Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"0" Degree Nozzle, All 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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).

$$Val := 2$$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 1.796$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$ Initial Flaw Length

$a_0 := 0.661 \cdot 0.12$ 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

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

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

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

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

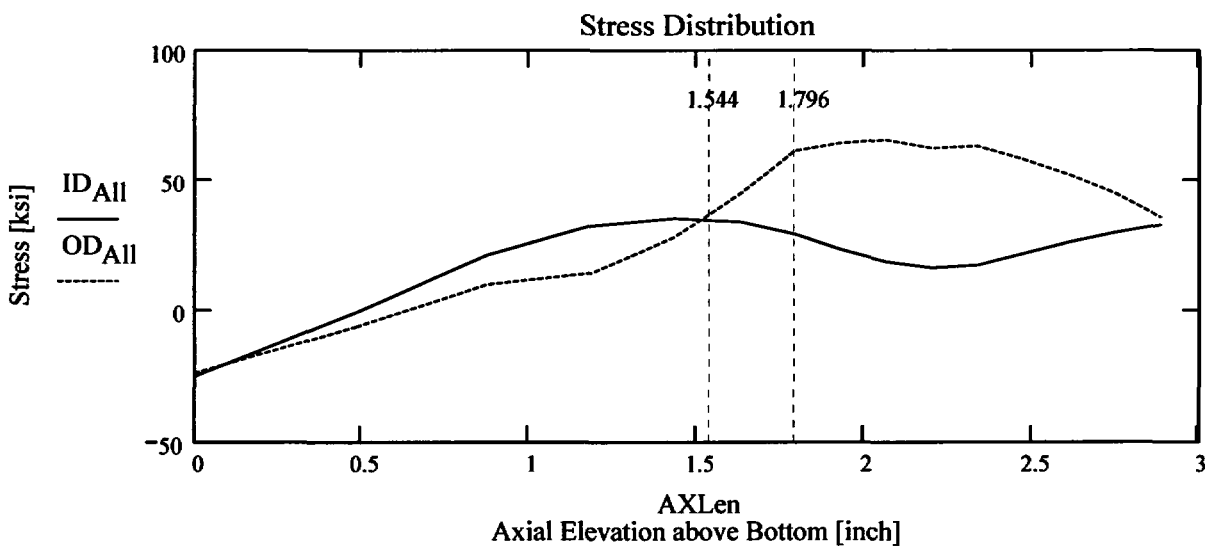
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum 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	-25.09	-27.55	-27.79	-25.62	-23.76
1	0.49	-0.56	-0.54	-2.11	-4.85	-6.16
2	0.87	21.52	18.64	17.12	14.84	10.09
3	1.19	32.75	28.49	24.14	19.64	14.45
4	1.44	35.67	29.6	26.17	25.59	28.42
5	1.64	34.24	29.57	28.29	35.41	45.38
6	1.8	29.45	29.81	31.39	43.34	61.71
7	1.93	23.67	26.5	33.26	47.61	64.65
8	2.07	18.93	24.56	33.97	49.07	65.88
9	2.2	16.54	22.85	34.79	49.52	62.8

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



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. 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).

$$Data := \begin{pmatrix} 0 & -25.088 & -27.546 & -27.787 & -25.624 & -23.763 \\ 0.485 & -0.563 & -0.539 & -2.111 & -4.851 & -6.157 \\ 0.874 & 21.515 & 18.635 & 17.122 & 14.843 & 10.089 \\ 1.186 & 32.751 & 28.494 & 24.136 & 19.645 & 14.45 \\ 1.436 & 35.667 & 29.598 & 26.166 & 25.589 & 28.417 \\ 1.635 & 34.244 & 29.574 & 28.286 & 35.408 & 45.379 \\ 1.796 & 29.45 & 29.814 & 31.385 & 43.337 & 61.713 \\ 1.932 & 23.674 & 26.502 & 33.261 & 47.609 & 64.65 \\ 2.068 & 18.928 & 24.564 & 33.968 & 49.071 & 65.876 \end{pmatrix}$$

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

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

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

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

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

Flaw center Location Location above Nozzle Bottom

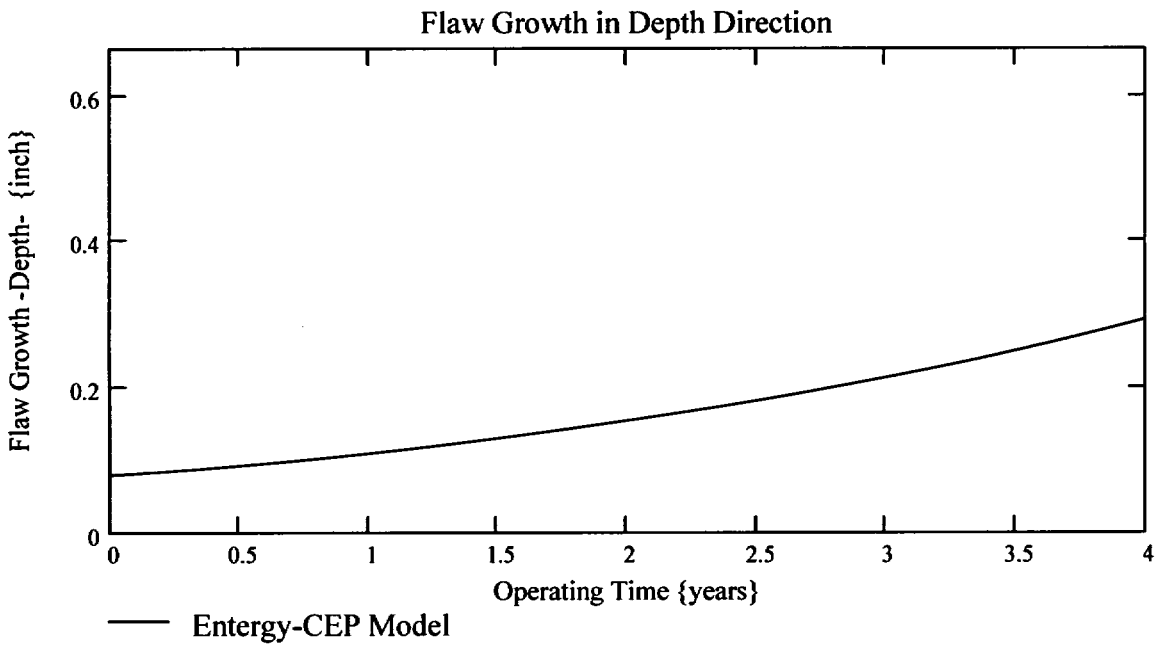
$U_{Tip} := FL_{Cntr} + c_0$

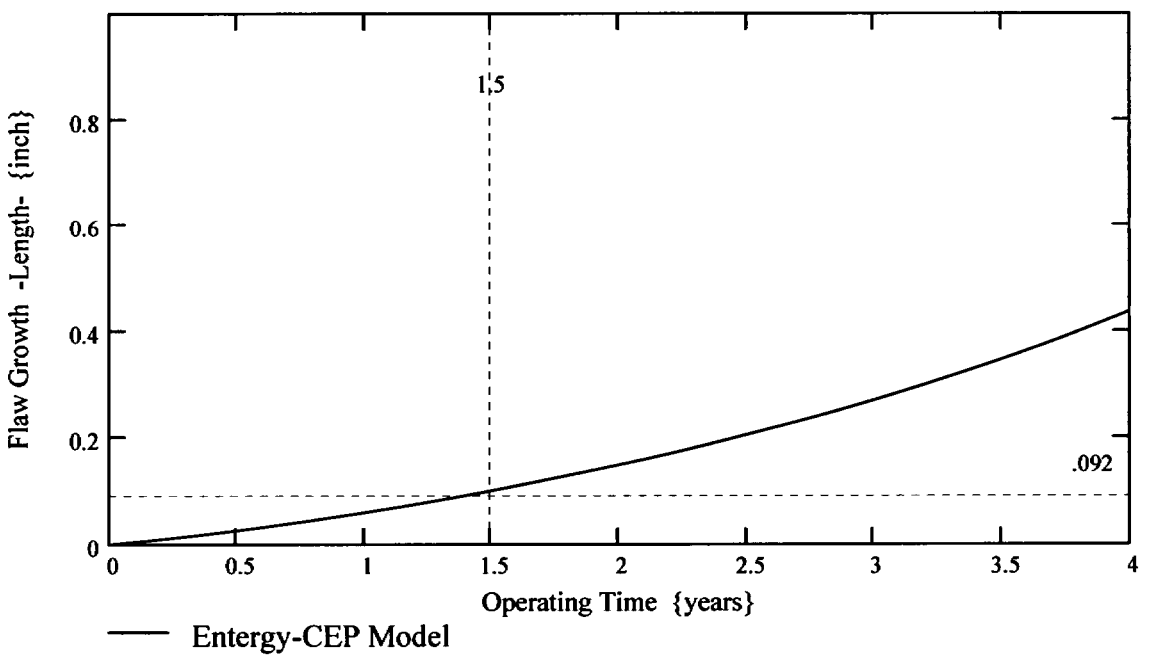
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

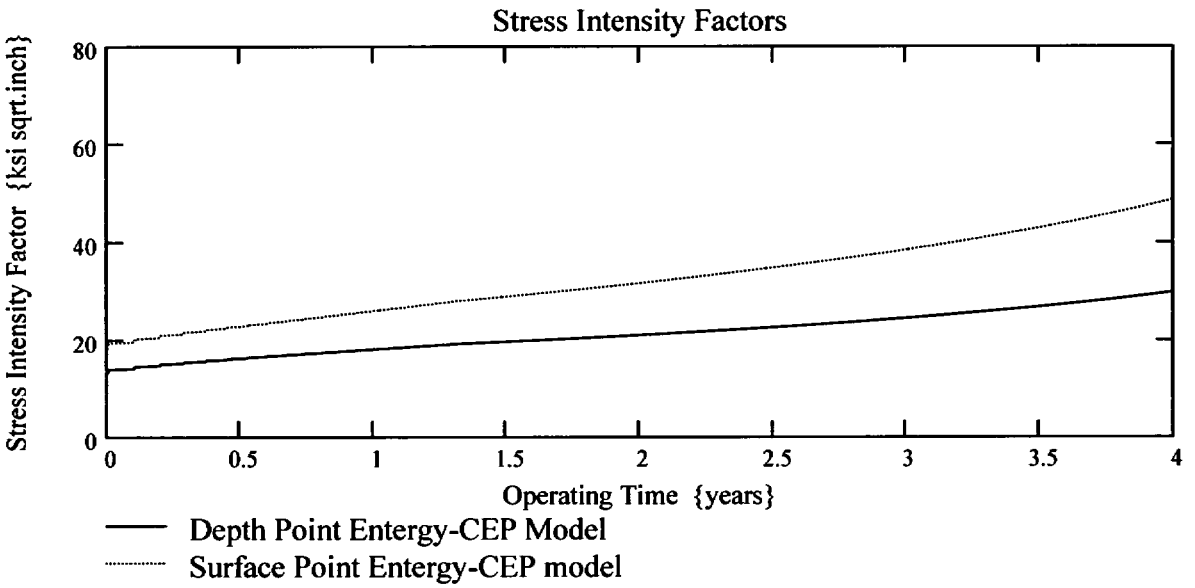
No User Input is required beyond this Point

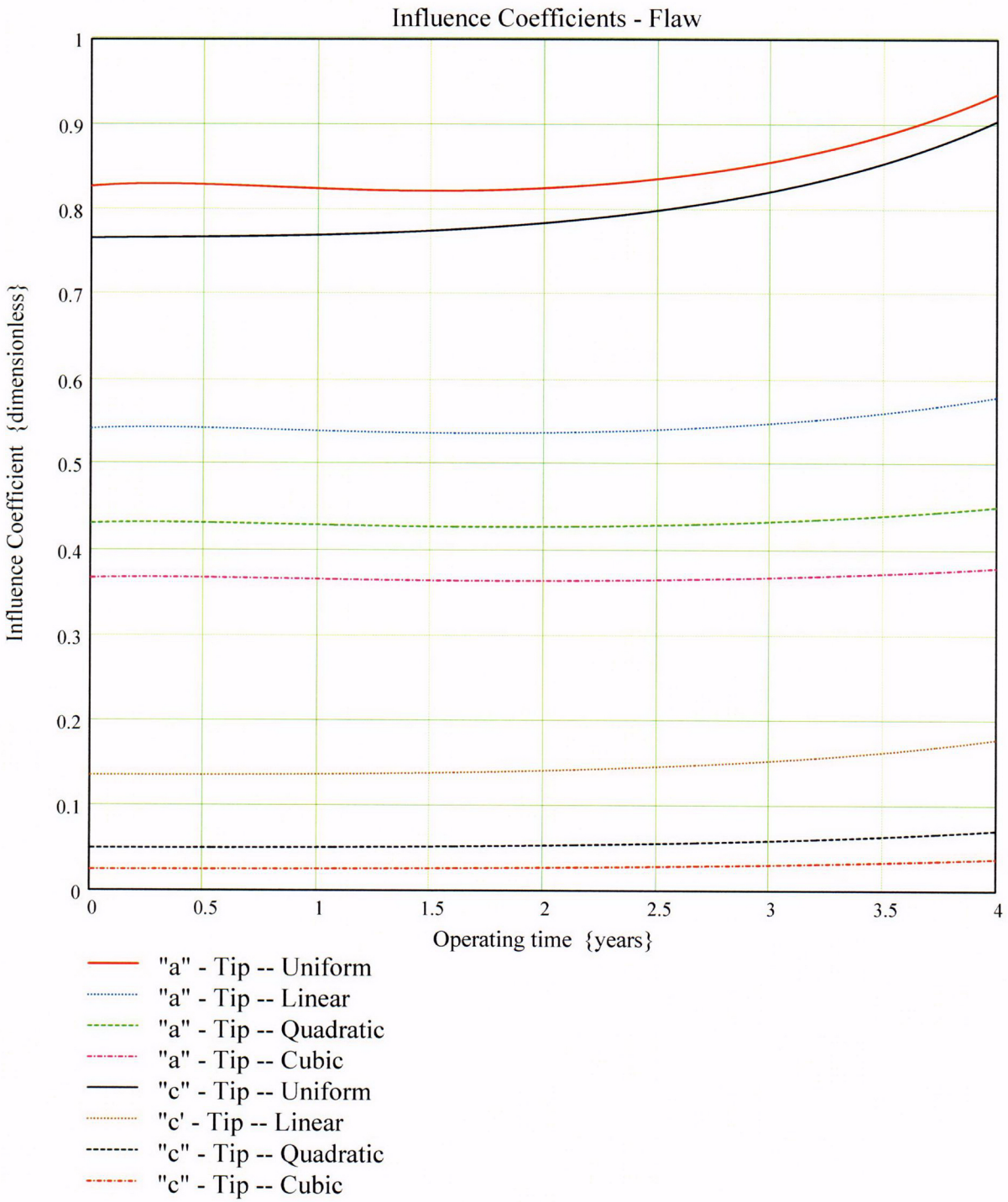
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.092$






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


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
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

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

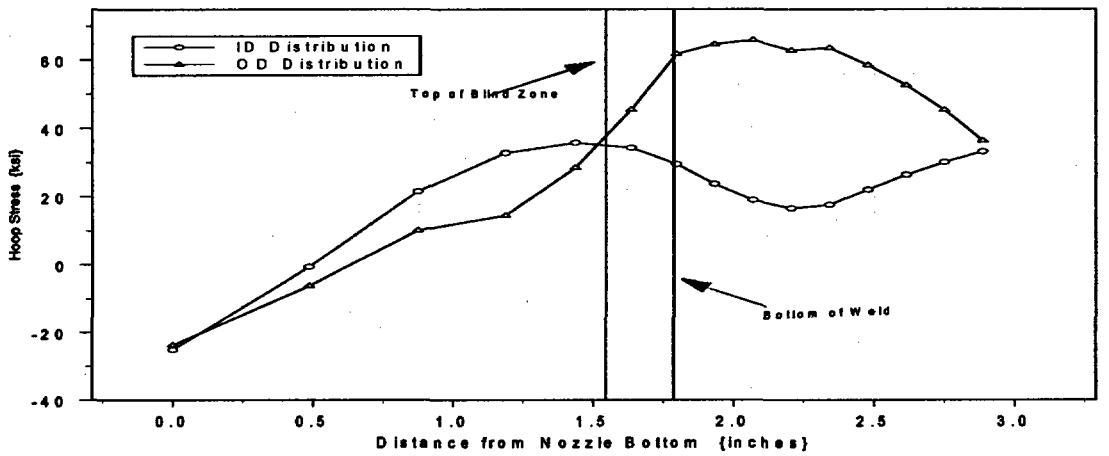
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

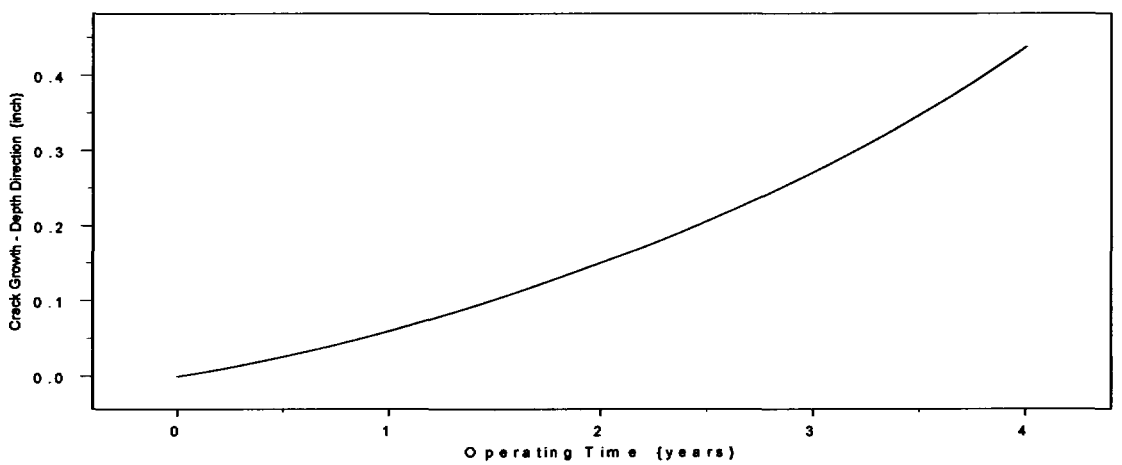
$CGR_{sambi_{(k,6)}}$ =

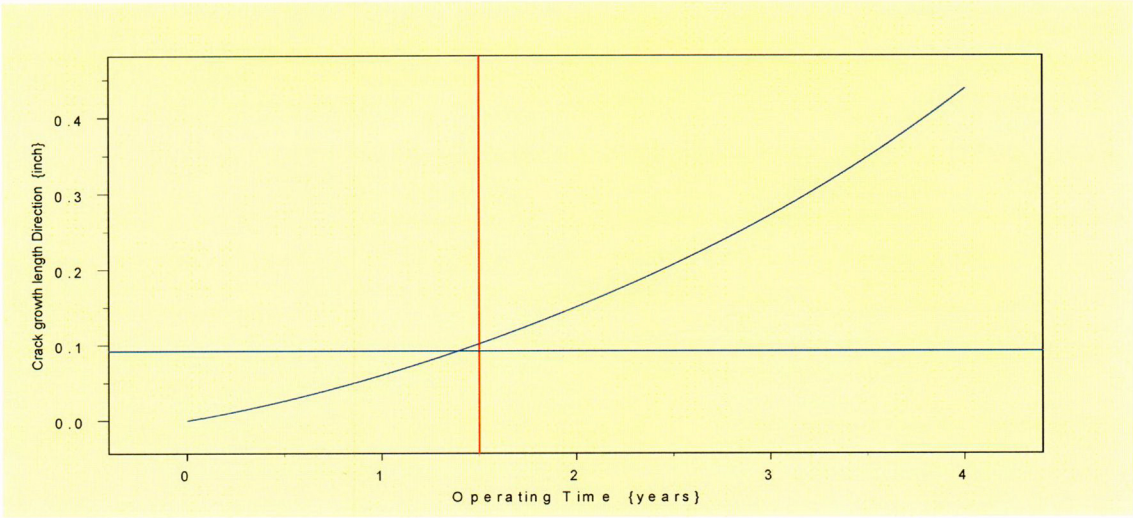
18.307
19.315
19.322
19.33
19.337
19.344
19.352
19.359
19.366
19.374
19.381
19.388
19.396
19.403
19.41
19.417

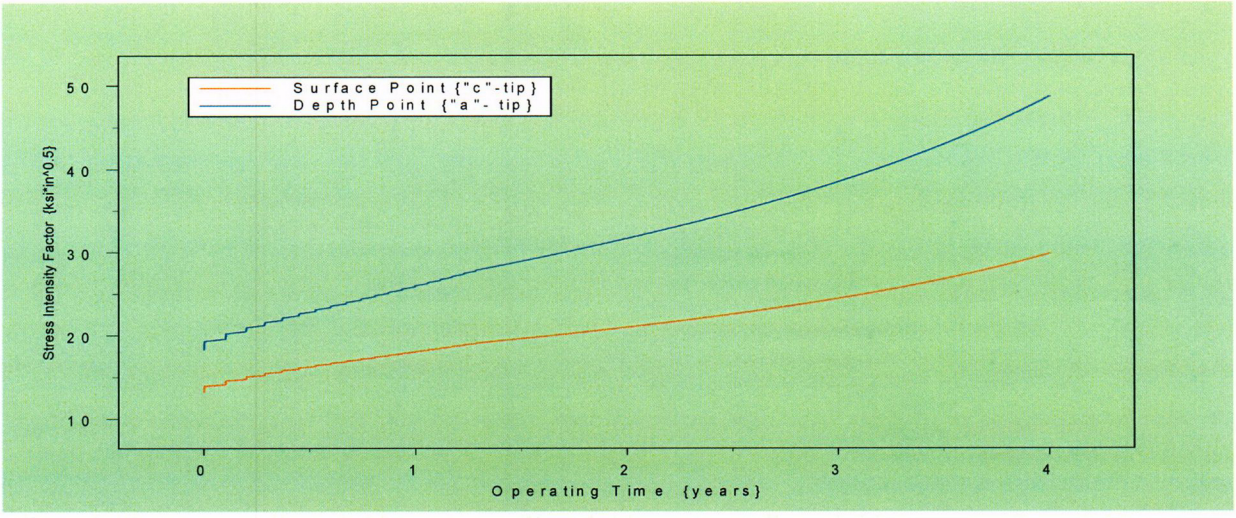
$CGR_{sambi_{(k,5)}}$ =

13.252
13.936
13.941
13.946
13.951
13.956
13.962
13.967
13.972
13.977
13.982
13.988
13.993
13.998
14.003
14.008


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress (ksi)
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Distance from Nozzle Bottom (inches)


Crack Growth - Depth Direction (inch)
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
Operating Time (years)


Crack growth length Direction {inch}
0.0
0.1
0.2
0.3
0.4
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
10
20
30
40
50
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"0"degree Nozzle, All 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 throughwall 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.

$UL_{Strs.Dist} := 1.796$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := .794$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	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 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.

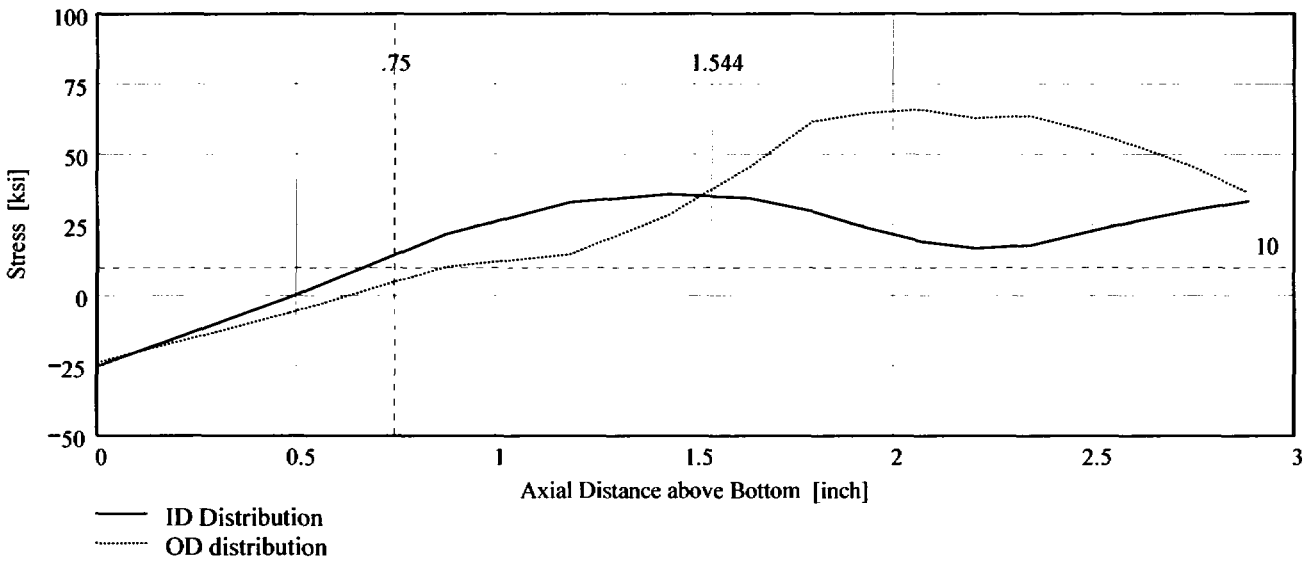
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "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	-25.09	-27.55	-27.79	-25.62	-23.76
1	0.49	-0.56	-0.54	-2.11	-4.85	-6.16
2	0.87	21.52	18.64	17.12	14.84	10.09
3	1.19	32.75	28.49	24.14	19.64	14.45
4	1.44	35.67	29.6	26.17	25.59	28.42
5	1.64	34.24	29.57	28.29	35.41	45.38
6	1.8	29.45	29.81	31.39	43.34	61.71
7	1.93	23.67	26.5	33.26	47.61	64.65
8	2.07	18.93	24.56	33.97	49.07	65.88
9	2.2	16.54	22.85	34.79	49.52	62.8
10	2.34	17.56	22.68	33.81	47.49	63.56

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



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).

$$Data := \begin{pmatrix} 0 & -25.088 & -27.546 & -27.787 & -25.624 & -23.763 \\ 0.485 & -0.563 & -0.539 & -2.111 & -4.851 & -6.157 \\ 0.874 & 21.515 & 18.635 & 17.122 & 14.843 & 10.089 \\ 1.186 & 32.751 & 28.494 & 24.136 & 19.645 & 14.45 \\ 1.436 & 35.667 & 29.598 & 26.166 & 25.589 & 28.417 \\ 1.635 & 34.244 & 29.574 & 28.286 & 35.408 & 45.379 \\ 1.796 & 29.45 & 29.814 & 31.385 & 43.337 & 61.713 \\ 1.932 & 23.674 & 26.502 & 33.261 & 47.609 & 64.65 \\ 2.068 & 18.928 & 24.564 & 33.968 & 49.071 & 65.876 \\ 2.204 & 16.541 & 22.854 & 34.789 & 49.525 & 62.795 \end{pmatrix}$$

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

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

$FL_{Cntr} := BZ - I$ 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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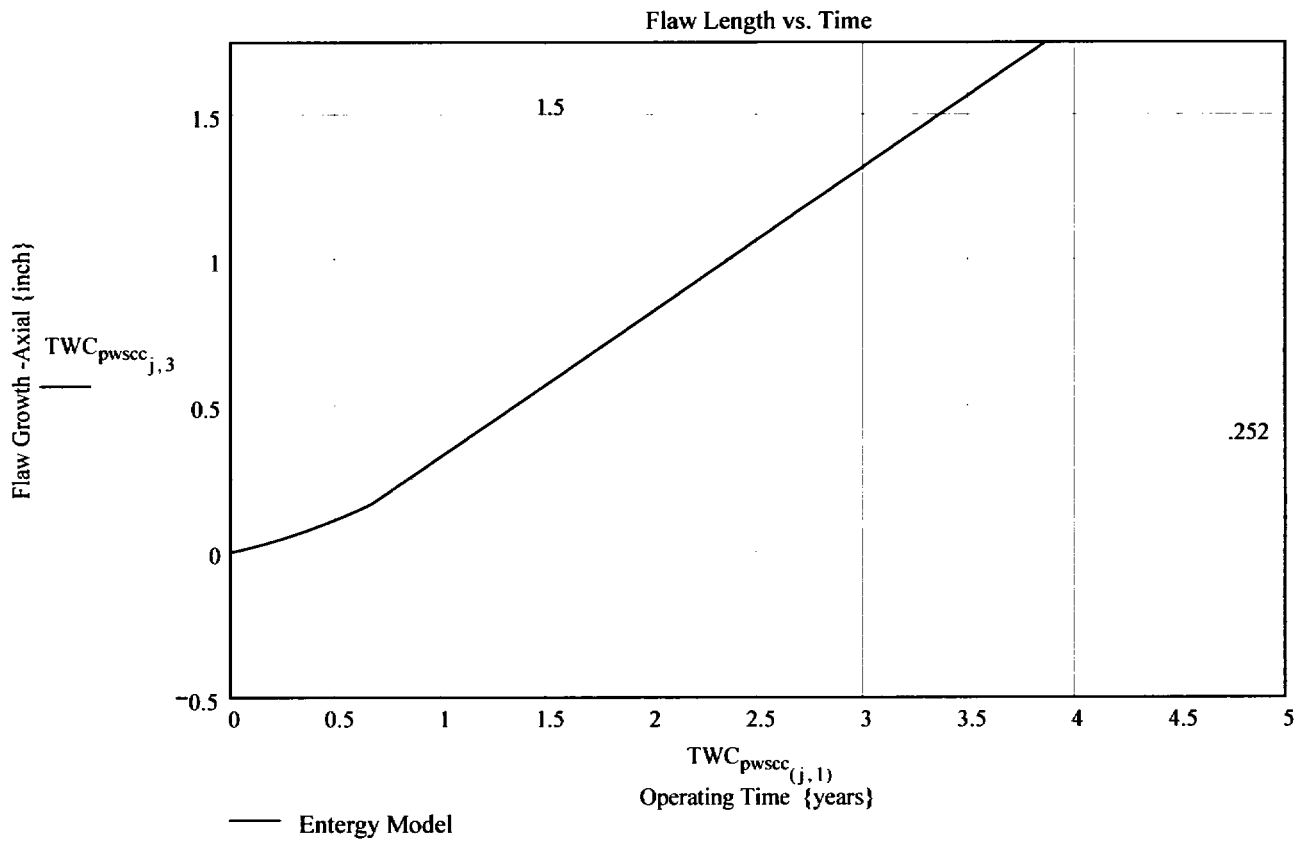
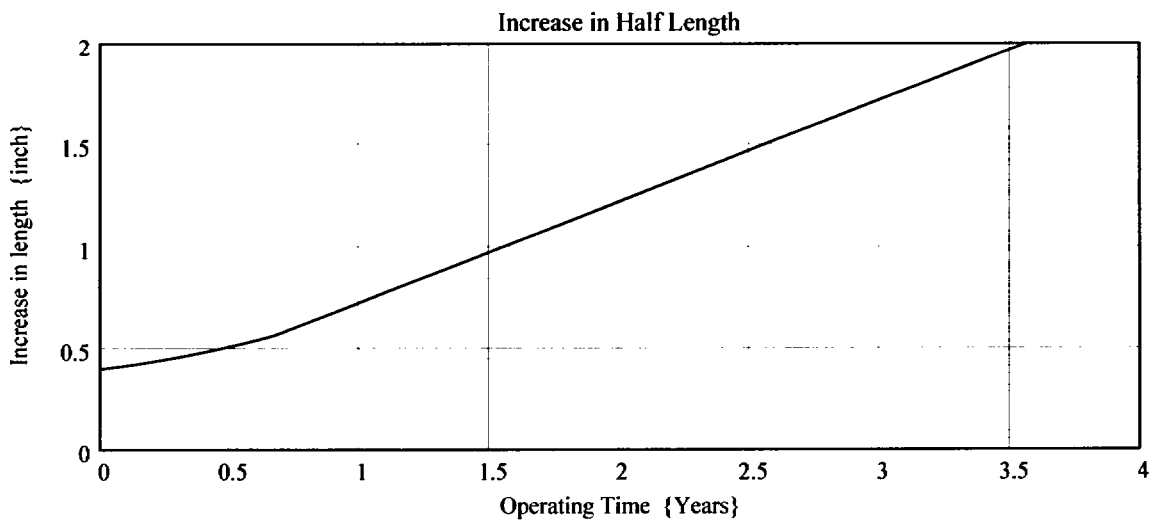
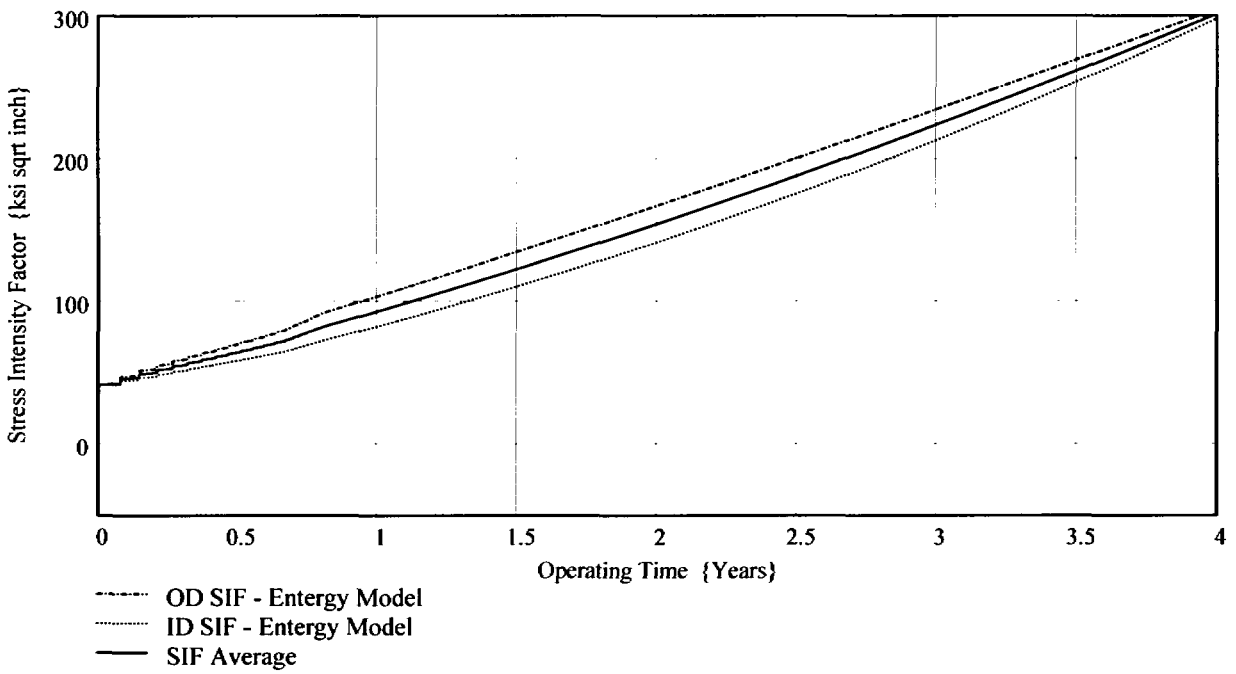
$Prop_{Length} = 0.252$






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

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

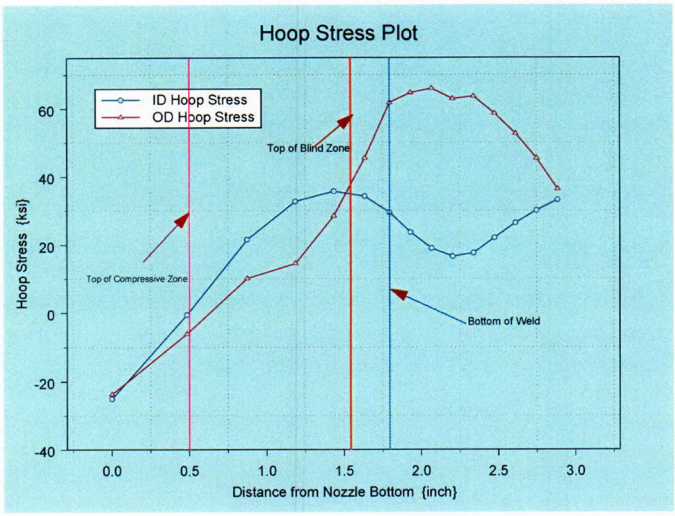
35.366
42.321
42.355
42.39
42.424
42.459
42.494
42.528
42.563
42.598
42.633
42.668
42.702
42.737
42.772
42.807

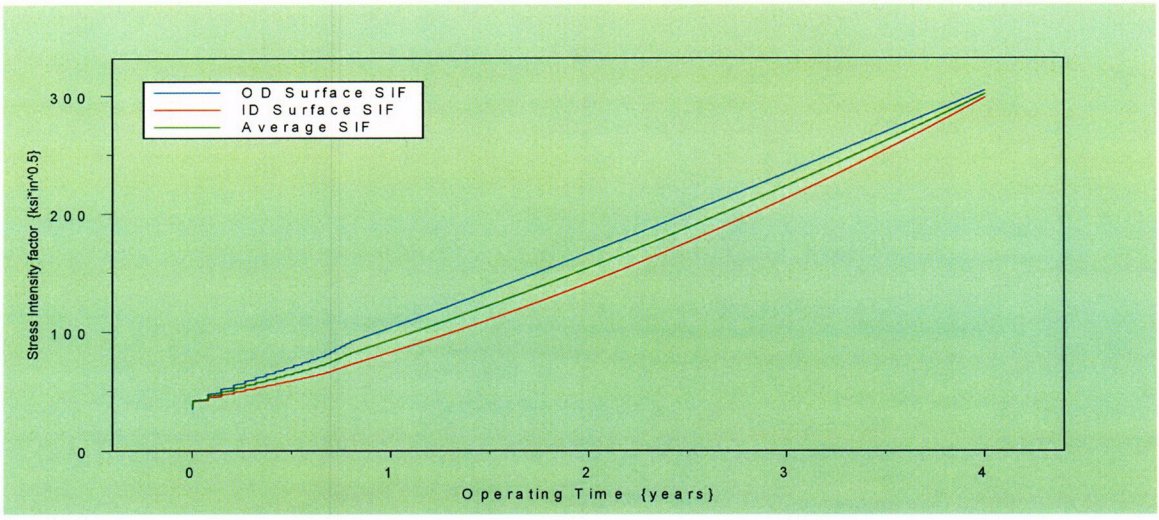
$TWC_{pwscc_{(j,7)}}$ =

37.917
41.494
41.524
41.555
41.586
41.616
41.647
41.678
41.708
41.739
41.77
41.801
41.832
41.863
41.894
41.925

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

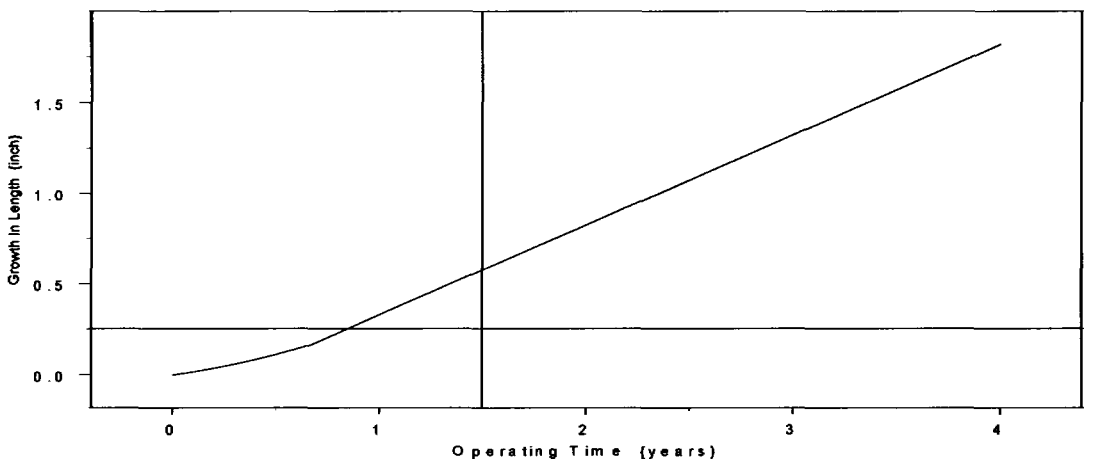
38.137
43.512
43.547
43.582
43.617
43.652
43.687
43.723
43.758
43.793
43.828
43.864
43.899
43.934
43.97
44.005





Developed by: *Verified by:*

C03


Growth in Length (inch)
1.5
1.0
0.5
0.0
0
1
2
3
4
Operating Time (years)

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

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8" Degree Nozzle, Downhill 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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.

$UL_{Strs.Dist} := 1.786$ Upper axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom).

Input Data :-

$L := 0.32$ Initial Flaw Length (Twice detectable length)

$a_0 := 0.661 \cdot 0.07$ Initial Flaw Depth (Minimum Detecteble Depth was 5% TW)

$od := 4.05$ 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

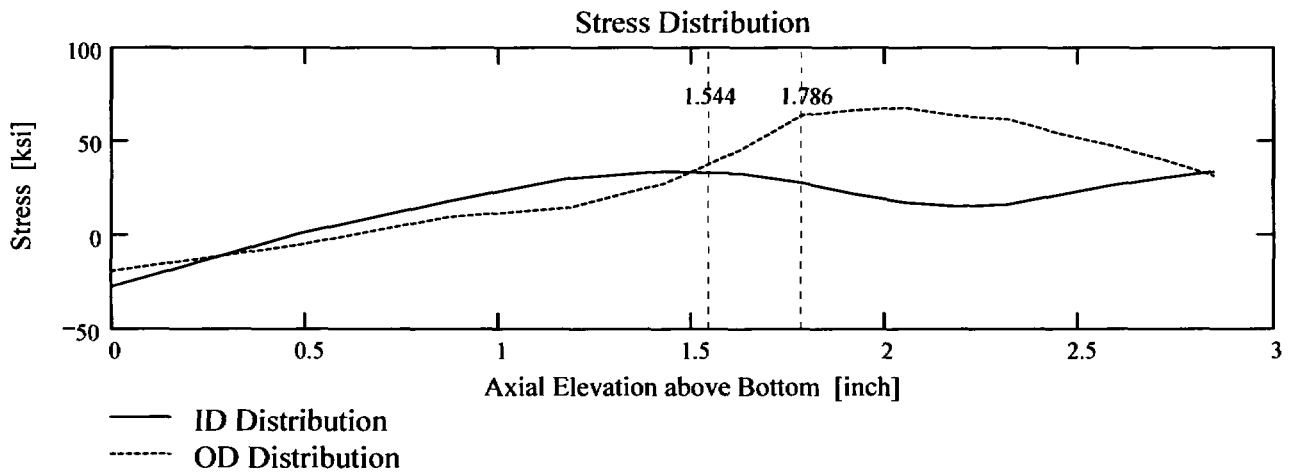
Stress Input Data

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)
Cloumn "2" = Quarter Thickness Stress data at each Elevation (ksi)
Cloumn "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	-27.4	-24.36	-22.21	-20.41	-18.98
1	0.48	0.63	-1.49	-3.6	-4.44	-5.27
2	0.87	17.66	16.42	14.61	12.41	9.38
3	1.18	29.8	26.05	22.72	18.95	14.2
4	1.43	33.62	27.79	24.8	24.32	26.99
5	1.63	32.36	28.47	27.59	34.28	45.1
6	1.79	27.39	28.92	31.39	43.88	63.72
7	1.92	21.5	25.56	33.55	48.09	66.36
8	2.05	16.94	23.79	34.06	49.47	67.67
9	2.18	14.83	22.26	34.78	49.05	63.38

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



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. Higlight 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 mosue 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 dtat 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.

$$Data := \begin{pmatrix} 0 & -27.404 & -24.356 & -22.209 & -20.407 & -18.978 \\ 0.483 & 0.633 & -1.486 & -3.599 & -4.44 & -5.268 \\ 0.87 & 17.665 & 16.422 & 14.61 & 12.415 & 9.376 \\ 1.18 & 29.798 & 26.049 & 22.723 & 18.95 & 14.201 \\ 1.428 & 33.623 & 27.792 & 24.8 & 24.321 & 26.989 \\ 1.627 & 32.364 & 28.469 & 27.591 & 34.284 & 45.104 \\ 1.786 & 27.394 & 28.918 & 31.388 & 43.882 & 63.718 \\ 1.919 & 21.498 & 25.556 & 33.55 & 48.089 & 66.365 \\ 2.051 & 16.944 & 23.793 & 34.064 & 49.472 & 67.672 \\ 2.183 & 14.834 & 22.263 & 34.779 & 49.055 & 63.377 \end{pmatrix}$$

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

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

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

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

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

Flaw center Location above Nozzle Bottom

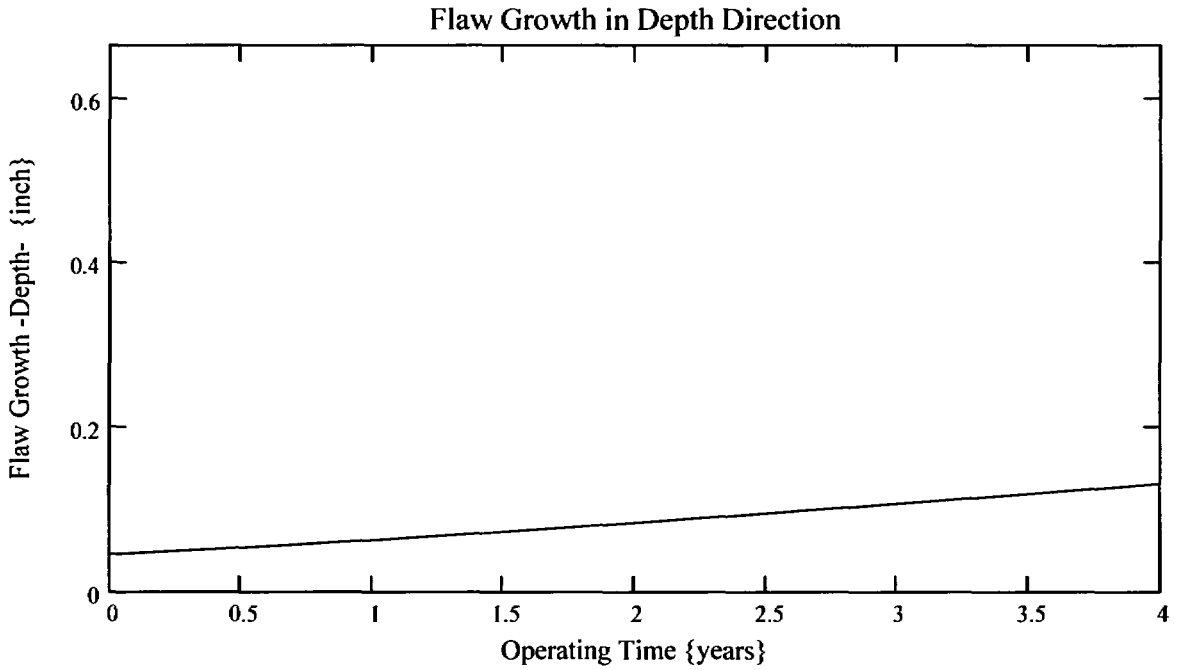
$$U_{Tip} := FL_{Cntr} + c_0$$

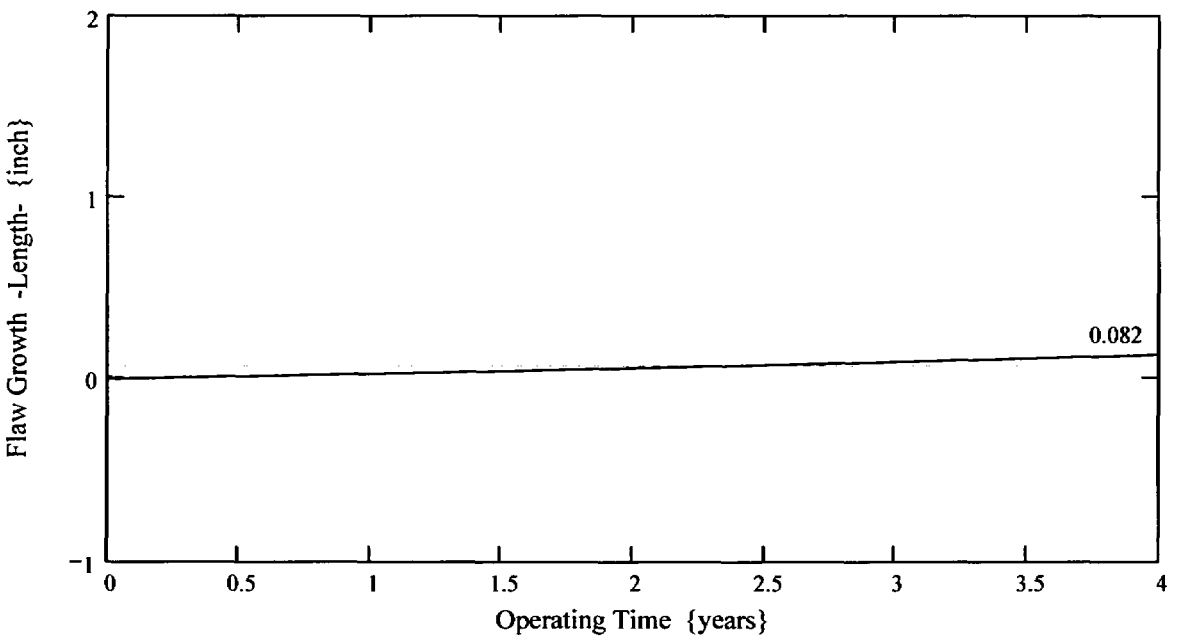
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

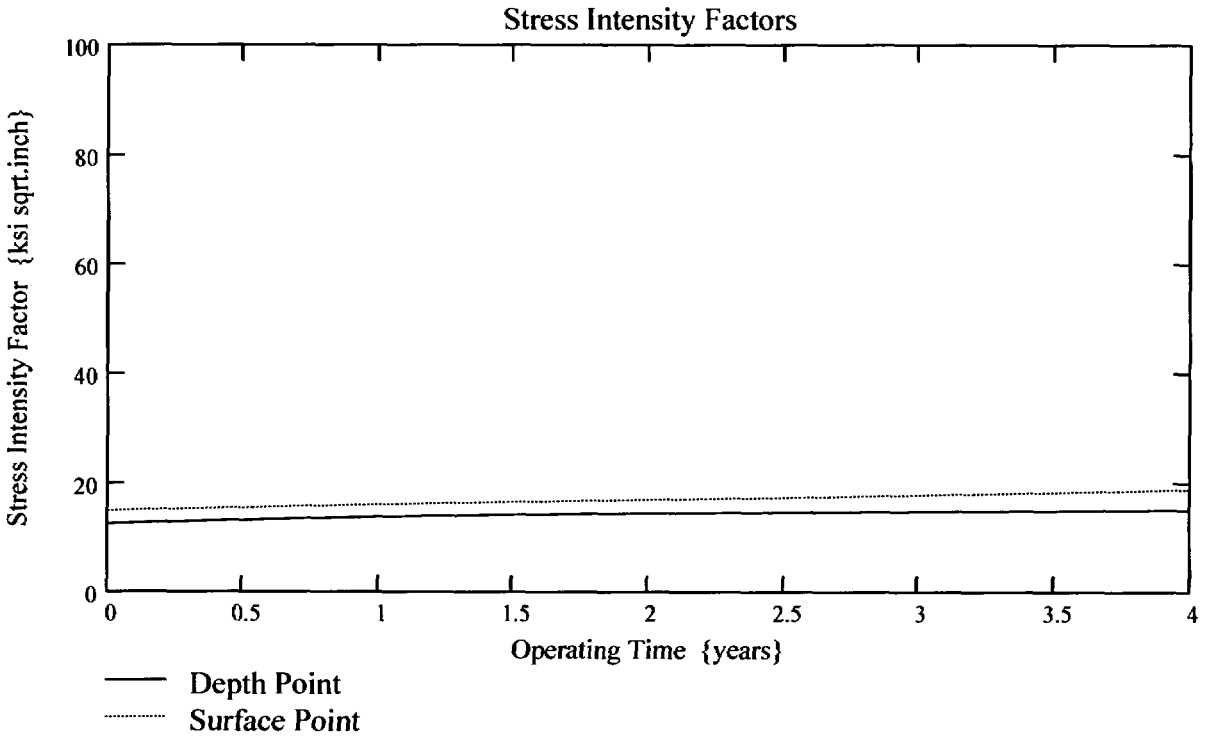
No User Input is required beyond this Point

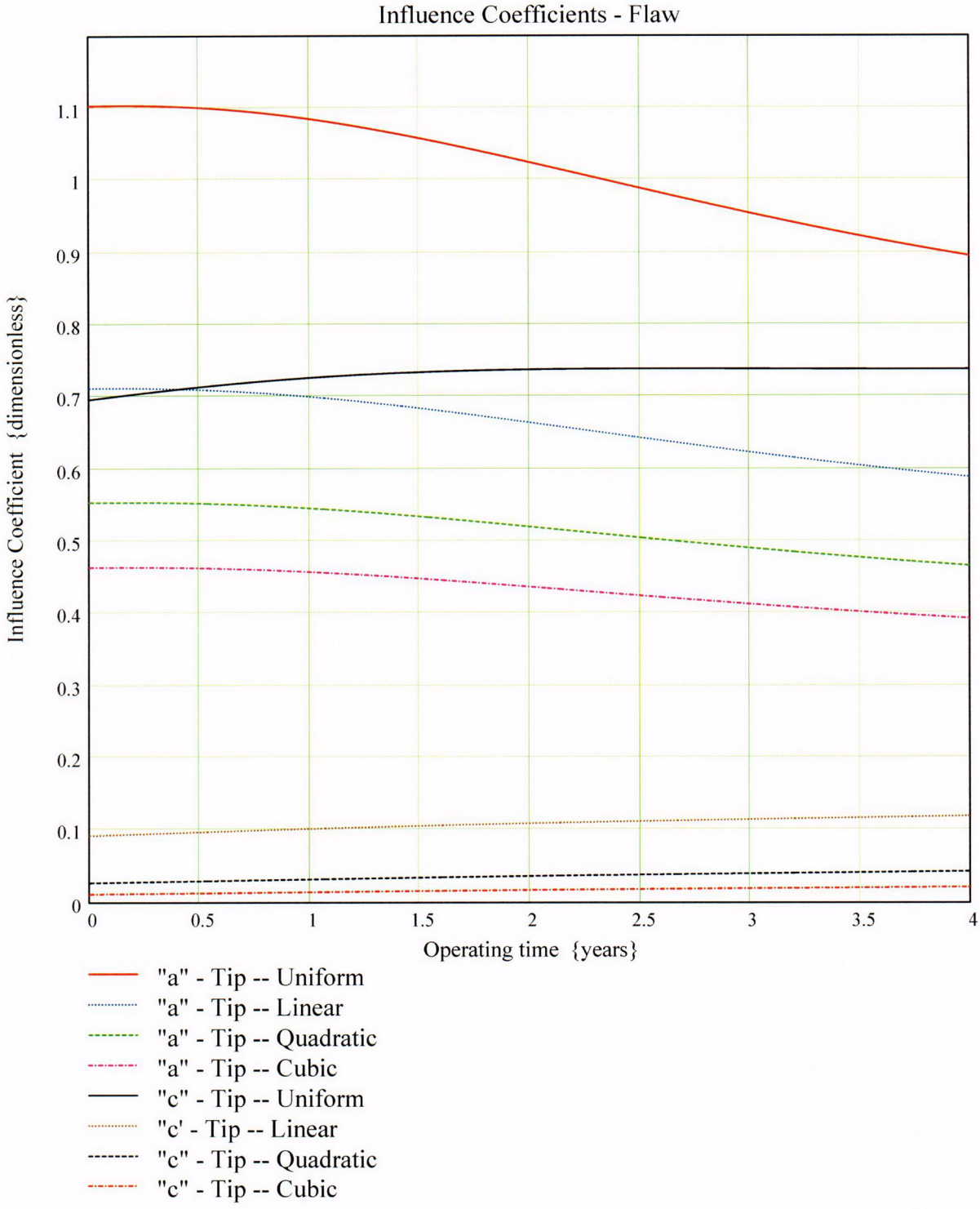
Sat Aug 09 10:59:39 AM 2003

$Prop_{Length} = 0.082$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
100
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

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

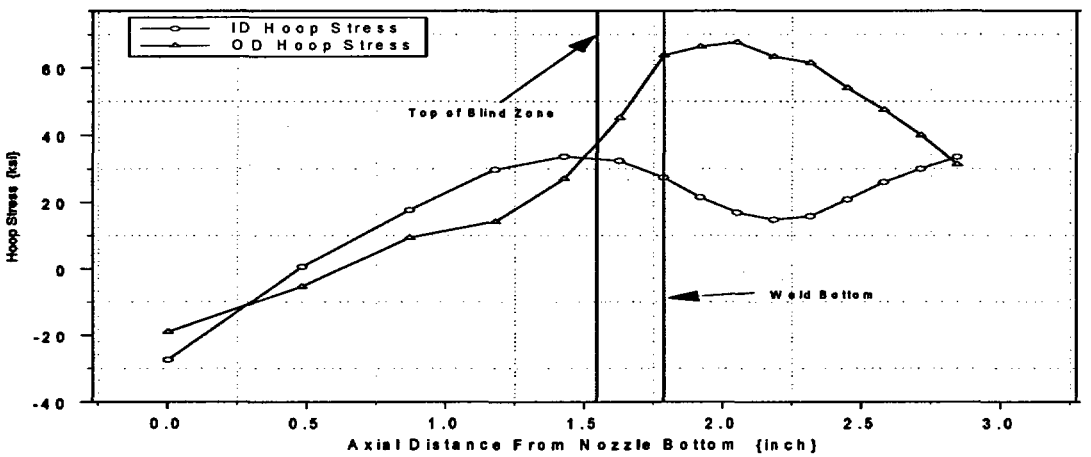
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103

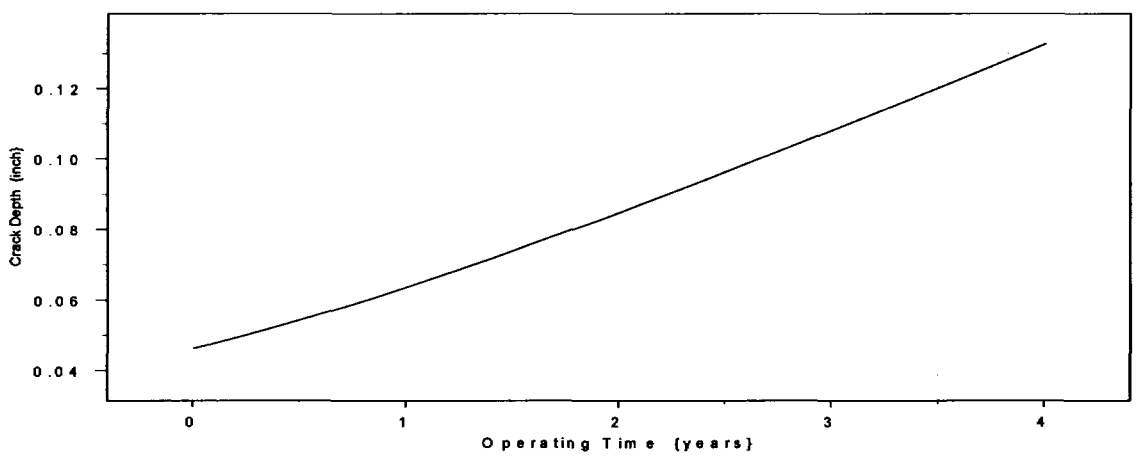
$CGR_{sambi_{(k,6)}}$ =

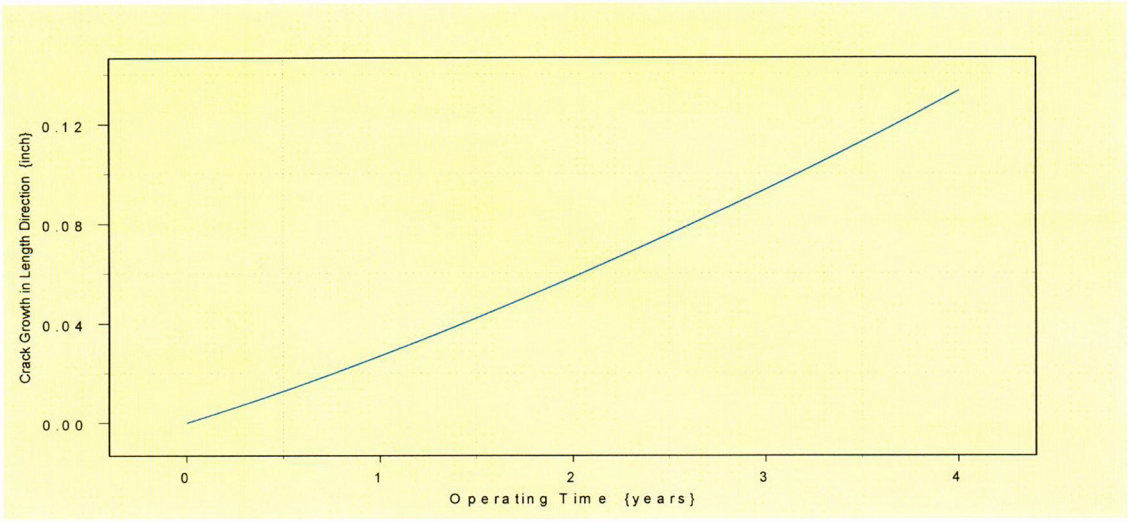
14.996
14.886
14.89
14.895
14.899
14.903
14.907
14.912
14.916
14.92
14.925
14.929
14.933
14.938
14.942
14.946

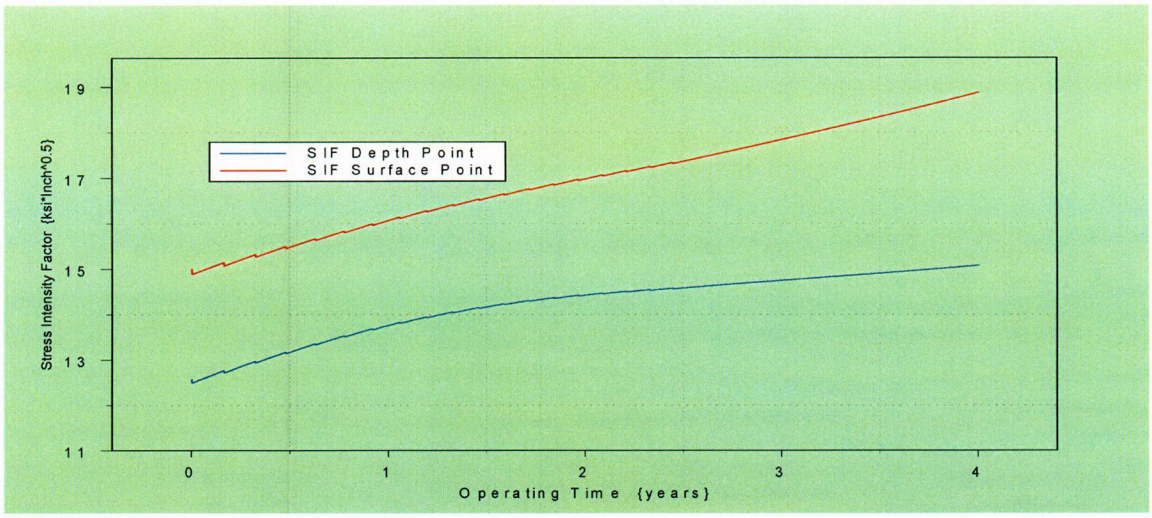
$CGR_{sambi_{(k,5)}}$ =

12.571
12.495
12.499
12.504
12.509
12.513
12.518
12.522
12.527
12.531
12.536
12.541
12.545
12.55
12.554
12.559


ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Weld Bottom
Hoop Stress (ksi)
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Axial Distance From Nozzle Bottom (inch)


Crack Depth (inch)
0.12
0.10
0.08
0.06
0.04
0
1
2
3
4
Operating Time (years)


Crack Growth in Length Direction {inch}
0.12
0.08
0.04
0.00
0
1
2
3
4
Operating Time {years}


Stress Intensity Factor {ksi*Inch^0.5}
19
17
15
13
11
SIF Depth Point
SIF Surface Point
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8" Degree Nozzle, Downhill 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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).

$$Val := 2$$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 1.786$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$ Initial Flaw Length

$a_0 := 0.661 \cdot 0.12$ 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

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

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

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

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

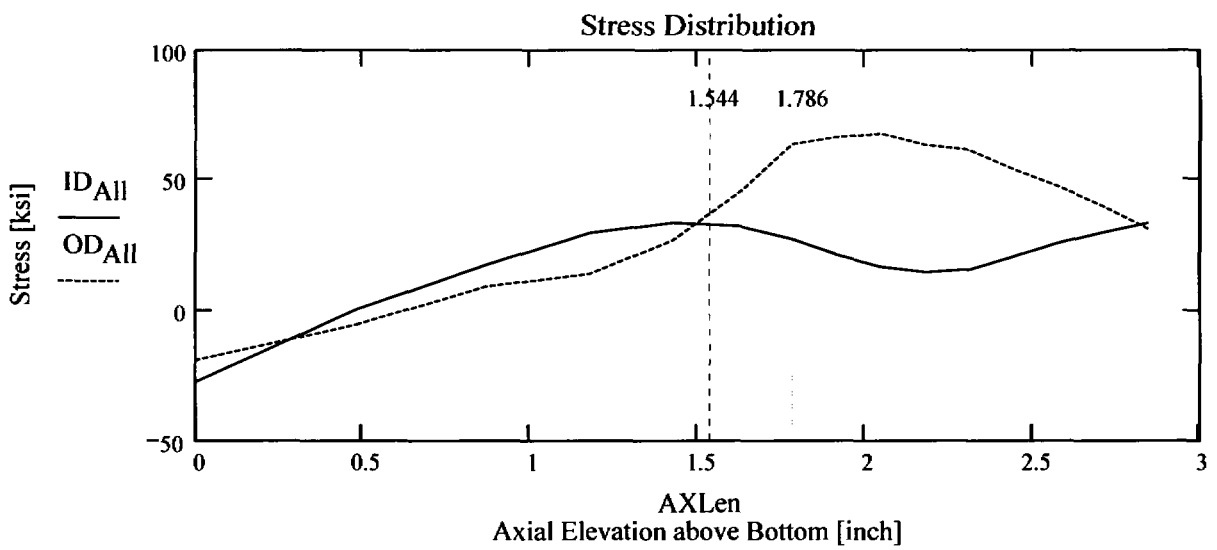
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum 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	-27.4	-24.36	-22.21	-20.41	-18.98
1	0.48	0.63	-1.49	-3.6	-4.44	-5.27
2	0.87	17.66	16.42	14.61	12.41	9.38
3	1.18	29.8	26.05	22.72	18.95	14.2
4	1.43	33.62	27.79	24.8	24.32	26.99
5	1.63	32.36	28.47	27.59	34.28	45.1
6	1.79	27.39	28.92	31.39	43.88	63.72
7	1.92	21.5	25.56	33.55	48.09	66.36
8	2.05	16.94	23.79	34.06	49.47	67.67
9	2.18	14.83	22.26	34.78	49.05	63.38

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



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. 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).

$$Data := \begin{pmatrix} 0 & -27.404 & -24.356 & -22.209 & -20.407 & -18.978 \\ 0.483 & 0.633 & -1.486 & -3.599 & -4.44 & -5.268 \\ 0.87 & 17.665 & 16.422 & 14.61 & 12.415 & 9.376 \\ 1.18 & 29.798 & 26.049 & 22.723 & 18.95 & 14.201 \\ 1.428 & 33.623 & 27.792 & 24.8 & 24.321 & 26.989 \\ 1.627 & 32.364 & 28.469 & 27.591 & 34.284 & 45.104 \\ 1.786 & 27.394 & 28.918 & 31.388 & 43.882 & 63.718 \\ 1.919 & 21.498 & 25.556 & 33.55 & 48.089 & 66.365 \\ 2.051 & 16.944 & 23.793 & 34.064 & 49.472 & 67.672 \end{pmatrix}$$

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

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

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

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

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

Flaw center Location Location above Nozzle Bottom

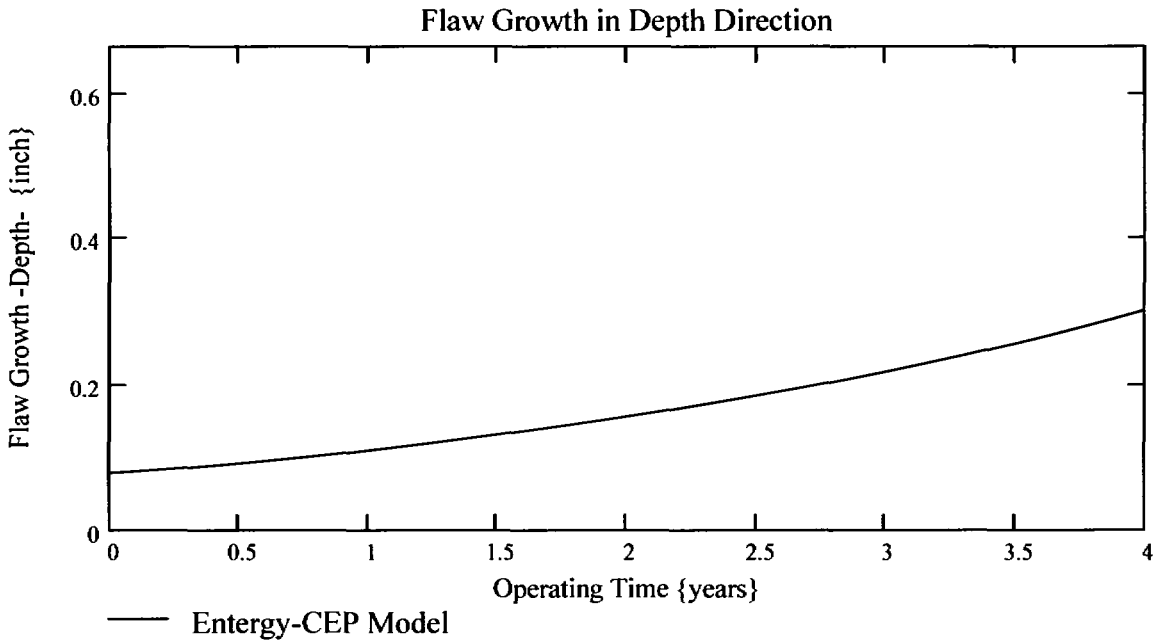
$U_{Tip} := FL_{Cntr} + c_0$

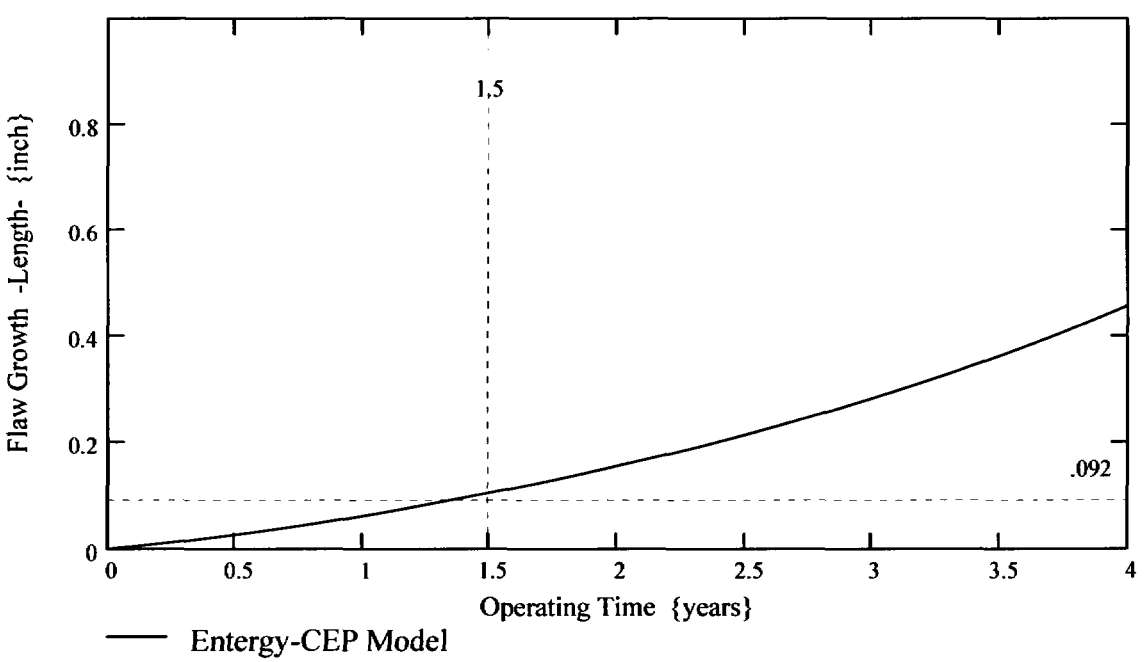
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

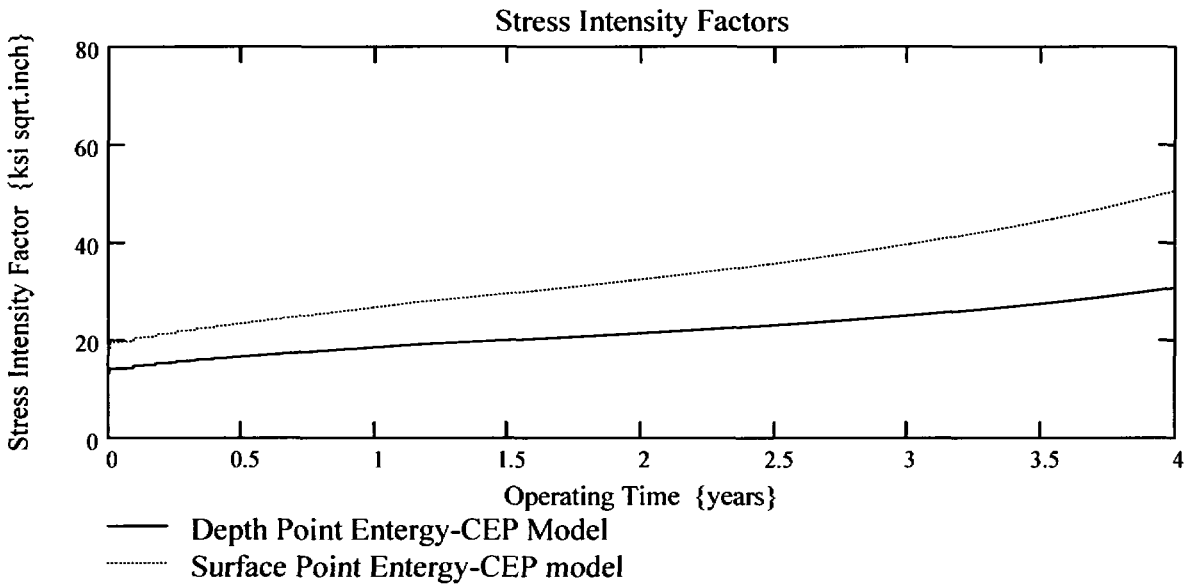
No User Input is required beyond this Point

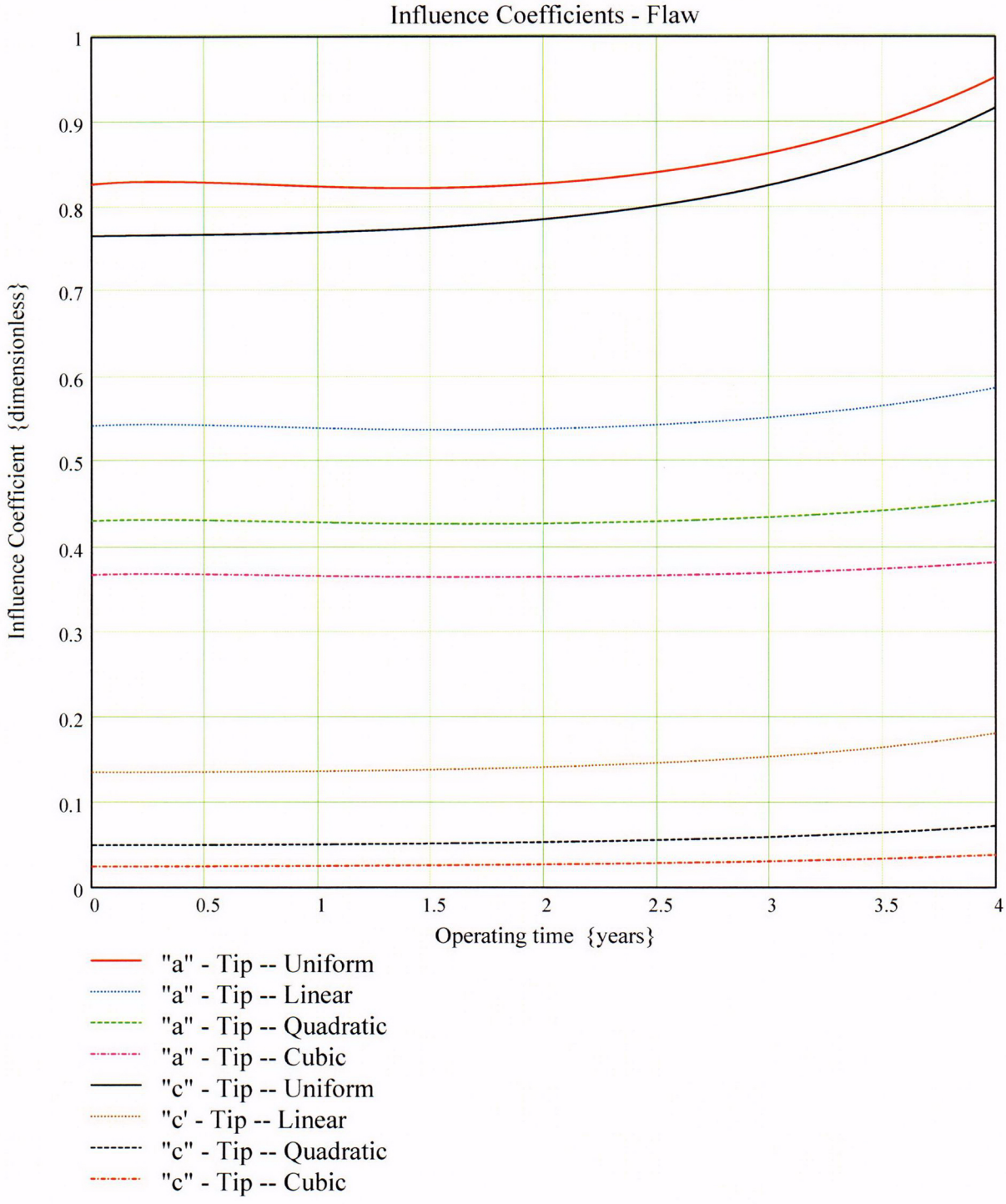
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.082$






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


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
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

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

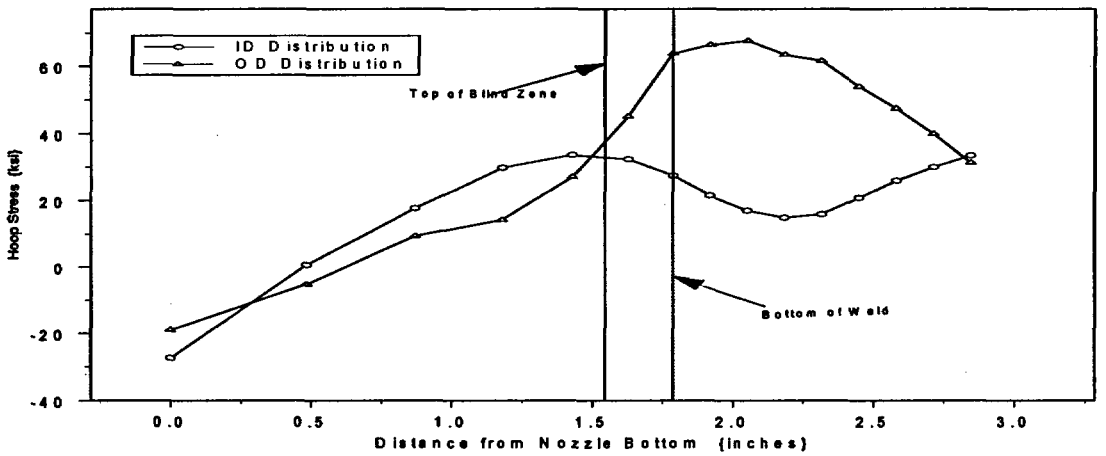
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

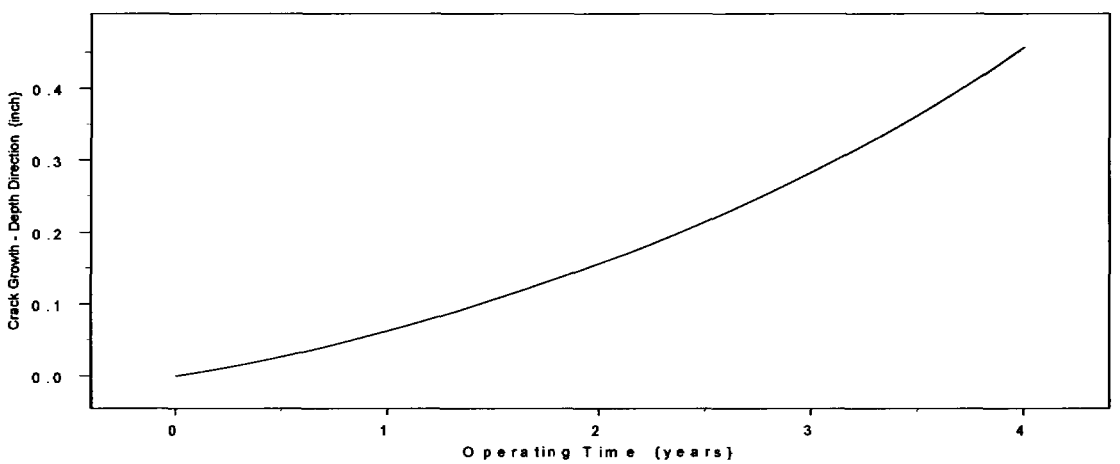
$CGR_{sambi_{(k,6)}}$ =

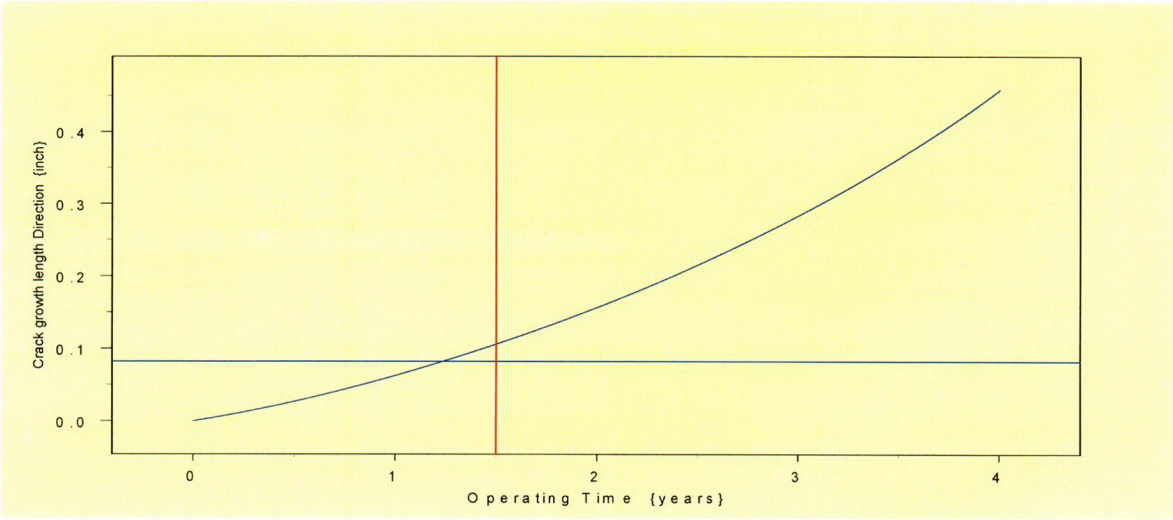
18.417
19.5
19.507
19.515
19.522
19.53
19.538
19.545
19.553
19.56
19.568
19.575
19.583
19.59
19.598
19.605

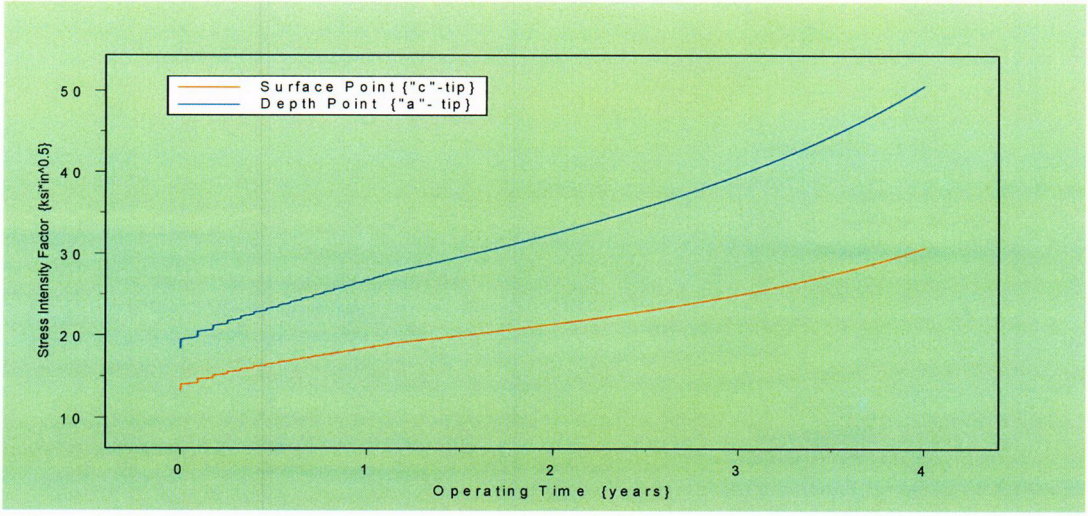
$CGR_{sambi_{(k,5)}}$ =

13.271
14.008
14.014
14.019
14.024
14.03
14.035
14.04
14.046
14.051
14.056
14.062
14.067
14.072
14.078
14.083


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress (ksi)
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Distance from Nozzle Bottom (inches)


Crack Growth - Depth Direction (inch)
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
Operating Time (years)


Crack growth length Direction {inch}
0.0
0.1
0.2
0.3
0.4
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
10
20
30
40
50
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8"Degree Nozzle, Downhill 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 throughwall 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.

$UL_{Strs.Dist} := 1.786$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := .794$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	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 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

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

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

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

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

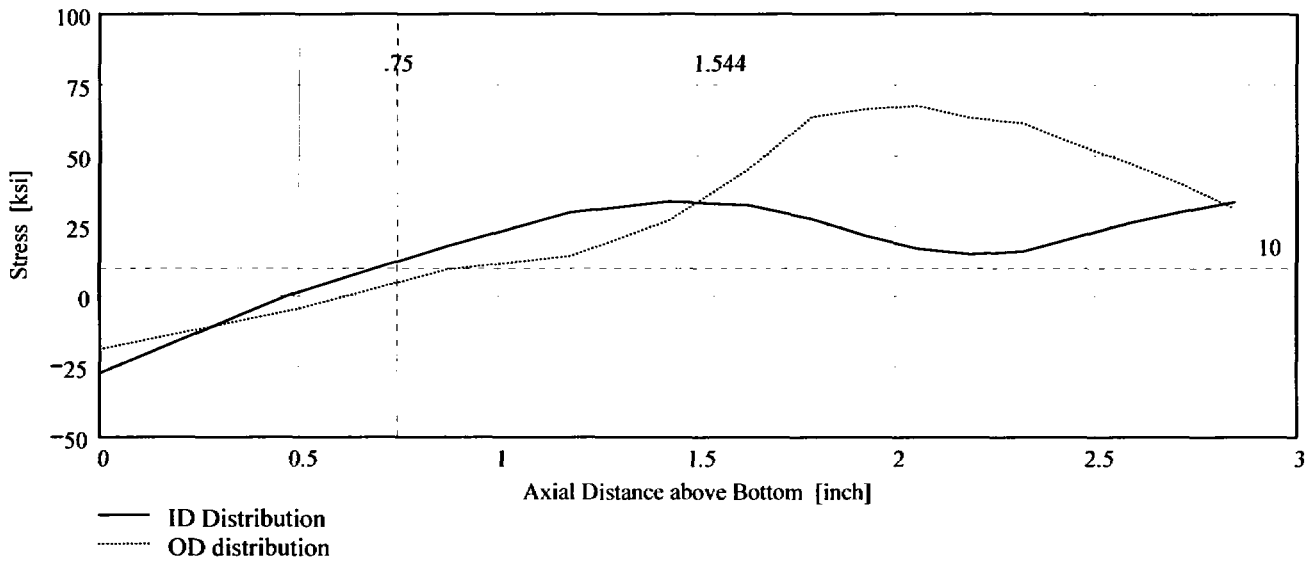
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "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	-27.4	-24.36	-22.21	-20.41	-18.98
1	0.48	0.63	-1.49	-3.6	-4.44	-5.27
2	0.87	17.66	16.42	14.61	12.41	9.38
3	1.18	29.8	26.05	22.72	18.95	14.2
4	1.43	33.62	27.79	24.8	24.32	26.99
5	1.63	32.36	28.47	27.59	34.28	45.1
6	1.79	27.39	28.92	31.39	43.88	63.72
7	1.92	21.5	25.56	33.55	48.09	66.36
8	2.05	16.94	23.79	34.06	49.47	67.67
9	2.18	14.83	22.26	34.78	49.05	63.38

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



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).

$$Data := \begin{pmatrix} 0 & -27.404 & -24.356 & -22.209 & -20.407 & -18.978 \\ 0.483 & 0.633 & -1.486 & -3.599 & -4.44 & -5.268 \\ 0.87 & 17.665 & 16.422 & 14.61 & 12.415 & 9.376 \\ 1.18 & 29.798 & 26.049 & 22.723 & 18.95 & 14.201 \\ 1.428 & 33.623 & 27.792 & 24.8 & 24.321 & 26.989 \\ 1.627 & 32.364 & 28.469 & 27.591 & 34.284 & 45.104 \\ 1.786 & 27.394 & 28.918 & 31.388 & 43.882 & 63.718 \\ 1.919 & 21.498 & 25.556 & 33.55 & 48.089 & 66.365 \\ 2.051 & 16.944 & 23.793 & 34.064 & 49.472 & 67.672 \\ 2.183 & 14.834 & 22.263 & 34.779 & 49.055 & 63.377 \end{pmatrix}$$

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

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

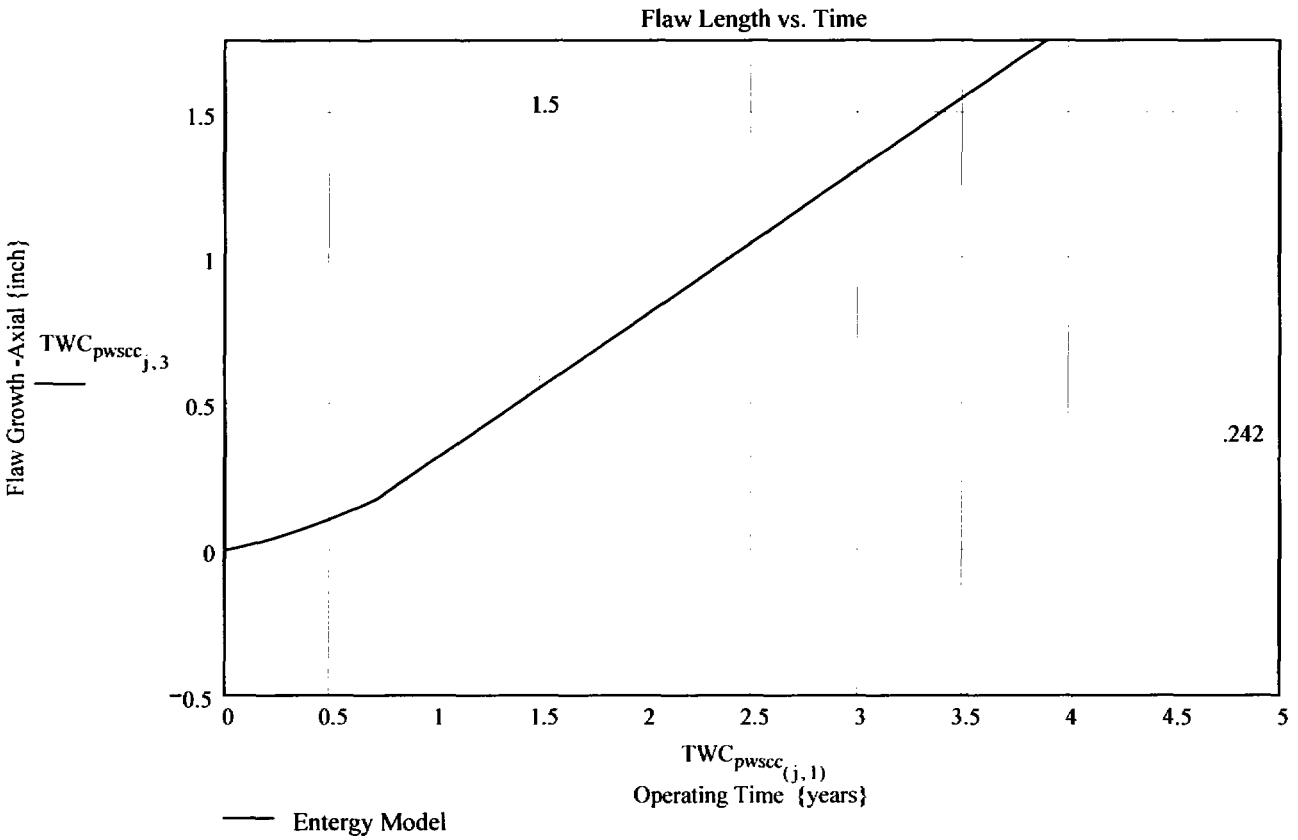
$FL_{Cntr} := BZ - l$ Flaw Center above Nozzle Bottom

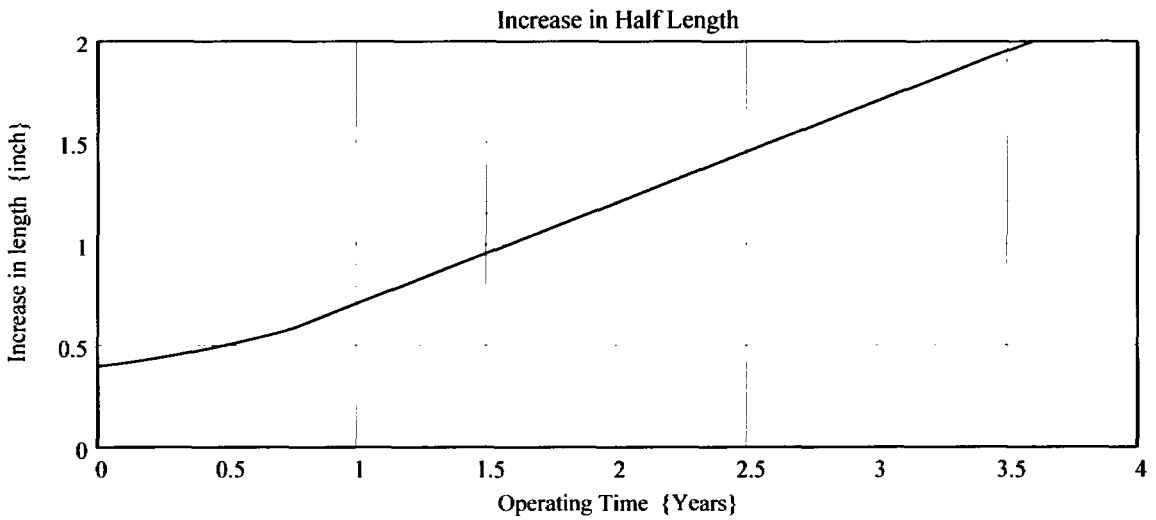
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - BZ}{20}$$

No User Input required beyond this Point

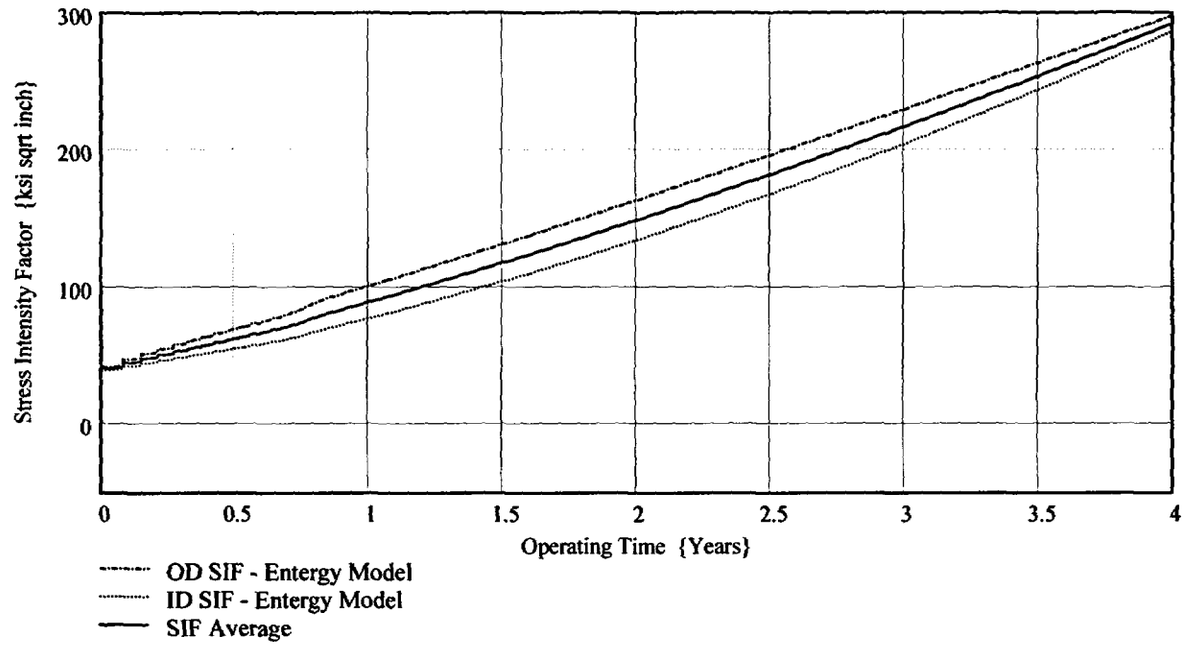
Sat Aug 09 11:44:49 AM 2003

$Prop_{Length} = 0.242$





Developed by: *Verified by:*



Developed by:

Verified by:

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

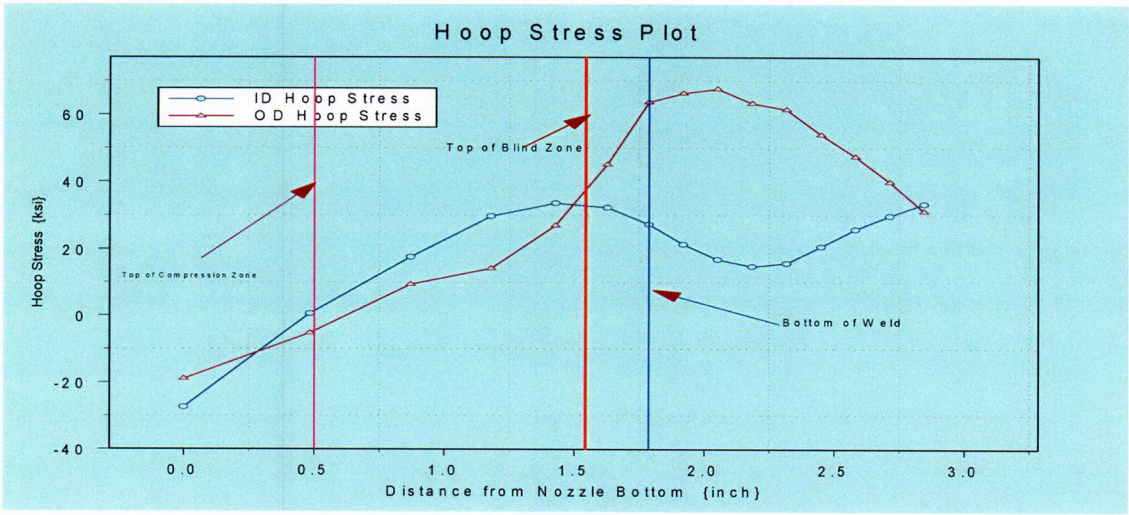
34.773
41.861
41.893
41.925
41.958
41.99
42.022
42.054
42.087
42.119
42.152
42.184
42.216
42.249
42.281
42.314

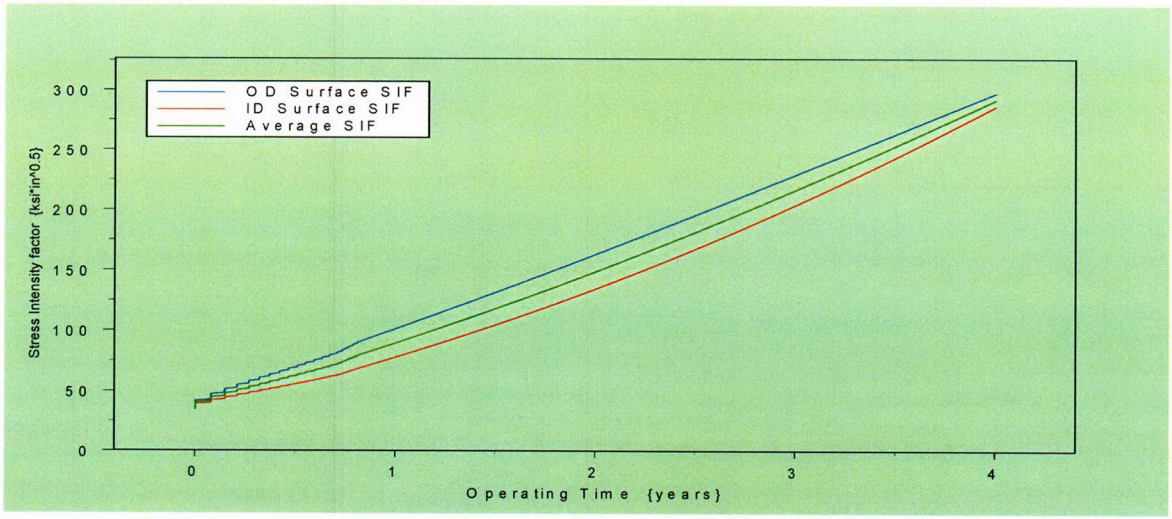
$TWC_{pwscc_{(j,7)}}$ =

35.756
39.204
39.232
39.26
39.288
39.316
39.344
39.373
39.401
39.429
39.457
39.485
39.513
39.542
39.57
39.598

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

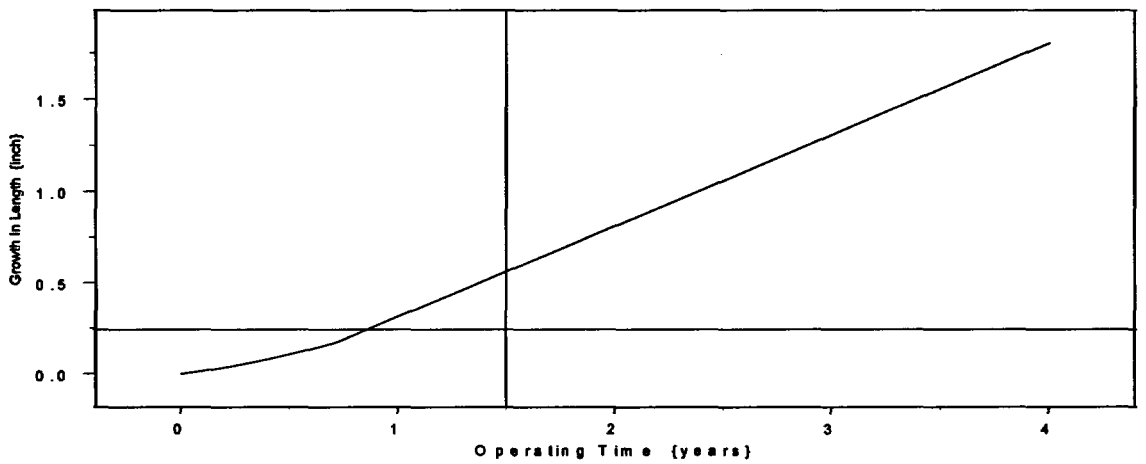
36.661
42.033
42.065
42.097
42.129
42.162
42.194
42.226
42.259
42.291
42.324
42.356
42.389
42.421
42.454
42.486





Developed by:	Verified by:

C08


Growth in Length (inch)
1.5
1.0
0.5
0.0
0
1
2
3
4
Operating Time (years)

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

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8" Degree Nozzle, Uphill 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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.

$UL_{Strs.Dist} := 2.386$ Upper axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom).

Input Data :-

$L := 0.32$ Initial Flaw Length (Twice detectable length)

$a_0 := 0.661 \cdot 0.07$ Initial Flaw Depth (Minimum Detecteble Depth was 5% TW)

$od := 4.05$ 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

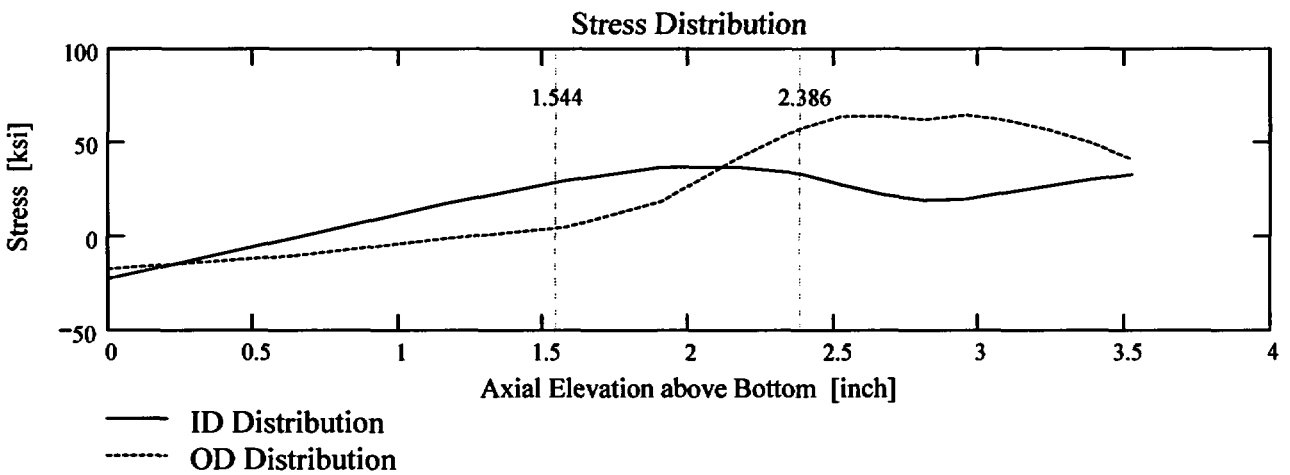
Stress Input Data

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)
Cloumn "2" = Quarter Thickness Stress data at each Elevation (ksi)
Cloumn "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	-22.34	-20.02	-18.96	-18.09	-17.15
1	0.64	-0.72	-3.67	-6.82	-8.7	-10.19
2	1.16	17.28	14.91	9.65	3.77	-1.22
3	1.58	29.36	26.5	20.58	13.8	4.75
4	1.91	36.5	30.92	25.41	21.15	18.37
5	2.17	36.54	30.33	27.24	32.61	41.48
6	2.39	33.13	31.54	31.44	42.45	57.26
7	2.53	27.12	28.37	33.43	47.23	63.83
8	2.67	21.96	26.11	34.41	48.85	63.88
9	2.81	18.99	24.12	35.2	49.9	62.11

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



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. Higlight 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 mosue 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 dtat 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.

$$Data := \begin{pmatrix} 0 & -22.34 & -20.022 & -18.961 & -18.087 & -17.153 \\ 0.645 & -0.722 & -3.667 & -6.821 & -8.696 & -10.19 \\ 1.162 & 17.28 & 14.912 & 9.653 & 3.766 & -1.22 \\ 1.575 & 29.359 & 26.501 & 20.582 & 13.796 & 4.753 \\ 1.907 & 36.503 & 30.924 & 25.411 & 21.15 & 18.374 \\ 2.173 & 36.536 & 30.331 & 27.24 & 32.606 & 41.485 \\ 2.386 & 33.132 & 31.54 & 31.442 & 42.452 & 57.257 \\ 2.528 & 27.116 & 28.37 & 33.434 & 47.233 & 63.826 \\ 2.67 & 21.957 & 26.115 & 34.408 & 48.851 & 63.884 \\ 2.813 & 18.993 & 24.124 & 35.202 & 49.904 & 62.107 \end{pmatrix}$$

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

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

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

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

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

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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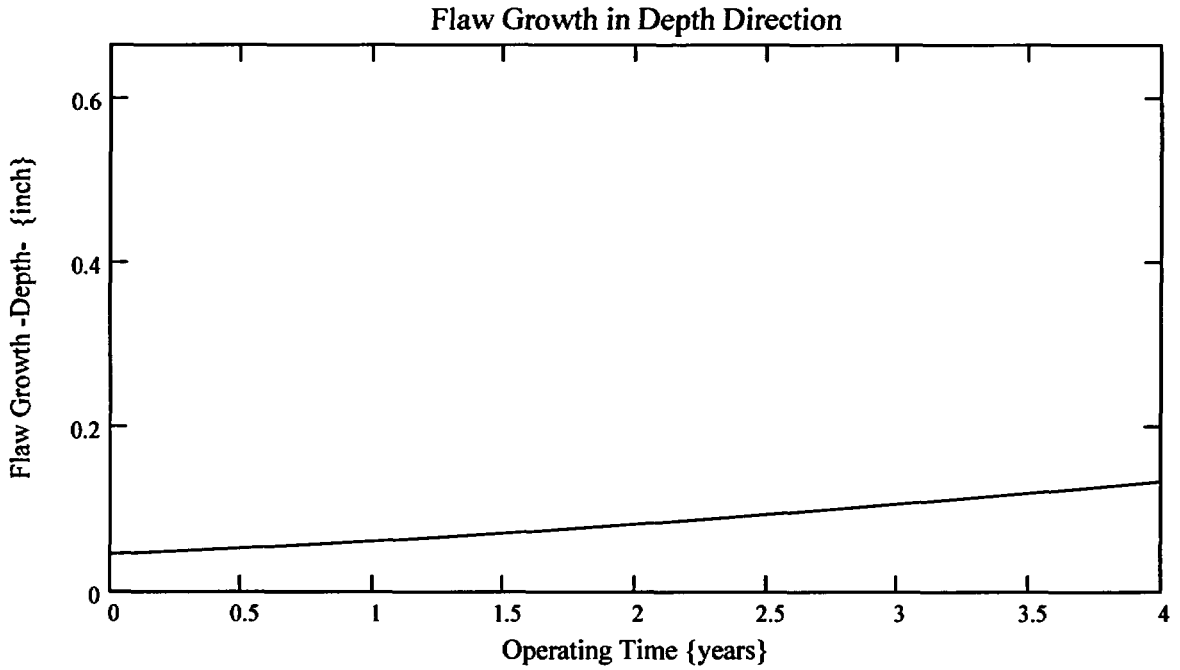
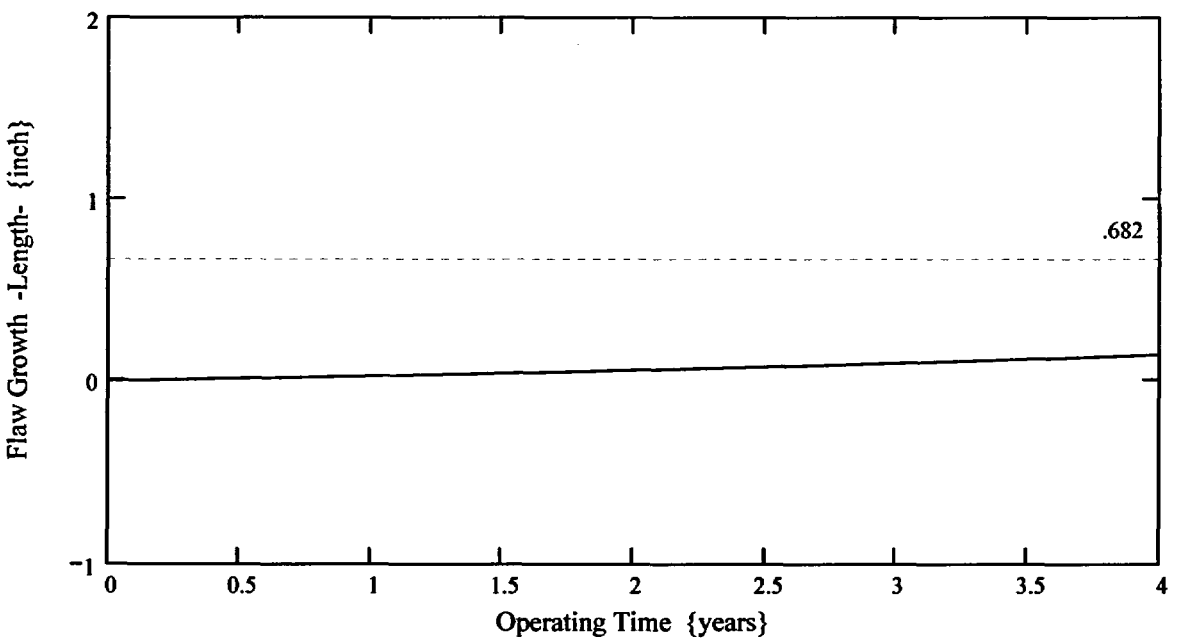
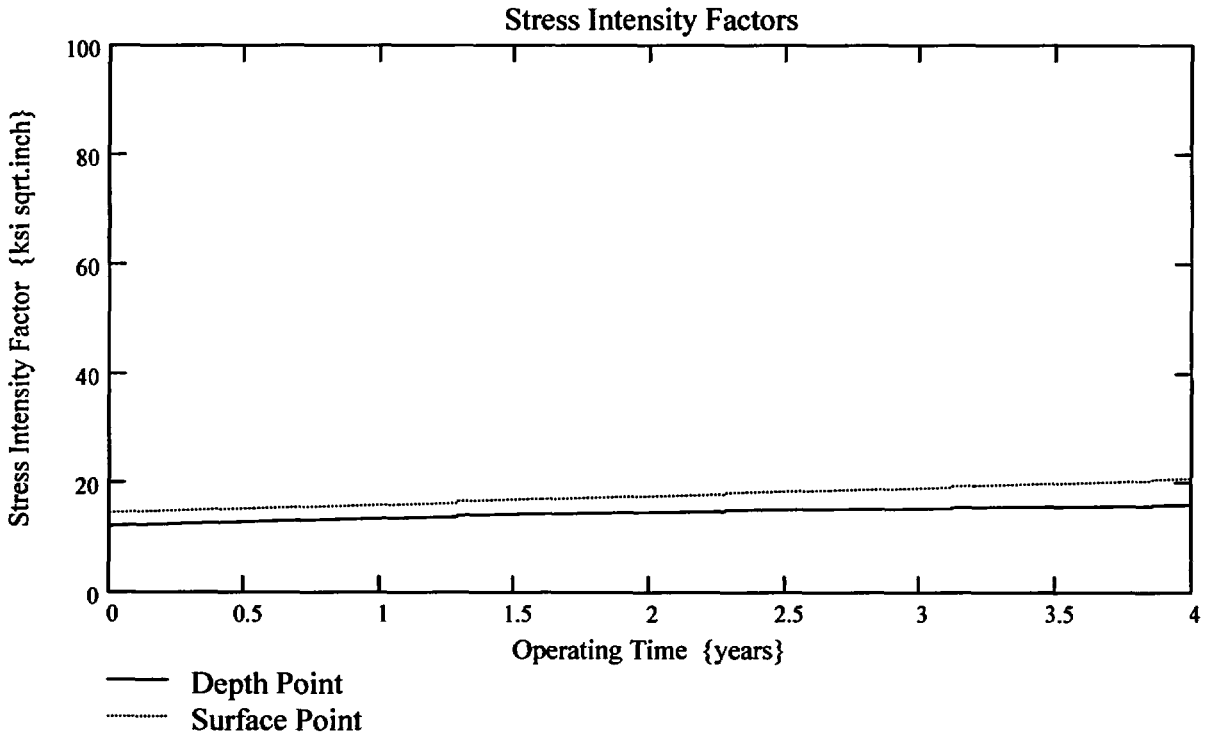
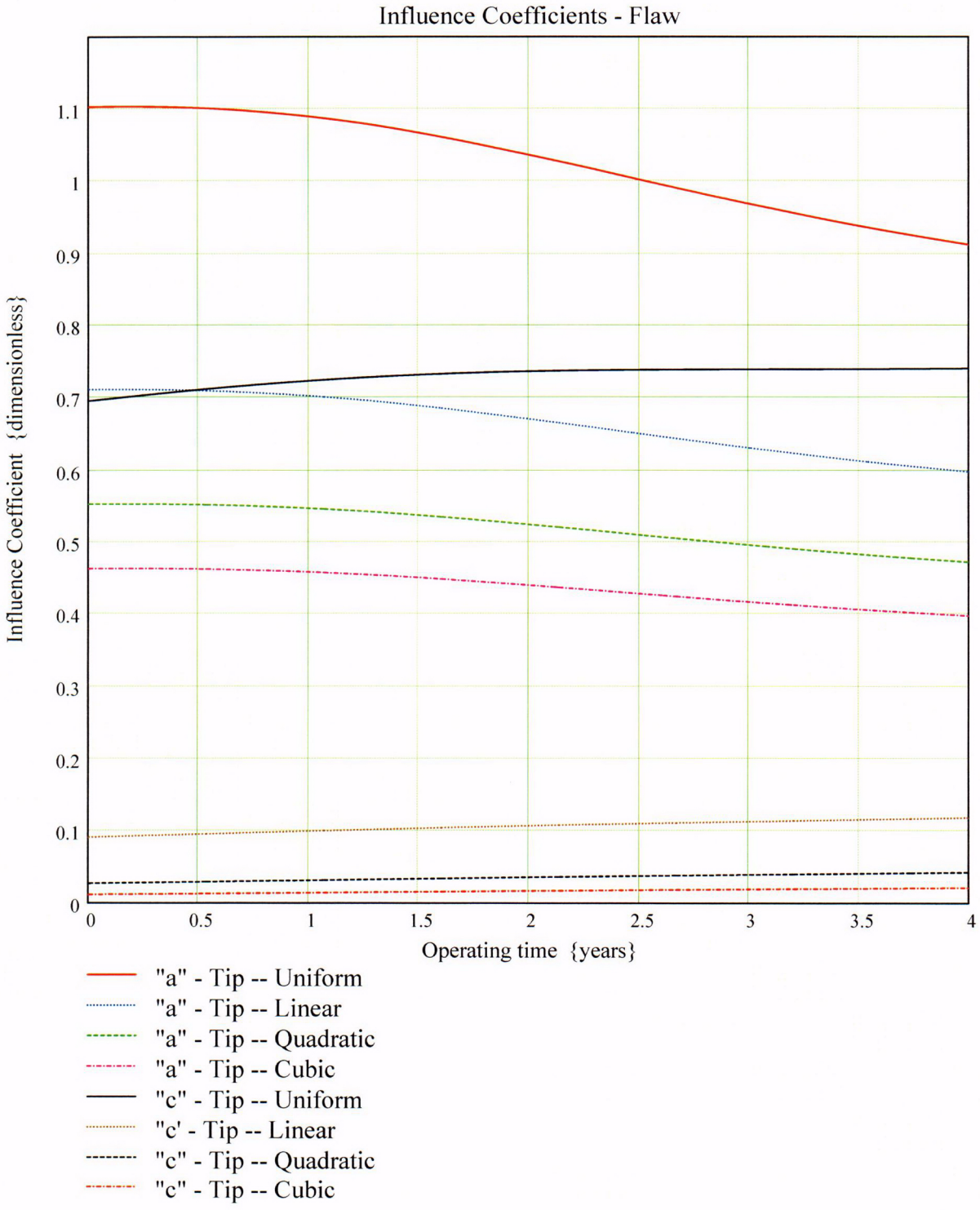
$Prop_{Length} = 0.682$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
100
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

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

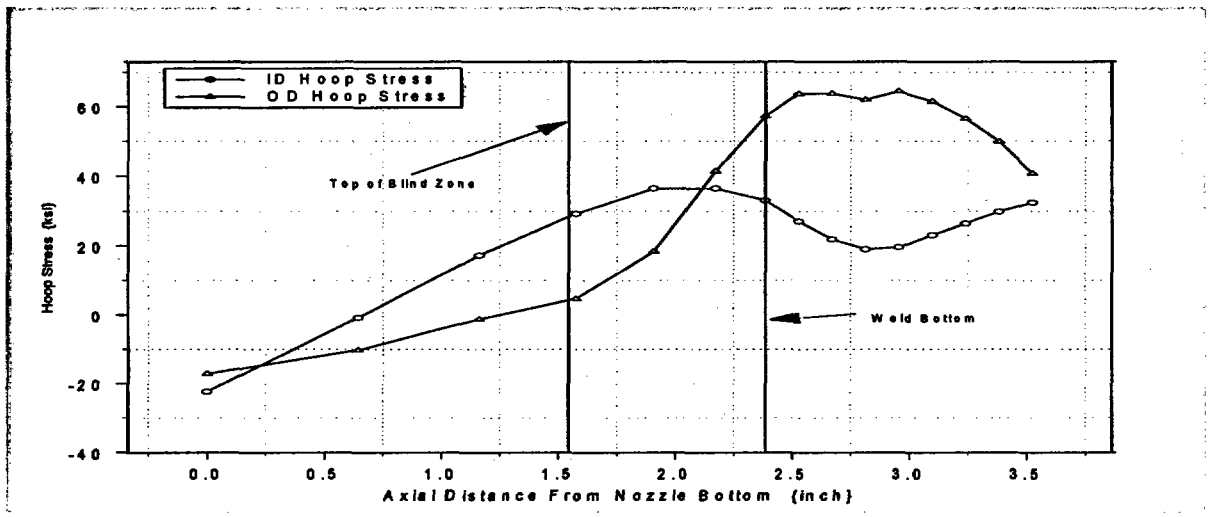
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103

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

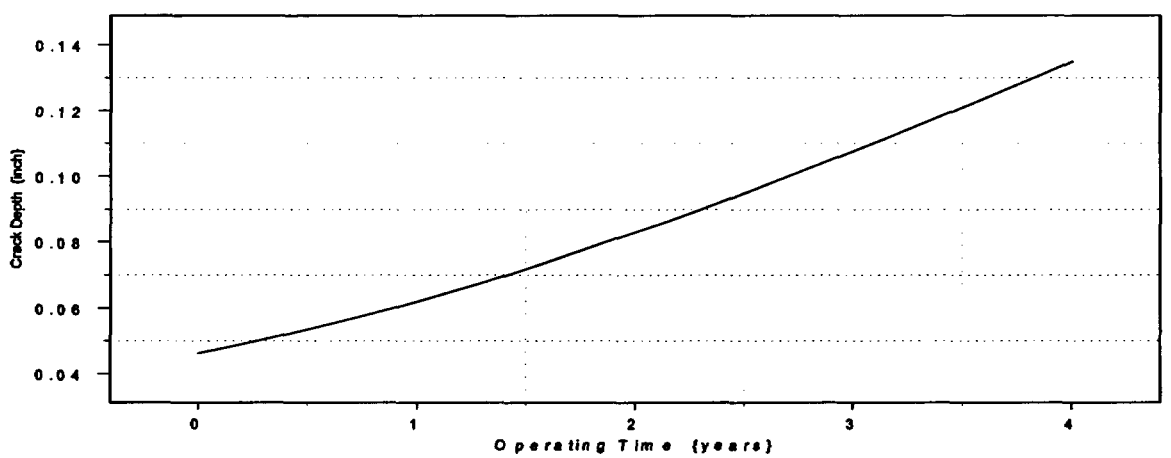
14.023
14.503
14.507
14.511
14.514
14.518
14.522
14.526
14.53
14.534
14.537
14.541
14.545
14.549
14.553
14.556

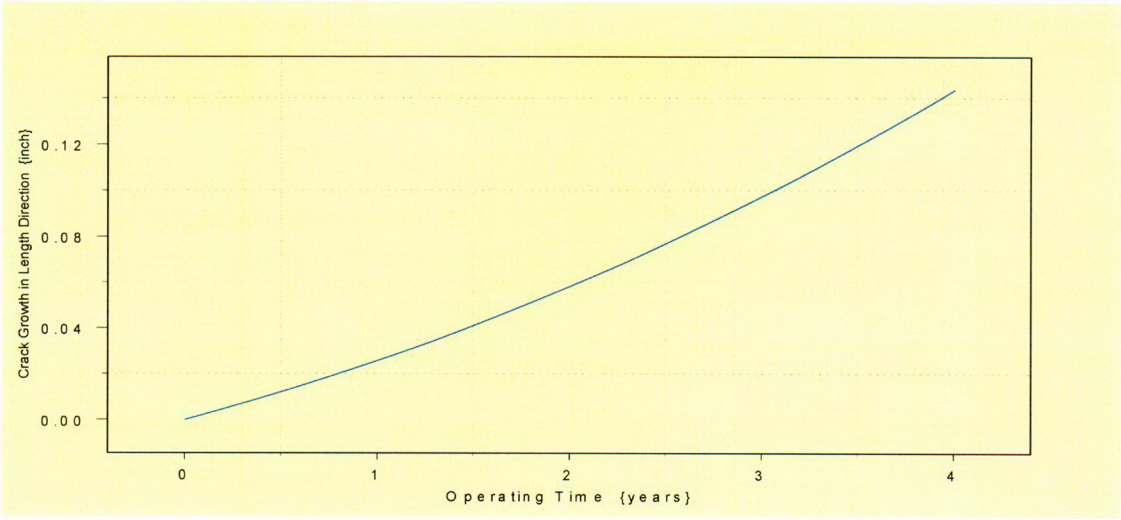
$CGR_{sambi_{(k,5)}}$ =

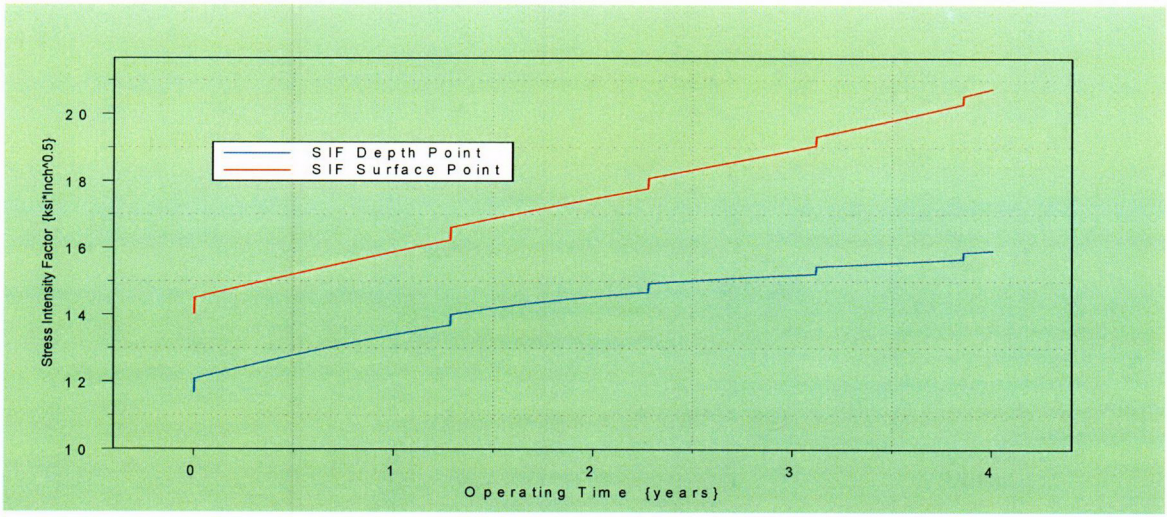
11.685
12.086
12.09
12.094
12.098
12.102
12.105
12.109
12.113
12.117
12.121
12.125
12.129
12.132
12.136
12.14



$$\left(\text{AllData}^{\langle 0\rangle}\quad \text{AllData}^{\langle 1\rangle}\quad \text{AllData}^{\langle 5\rangle}\right)$$




Crack Growth in Length Direction {inch}
0.12
0.08
0.04
0.00
0
1
2
3
4
Operating Time {years}


Stress Intensity Factor {ksi*inch^0.5}
20
18
16
14
12
10
SIF Depth Point
SIF Surface Point
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8" Degree Nozzle, Uphill 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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).

$$Val := 2$$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 2.386$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$ Initial Flaw Length

$a_0 := 0.661 \cdot 0.12$ 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

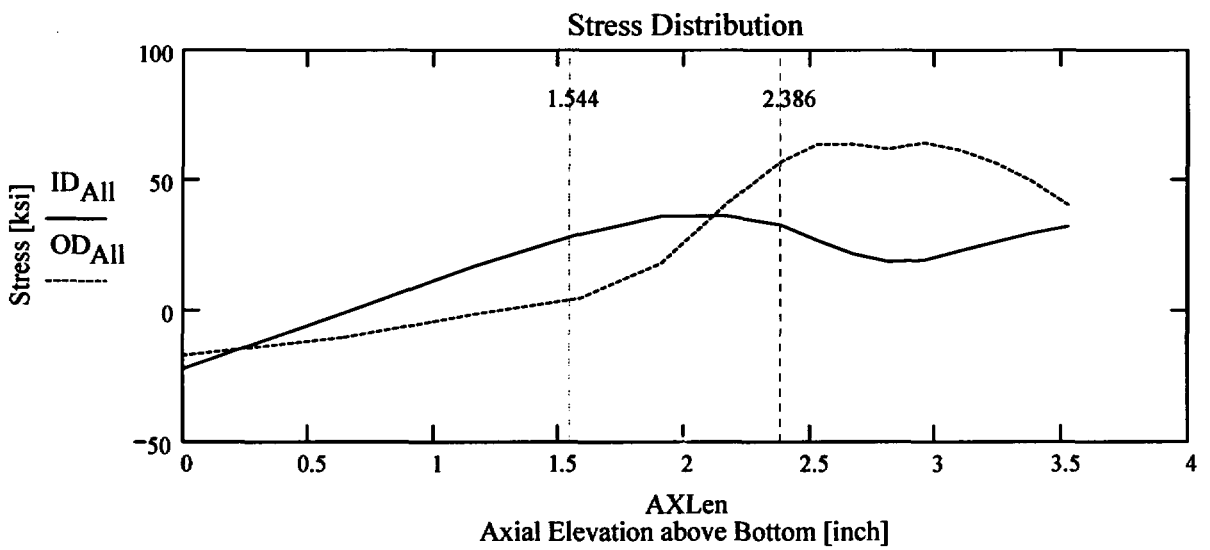
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum 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	-22.34	-20.02	-18.96	-18.09	-17.15
1	0.64	-0.72	-3.67	-6.82	-8.7	-10.19
2	1.16	17.28	14.91	9.65	3.77	-1.22
3	1.58	29.36	26.5	20.58	13.8	4.75
4	1.91	36.5	30.92	25.41	21.15	18.37
5	2.17	36.54	30.33	27.24	32.61	41.48
6	2.39	33.13	31.54	31.44	42.45	57.26
7	2.53	27.12	28.37	33.43	47.23	63.83
8	2.67	21.96	26.11	34.41	48.85	63.88
9	2.81	18.99	24.12	35.2	49.9	62.11

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



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. 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).

$$Data := \begin{pmatrix} 0 & -22.34 & -20.022 & -18.961 & -18.087 & -17.153 \\ 0.645 & -0.722 & -3.667 & -6.821 & -8.696 & -10.19 \\ 1.162 & 17.28 & 14.912 & 9.653 & 3.766 & -1.22 \\ 1.575 & 29.359 & 26.501 & 20.582 & 13.796 & 4.753 \\ 1.907 & 36.503 & 30.924 & 25.411 & 21.15 & 18.374 \\ 2.173 & 36.536 & 30.331 & 27.24 & 32.606 & 41.485 \\ 2.386 & 33.132 & 31.54 & 31.442 & 42.452 & 57.257 \\ 2.528 & 27.116 & 28.37 & 33.434 & 47.233 & 63.826 \\ 2.67 & 21.957 & 26.115 & 34.408 & 48.851 & 63.884 \end{pmatrix}$$

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

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

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

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

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

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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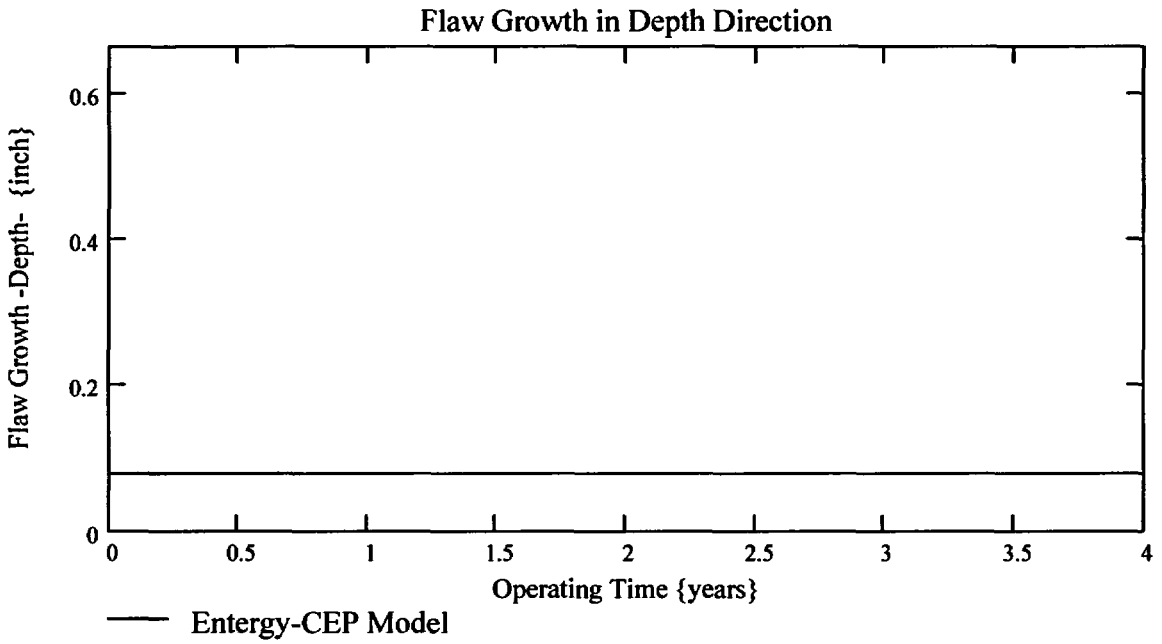
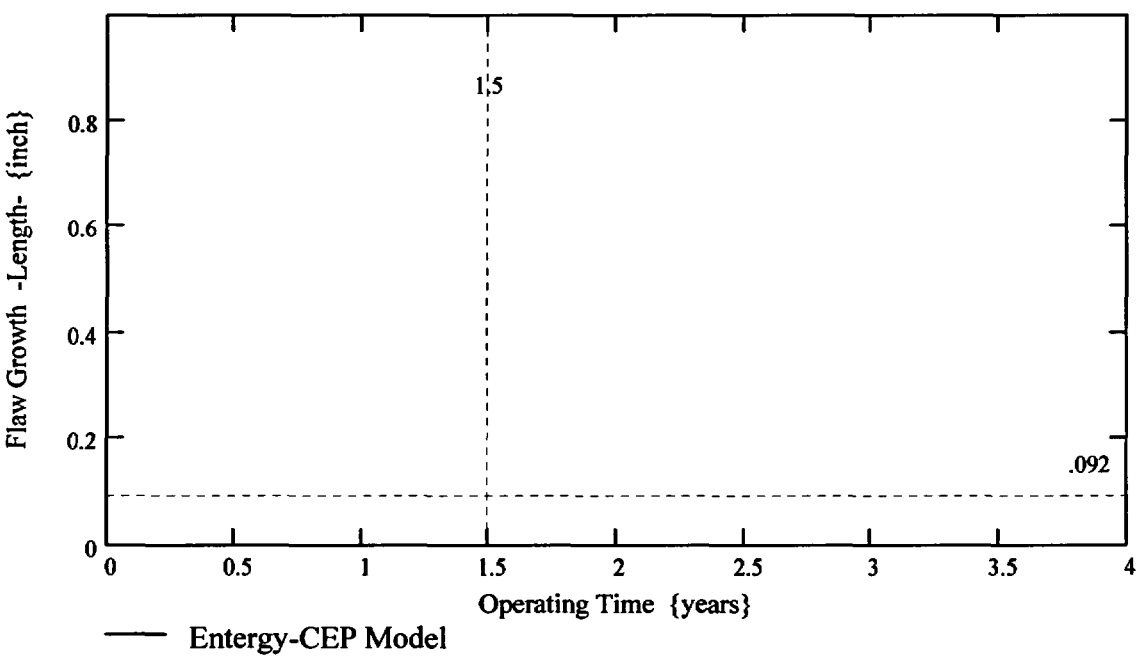
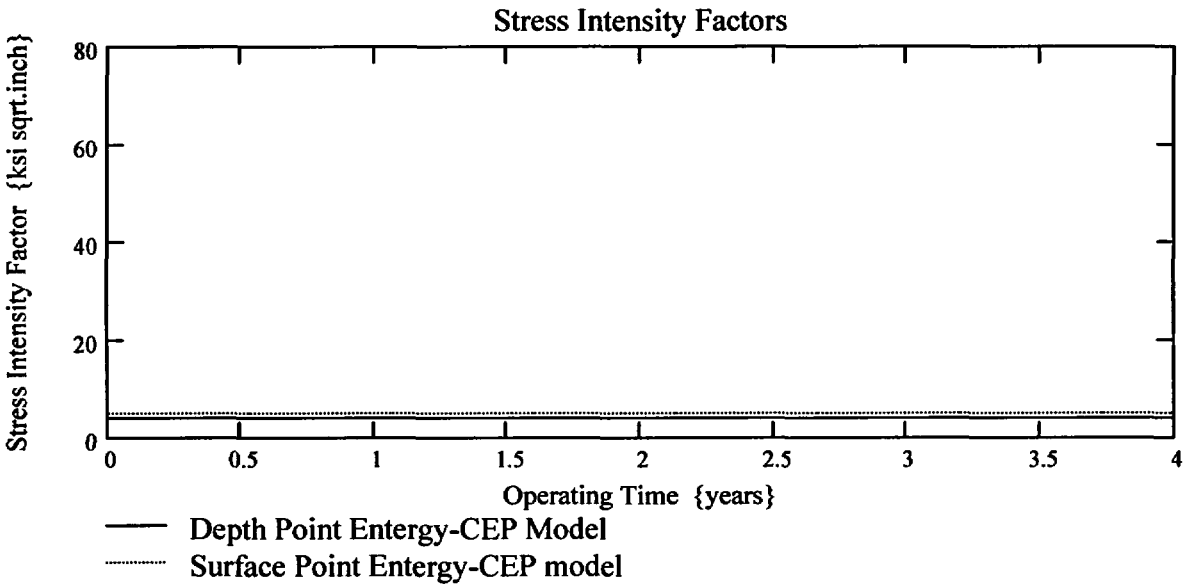
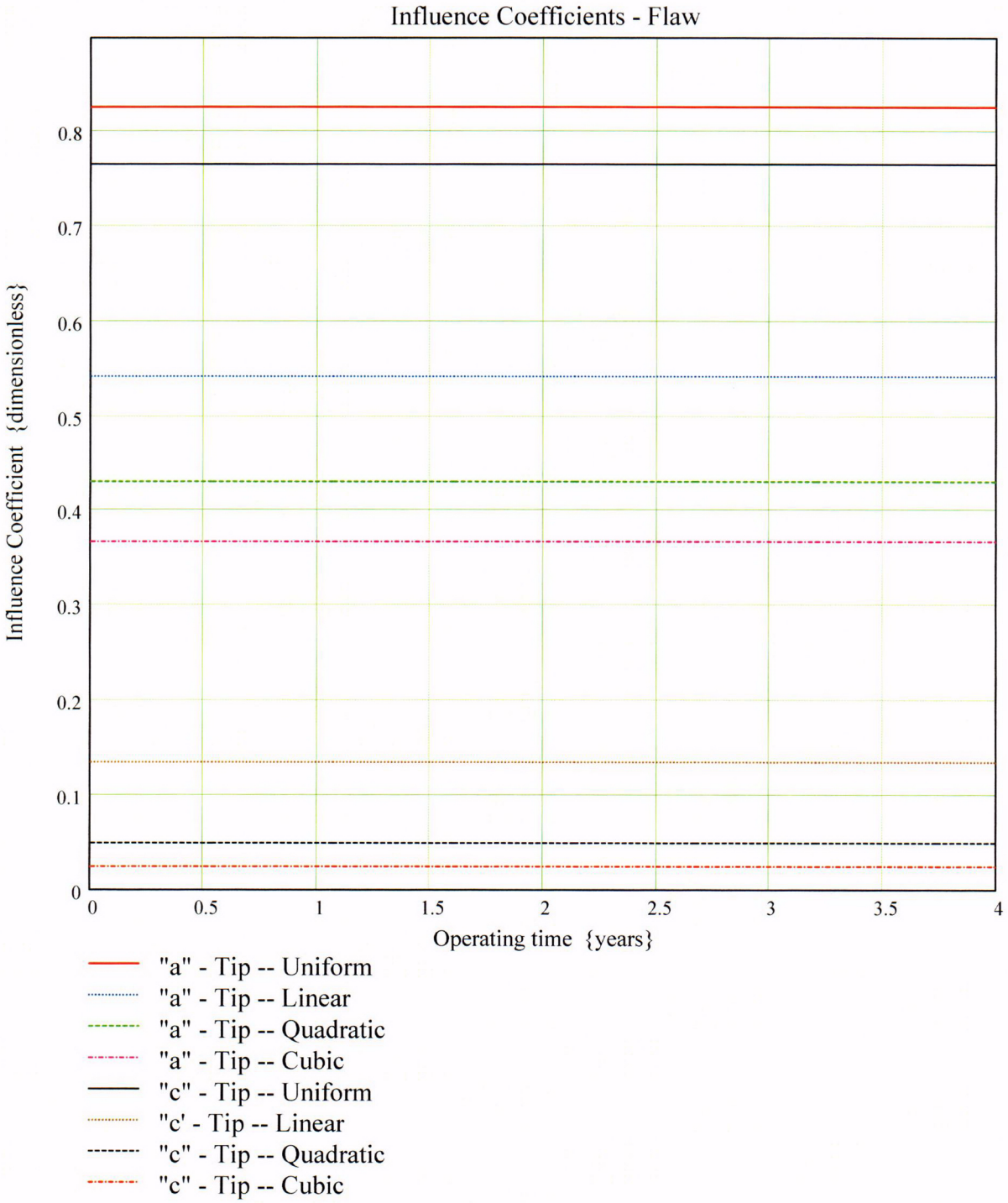
$Prop_{Length} = 0.682$






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


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

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

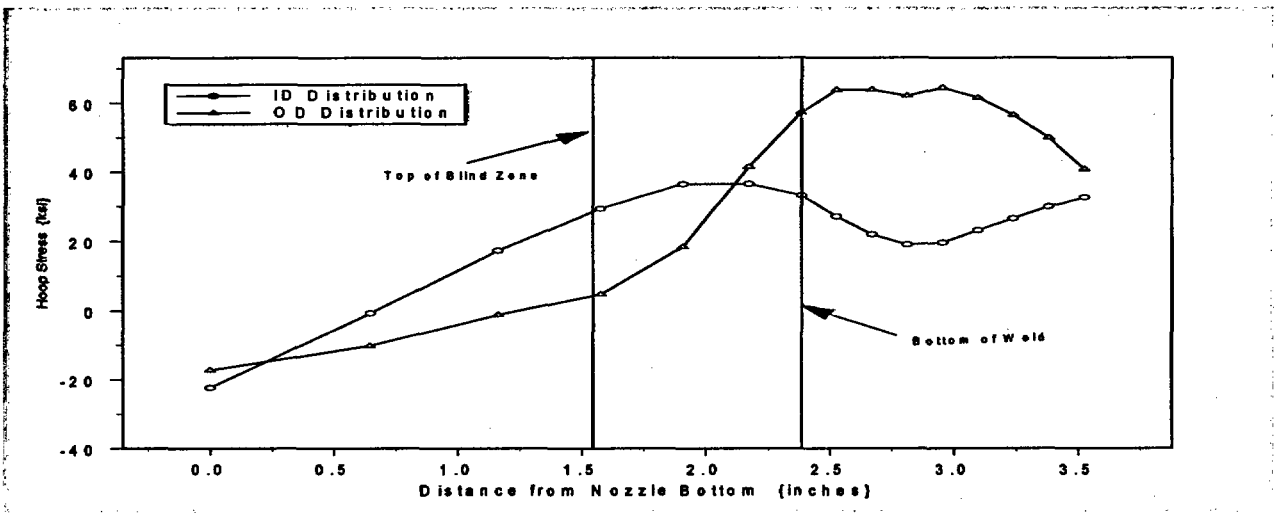
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827
0.827

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

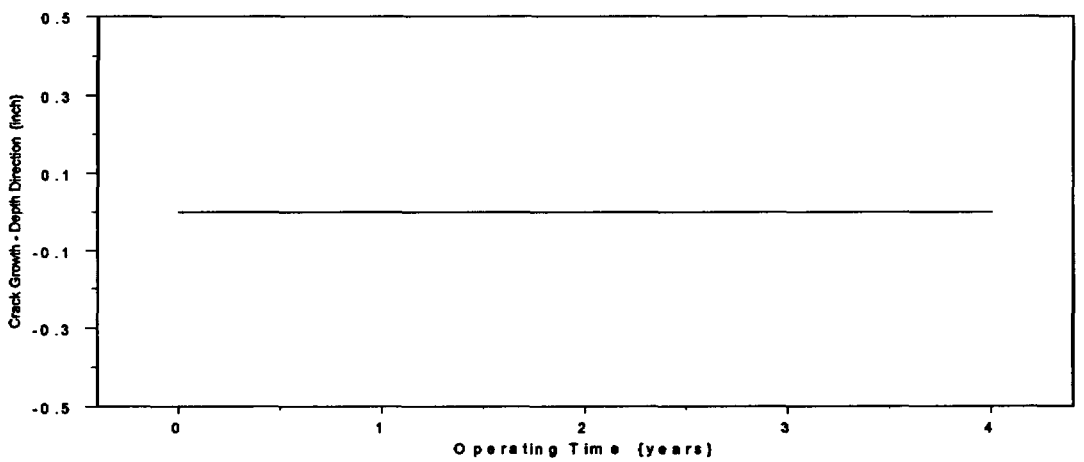
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099
5.099

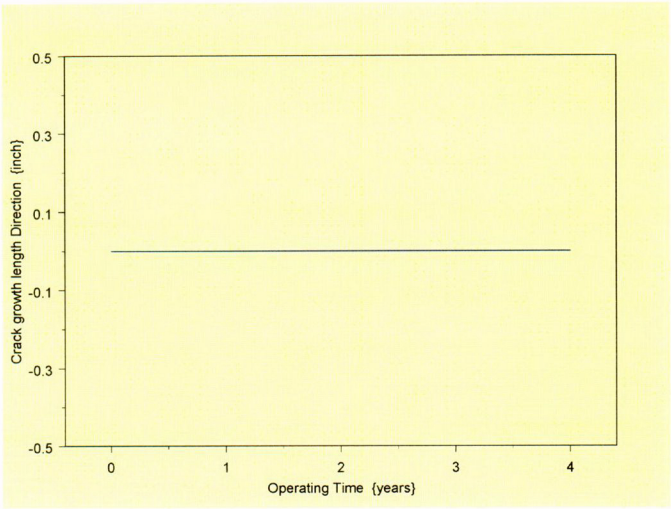
$CGR_{sambi_{(k,5)}}$ =

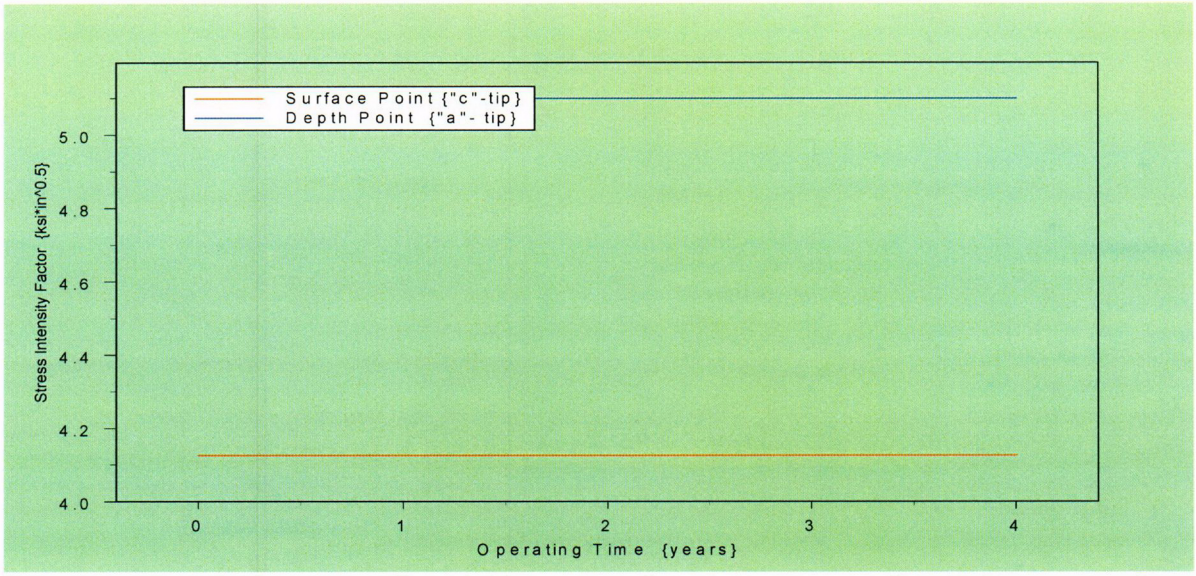
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125
4.125



$$\left(\mathrm{AXLen}^{\langle 0\rangle}\ \ \mathrm{ID}_{\mathrm{All}}{}^{\langle 0\rangle}\ \ \mathrm{OD}_{\mathrm{All}}{}^{\langle 0\rangle}\right)$$




0.5
0.3
0.1
-0.1
-0.3
-0.5
Crack growth length Direction {inch}
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
5.0
4.8
4.6
4.4
4.2
4.0
Stress Intensity Factor {ksi*in^0.5}
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8"Degree Nozzle, Uphill 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 throughwall 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.

$UL_{Strs.Dist} := 2.386$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.344$	Initial Flaw Length TW axial (Based on 10 Ksi average stress)
$od := 4.05$	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 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.

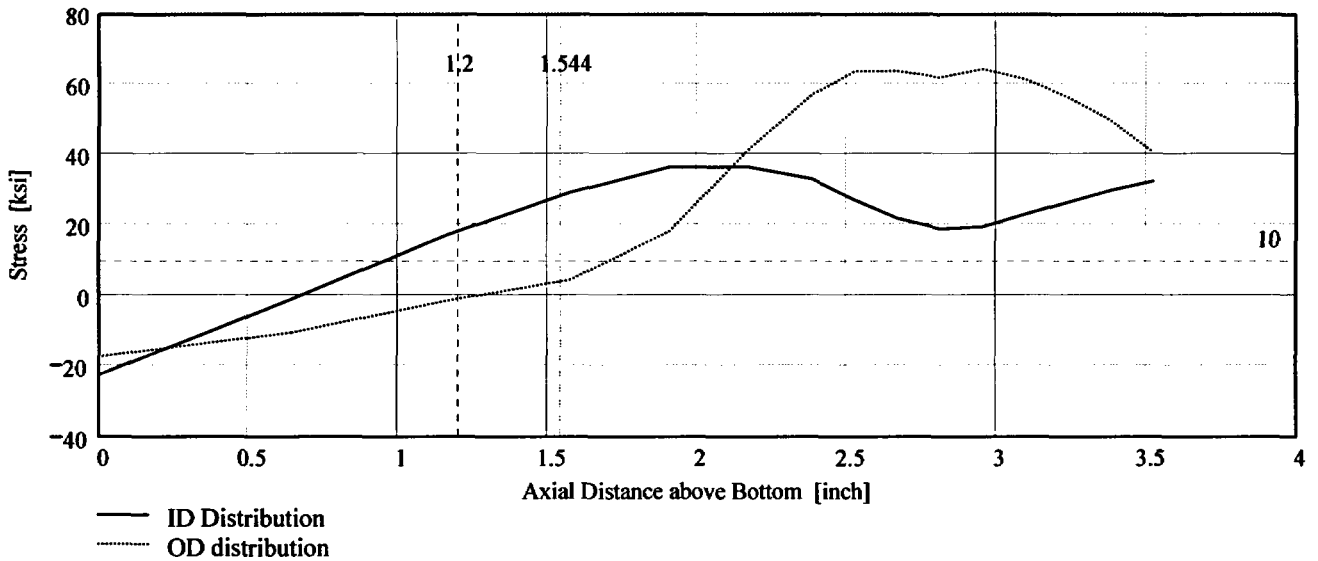
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "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	-22.34	-20.02	-18.96	-18.09	-17.15
1	0.64	-0.72	-3.67	-6.82	-8.7	-10.19
2	1.16	17.28	14.91	9.65	3.77	-1.22
3	1.58	29.36	26.5	20.58	13.8	4.75
4	1.91	36.5	30.92	25.41	21.15	18.37
5	2.17	36.54	30.33	27.24	32.61	41.48
6	2.39	33.13	31.54	31.44	42.45	57.26
7	2.53	27.12	28.37	33.43	47.23	63.83
8	2.67	21.96	26.11	34.41	48.85	63.88
9	2.81	18.99	24.12	35.2	49.9	62.11
10	2.96	19.58	24.12	34.38	48.41	64.46
11	3.1	23.12	24.38	33.3	45.65	61.6

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



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).

$$Data := \begin{pmatrix} 0 & -22.34 & -20.022 & -18.961 & -18.087 & -17.153 \\ 0.645 & -0.722 & -3.667 & -6.821 & -8.696 & -10.19 \\ 1.162 & 17.28 & 14.912 & 9.653 & 3.766 & -1.22 \\ 1.575 & 29.359 & 26.501 & 20.582 & 13.796 & 4.753 \\ 1.907 & 36.503 & 30.924 & 25.411 & 21.15 & 18.374 \\ 2.173 & 36.536 & 30.331 & 27.24 & 32.606 & 41.485 \\ 2.386 & 33.132 & 31.54 & 31.442 & 42.452 & 57.257 \\ 2.528 & 27.116 & 28.37 & 33.434 & 47.233 & 63.826 \\ 2.67 & 21.957 & 26.115 & 34.408 & 48.851 & 63.884 \\ 2.813 & 18.993 & 24.124 & 35.202 & 49.904 & 62.107 \\ 2.955 & 19.578 & 24.12 & 34.376 & 48.405 & 64.458 \\ 3.098 & 23.12 & 24.375 & 33.301 & 45.647 & 61.604 \end{pmatrix}$$

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

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

$FL_{Cntr} := BZ - 1$ 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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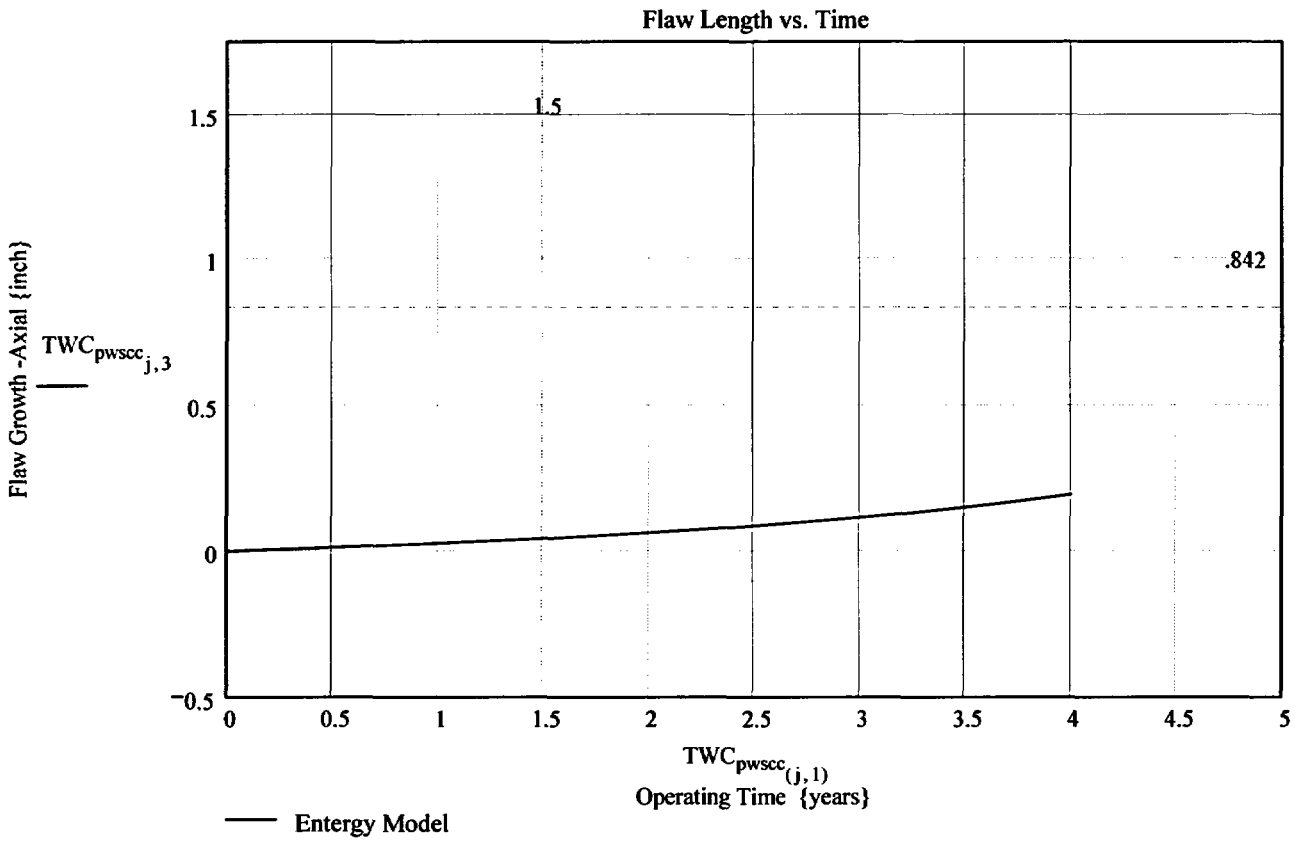
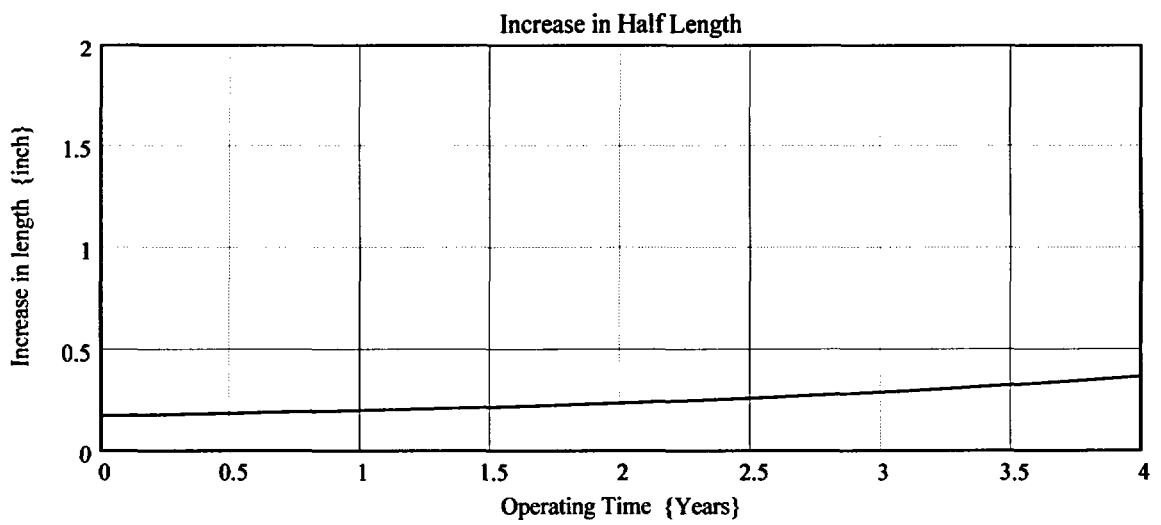
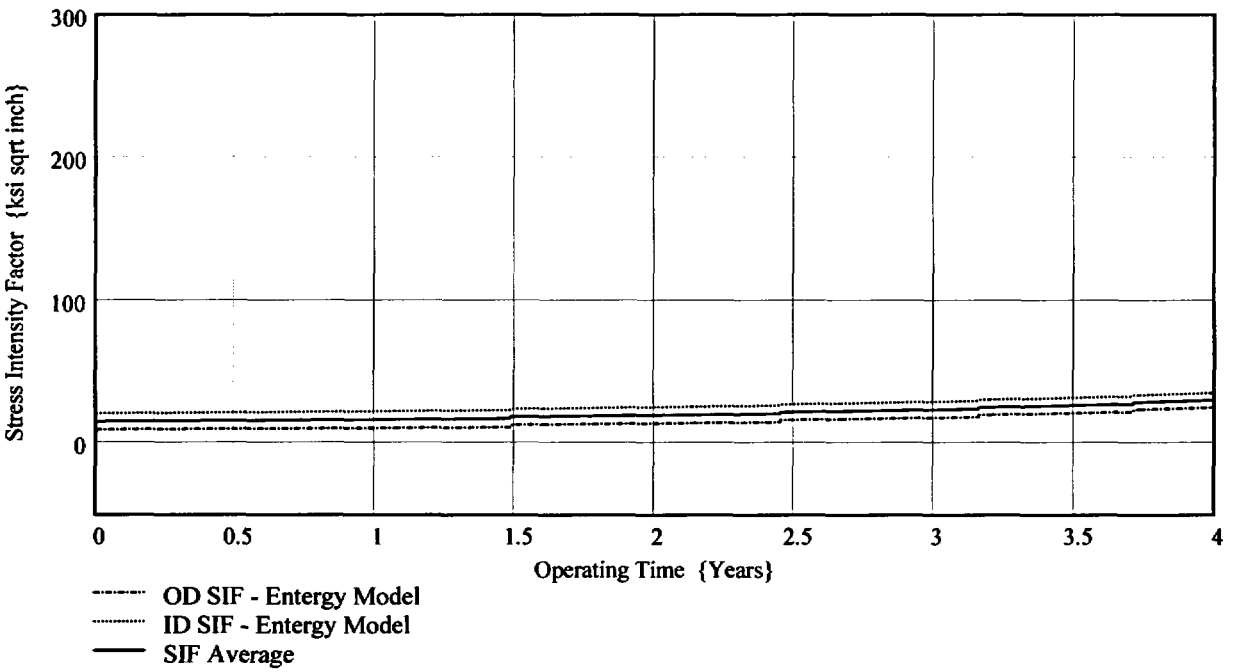
$Prop_{Length} = 0.842$






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

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

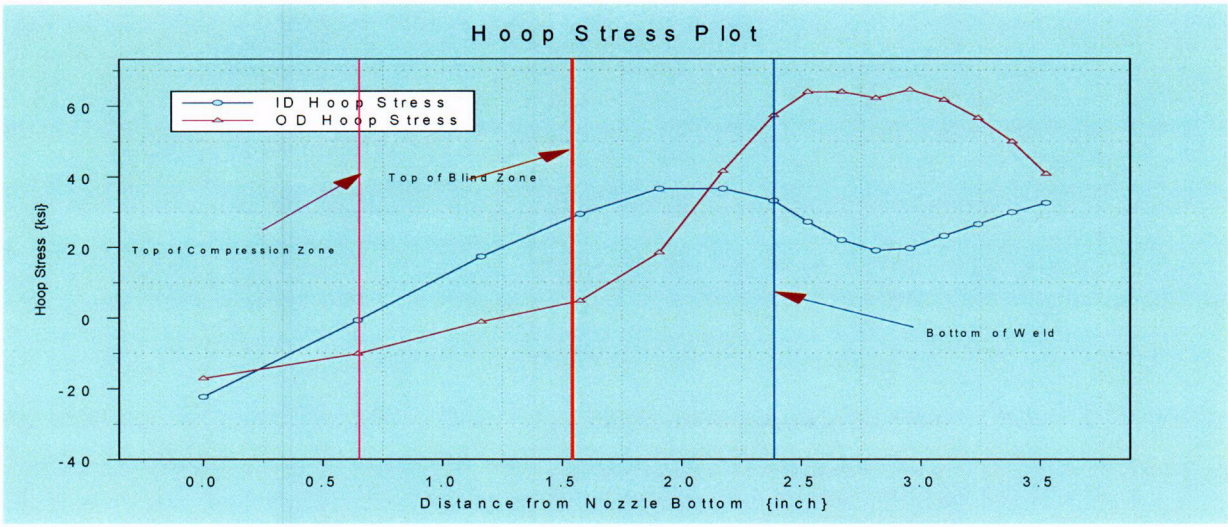
7.288
9.187
9.189
9.192
9.194
9.197
9.2
9.202
9.205
9.208
9.21
9.213
9.215
9.218
9.221
9.223

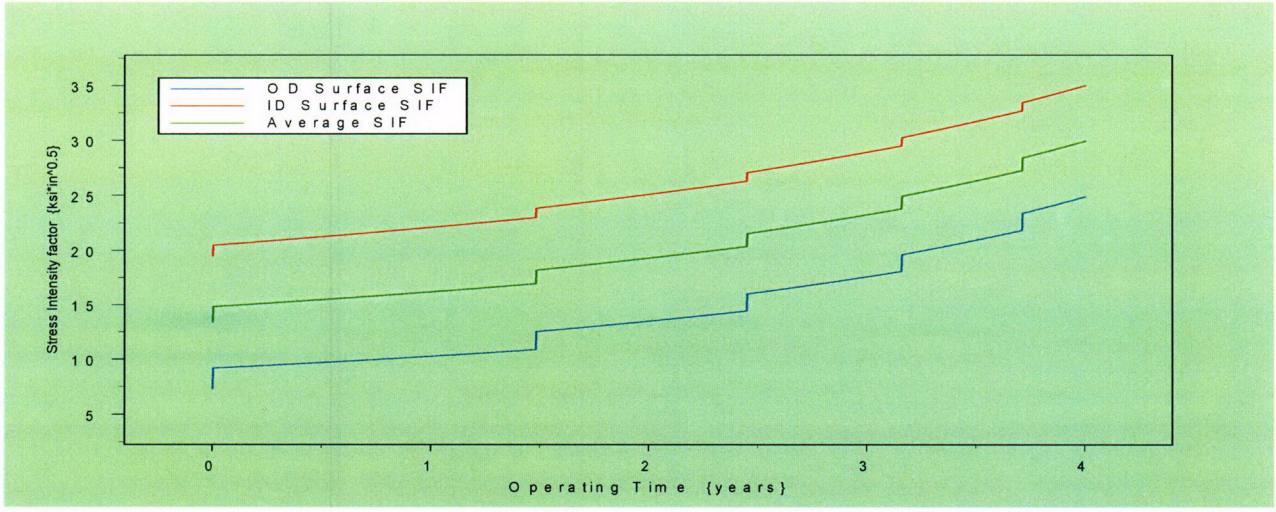
$TWC_{pwscc_{(j,7)}}$ =

19.481
20.457
20.461
20.465
20.469
20.473
20.477
20.481
20.485
20.489
20.493
20.497
20.501
20.505
20.51
20.514

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

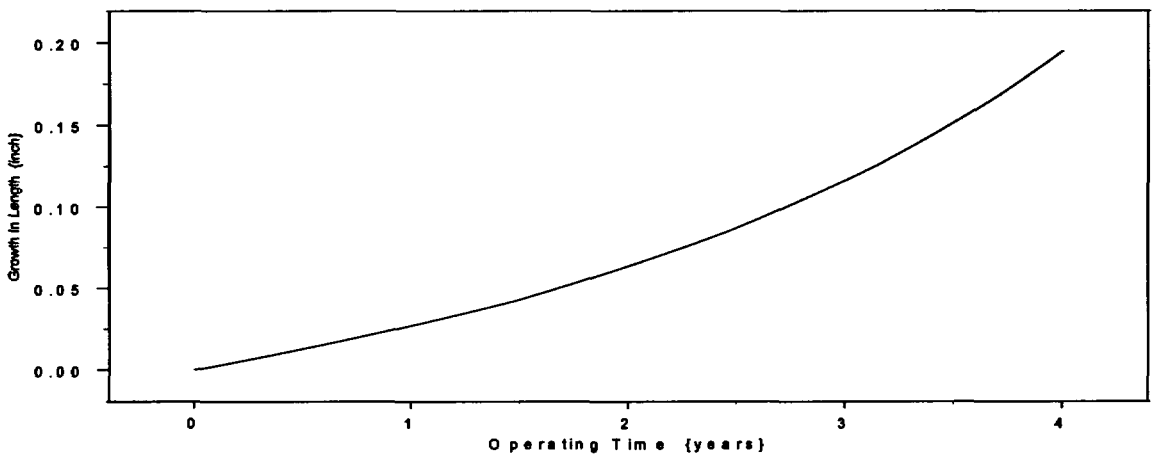
13.773
15.225
15.228
15.232
15.235
15.239
15.243
15.246
15.25
15.253
15.257
15.26
15.264
15.267
15.271
15.275





Developed by: *Verified by:*

C13


0.20
0.15
0.10
0.05
0.00
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 Porgrams, Entergy Operations Inc.

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8" Degree Nozzle, Mid-Plane 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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.

$UL_{Strs.Dist} := 2.087$ Upper axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom).

Input Data :-

$L := 0.32$ Initial Flaw Length (Twice detectable length)

$a_0 := 0.661 \cdot 0.07$ Initial Flaw Depth (Minimum Detecteble Depth was 5% TW)

$od := 4.05$ 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

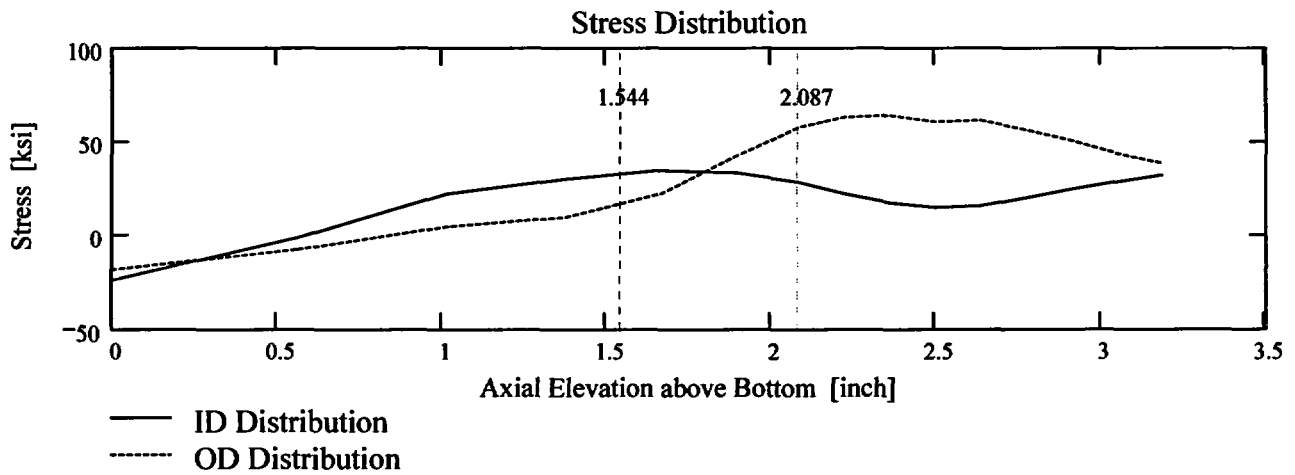
Stress Input Data

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)
Cloumn "2" = Quarter Thickness Stress data at each Elevation (ksi)
Cloumn "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	-24.18	-21.84	-20.55	-19.44	-18.5
1	0.56	-1.41	-3.32	-4.98	-6.48	-7.75
2	1.02	22.03	16.77	12.53	8.72	4.43
3	1.38	29.96	26.48	21.85	16.05	9.43
4	1.67	34.51	28.44	24.2	22.09	22.08
5	1.9	33.22	28.07	26.32	32.42	42.48
6	2.09	28.22	28.59	29.91	41.71	57.59
7	2.22	22.01	25.06	31.61	45.62	63.12
8	2.36	17.22	23.06	32.35	47.57	64.11
9	2.5	14.68	21.28	33.22	47.8	60.65

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



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. Higlight 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 mosue 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 dtat 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.

$$Data := \begin{pmatrix} 0 & -24.18 & -21.838 & -20.55 & -19.438 & -18.504 \\ 0.564 & -1.412 & -3.32 & -4.982 & -6.476 & -7.753 \\ 1.016 & 22.032 & 16.773 & 12.529 & 8.722 & 4.428 \\ 1.378 & 29.956 & 26.483 & 21.849 & 16.053 & 9.428 \\ 1.668 & 34.51 & 28.439 & 24.198 & 22.09 & 22.082 \\ 1.9 & 33.218 & 28.069 & 26.319 & 32.416 & 42.48 \\ 2.087 & 28.217 & 28.594 & 29.911 & 41.713 & 57.592 \\ 2.224 & 22.006 & 25.059 & 31.606 & 45.624 & 63.118 \\ 2.361 & 17.219 & 23.064 & 32.349 & 47.567 & 64.115 \end{pmatrix}$$

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

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

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

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

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

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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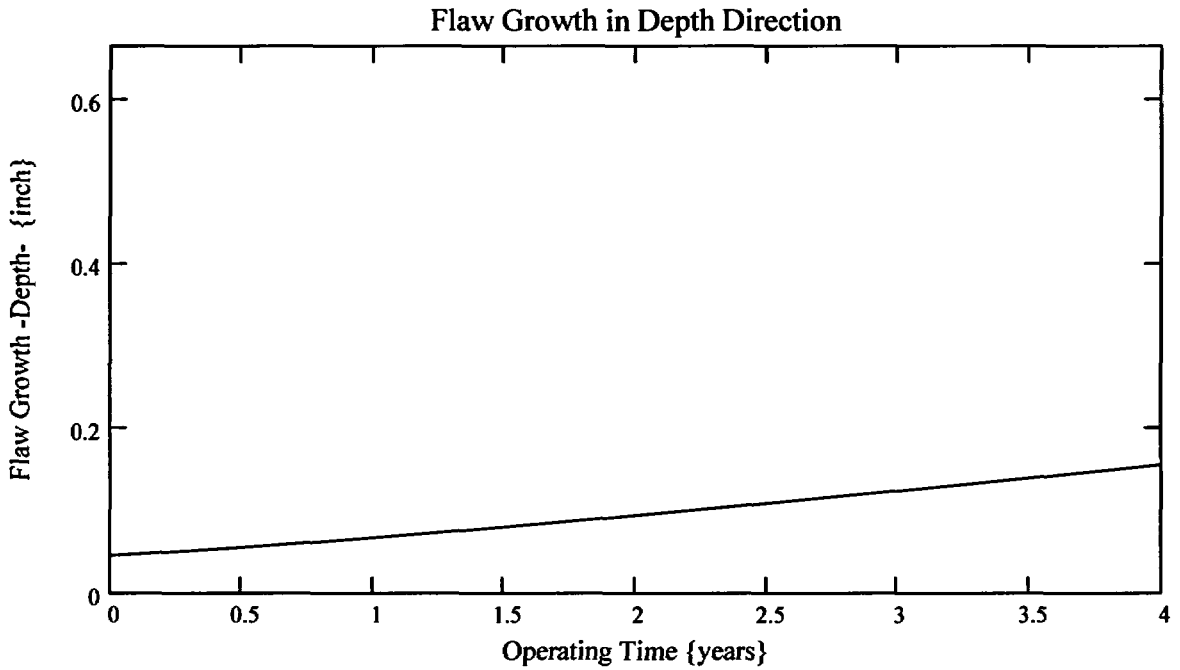
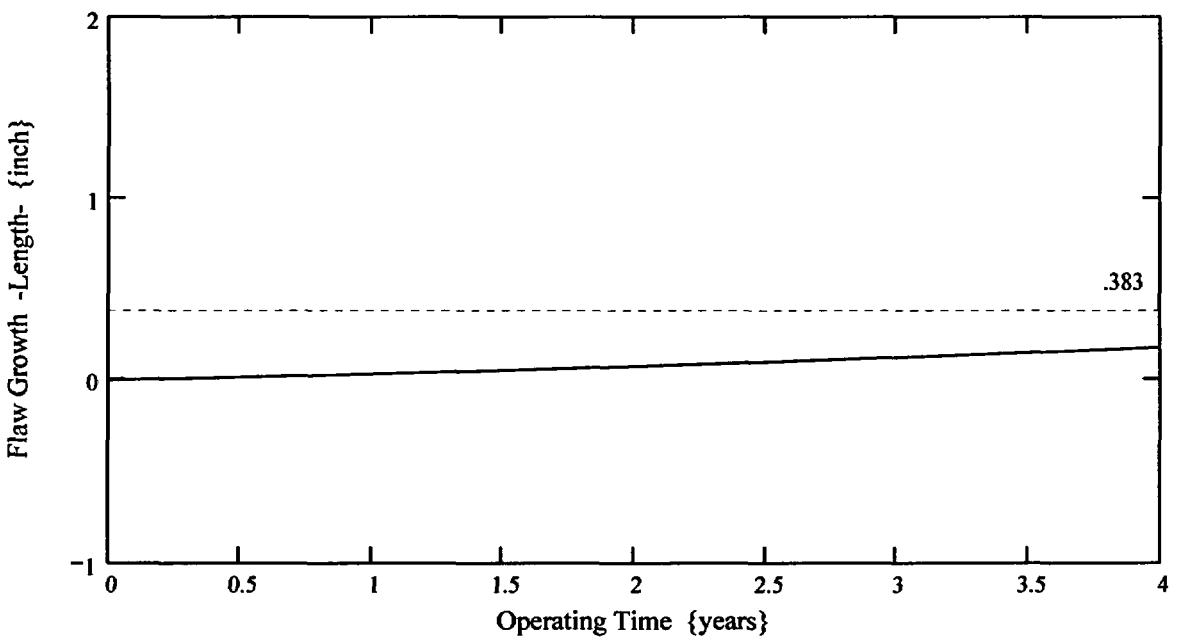
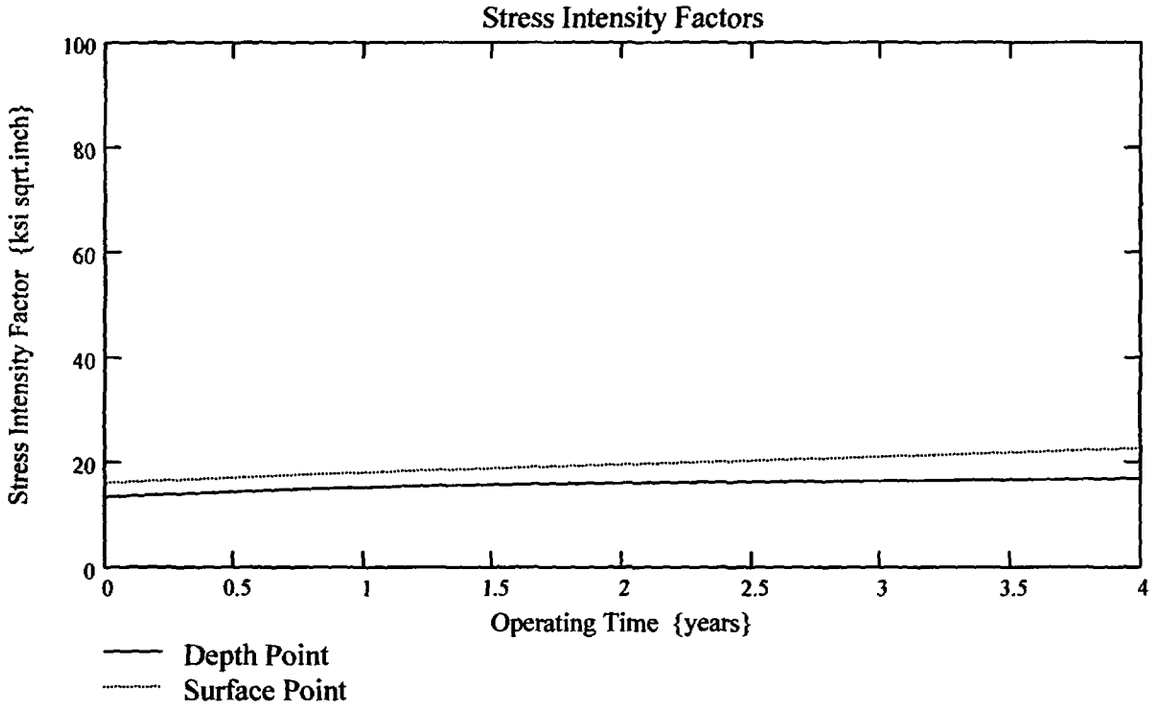
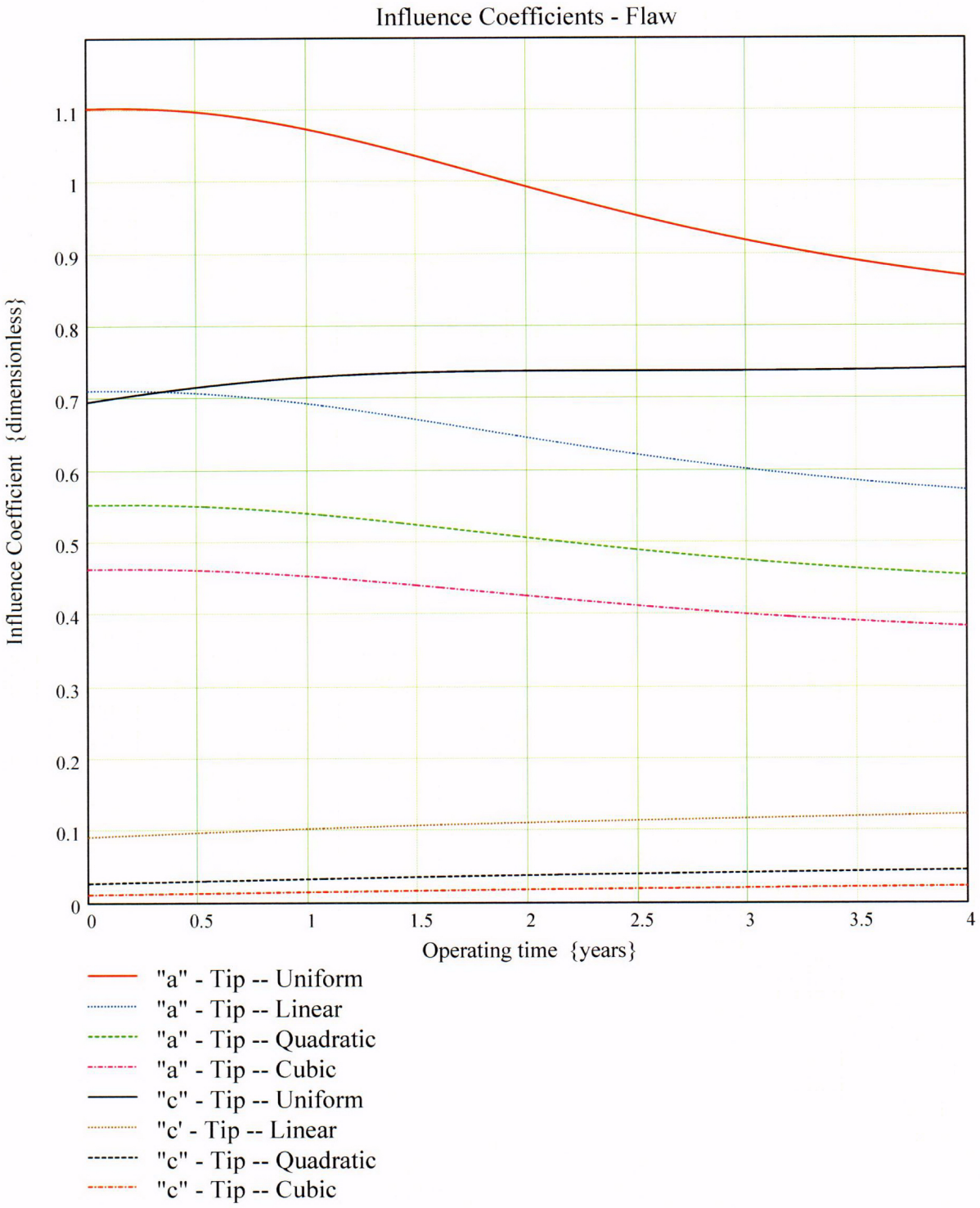
$Prop_{Length} = 0.383$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
100
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

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

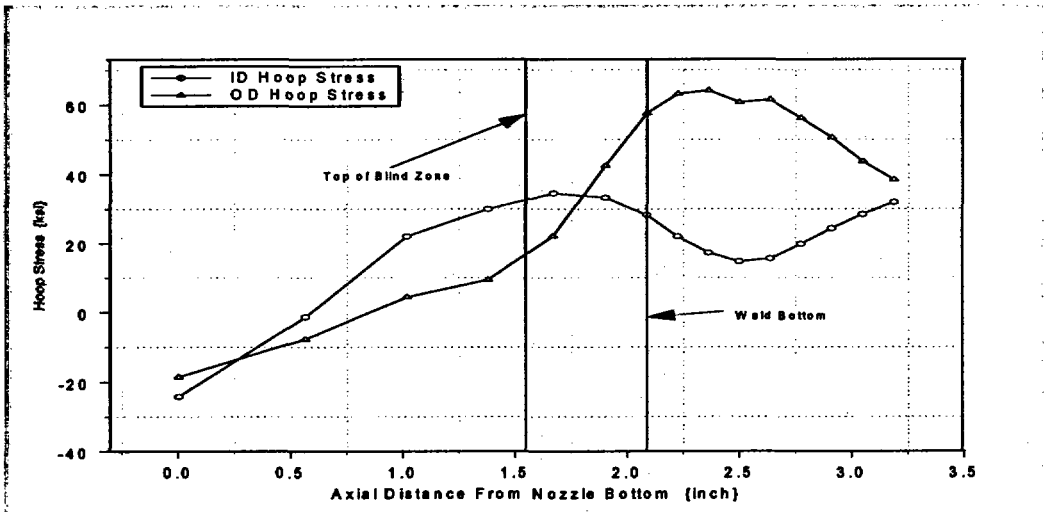
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103

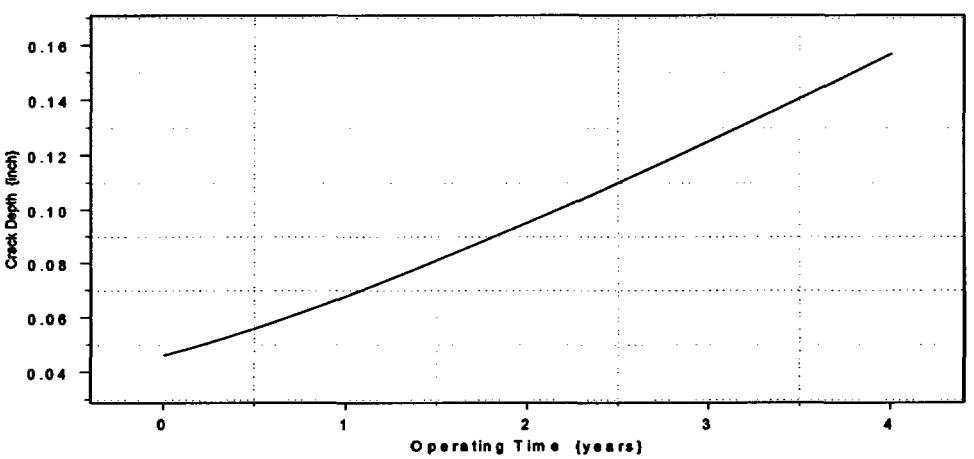
$CGR_{sambi_{(k,6)}}$ =

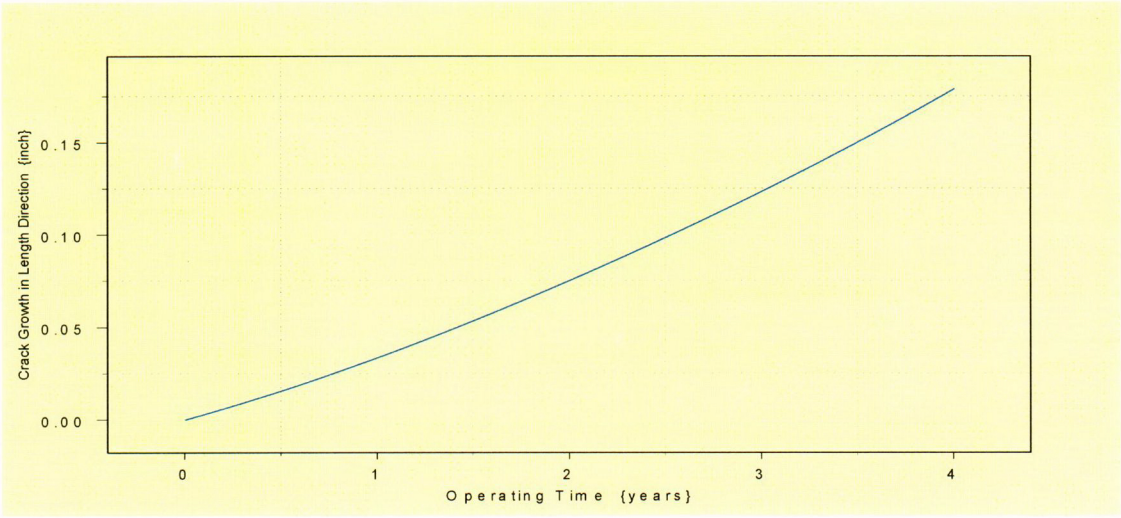
15.797
15.981
15.987
15.993
15.998
16.004
16.009
16.015
16.02
16.026
16.031
16.037
16.042
16.048
16.053
16.059

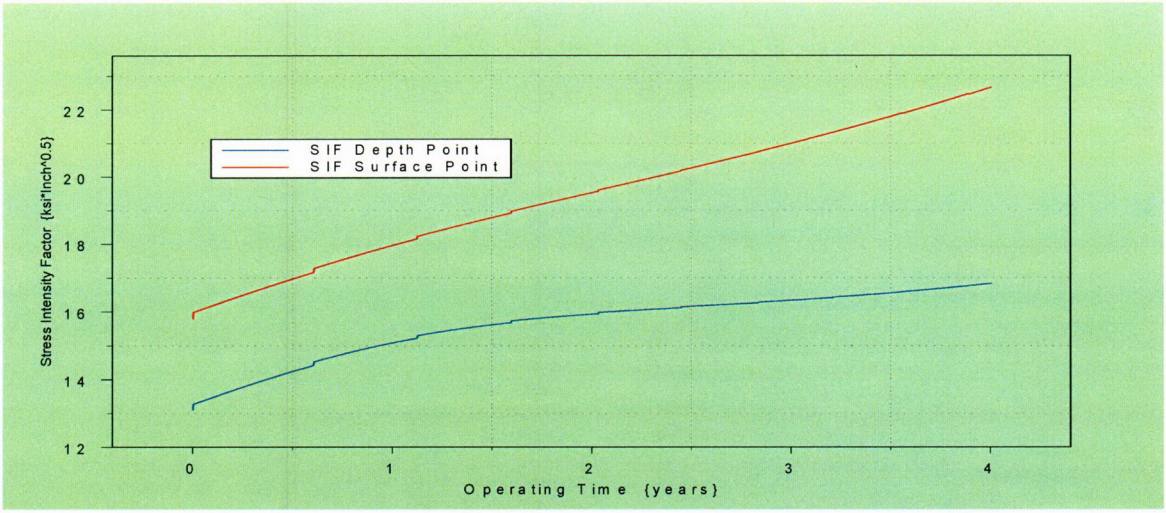
$CGR_{sambi_{(k,5)}}$ =

13.11
13.273
13.279
13.284
13.29
13.296
13.301
13.307
13.313
13.318
13.324
13.33
13.335
13.341
13.347
13.352


ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Weld Bottom
Hoop Stress (ksi)
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Axial Distance From Nozzle Bottom (inch)


Crack Depth (inch)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0
1
2
3
4
Operating Time (years)


Crack Growth in Length Direction {inch}
0.15
0.10
0.05
0.00
0
1
2
3
4
Operating Time {years}


Stress Intensity Factor {ksi*inch^0.5}
22
20
18
16
14
12
SIF Depth Point
SIF Surface Point
0
1
2
3
4
Operating Time {years}

Primary Water Stress Corrosion Crack Growth Analysis - OD SurfaceFlaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8" Degree Nozzle, Mid-Plane 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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).

$$Val := 2$$

Upper Limit to be selected for stress distribution (e.g. Weld bottom). This is the elevation from Nozzle Bottom. Enter this value below

$UL_{Strs.Dist} := 2.087$ Upper Axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.32$ Initial Flaw Length

$a_0 := 0.661 \cdot 0.12$ 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

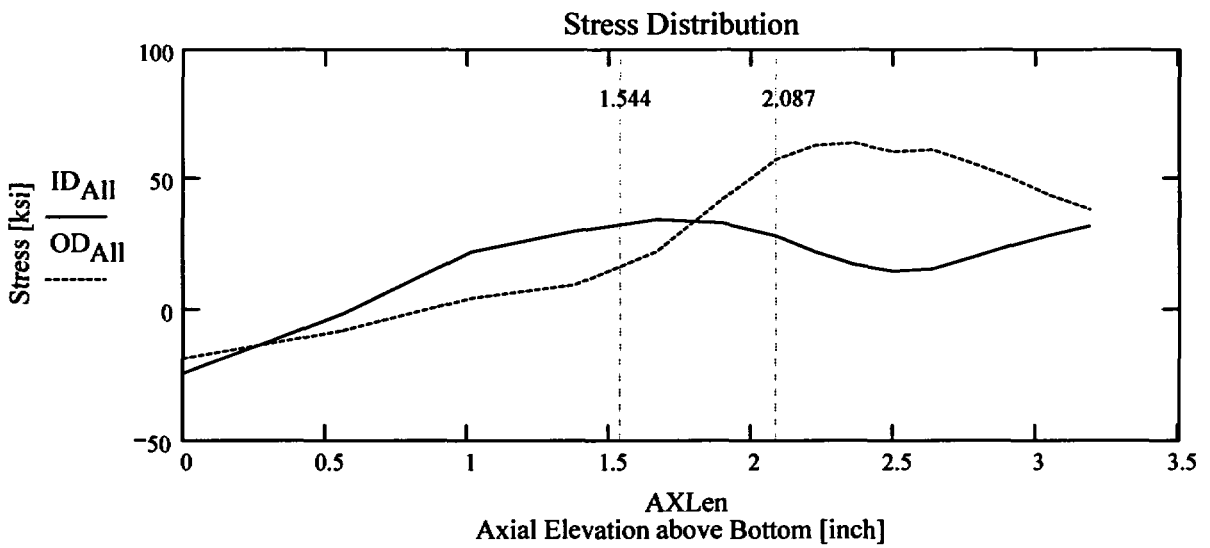
Stress Input Data

Input all available Nodal stress data in the table below. The column designations are as follows:
Column "0" = Axial distance from minumum 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	-24.18	-21.84	-20.55	-19.44	-18.5
1	0.56	-1.41	-3.32	-4.98	-6.48	-7.75
2	1.02	22.03	16.77	12.53	8.72	4.43
3	1.38	29.96	26.48	21.85	16.05	9.43
4	1.67	34.51	28.44	24.2	22.09	22.08
5	1.9	33.22	28.07	26.32	32.42	42.48
6	2.09	28.22	28.59	29.91	41.71	57.59
7	2.22	22.01	25.06	31.61	45.62	63.12
8	2.36	17.22	23.06	32.35	47.57	64.11
9	2.5	14.68	21.28	33.22	47.8	60.65

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



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. 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).

$$Data := \begin{pmatrix} 0 & -24.18 & -21.838 & -20.55 & -19.438 & -18.504 \\ 0.564 & -1.412 & -3.32 & -4.982 & -6.476 & -7.753 \\ 1.016 & 22.032 & 16.773 & 12.529 & 8.722 & 4.428 \\ 1.378 & 29.956 & 26.483 & 21.849 & 16.053 & 9.428 \\ 1.668 & 34.51 & 28.439 & 24.198 & 22.09 & 22.082 \\ 1.9 & 33.218 & 28.069 & 26.319 & 32.416 & 42.48 \\ 2.087 & 28.217 & 28.594 & 29.911 & 41.713 & 57.592 \\ 2.224 & 22.006 & 25.059 & 31.606 & 45.624 & 63.118 \\ 2.361 & 17.219 & 23.064 & 32.349 & 47.567 & 64.115 \end{pmatrix}$$

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

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

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

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

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

Flaw center Location Location above Nozzle Bottom

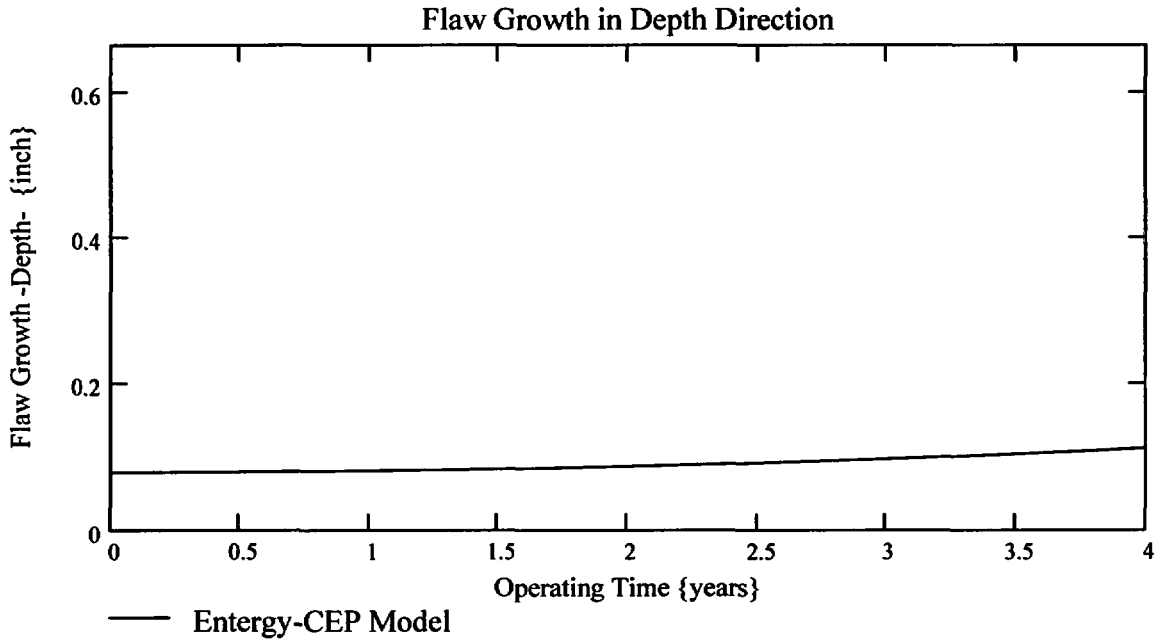
$U_{Tip} := FL_{Cntr} + c_0$

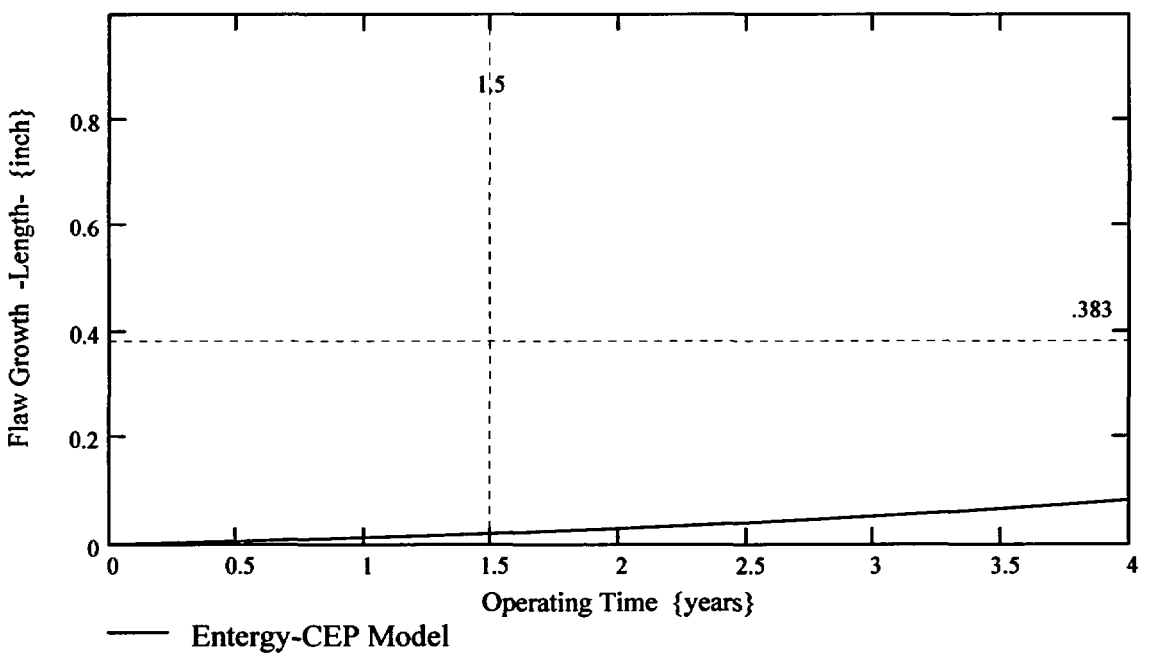
$$Inc_{Strs.avg} := \frac{UL_{Strs.Dist} - U_{Tip}}{20}$$

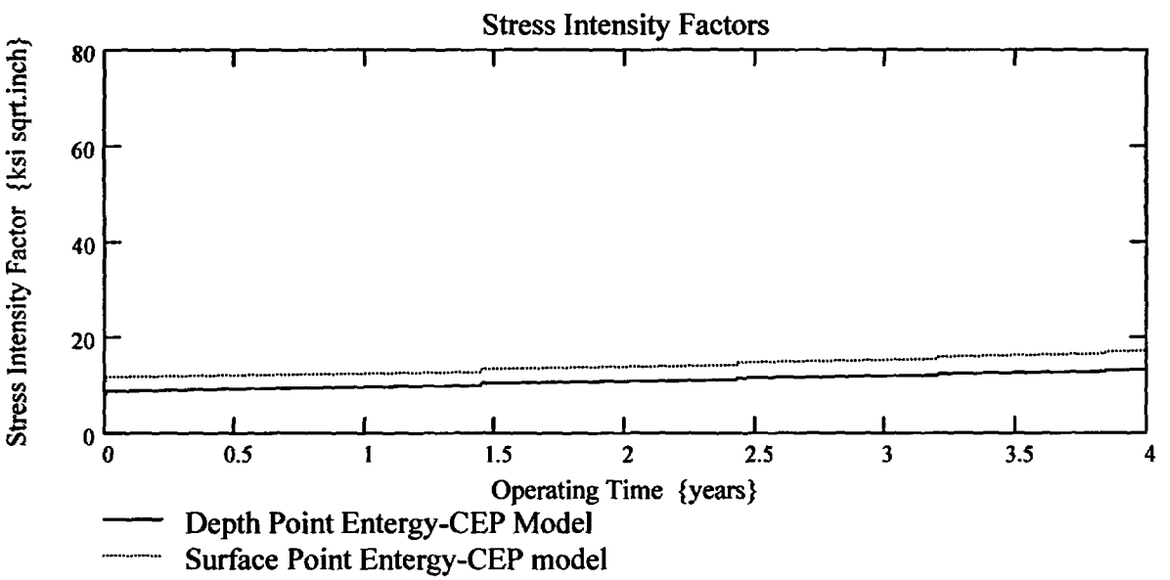
No User Input is required beyond this Point

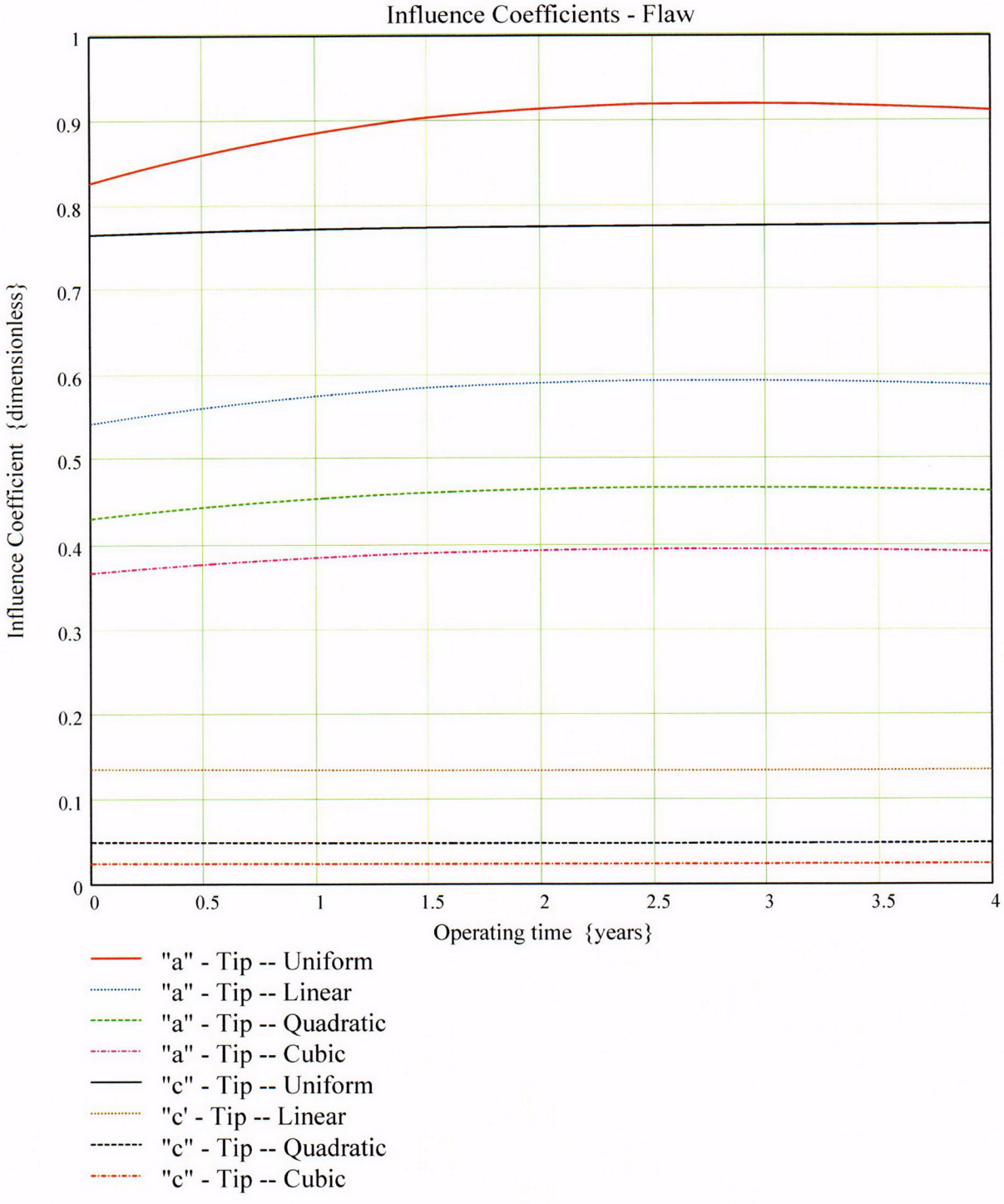
Sat Aug 09 10:21:18 AM 2003

$Prop_{Length} = 0.383$






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


Influence Coefficients - Flaw
Influence Coefficient {dimensionless}
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

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

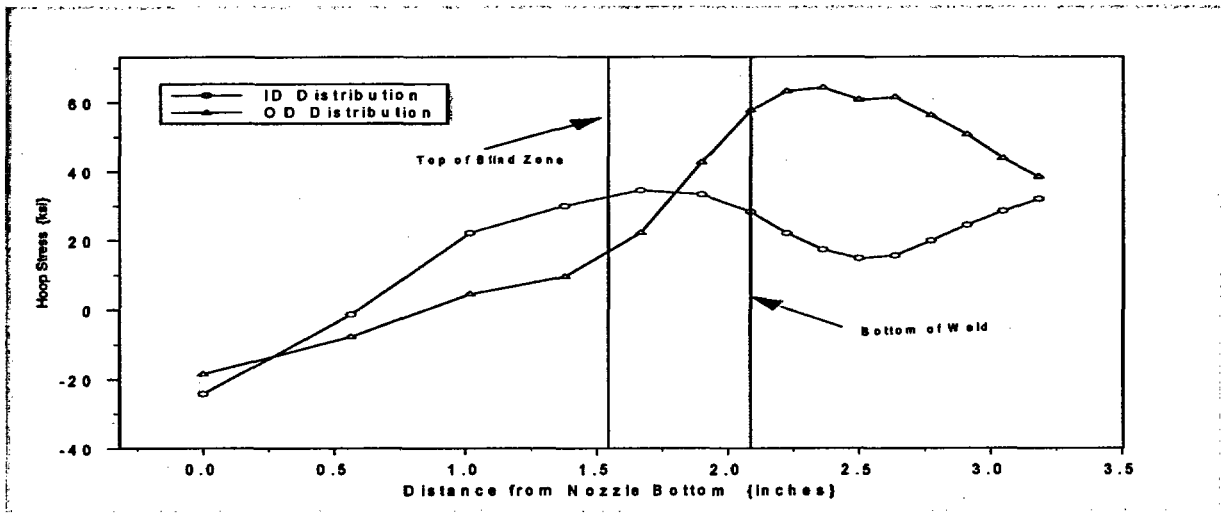
0.827
0.827
0.827
0.827
0.827
0.828
0.828
0.828
0.828
0.828
0.829
0.829
0.829
0.829
0.829
0.83

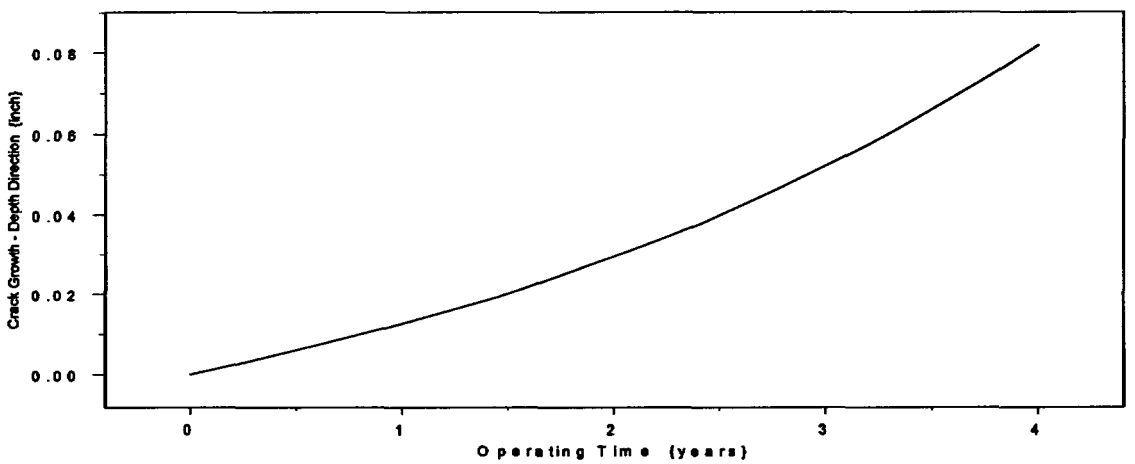
$CGR_{sambi_{(k,6)}}$ =

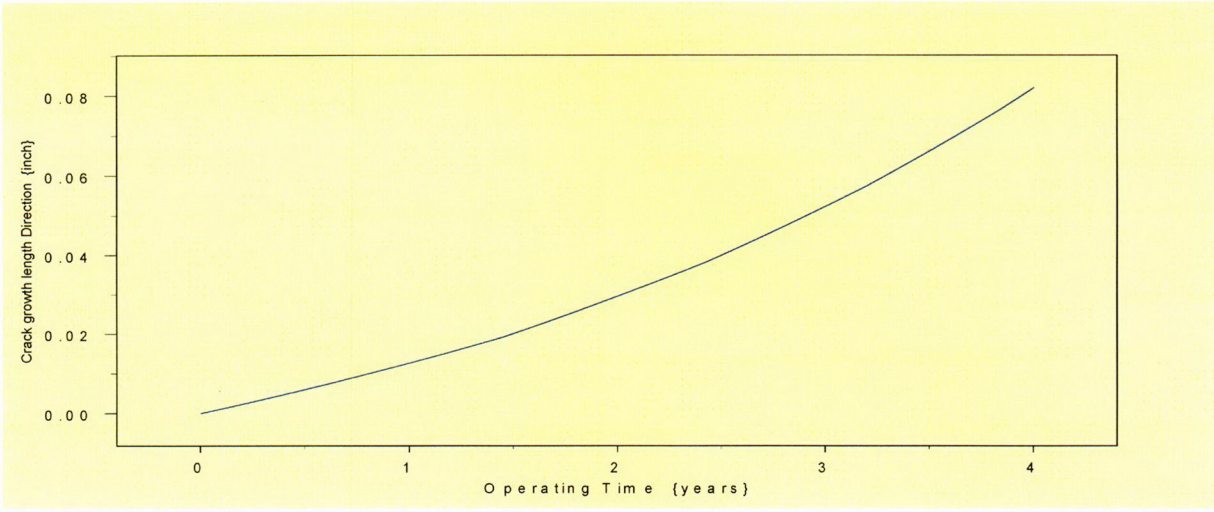
10.735
11.648
11.65
11.652
11.654
11.656
11.658
11.66
11.662
11.663
11.665
11.667
11.669
11.671
11.673
11.675

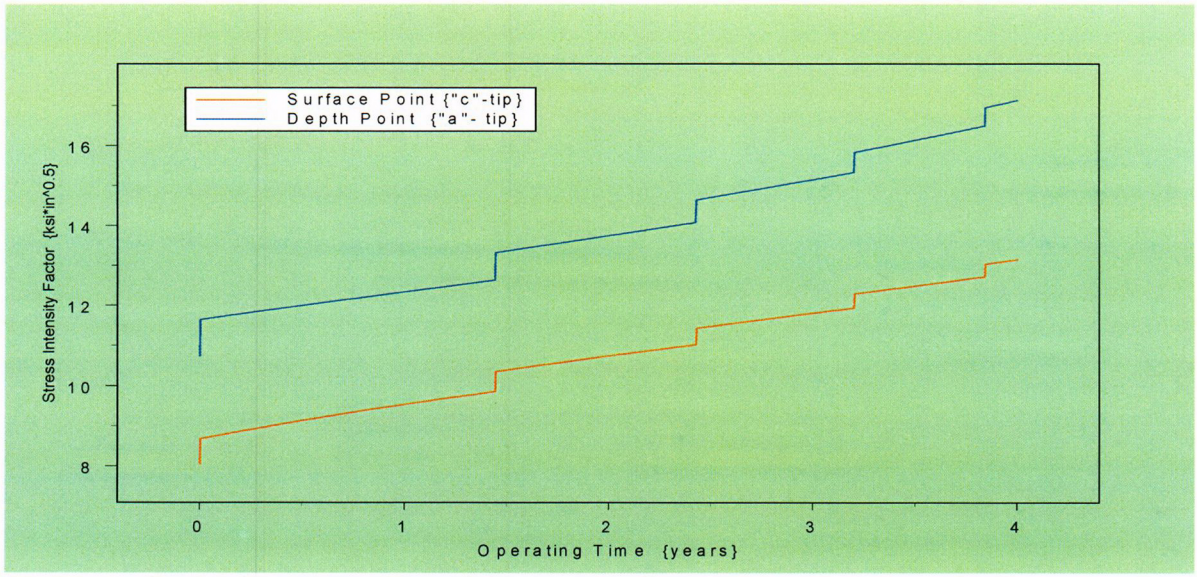
$CGR_{sambi_{(k,5)}}$ =

8.046
8.676
8.679
8.681
8.684
8.687
8.689
8.692
8.694
8.697
8.7
8.702
8.705
8.707
8.71
8.713


ID Distribution
OD Distribution
Top of Blind Zone
Bottom of Weld
Hoop Stress (ksi)
60
40
20
0
-20
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Distance from Nozzle Bottom (inches)


Crack Growth - Depth Direction (inch)
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
Operating Time (years)


Crack growth length Direction {inch}
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
Operating Time {years}


Surface Point {"c"-tip}
Depth Point {"a"- tip}
Stress Intensity Factor {ksi*in^0.5}
16
14
12
10
8
0
1
2
3
4
Operating Time {years}

Stress Corrosion Crack Growth Analysis Throughwall flaw

Developed by Central Engineering Programs, Entergy Operations Inc

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

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"8"Degree Nozzle, Mid-Plane 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 throughwall 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.

$UL_{Strs.Dist} := 2.087$ Upper axial Extent for Stress Distribution to be used in the analysis (Axial distance above nozzle bottom)

Input Data :-

$L := 0.744$ Initial Flaw Length TW axial (Based on 10 Ksi average stress)

$od := 4.05$ 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

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

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

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

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

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

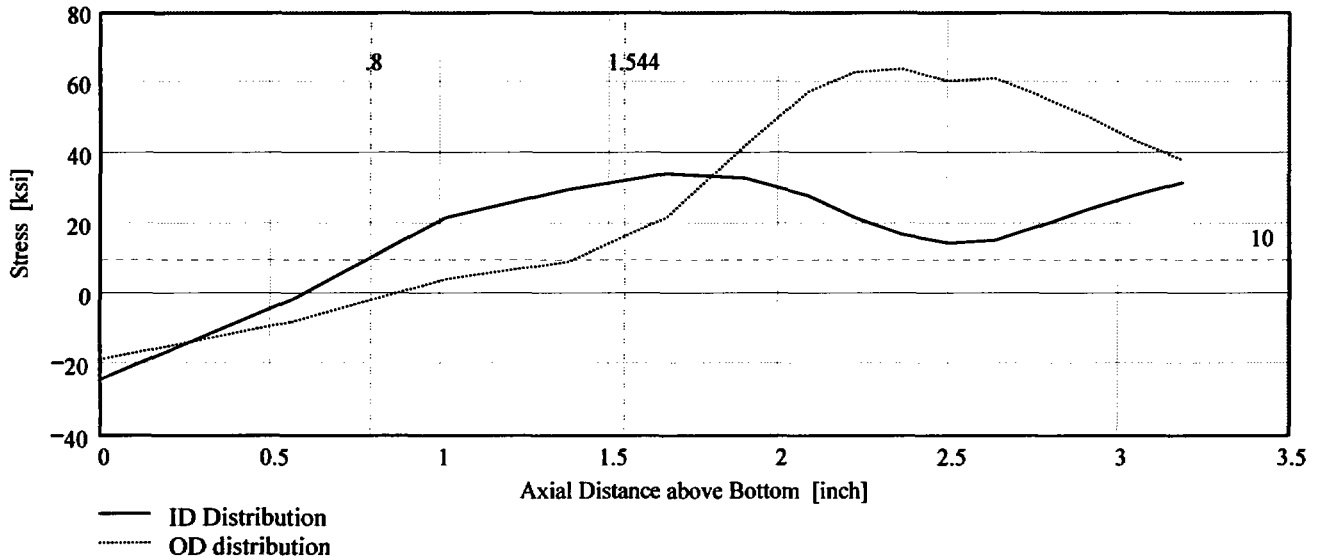
Stress Input Data

Import the Required data from applicable Excel spread Sheet. The column designations are as follows:
Cloumn "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	-24.18	-21.84	-20.55	-19.44	-18.5
1	0.56	-1.41	-3.32	-4.98	-6.48	-7.75
2	1.02	22.03	16.77	12.53	8.72	4.43
3	1.38	29.96	26.48	21.85	16.05	9.43
4	1.67	34.51	28.44	24.2	22.09	22.08
5	1.9	33.22	28.07	26.32	32.42	42.48
6	2.09	28.22	28.59	29.91	41.71	57.59
7	2.22	22.01	25.06	31.61	45.62	63.12
8	2.36	17.22	23.06	32.35	47.57	64.11
9	2.5	14.68	21.28	33.22	47.8	60.65

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



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).

$$Data := \begin{pmatrix} 0 & -24.18 & -21.838 & -20.55 & -19.438 & -18.504 \\ 0.564 & -1.412 & -3.32 & -4.982 & -6.476 & -7.753 \\ 1.016 & 22.032 & 16.773 & 12.529 & 8.722 & 4.428 \\ 1.378 & 29.956 & 26.483 & 21.849 & 16.053 & 9.428 \\ 1.668 & 34.51 & 28.439 & 24.198 & 22.09 & 22.082 \\ 1.9 & 33.218 & 28.069 & 26.319 & 32.416 & 42.48 \\ 2.087 & 28.217 & 28.594 & 29.911 & 41.713 & 57.592 \\ 2.224 & 22.006 & 25.059 & 31.606 & 45.624 & 63.118 \\ 2.361 & 17.219 & 23.064 & 32.349 & 47.567 & 64.115 \end{pmatrix}$$

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

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

$FL_{Cntr} := BZ - l$ 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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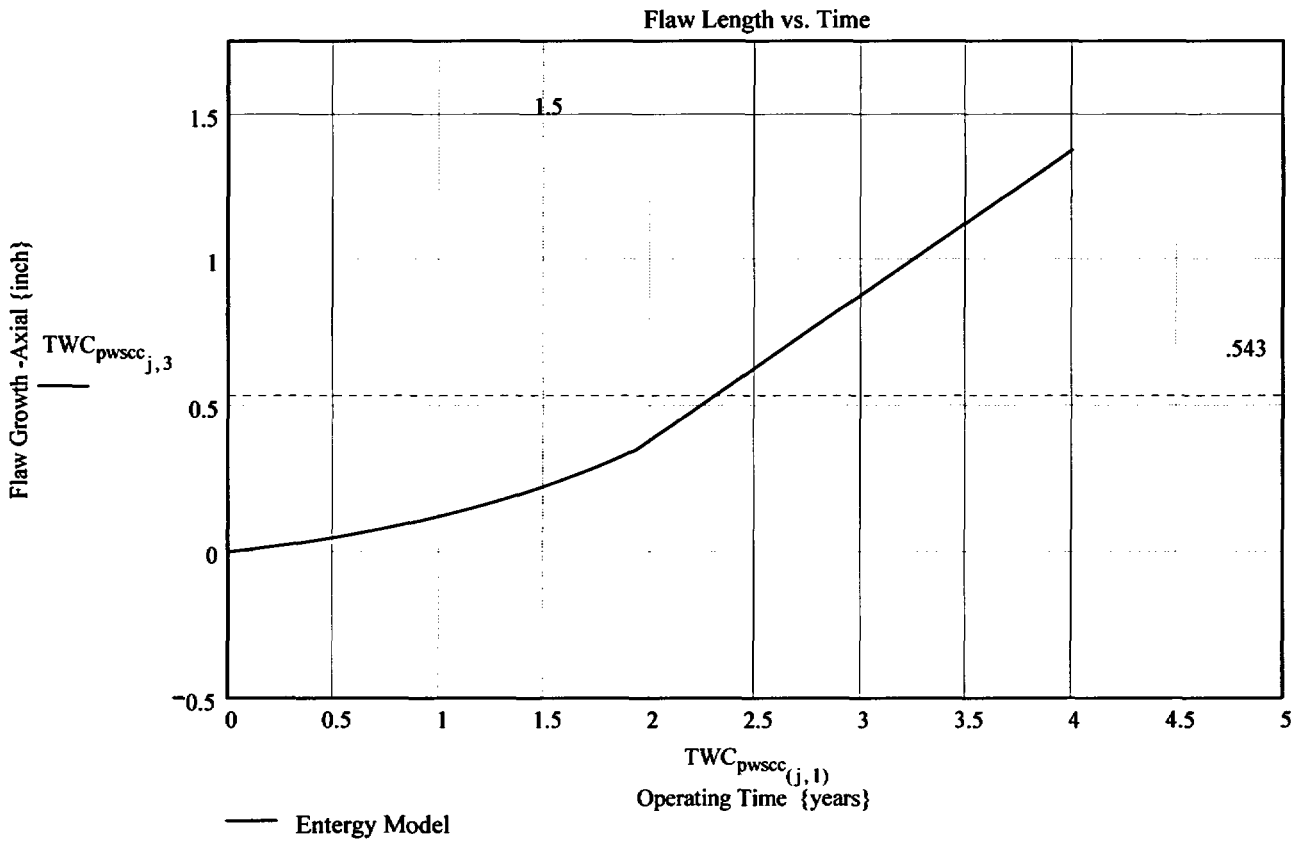
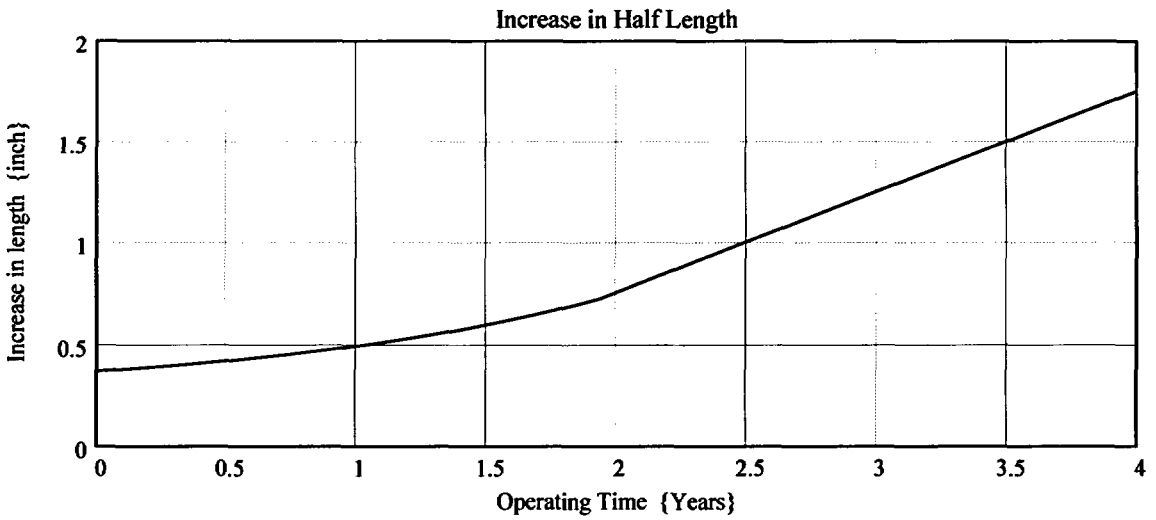
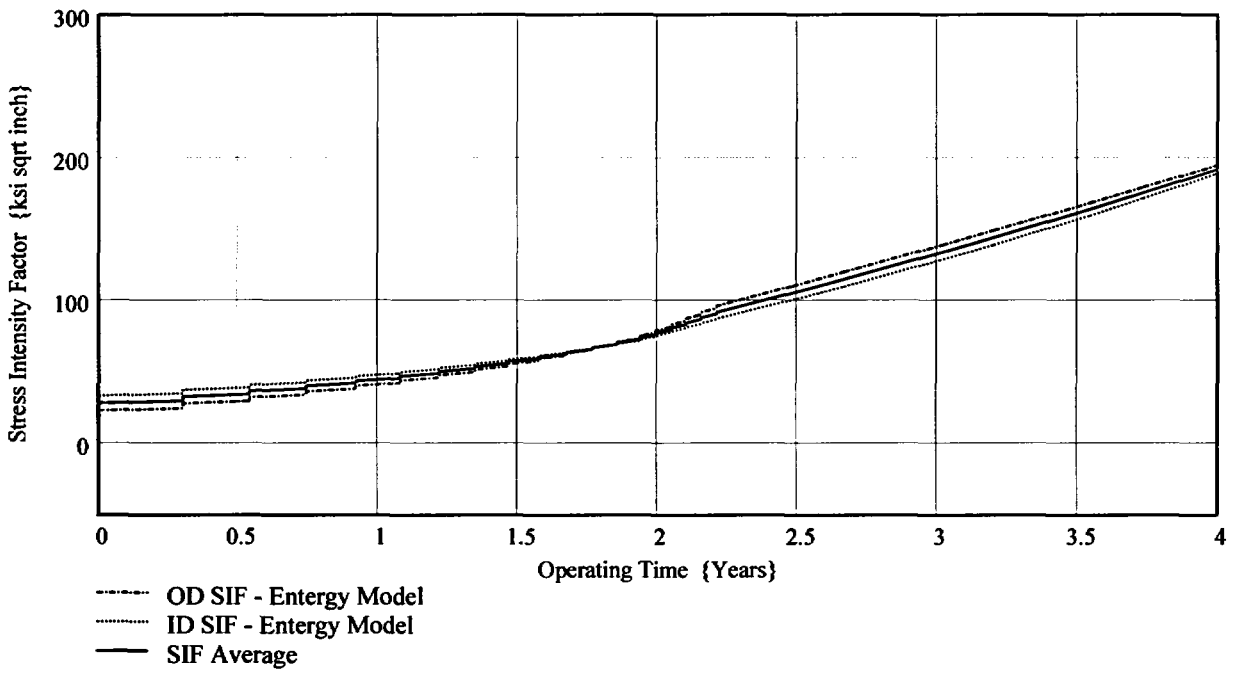
$Prop_{Length} = 0.543$





Developed by: *Verified by:*


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

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

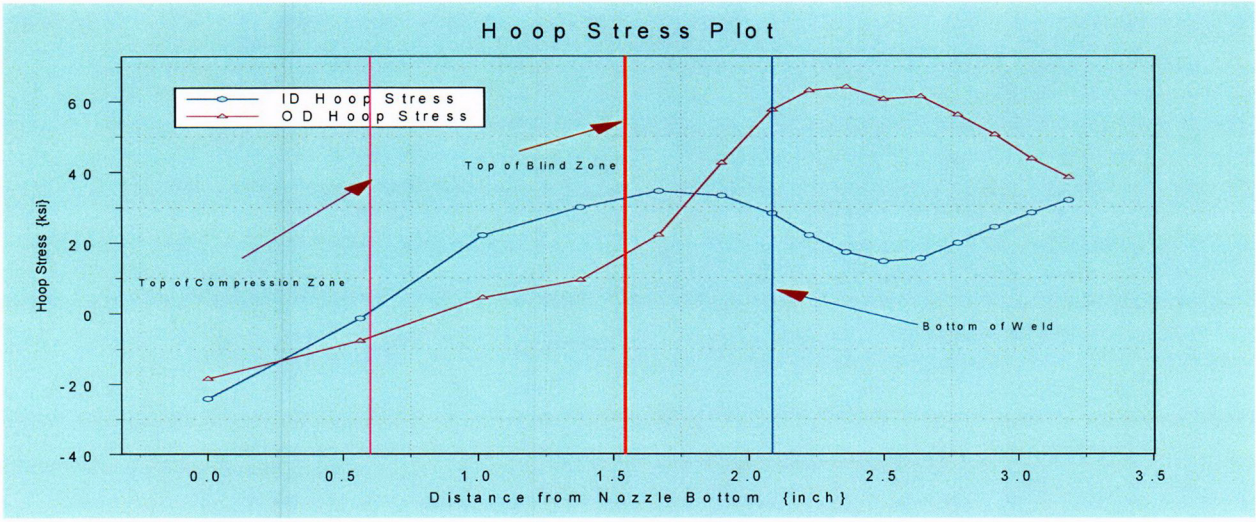
18.194
23.154
23.166
23.178
23.191
23.203
23.215
23.228
23.24
23.252
23.265
23.277
23.289
23.302
23.314
23.327

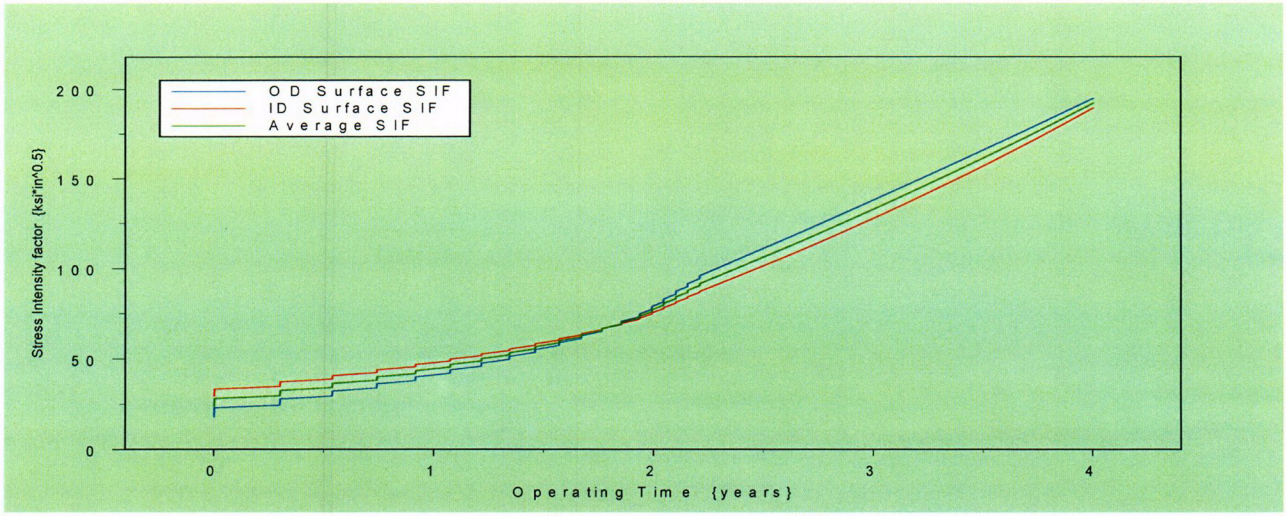
$TWC_{pwscc_{(j,7)}}$ =

29.656
33.394
33.407
33.419
33.432
33.445
33.458
33.471
33.483
33.496
33.509
33.522
33.535
33.548
33.561
33.573

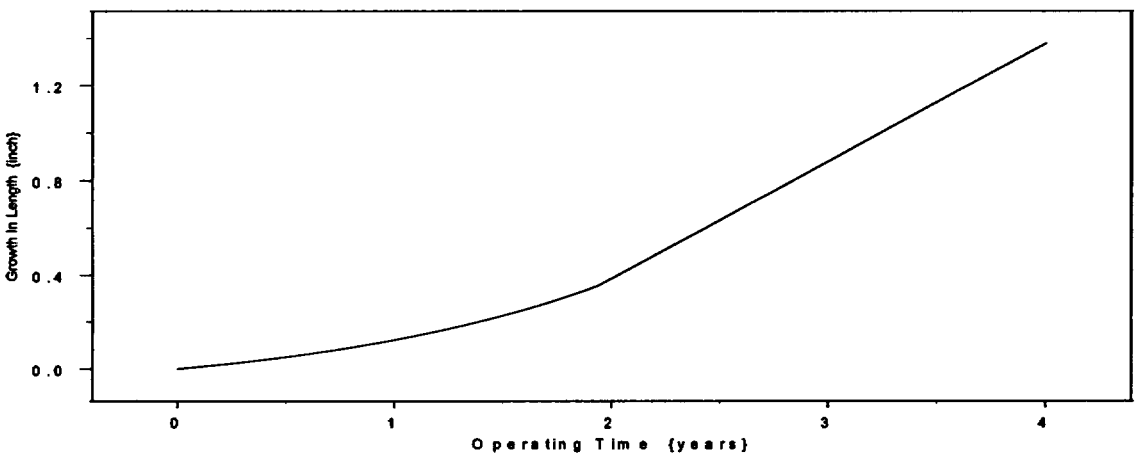
$TWC_{pwscc_{(j,8)}}$ =

25.114
29.591
29.605
29.619
29.632
29.646
29.66
29.674
29.687
29.701
29.715
29.729
29.742
29.756
29.77
29.784





Developed by: *Verified by:*


1.2
0.8
0.4
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 Porgrams, Entergy Operations Inc.

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

Refrences :

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

Arkansas Nuclear One Unit 2

Component : Reactor Vessel CEDM -"28" Degree Nozzle, Downhill 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 necessar 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 represnets the reference point elevation measured upward from the nozzle end.

$$Ref_{Point} := 1.544$$

To place the flaw with repsect 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.

$UL_{Strs.Dist} := 1.704$ Upper axial Extent for Stress Distribution to be used in the Analysis (Axial distance above nozzle bottom).

Input Data :-

$L := 0.32$ Initial Flaw Length (Twice detectable length)

$a_0 := 0.661 \cdot 0.07$ Initial Flaw Depth (Minimum Detecteble Depth was 5% TW)

$od := 4.05$ 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

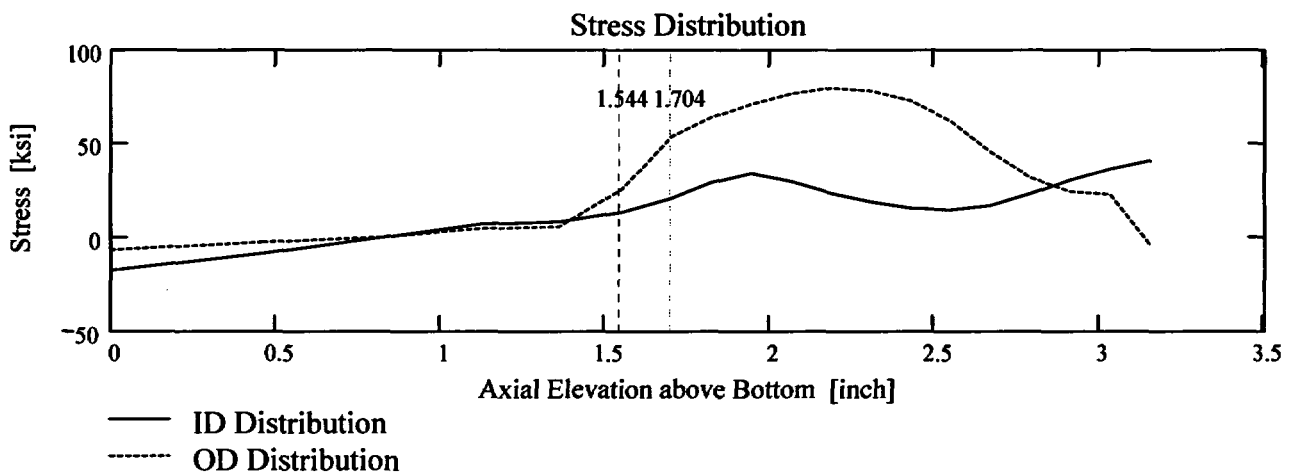
Stress Input Data

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)
Cloumn "2" = Quarter Thickness Stress data at each Elevation (ksi)
Cloumn "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	-17.41	-13.55	-11.11	-8.88	-6.63
1	0.46	-8.49	-6.31	-4.92	-3.71	-2.54
2	0.83	0.09	0.18	0.11	0.19	0.28
3	1.13	7.03	6.95	6.31	5.21	4.65
4	1.36	8.22	10.95	10.85	9.51	5.65
5	1.55	13.27	16.41	16.06	17.13	25.26
6	1.7	20.63	22.24	25.41	43.58	53.78
7	1.83	29.04	28.83	31.29	53.55	64.08
8	1.95	33.95	30.93	36.41	61.6	71.01
9	2.07	29.59	31.79	40.54	64.61	76.42

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



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. Higlight 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 mosue 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 dtat 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.

$$Data := \begin{pmatrix} 0 & -17.414 & -13.552 & -11.113 & -8.884 & -6.628 \\ 0.461 & -8.494 & -6.31 & -4.924 & -3.706 & -2.541 \\ 0.83 & 0.089 & 0.179 & 0.11 & 0.186 & 0.284 \\ 1.126 & 7.025 & 6.953 & 6.314 & 5.208 & 4.646 \\ 1.363 & 8.215 & 10.954 & 10.85 & 9.512 & 5.646 \\ 1.552 & 13.266 & 16.41 & 16.061 & 17.131 & 25.256 \\ 1.704 & 20.627 & 22.237 & 25.413 & 43.58 & 53.784 \\ 1.825 & 29.036 & 28.83 & 31.285 & 53.547 & 64.082 \\ 1.946 & 33.945 & 30.929 & 36.407 & 61.6 & 71.01 \\ 2.066 & 29.591 & 31.788 & 40.536 & 64.612 & 76.418 \end{pmatrix}$$

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

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

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

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

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

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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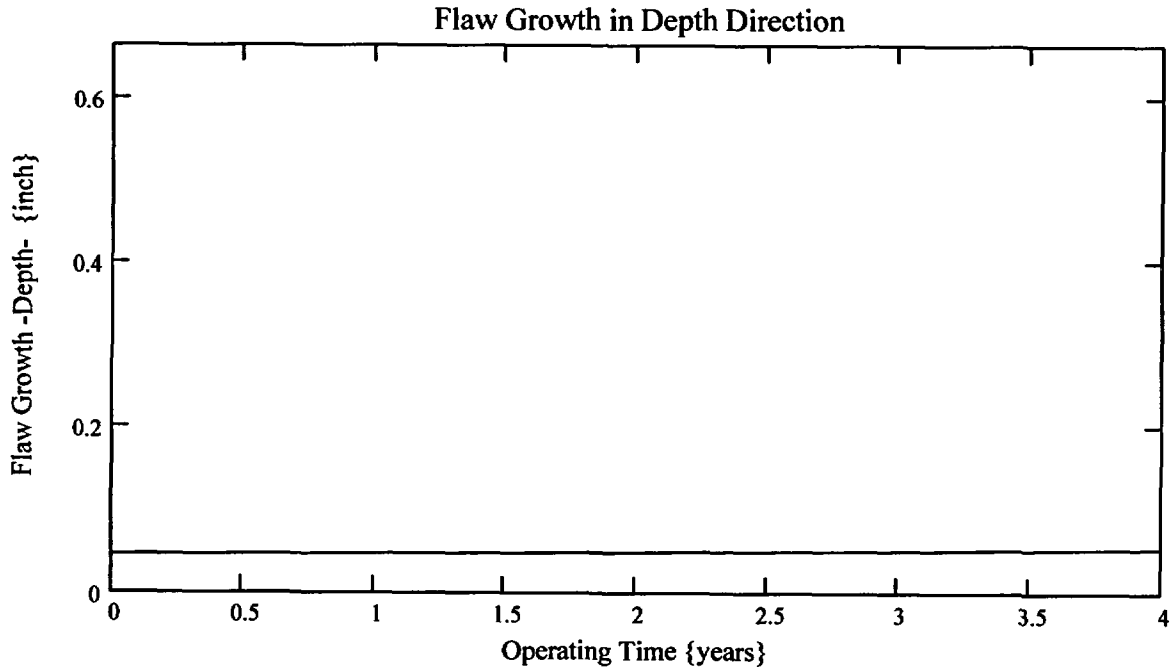
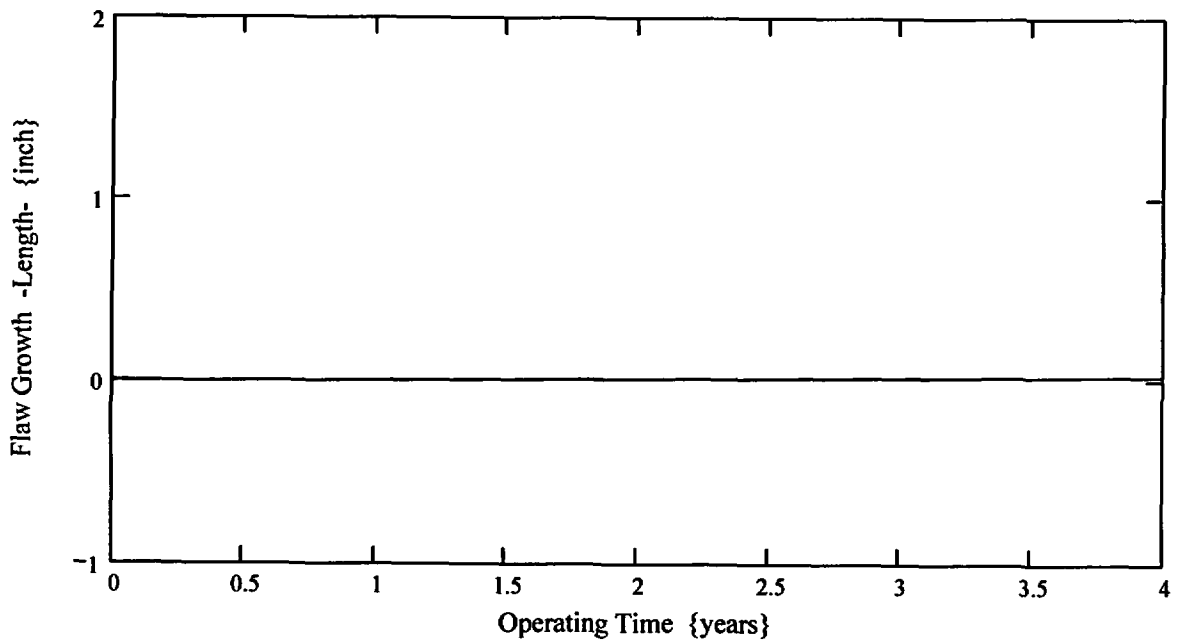
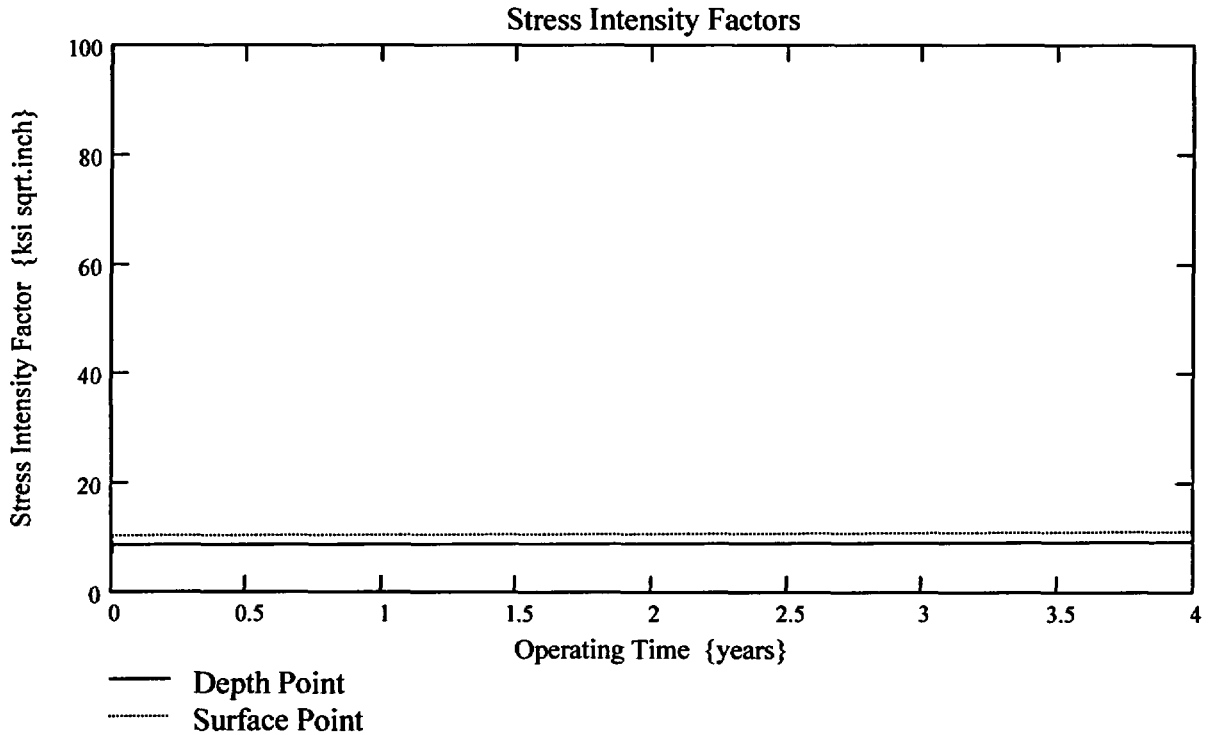
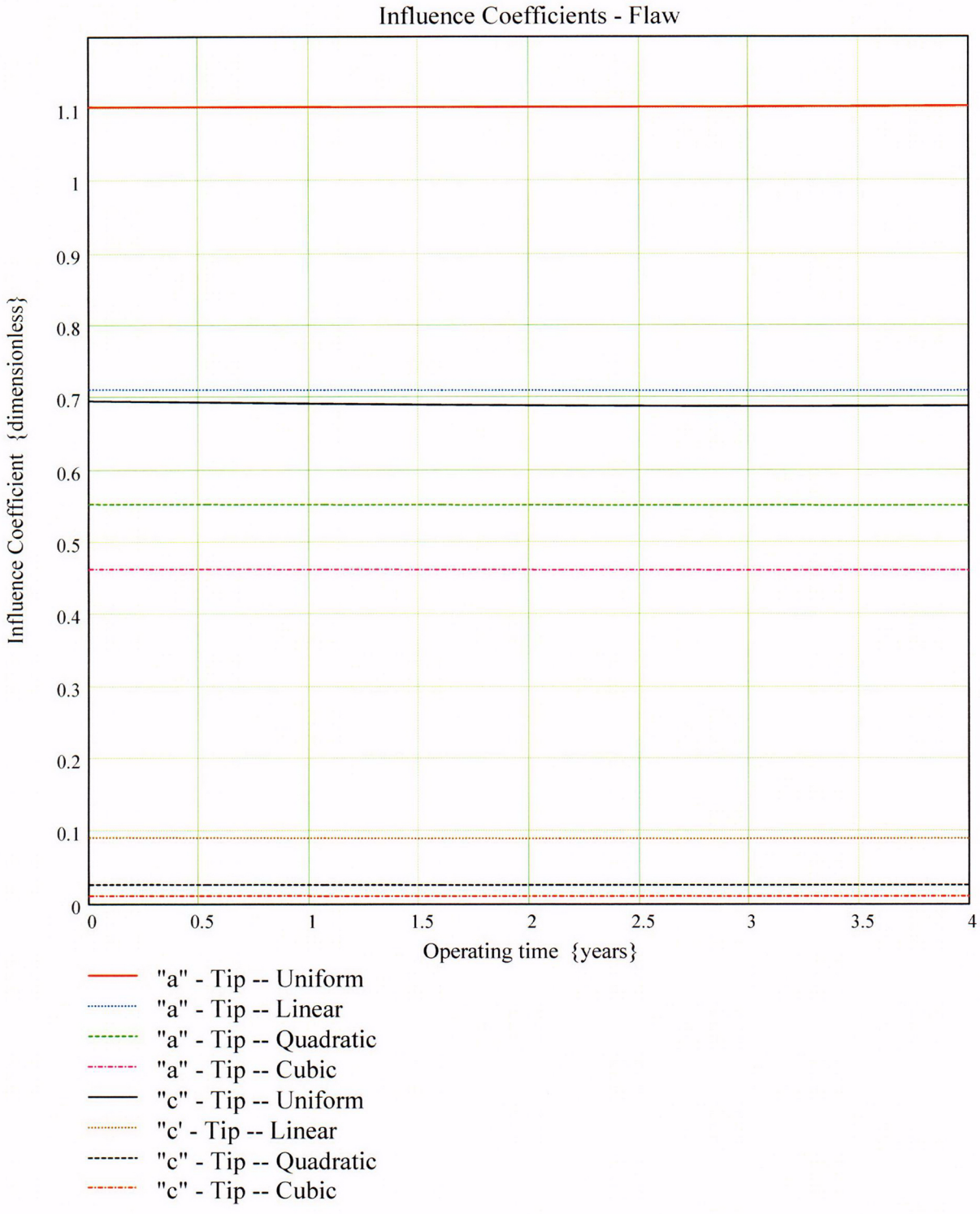
$Prop_{Length} = 0$






Stress Intensity Factors
Stress Intensity Factor {ksi sqrt.inch}
100
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

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

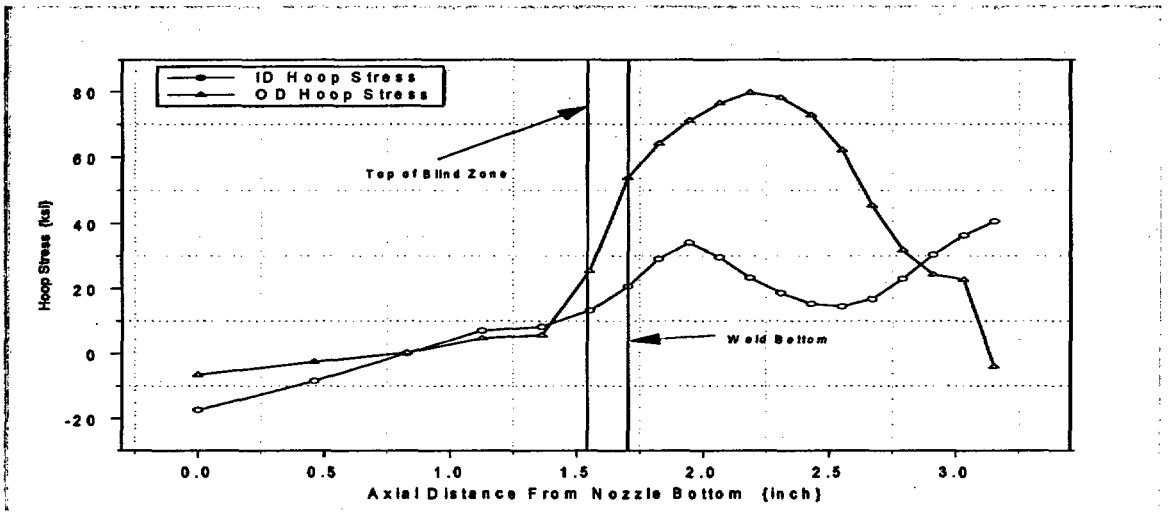
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103
1.103

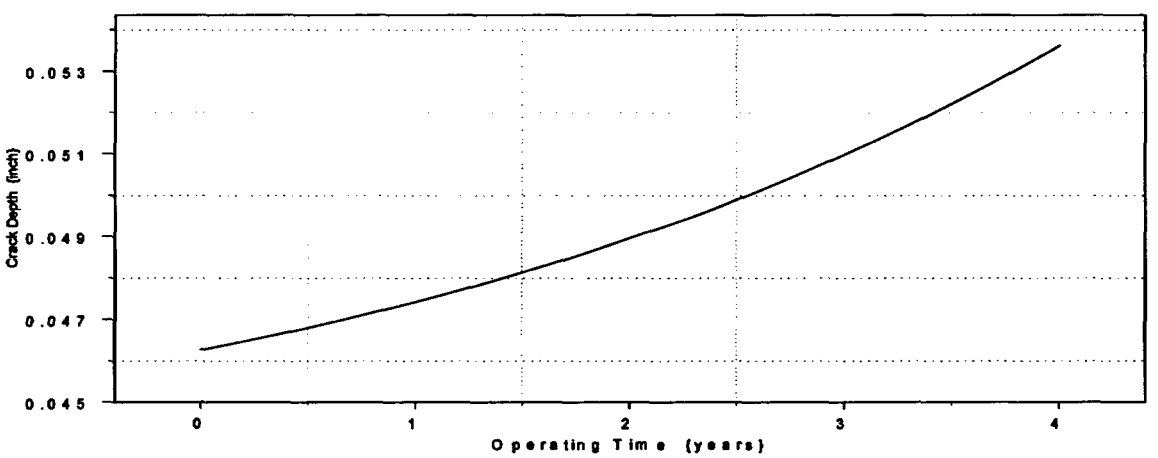
$CGR_{sambi_{(k,6)}}$ =

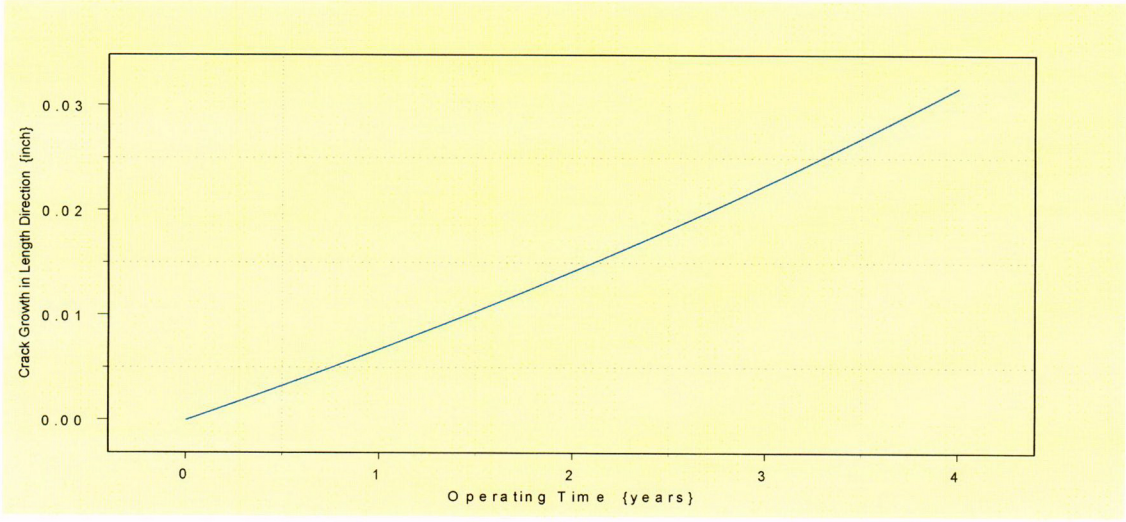
8.464
10.317
10.318
10.318
10.318
10.319
10.319
10.32
10.32
10.321
10.321
10.322
10.322
10.323
10.323
10.323

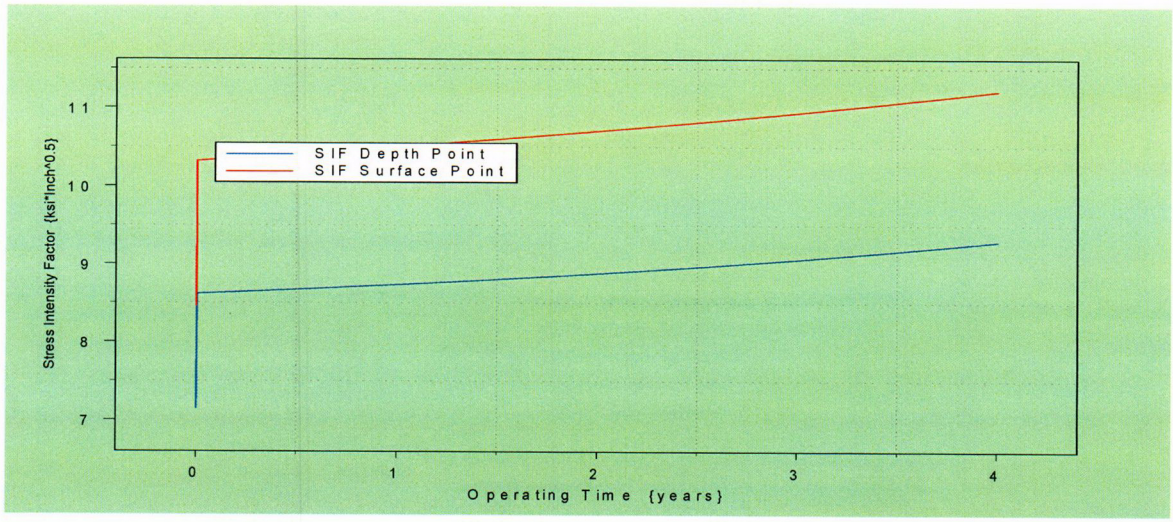
$CGR_{sambi_{(k,5)}}$ =

7.148
8.617
8.617
8.618
8.618
8.618
8.618
8.619
8.619
8.619
8.62
8.62
8.62
8.62
8.621
8.621


ID Hoop Stress
OD Hoop Stress
Top of Blind Zone
Weld Bottom
Hoop Stress (ksi)
80
60
40
20
0
-20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Axial Distance From Nozzle Bottom (inch)


Crack Depth (inch)
0.053
0.051
0.049
0.047
0.045
0
1
2
3
4
Operating Time (years)


Crack Growth in Length Direction {inch}
0.03
0.02
0.01
0.00
0
1
2
3
4
Operating Time {years}


Stress Intensity Factor {ksi*Inch^0.5}
11
10
9
8
7
SIF Depth Point
SIF Surface Point
0
1
2
3
4
Operating Time {years}