad R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{cases} Ref_{Point} - c_0 & \text{if } Val = 1 \\ Ref_{Point} & \text{if } Val = 2 \\ Ref_{Point} + c_0 & \text{otherwise} \end{cases}$$

Flaw center Location Location above Nozzle Bottom

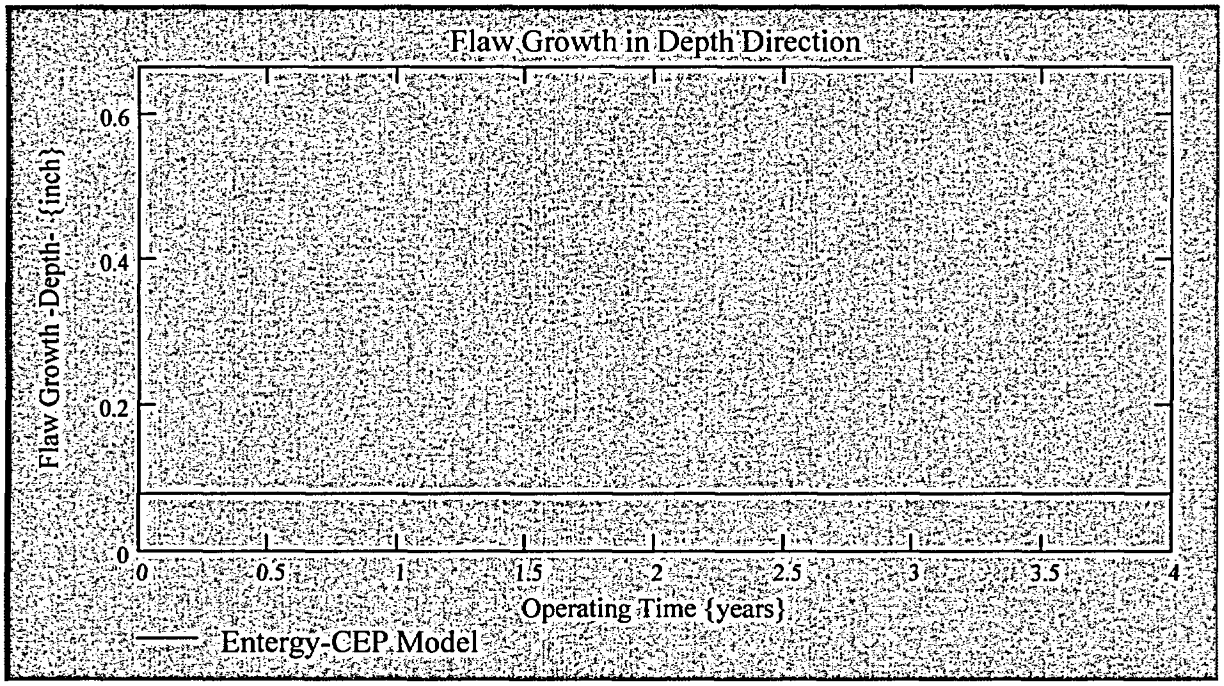
$U_{Tip} := FL_{Cntr} + c_0$

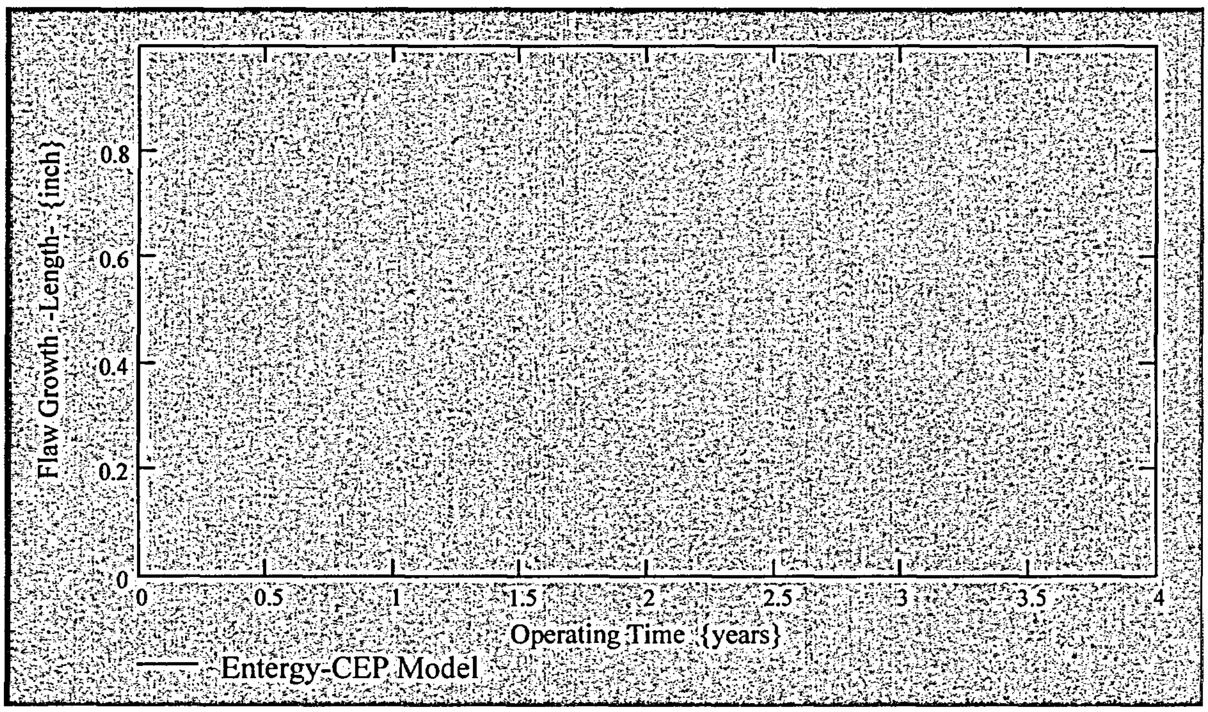
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

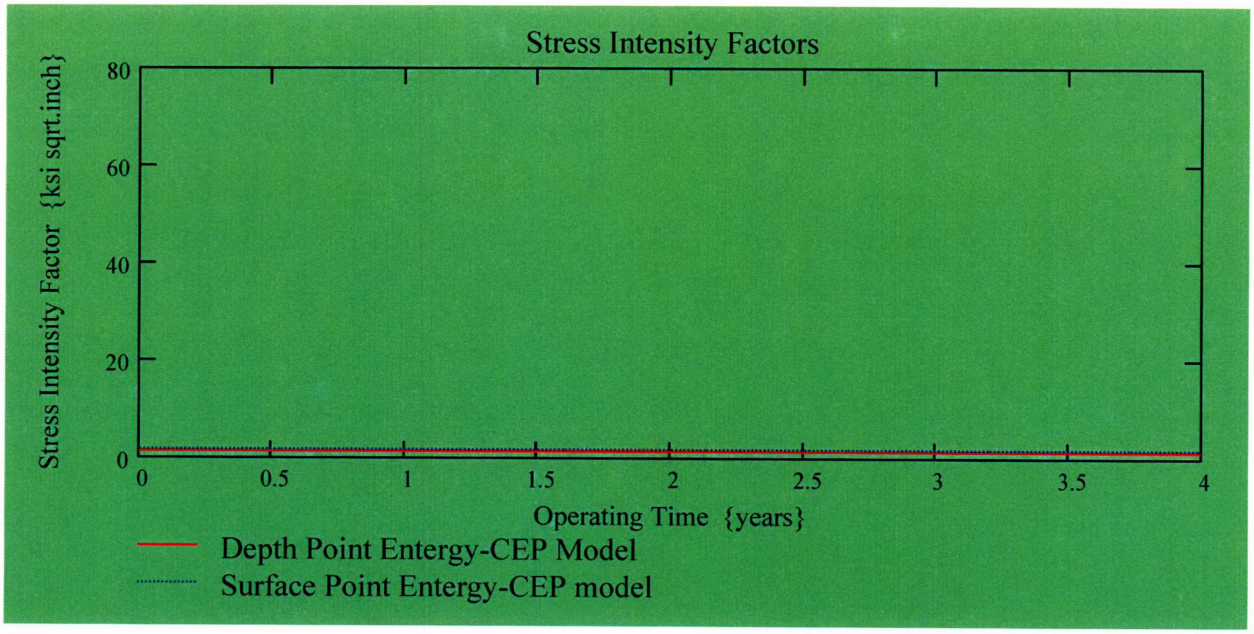
No User Input is required beyond this Point

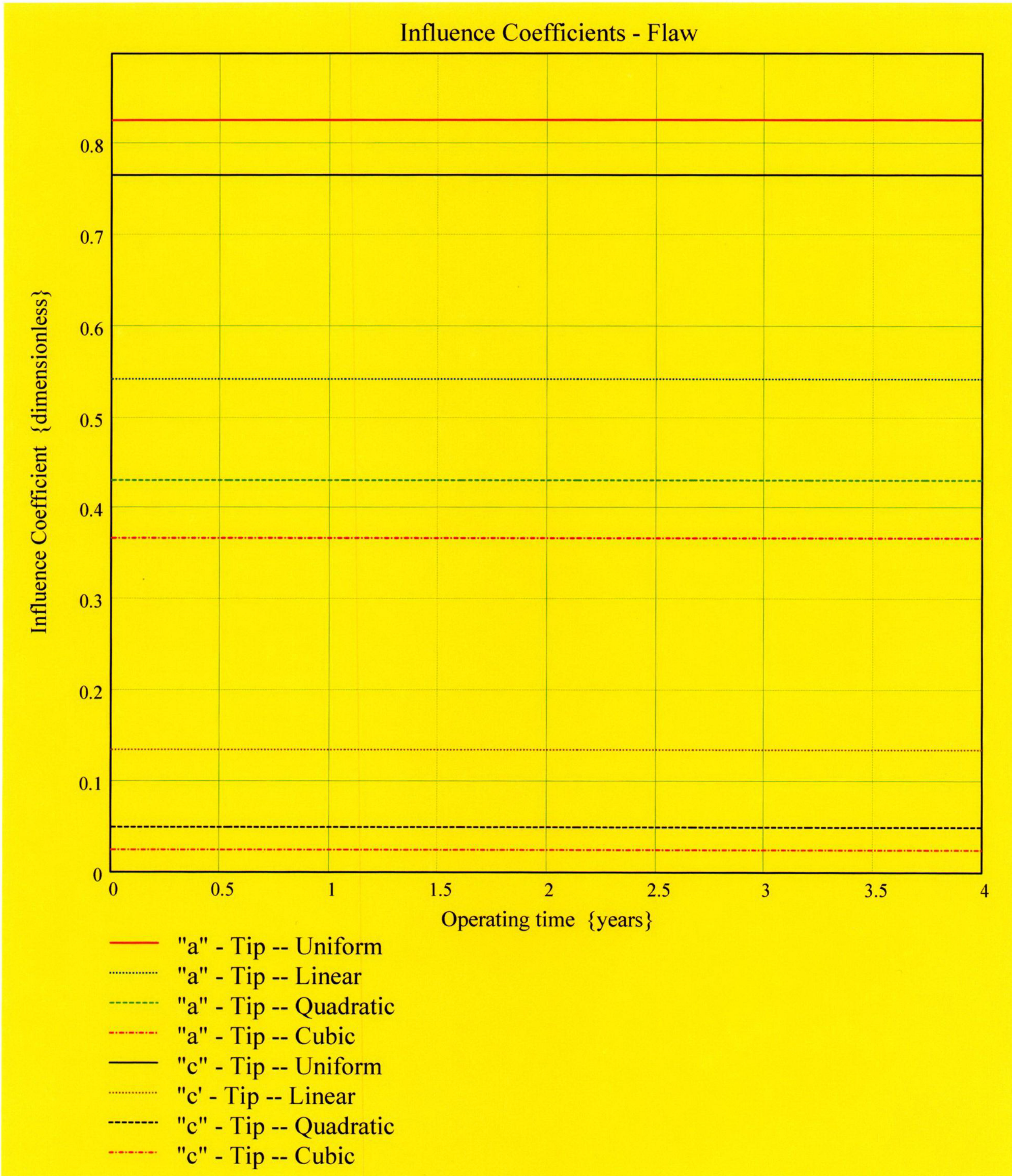
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.477$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model



Developed by:
J. S. Brihmadesam

Verified by:
B. C. Gray

$CGR_{sambi_{(k,8)}} =$

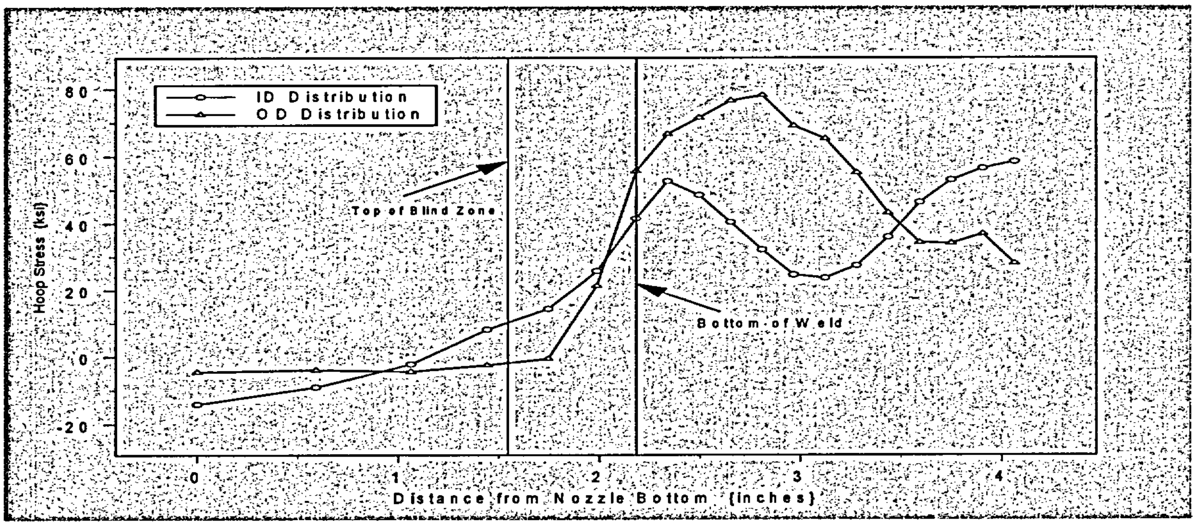
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

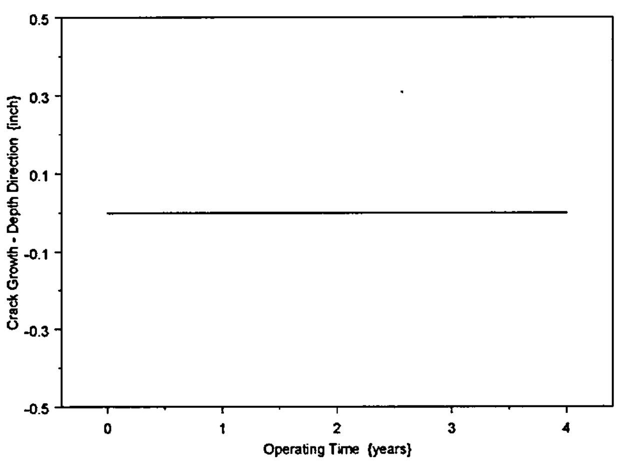
$CGR_{sambi_{(k,6)}} =$

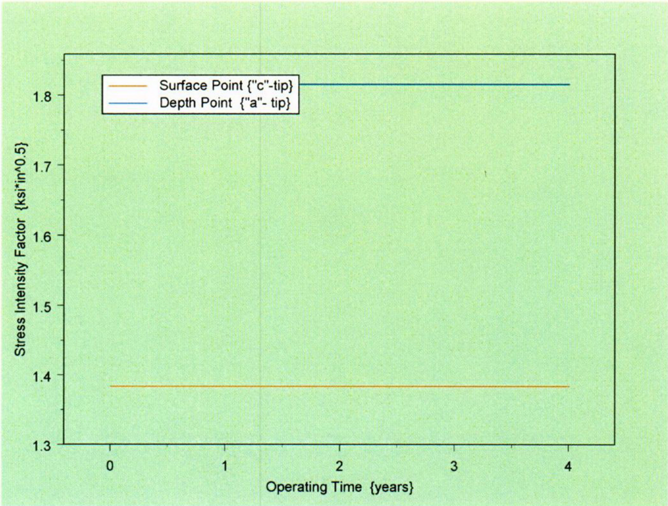
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816
1.816

$CGR_{sambi_{(k,5)}} =$

1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384
1.384


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress (ksi)
80
60
40
20
0
-20
0
1
2
3
4
Distance from Nozzle Bottom (inches)


0.5
0.3
0.1
-0.1
-0.3
-0.5
Crack Growth - Depth Direction (inch)
0
1
2
3
4
Operating Time (years)


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
1.8
1.7
1.6
1.5
1.4
1.3
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Through-wall flaw

Developed by Central Engineering Programs, Entergy Operations Inc.
Developed by: J. S. Brihmadesam **Verified by: B. C. Gray**

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thick-wall Cylinder)

References :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"29.1"degree Nozzle, "0" Degree Azimuth 1.544 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1 .***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The through-wall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg. Blind Zone) above the nozzle bottom in inches.

BZ = 1.544   Location of Blind Zone above nozzle bottom (inch)

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist}$ = 2.18   Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

The Highlighted Entries below remains constant for WSES-3 and should not be changed

Input Data :-

$L := 0.25$ — Initial Crack Length TW axial Based on Stress Distribution. Bottom end of Crack to be set @ approximately 10ksi.

$od := 4.05$ — Tube OD

$id := 2.728$ — Tube ID

$P_{Int} := 2.235$ — Design Operating Pressure (internal)

$Years := 4$ — Number of Operating Years

$I_{lim} := 1500$ — Iteration limit for Crack Growth loop

$T := 604$ — Estimate of Operating Temperature

$v := 0.307$ — Poissons ratio @ 600 F

$\alpha_{0c} := 2.67 \cdot 10^{-12}$ — Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg F

$Q_g := 31.0$ — Thermal activation Energy for Crack Growth (MRP)

$T_{ref} := 617$ — Reference Temperature for normalizing Data deg F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$

$$Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^5$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

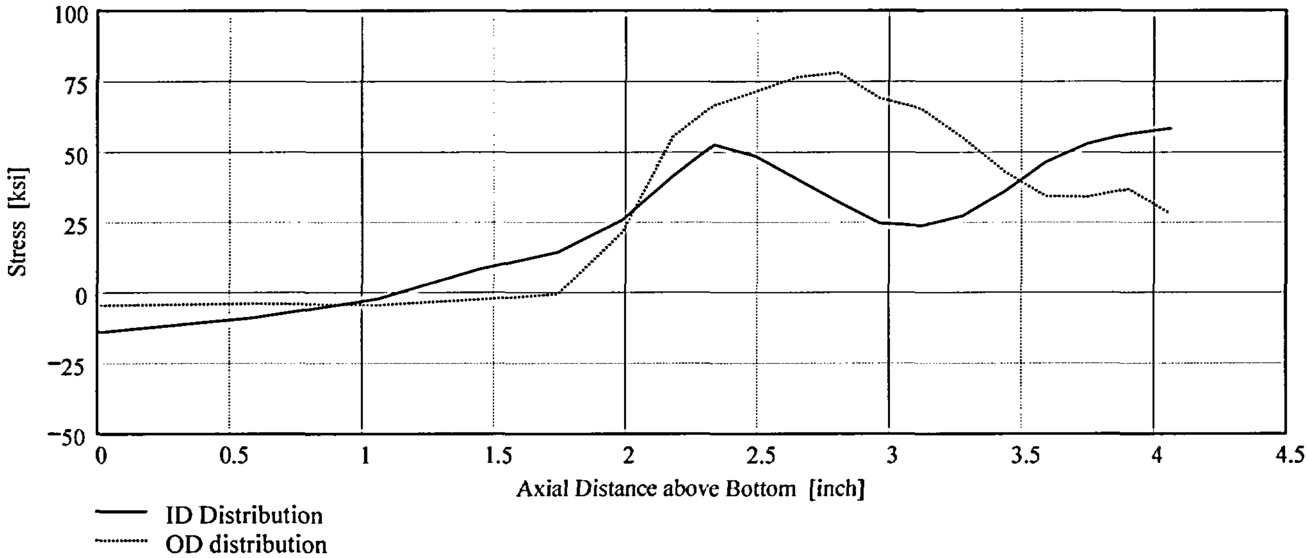
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Column "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-14.12	-10.61	-8.6	-6.67	-4.57
1	0.59	-9	-7.12	-5.97	-4.98	-3.96
2	1.06	-2.28	-2.81	-3.53	-4.07	-4.39
3	1.44	8.13	5.39	2.03	-0.49	-2.55
4	1.74	14.35	12.4	8.32	4.62	-0.62
5	1.99	25.68	22.47	16.06	14.29	21.33
6	2.18	41.45	35.84	33.39	49.7	55.56
7	2.34	52.64	44.8	43.23	62.87	66.64
8	2.49	48.49	45.8	49.07	69.13	71.44
9	2.65	40.38	42.43	49.87	69.01	76.54
10	2.81	32.13	38.24	49.3	66.99	78.11
11	2.96	24.6	34.87	46.68	60.59	69.07

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $AllID := Data_{All}^{\langle 1 \rangle}$ $AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table, click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0.59 & -9.002 & -7.115 & -5.966 & -4.979 & -3.958 \\ 1.062 & -2.278 & -2.811 & -3.527 & -4.069 & -4.39 \\ 1.44 & 8.127 & 5.389 & 2.032 & -0.491 & -2.546 \\ 1.744 & 14.353 & 12.404 & 8.325 & 4.616 & -0.624 \\ 1.987 & 25.675 & 22.473 & 16.062 & 14.285 & 21.33 \\ 2.181 & 41.453 & 35.841 & 33.389 & 49.701 & 55.565 \\ 2.338 & 52.639 & 44.805 & 43.227 & 62.866 & 66.642 \\ 2.495 & 48.491 & 45.796 & 49.068 & 69.125 & 71.441 \\ 2.651 & 40.376 & 42.428 & 49.872 & 69.009 & 76.543 \\ 2.808 & 32.134 & 38.242 & 49.303 & 66.994 & 78.115 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $\quad ID := Data^{\langle 1 \rangle}$ $\quad OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $\quad R_{OD} := regress(Axl, OD, 3)$

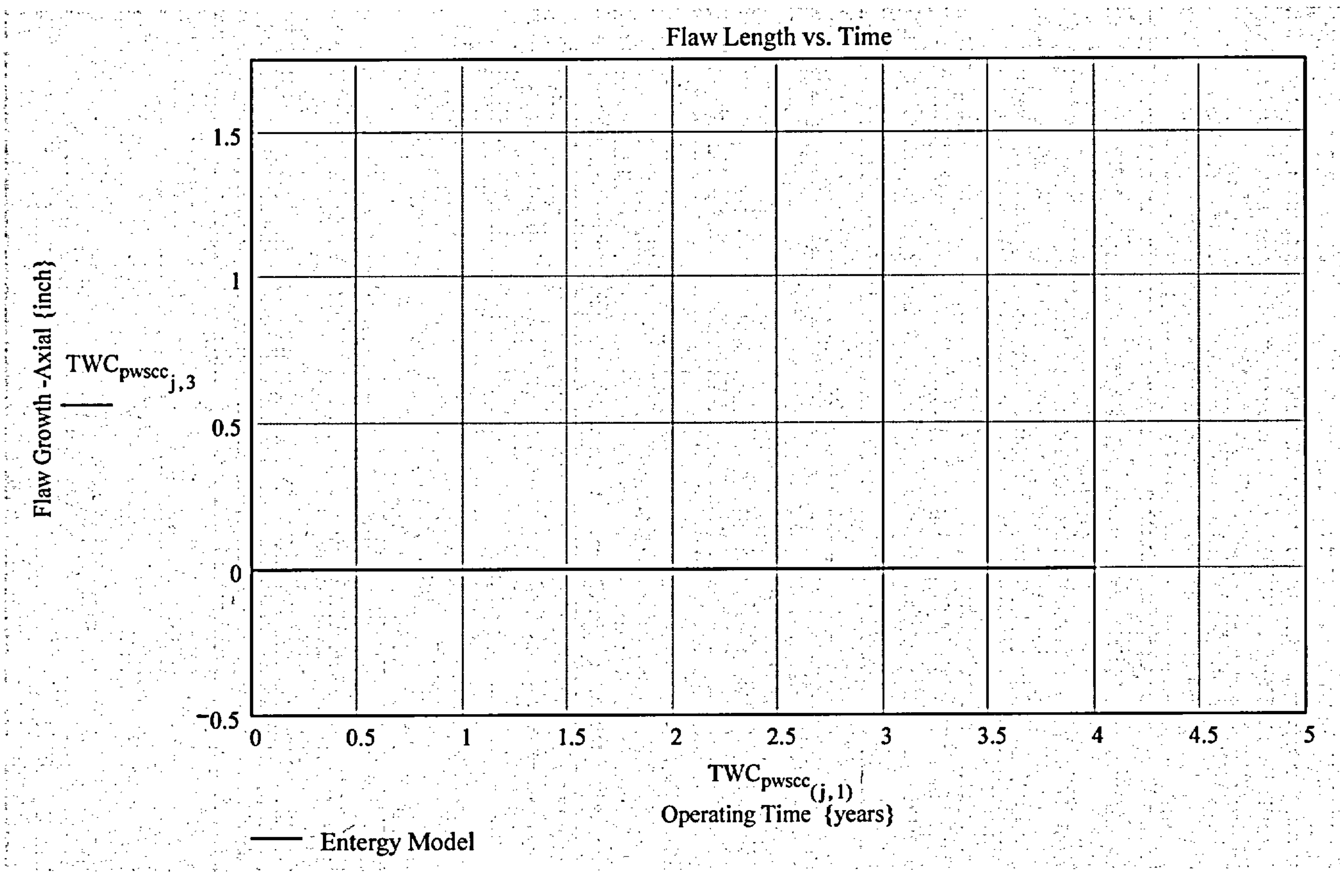
$FL_{Cntr} := BZ - 1$ Flaw Center above Nozzle Bottom

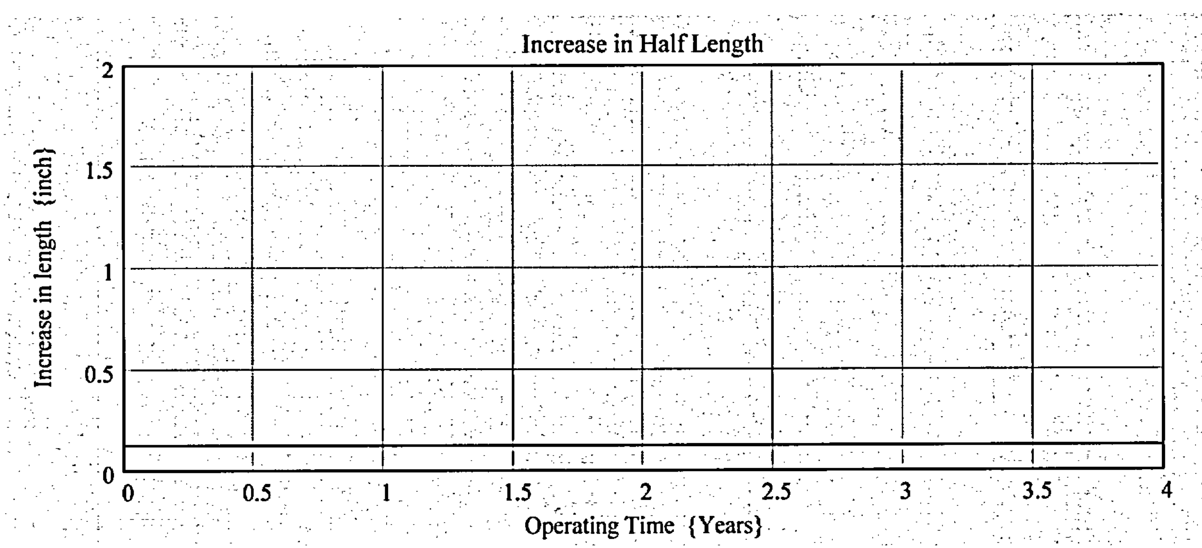
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

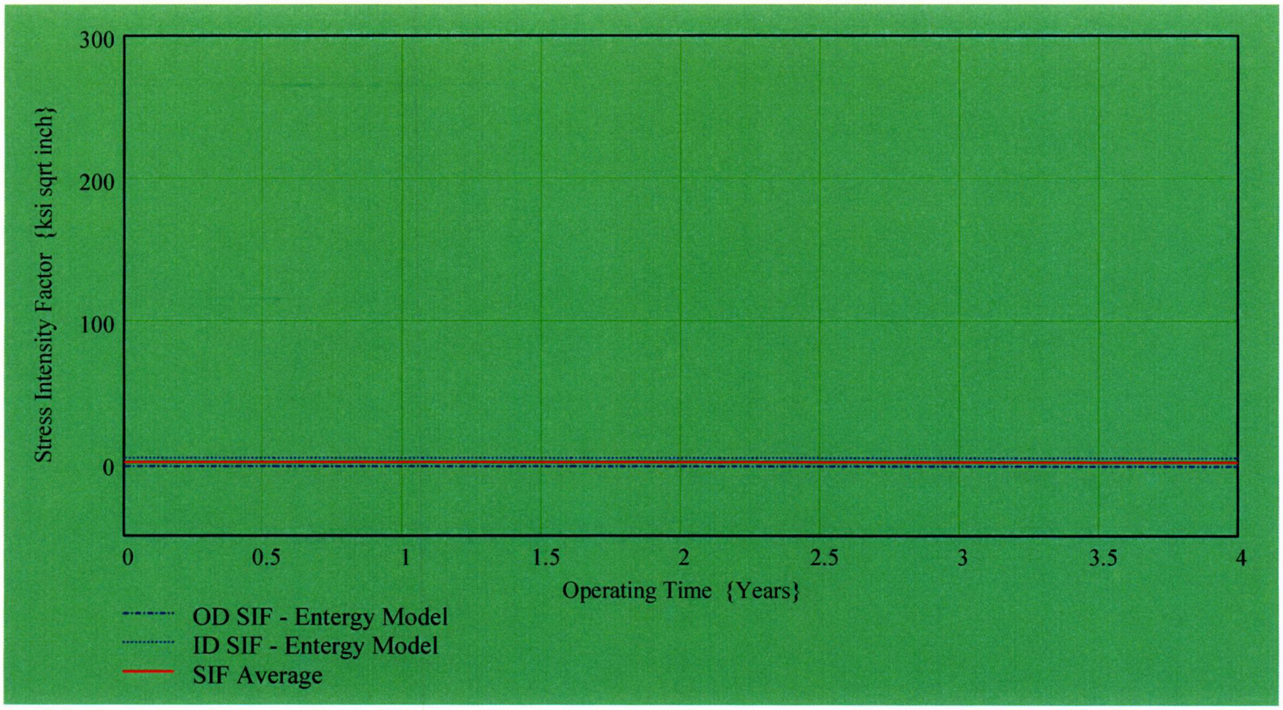
No User Input required beyond this Point

Sat Aug 09 11:44:49 AM 2003

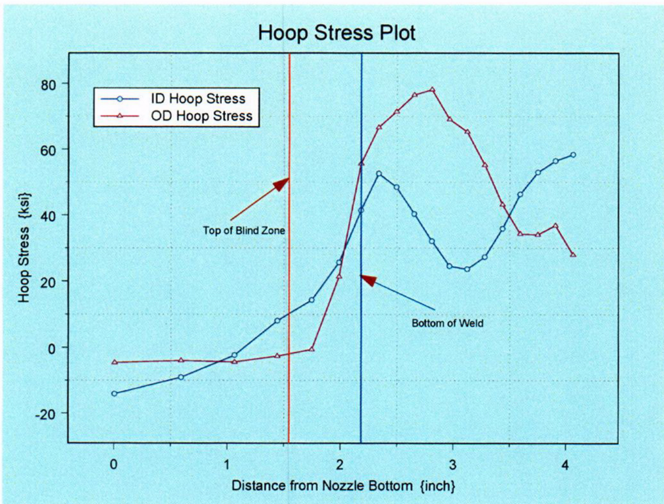
$Prop_{Length} = 0.637$

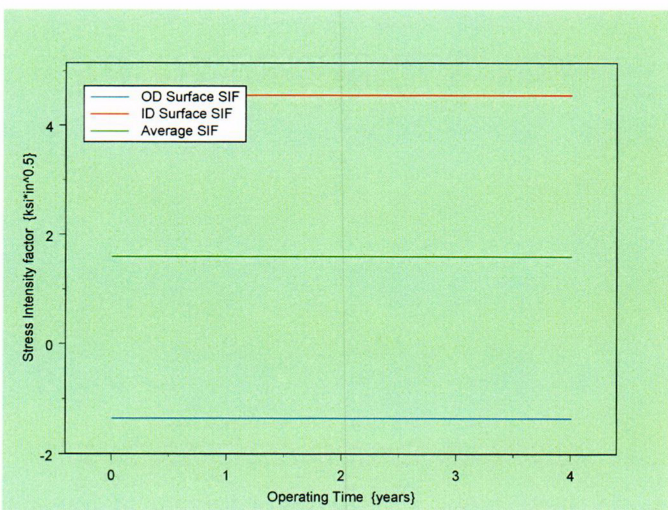


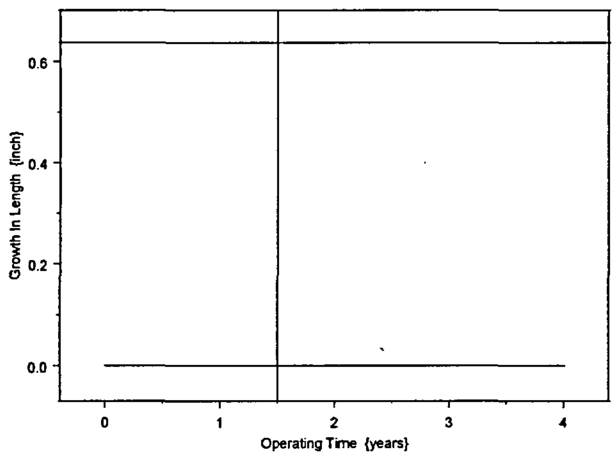



300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$	$TWC_{pwscc_{(j,7)}} =$	$TWC_{pwscc_{(j,8)}} =$
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674
-1.354	4.553	1.674


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Bottom of Weld
Hoop Stress {ksi}
80
60
40
20
0
-20
0
1
2
3
4
Distance from Nozzle Bottom {inch}


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
4
2
0
-2
0
1
2
3
4
Operating Time {years}


0.6
0.4
0.2
0.0
Growth In Length {inch}
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis ID flaw;
Developed by Central Engineering Programs, Entergy Operations Inc.

Developed by: J. S. Brihmadesam ***Verified by: B. C. Gray***

References :

1) "Stress Intensity factors for Part-through Surface Cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"29.1" Degree Nozzle, "180" Degree Azimuth, 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.*** *The correction is applied in the determination of the crack extension to obtain the value in inch/hr.*

ID Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessary to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represents the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.544$

To place the flaw with respect to the reference point, the flaw tips and center can be located as follows:
1) The Upper "C - tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "C - tip" located at the reference point (Enter 3).

$Val := 2$

The Input Below is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{Strs.Dist} := 5.16$

Upper axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom).

The highlighted region below remians constant for WSES-3 and should not be changed!

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.04627$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg F

$R_o := \frac{od}{2}$ $\qquad R_{id} := \frac{id}{2}$ $\qquad t := R_o - R_{id}$ $\qquad R_m := R_{id} + \frac{t}{2}$ $\qquad Tim_{opr} := Years \cdot 365 \cdot 24$

$CF_{inhr} := 1.417 \cdot 10^5$ $\qquad C_{blk} := \frac{Tim_{opr}}{I_{lim}}$ $\qquad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right|$ $\qquad c_0 := \frac{L}{2}$ $\qquad R_t := \frac{R_m}{t}$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

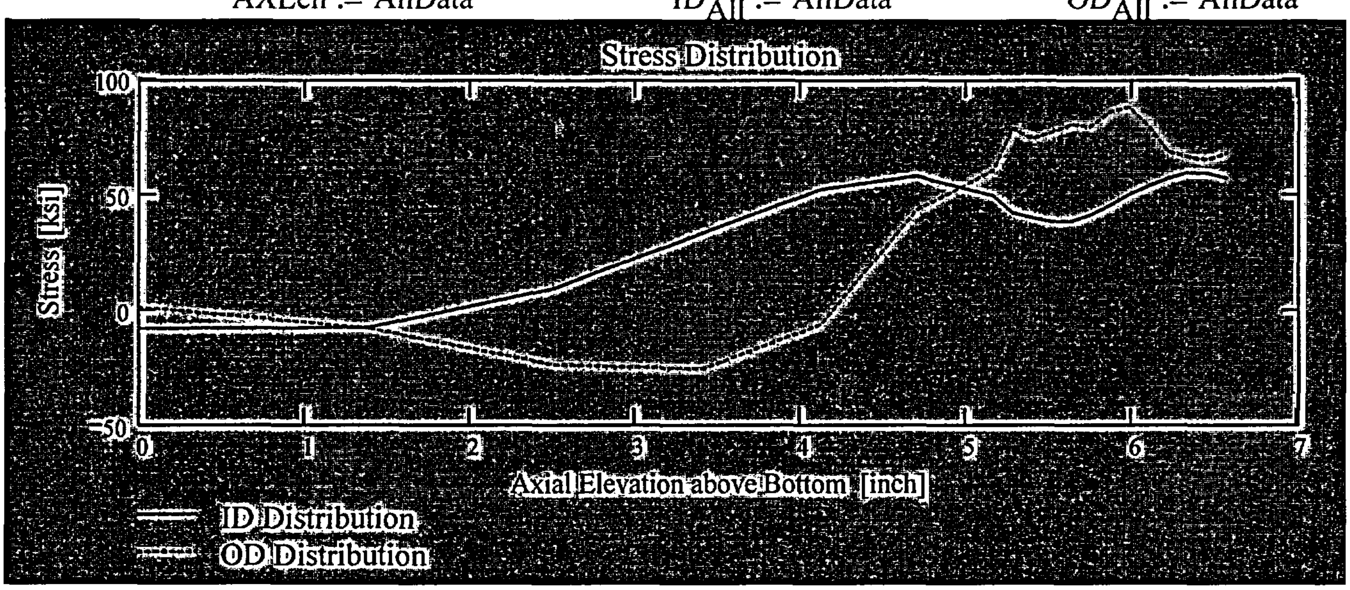
Stress Input Data

nput all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minimum to maximum recorded on data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-7.86	-4.21	-2.26	-0.33	1.66
1	1.4	-7.37	-7.03	-7.47	-7.78	-7.78
2	2.51	9.69	1.33	-9.45	-17.45	-23.77
3	3.41	33.86	32.36	12.26	-12.43	-25.5
4	4.13	52.72	49.98	44.3	16.3	-6.04
5	4.7	58.42	51.45	44.99	43.35	43.69
6	5.16	49.9	49.61	50.98	60.47	60.78
7	5.28	42.5	47.8	56.69	75.7	78.96
8	5.39	40.41	46.01	60.82	78.52	74.75
9	5.51	38.57	45.68	61.29	79.5	77.41

$AXLen := AllData^{\langle 0 \rangle}$ $ID_{All} := AllData^{\langle 1 \rangle}$ $OD_{All} := AllData^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Highlight the region in the above table representing the region to be selected (click on the first cell for selection and drag the mouse whilst holding the left mouse button down. Once this is done click the right mouse button and select "Copy Selection", this will copy the selected area on to the clipboard. Then click on the "Matrix" below (to the right of the data statement) to highlight the entire matrix and delete it from the edit menu. When the Mathcad input symbol appears, use the paste function in the tool bar to paste the selection.

$$Data := \begin{pmatrix} 0 & -7.856 & -4.209 & -2.262 & -0.333 & 1.664 \\ 1.395 & -7.372 & -7.026 & -7.468 & -7.776 & -7.782 \\ 2.513 & 9.689 & 1.331 & -9.445 & -17.448 & -23.769 \\ 3.408 & 33.861 & 32.362 & 12.257 & -12.427 & -25.502 \\ 4.125 & 52.72 & 49.983 & 44.295 & 16.295 & -6.038 \\ 4.7 & 58.423 & 51.453 & 44.992 & 43.352 & 43.691 \\ 5.16 & 49.9 & 49.607 & 50.983 & 60.468 & 60.778 \\ 5.277 & 42.502 & 47.798 & 56.694 & 75.697 & 78.963 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $MD := Data^{\langle 3 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $TQ := Data^{\langle 4 \rangle}$ $QT := Data^{\langle 2 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \begin{cases} Ref_{Point} - c_0 & \text{if } Val = 1 \\ Ref_{Point} & \text{if } Val = 2 \\ Ref_{Point} + c_0 & \text{otherwise} \end{cases}$$

Flaw center Location above Nozzle Bottom

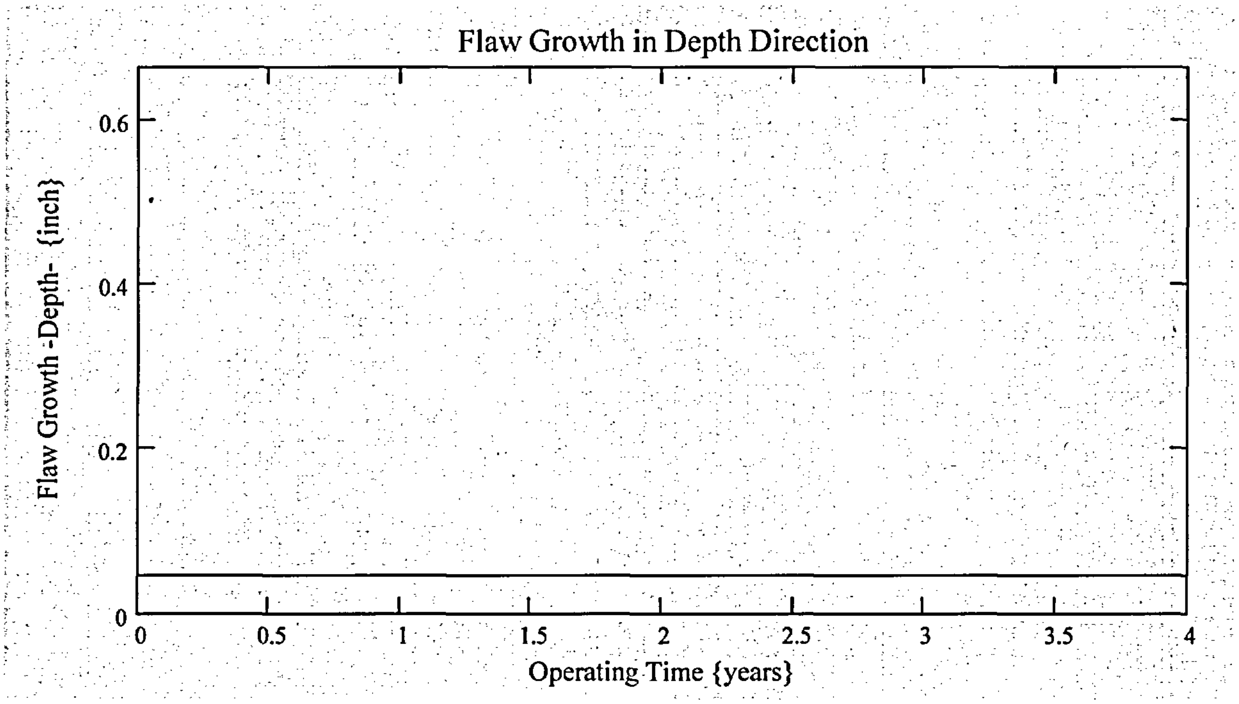
$$U_{Tip} := FL_{Cntr} + c_0$$

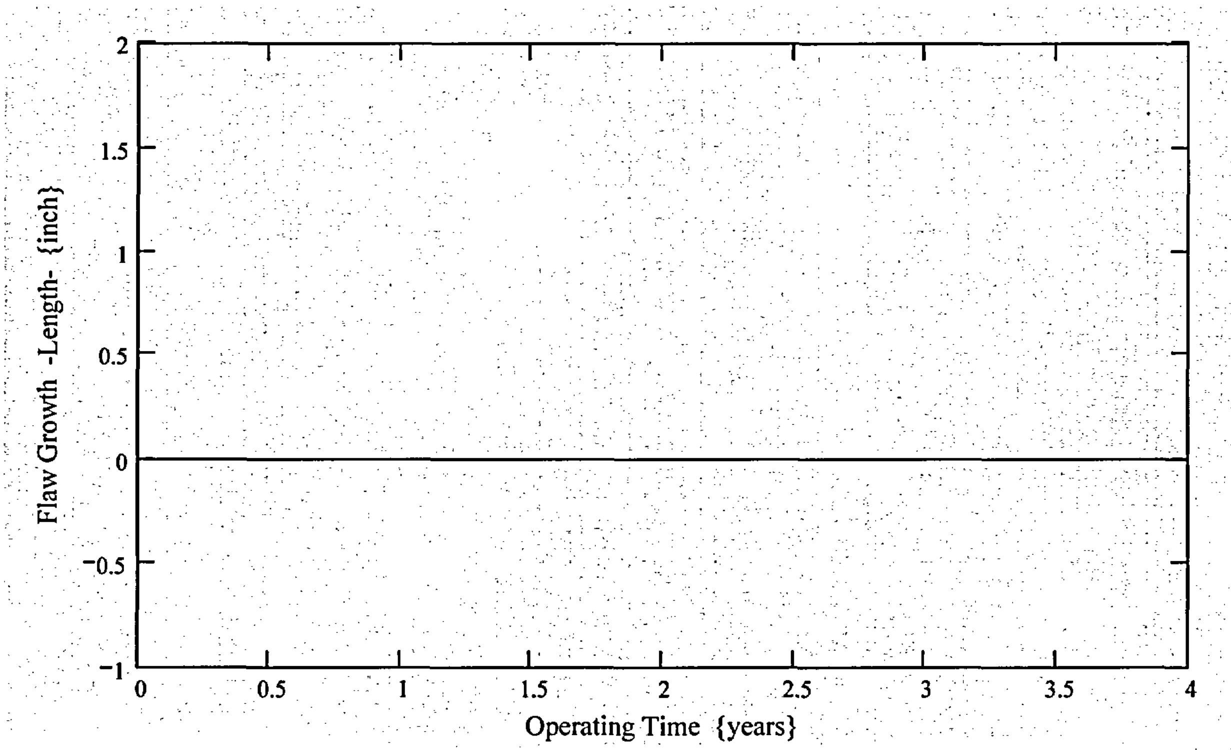
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

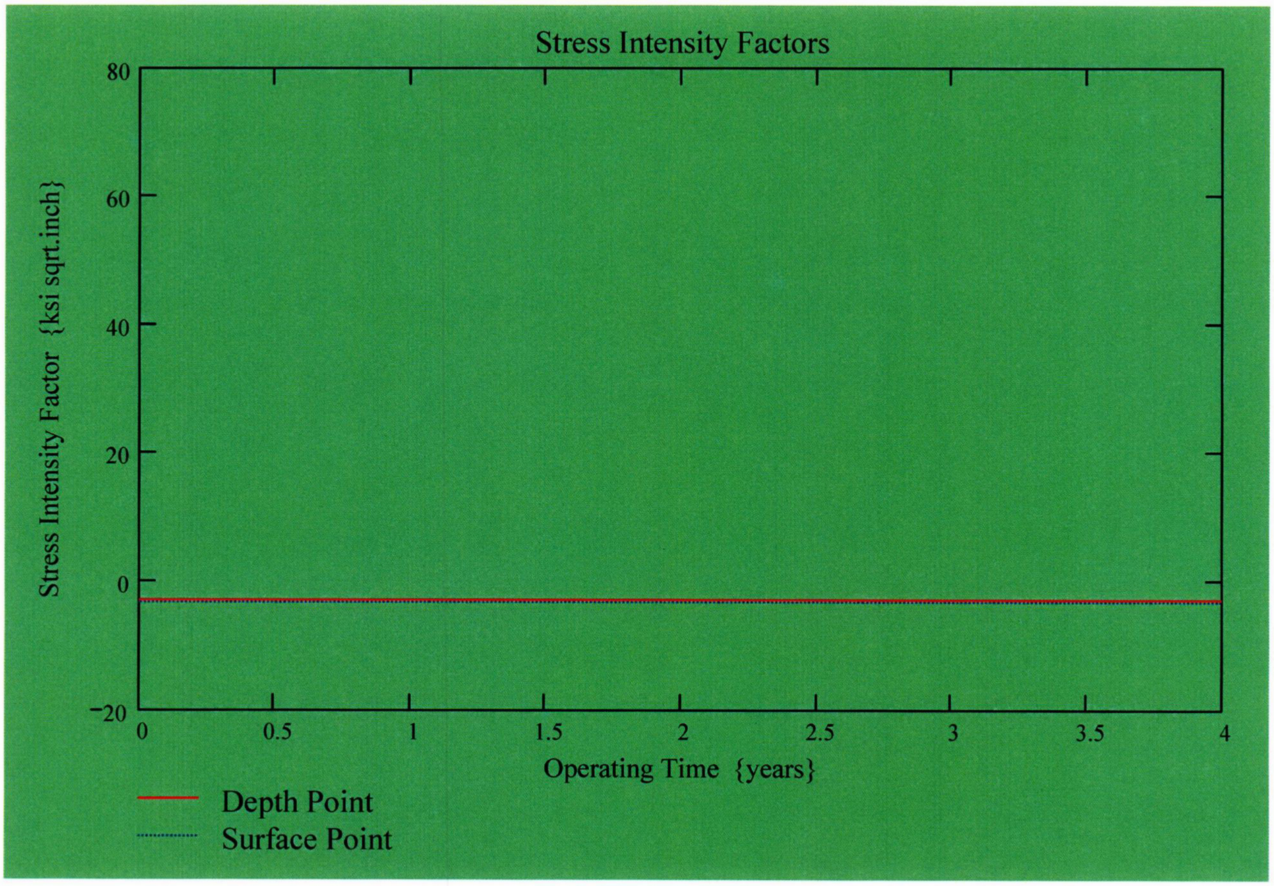
No User Input is required beyond this Point

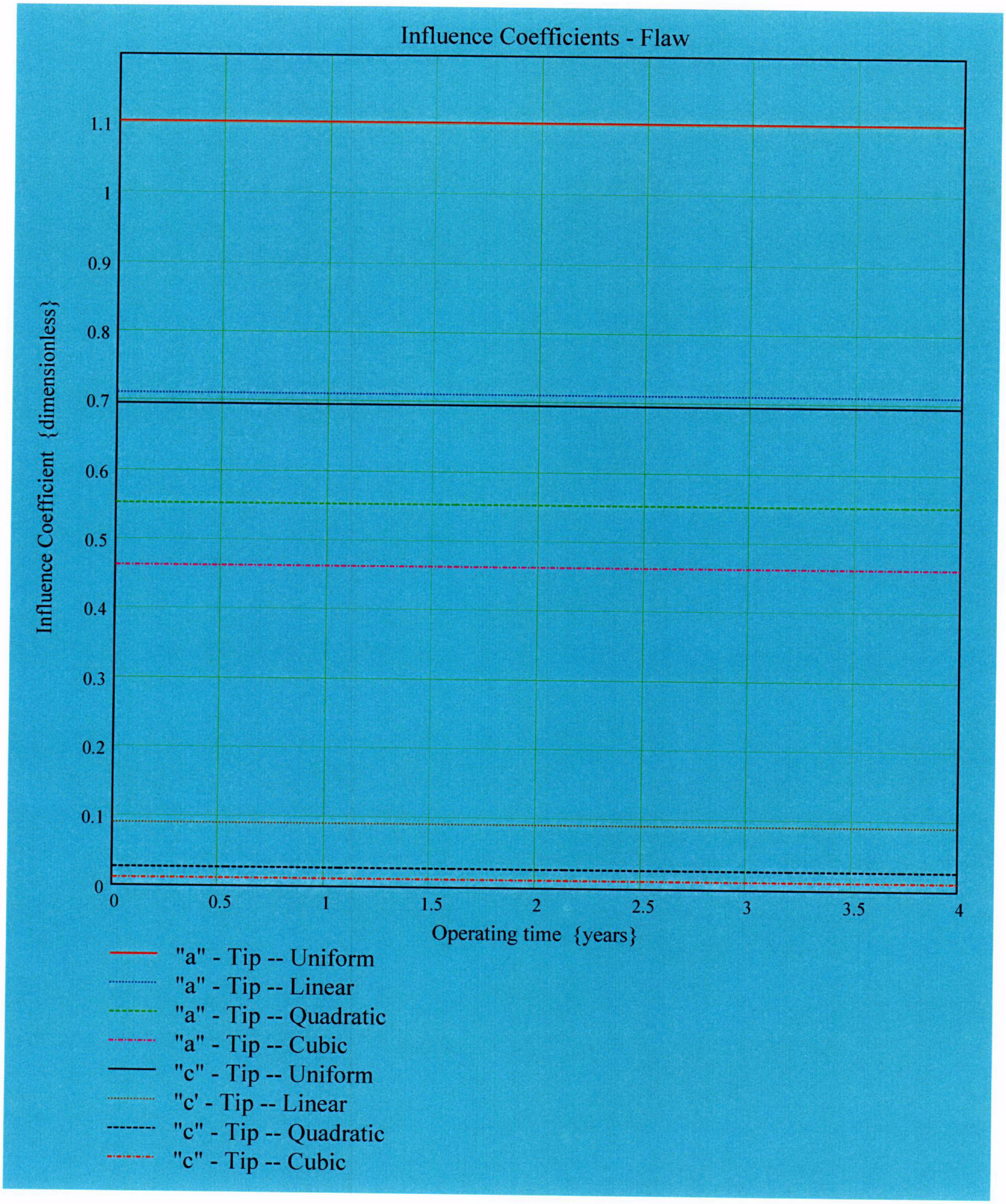
Sat Aug 09 10:59:39 AM 2003

$Prop_{Length} = 3.456$

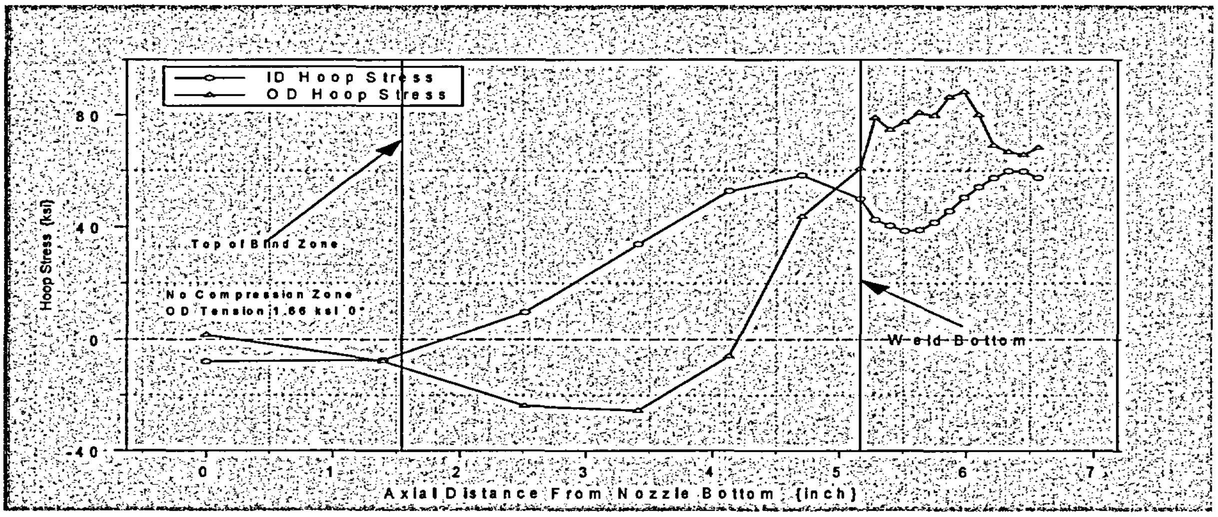


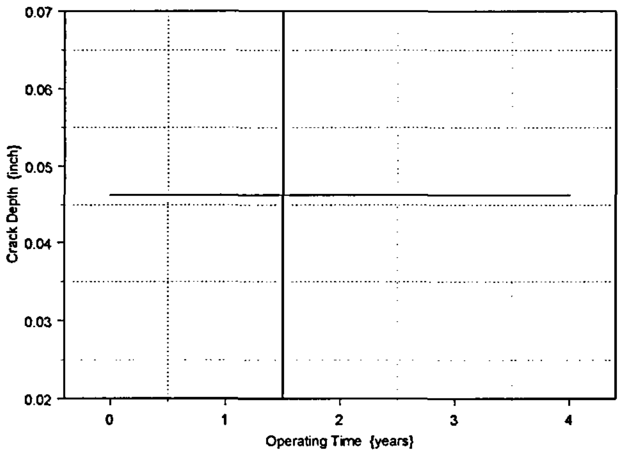


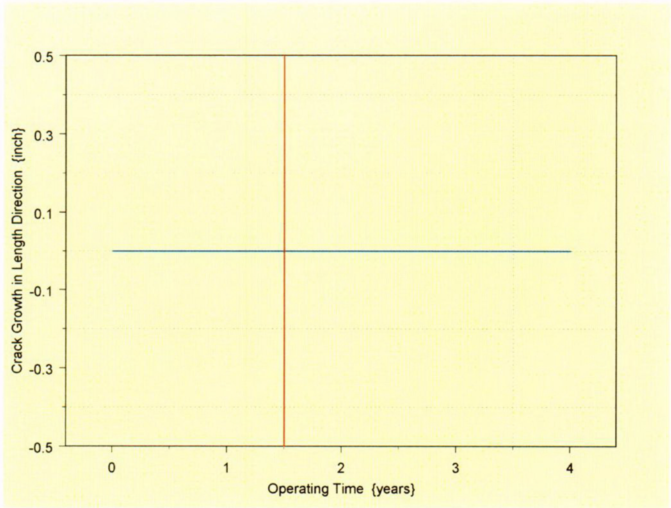

Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
80
60
40
20
0
−20
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point
Surface Point

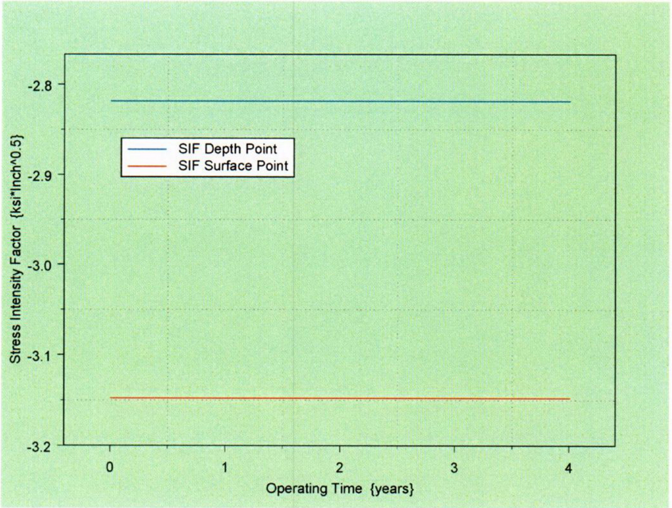

Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$	$CGR_{sambi_{(k,6)}} =$	$CGR_{sambi_{(k,5)}} =$
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818
1.103	-3.148	-2.818


ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
No Compression Zone
OD Tension 1.66 ksi 0"
Weld Bottom
Hoop Stress (ksi)
80
40
0
-40
0
1
2
3
4
5
6
7
Axial Distance From Nozzle Bottom (inch)


0.07
0.06
0.05
0.04
0.03
0.02
Crack Depth (inch)
0
1
2
3
4
Operating Time (years)


0.5
0.3
0.1
-0.1
-0.3
-0.5
Crack Growth in Length Direction {inch}
0
1
2
3
4
Operating Time {years}


-2.8
-2.9
-3.0
-3.1
-3.2
Stress Intensity Factor {ksi*Inch^0.5}
SIF Depth Point
SIF Surface Point
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD Surface Flaw

Developed by Central Engineering Programs, Entergy Operations Inc.
Developed by: J. S. Brihmadesam Verified by: B. C. Gray

References :

1) "Stress Intensity factors for Part-through Surface Cracks"; NASA TM-11707; July 1992.
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"29.1" Degree Nozzle, "180" Degree Azimuth, 1.544" above Nozzle Bottom

Calculation Basis: MRP 75 th Percentile and Flaw Face Pressurized

Mean Radius -to- Thickness Ratio:- "R_m/t" -- between 1.0 and 300.0

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1.***
The correction is applied in the determination of the crack extension to obtain the value in inch/hr.

OD Surface Flaw

The first Required input is a location for a point on the tube elevation to define the point of interest (e.g. The top of the Blind Zone, or bottom of fillet weld etc.). This reference point is necessary to evaluate the stress distribution on the flaw both for the initial flaw and for a growing flaw. This is defined as the reference point. Enter a number (inch) that represents the reference point elevation measured upward from the nozzle end.

$Ref_{Point} := 1.544$

To place the flaw with respect to the reference point, the flaw tips and center can be located as follows:

1) The Upper "C- tip" located at the reference point (Enter 1)
2) The Center of the flaw at the reference point (Enter 2)
3) The lower "C- tip" located at the reference point (Enter 3).

$Val := 2$

Enter the Upper Extent of the Stress Distribution used for the analysis

$UL_{StrsDist} := 5.16$

Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

The regions highlighted below remain constant for WSES-3 analysis and should not be changed

Input Data :-

$L := 0.32$	Initial Flaw Length
$a_0 := 0.07932$	Initial Flaw Depth
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCC Model for I-600 Wrought @ 617 deg F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg F

$$R_o := \frac{od}{2} \qquad R_{id} := \frac{id}{2} \qquad t := R_o - R_{id} \qquad R_m := R_{id} + \frac{t}{2} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$CF_{inhr} := 1.417 \cdot 10^{5} \qquad C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left| \frac{I_{lim}}{50} \right| \qquad c_0 := \frac{L}{2} \qquad R_t := \frac{R_m}{t}$$

$$C_{01} := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c}$$ Temperature Correction for Coefficient Alpha

$C_0 := C_{01}$ 75 th percentile MRP-55 Revision 1

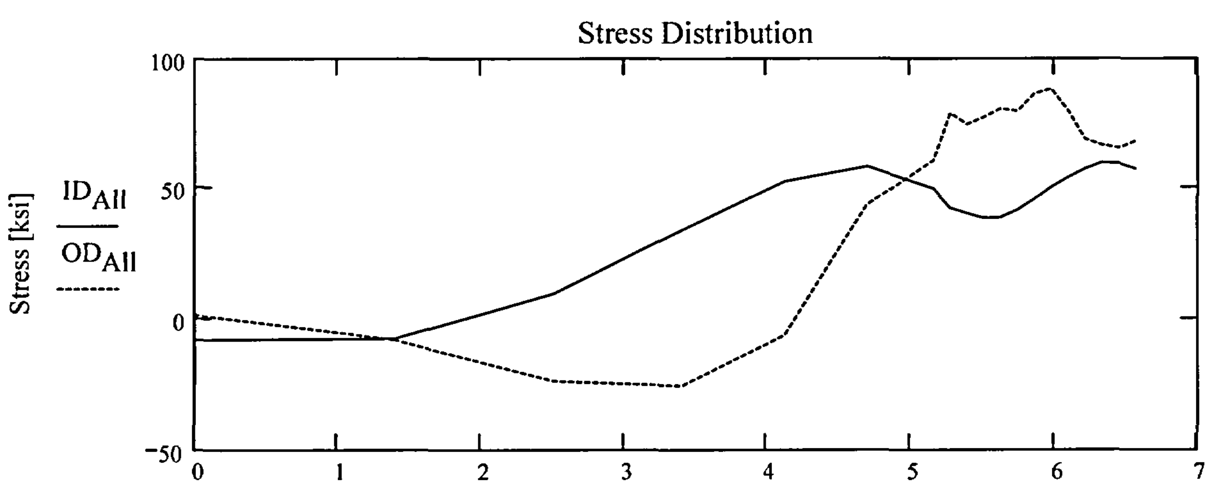
Stress Input Data

Import all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minimum to maximum recorded on data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "2" = Quarter Thickness Stress data at each Elevation (ksi)
Column "3" = Mid Thickness Stress data at each Elevation (ksi)
Column "4" = Three Quarter Thickness Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

AllData :=

	0	1	2	3	4	5
0	0	-7.86	-4.21	-2.26	-0.33	1.66
1	1.4	-7.37	-7.03	-7.47	-7.78	-7.78
2	2.51	9.69	1.33	-9.45	-17.45	-23.77
3	3.41	33.86	32.36	12.26	-12.43	-25.5
4	4.13	52.72	49.98	44.3	16.3	-6.04
5	4.7	58.42	51.45	44.99	43.35	43.69
6	5.16	49.9	49.61	50.98	60.47	60.78
7	5.28	42.5	47.8	56.69	75.7	78.96
8	5.39	40.41	46.01	60.82	78.52	74.75
9	5.51	38.57	45.68	61.29	79.5	77.41

$AXLen := AllData^{\langle 0 \rangle}$ $ID_{All} := AllData^{\langle 1 \rangle}$ $OD_{All} := AllData^{\langle 5 \rangle}$



AXLen
Axial Elevation above Bottom [inch]

Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table, click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 1.395 & -7.372 & -7.026 & -7.468 & -7.776 & -7.782 \\ 2.513 & 9.689 & 1.331 & -9.445 & -17.448 & -23.769 \\ 3.408 & 33.861 & 32.362 & 12.257 & -12.427 & -25.502 \\ 4.125 & 52.72 & 49.983 & 44.295 & 16.295 & -6.038 \\ 4.7 & 58.423 & 51.453 & 44.992 & 43.352 & 43.691 \\ 5.16 & 49.9 & 49.607 & 50.983 & 60.468 & 60.778 \\ 5.277 & 42.502 & 47.798 & 56.694 & 75.697 & 78.963 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $MD := Data^{\langle 3 \rangle}$ $ID := Data^{\langle 1 \rangle}$ $TQ := Data^{\langle 4 \rangle}$ $QT := Data^{\langle 2 \rangle}$ $OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $R_{QT} := regress(Axl, QT, 3)$

$R_{OD} := regress(Axl, OD, 3)$

$R_{MD} := regress(Axl, MD, 3)$ $R_{TQ} := regress(Axl, TQ, 3)$

$$FL_{Cntr} := \left| \begin{array}{l} Ref_{Point} - c_0 \ \text{ if } Val = 1 \\ Ref_{Point} \ \text{ if } Val = 2 \\ Ref_{Point} + c_0 \ \text{ otherwise} \end{array} \right.$$

Flaw center Location Location above Nozzle Bottom

$U_{Tip} := FL_{Cntr} + c_0$

$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

No User Input is required beyond this Point

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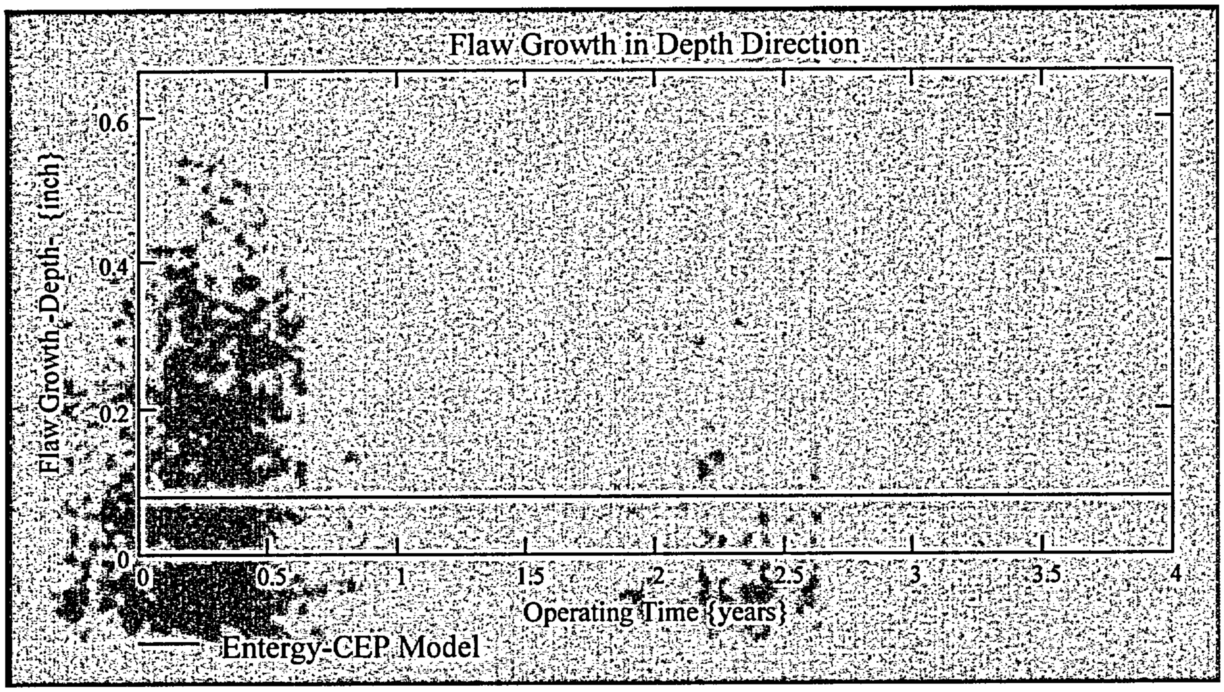
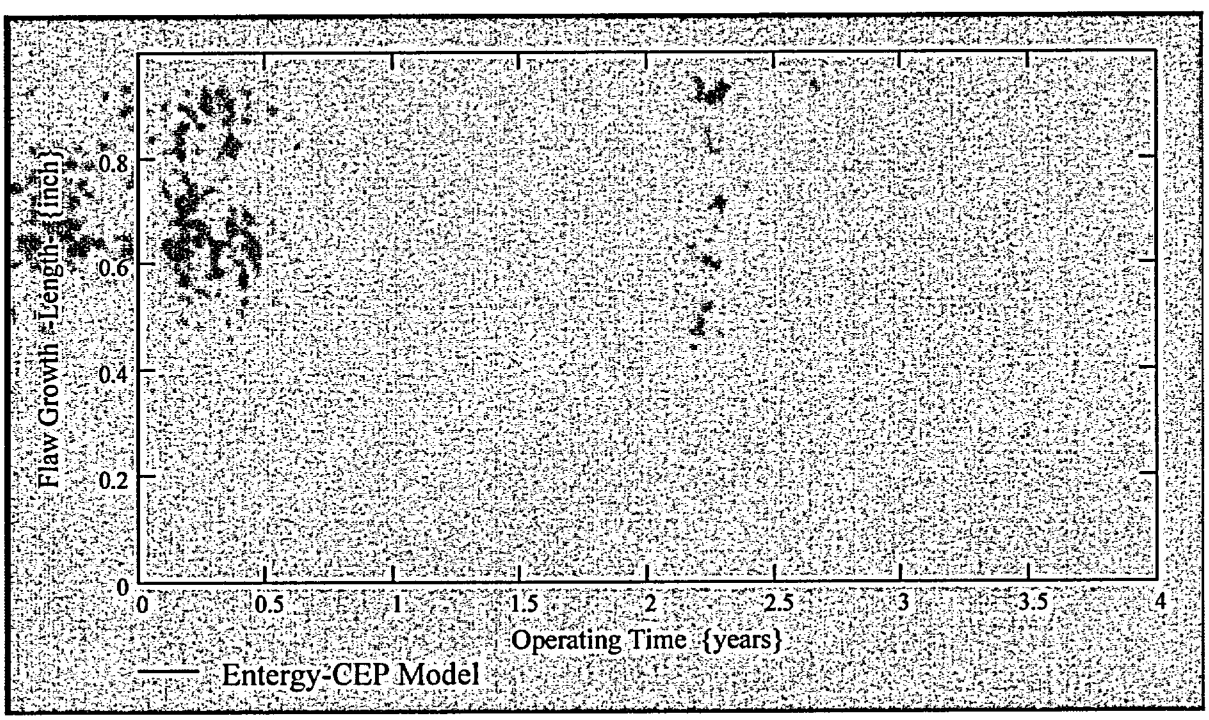
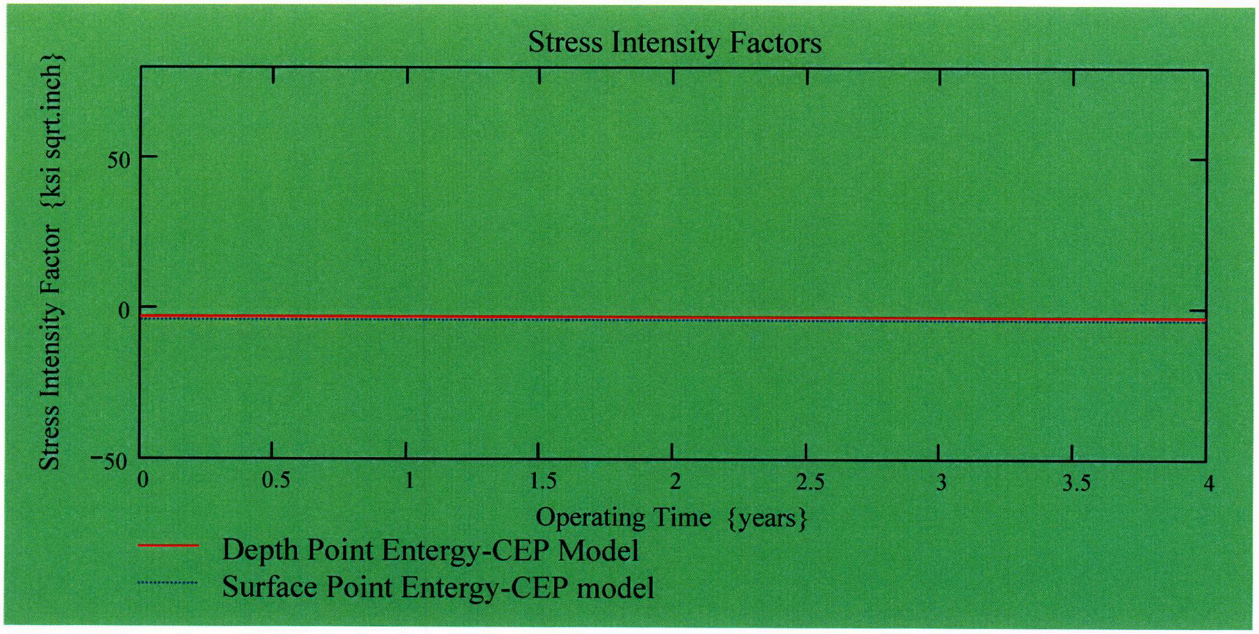
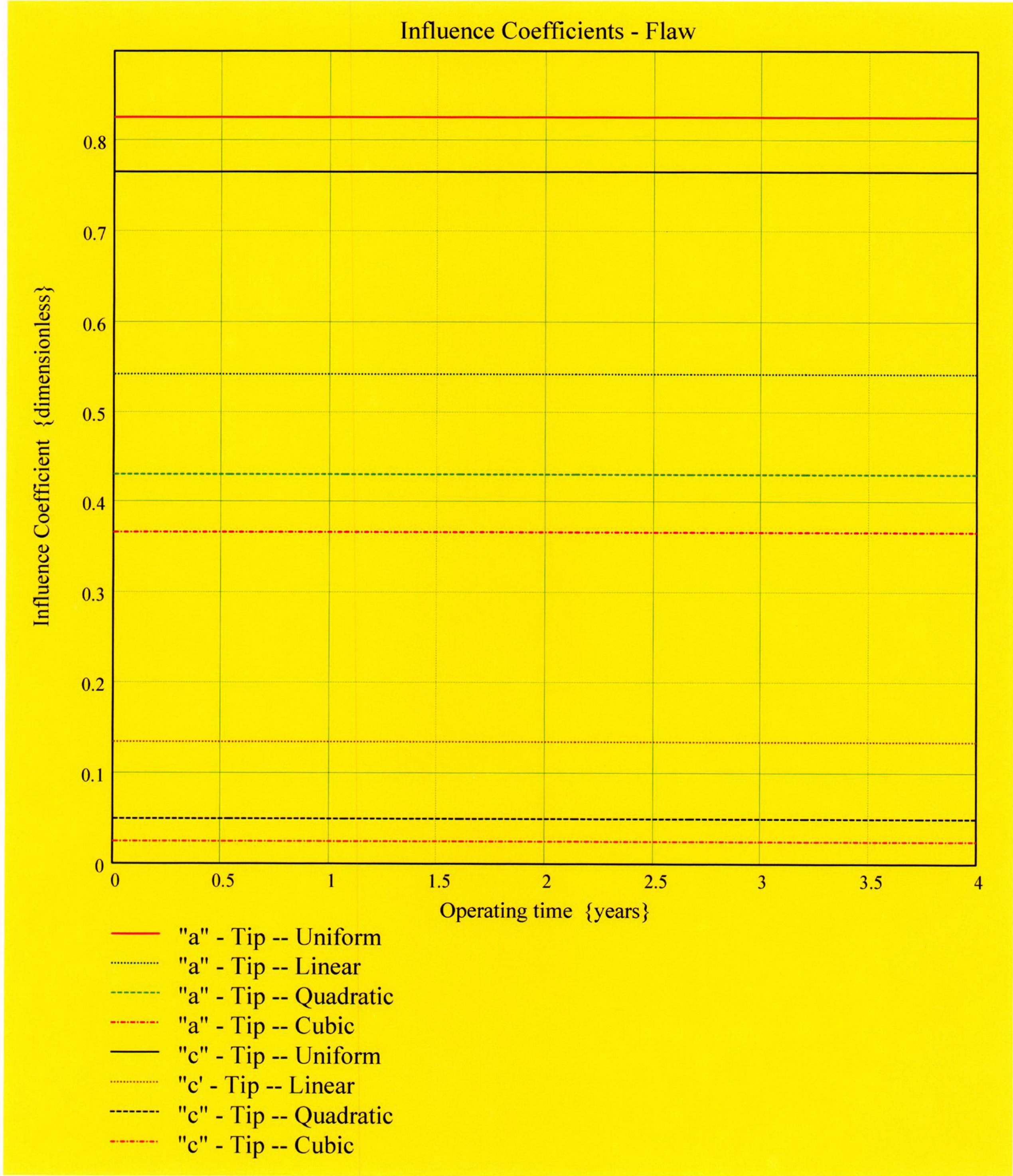
$Prop_{Length} = 3.456$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
50
0
−50
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {years}
Depth Point Entergy-CEP Model
Surface Point Entergy-CEP model


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating time {years}
"a" - Tip -- Uniform
"a" - Tip -- Linear
"a" - Tip -- Quadratic
"a" - Tip -- Cubic
"c" - Tip -- Uniform
"c' - Tip -- Linear
"c" - Tip -- Quadratic
"c" - Tip -- Cubic

$CGR_{sambi_{(k,8)}} =$

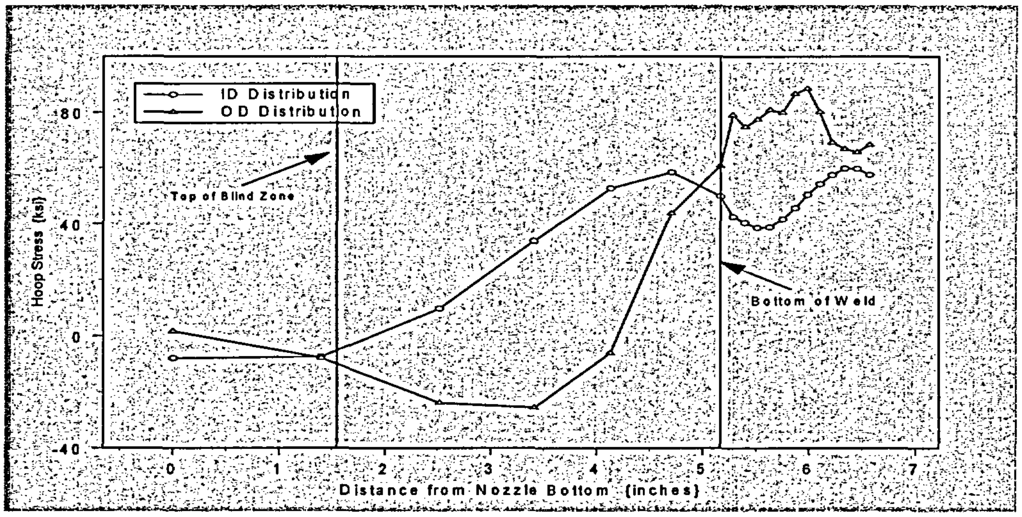
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

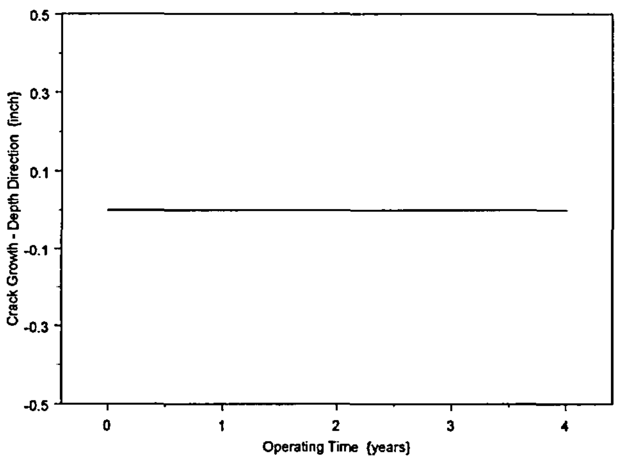
$CGR_{sambi_{(k,6)}} =$

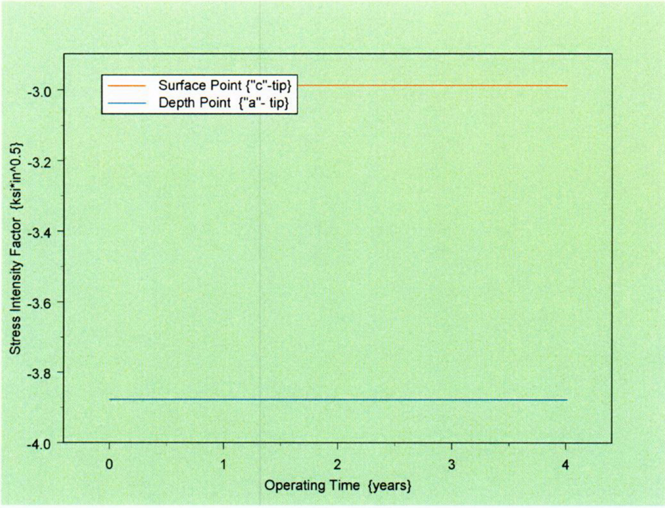
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878
-3.878

$CGR_{sambi_{(k,5)}} =$

-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988
-2.988


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress (ksi)
Distance from Nozzle Bottom (inches)


Crack Growth - Depth Direction (inch)
Operating Time (years)


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
-3.0
-3.2
-3.4
-3.6
-3.8
-4.0
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Through-wall flaw

Developed by Central Engineering Programs, Entergy Operations Inc.
Developed by: J. S. Brihmadesam **Verified by: B. C. Gray**

Note : Only for use when $R_{outside}/t$ is between 2.0 and 5.0 (Thick-wall Cylinder)

References :

1) ASME PVP paper PVP-350, Page 143; 1997 {Fracture Mechanics Model}
2) Crack Growth of Alloy 600 Base Metal in PWR Environments; EPRI MRP Report MRP 55 Rev. 1, 2002

Waterford Steam Electric Station Unit 3

Component : Reactor Vessel CEDM -"29.1"degree Nozzle, "180" Degree Azimuth 1.544 inch above Nozzle Bottom

Calculation Reference: MRP 75 th Percentile and Flaw Pressurized

Note : ***Used the Metric form of the equation from EPRI MRP 55-Rev. 1*** **.**
The correction is applied in the determination of the crack extension to obtain the value in inch/hr .

Through Wall Axial Flaw

The first Input is to locate the Reference Line (eg. top of the Blind Zone). The through-wall flaw "Upper Tip" is located at the Reference Line.

Enter the elevation of the Reference Line (eg. Blind Zone) above the nozzle bottom in inches.

BZ = 1.544   Location of Blind Zone above nozzle bottom (inch)

The Second Input is the Upper Limit for the evaluation, which is the bottom of the fillet weld leg. This is shown on the Excel spread sheet as weld bottom. Enter this dimension (measured from nozzle bottom) below.

$UL_{StrsDist}$ = 5.16   Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

The Highlighted Entries below remains constant for WSES-3 and should not be changed!

Input Data :-

$L := 0.25$	Initial Crack Length TW axial Based on Stress Distribution. Bottom end of Crack to be set @ approximately 10ksi.
$od := 4.05$	Tube OD
$id := 2.728$	Tube ID
$P_{Int} := 2.235$	Design Operating Pressure (internal)
$Years := 4$	Number of Operating Years
$I_{lim} := 1500$	Iteration limit for Crack Growth loop
$T := 604$	Estimate of Operating Temperature
$\nu := 0.307$	Poissons ratio @ 600 F
$\alpha_{0c} := 2.67 \cdot 10^{-12}$	Constant in MRP PWSCG Model for I-600 Wrought @ 617 deg F
$Q_g := 31.0$	Thermal activation Energy for Crack Growth (MRP)
$T_{ref} := 617$	Reference Temperature for normalizing Data deg F

$$C_0 := e^{\left[\frac{-Q_g}{1.103 \cdot 10^{-3}} \cdot \left(\frac{1}{T+459.67} - \frac{1}{T_{ref}+459.67}\right)\right]} \cdot \alpha_{0c} \qquad Tim_{opr} := Years \cdot 365 \cdot 24$$

$$R_o := \frac{od}{2} \qquad R_i := \frac{id}{2} \qquad t := R_o - R_i \qquad R_m := R_i + \frac{t}{2} \qquad CF_{inhr} := 1.417 \cdot 10^5$$

$$C_{blk} := \frac{Tim_{opr}}{I_{lim}} \qquad Prnt_{blk} := \left|\frac{I_{lim}}{50}\right| \qquad l := \frac{L}{2}$$

Stress Distribution in the tube. The outside surface is the reference surface for all analysis in accordance with the reference.

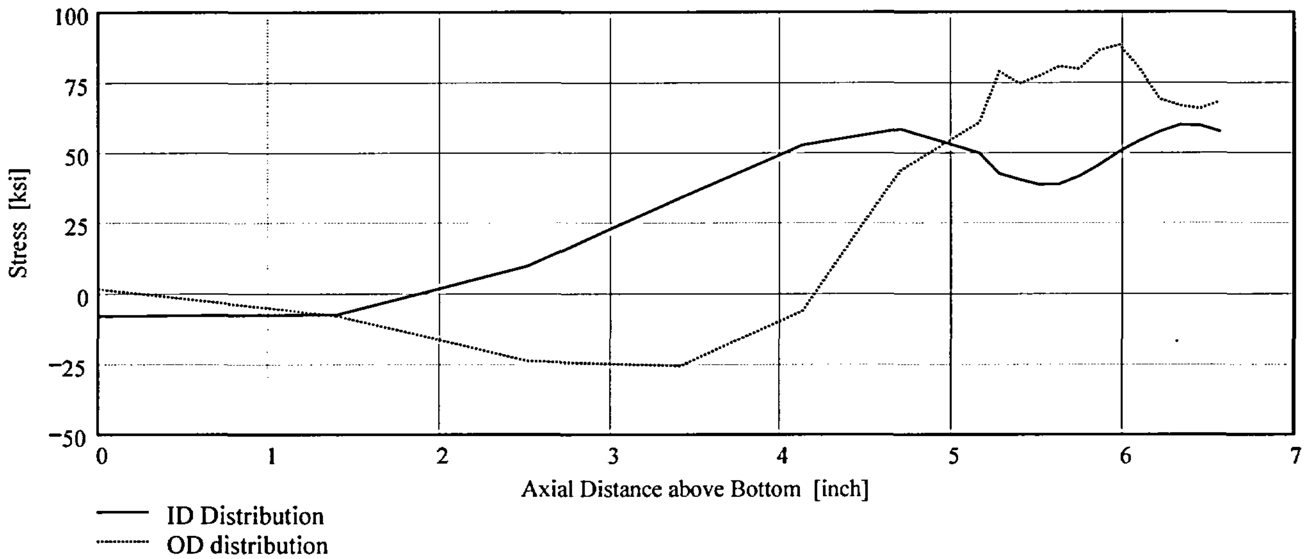
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Column "0" = Axial distance from Minimum to Maximum recorded on the data sheet (inches)
Column "1" = ID Stress data at each Elevation (ksi)
Column "5" = OD Stress data at each Elevation (ksi)

$Data_{All} :=$

	0	1	2	3	4	5
0	0	-7.86	-4.21	-2.26	-0.33	1.66
1	1.4	-7.37	-7.03	-7.47	-7.78	-7.78
2	2.51	9.69	1.33	-9.45	-17.45	-23.77
3	3.41	33.86	32.36	12.26	-12.43	-25.5
4	4.13	52.72	49.98	44.3	16.3	-6.04
5	4.7	58.42	51.45	44.99	43.35	43.69
6	5.16	49.9	49.61	50.98	60.47	60.78
7	5.28	42.5	47.8	56.69	75.7	78.96
8	5.39	40.41	46.01	60.82	78.52	74.75
9	5.51	38.57	45.68	61.29	79.5	77.41

$AllAxl := Data_{All}^{\langle 0 \rangle}$ $AllID := Data_{All}^{\langle 1 \rangle}$ $AllOD := Data_{All}^{\langle 5 \rangle}$



Observing the stress distribution select the region in the table above labeled $Data_{All}$ that represents the region of interest. This needs to be done especially for distributions that have a large compressive stress at the nozzle bottom and high tensile stresses at the J-weld location. Copy the selection in the above table, click on the "Data" statement below and delete it from the edit menu. Type "Data and the Mathcad "equal" sign (Shift-Colon) then insert the same to the right of the Mathcad Equals sign below (paste symbol).

$$Data := \begin{pmatrix} 0 & -7.856 & -4.209 & -2.262 & -0.333 & 1.664 \\ 1.395 & -7.372 & -7.026 & -7.468 & -7.776 & -7.782 \\ 2.513 & 9.689 & 1.331 & -9.445 & -17.448 & -23.769 \\ 3.408 & 33.861 & 32.362 & 12.257 & -12.427 & -25.502 \\ 4.125 & 52.72 & 49.983 & 44.295 & 16.295 & -6.038 \\ 4.7 & 58.423 & 51.453 & 44.992 & 43.352 & 43.691 \\ 5.16 & 49.9 & 49.607 & 50.983 & 60.468 & 60.778 \\ 5.277 & 42.502 & 47.798 & 56.694 & 75.697 & 78.963 \end{pmatrix}$$

$Axl := Data^{\langle 0 \rangle}$ $\quad ID := Data^{\langle 1 \rangle}$ $\quad OD := Data^{\langle 5 \rangle}$

$R_{ID} := regress(Axl, ID, 3)$ $\quad R_{OD} := regress(Axl, OD, 3)$

$FL_{Cntr} := BZ - 1$ Flaw Center above Nozzle Bottom

$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

No User Input required beyond this Point

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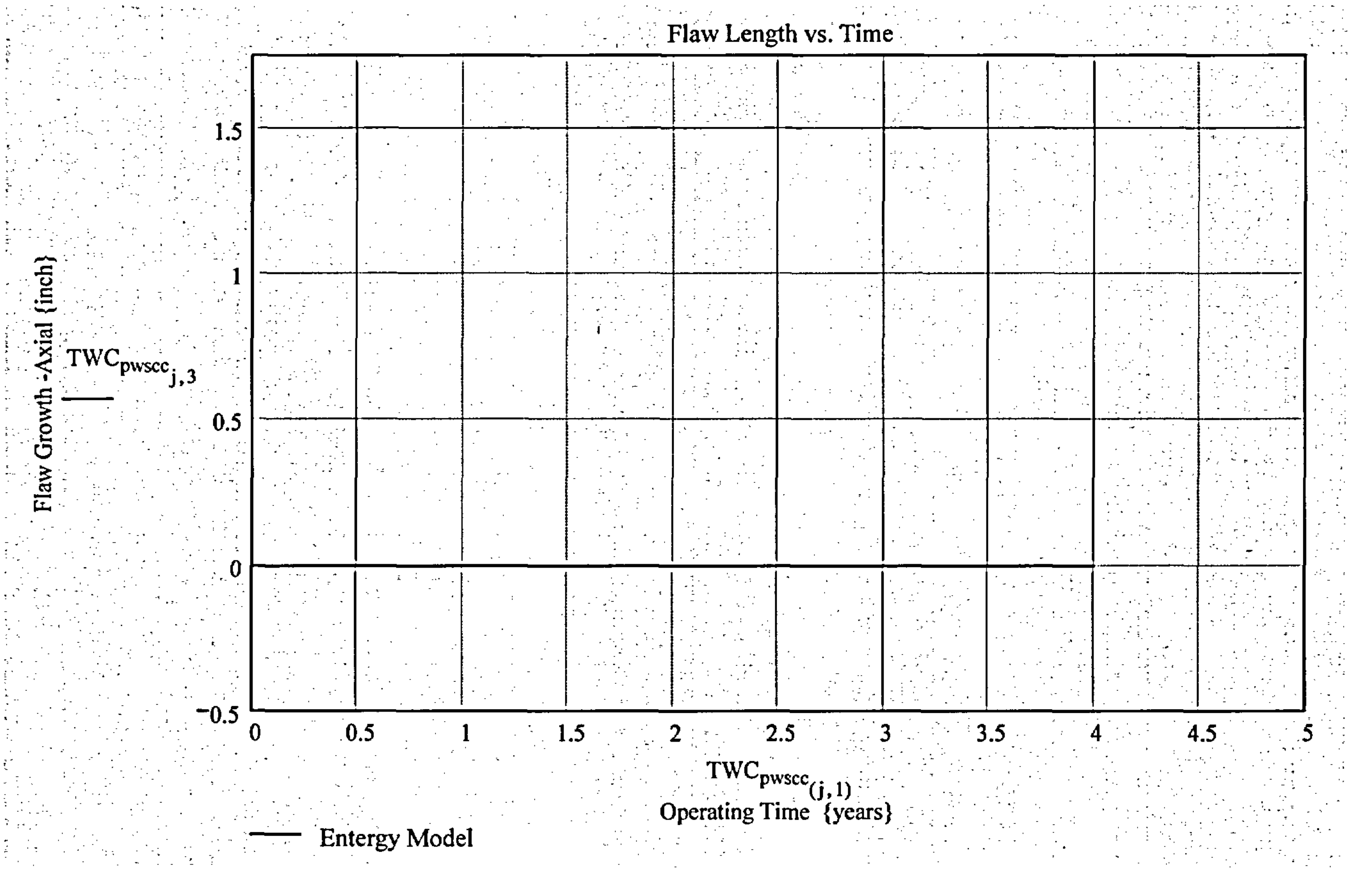
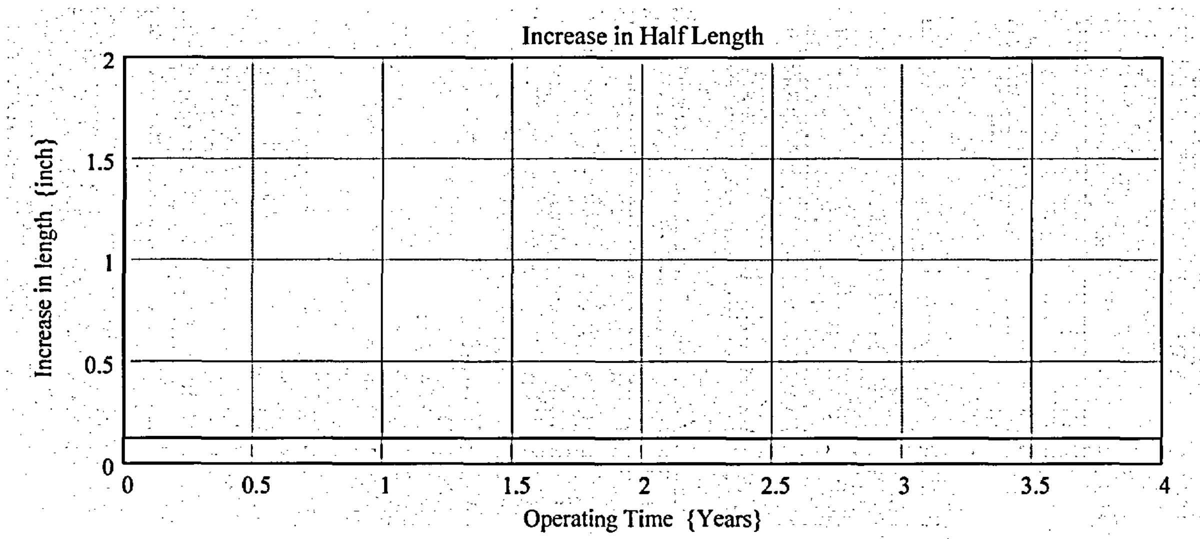
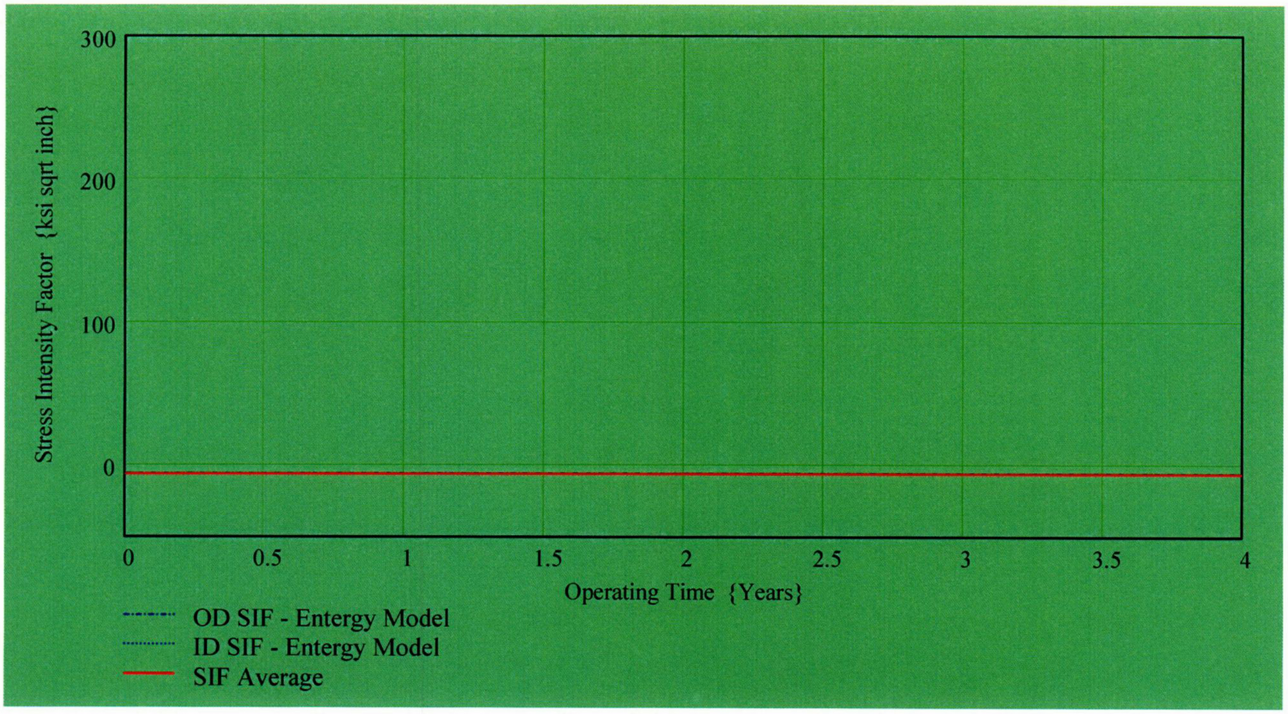
$Prop_{Length} = 3.616$






300
200
100
0
Stress Intensity Factor {ksi sqrt inch}
0
0.5
1
1.5
2
2.5
3
3.5
4
Operating Time {Years}
OD SIF - Entergy Model
ID SIF - Entergy Model
SIF Average

$TWC_{pwscc_{(j,6)}} =$

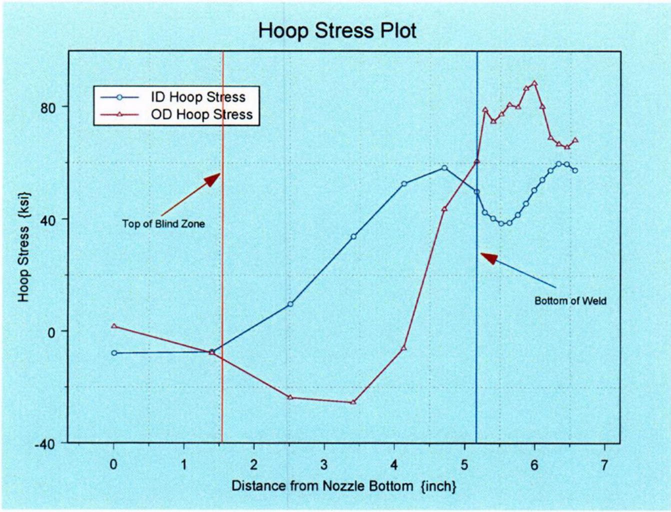
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647
-5.647

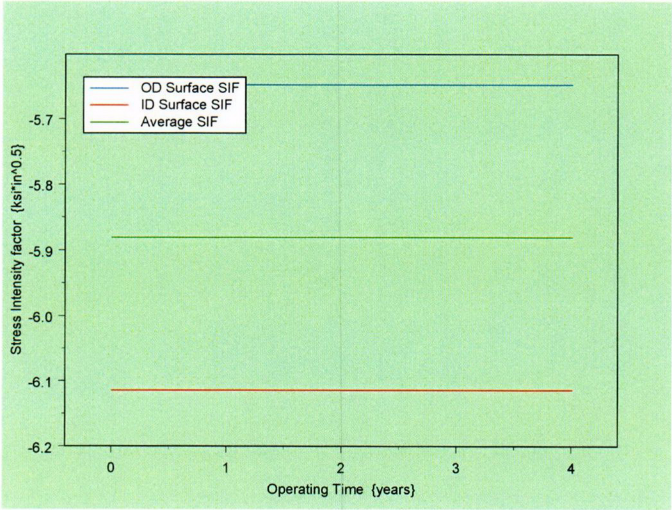
$TWC_{pwscc_{(j,7)}} =$

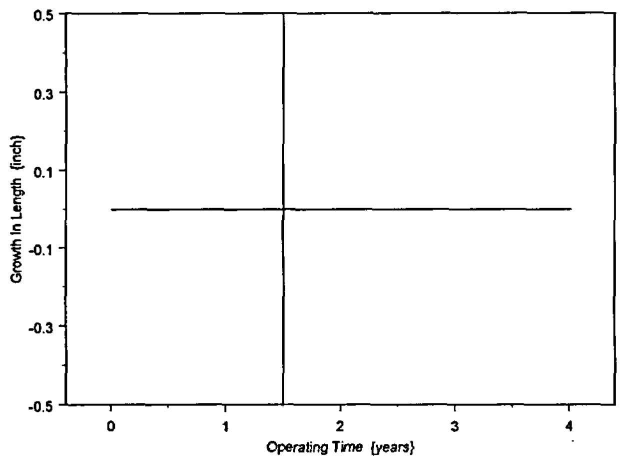
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114
-6.114

$TWC_{pwscc_{(j,8)}} =$

-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954
-5.954


Hoop Stress Plot
ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Bottom of Weld
Hoop Stress {ksi}
Distance from Nozzle Bottom {inch}


OD Surface SIF
ID Surface SIF
Average SIF
Stress Intensity factor {ksi*in^0.5}
Operating Time {years}


0.5
0.3
0.1
-0.1
-0.3
-0.5
Growth In Length (inch)
0
1
2
3
4
Operating Time (years)