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Flaw Acceptance Handbook for Crystal River Unit 3 Reactor Pressure Vessel and Nozzle Weld Inspections

Prepared for:

Florida Power Corporation
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Prepared by:

Structural Integrity Associates, Inc.

Prepared by: C. C. Markovits   Date: 1/31/96

Reviewed by: N. G. Cofie   Date: 2/1/96

Approved by: A. F. Deardorff   Date: 2/1/96

Structural Integrity Associates, Inc.

Table of Contents

Table of Contents (concluded)

List of Tables

List of Figures

1.0 INTRODUCTION

In preparation for the in-service inspection (ISI) of the reactor pressure vessel (RPV) at Crystal River Unit 3 (CR-3) during the Spring 1996 outage, Florida Power Corporation (FPC) contracted with Structural Integrity Associates (SI) to develop flaw acceptance diagrams for the reactor pressure vessel welds, including those at the vessel inlet, outlet, and core flood nozzles. This will allow for rapid evaluation of flaws in case that flaw indications are found during the vessel examinations.

This report contains a definition of acceptable flaw sizes that can be used during the vessel inspection to perform rapid assessment of flaw indications. These flaw acceptance guidelines are provided in graphical format in the appendices of this report and are based on the methods contained in ASME Code, Section XI. The evaluation methods have been supplemented by more sophisticated evaluation techniques, where Section XI, Appendix A, may not be completely definitive for the evaluation (e.g., for cladding stress intensity factors). An evaluation of vessel materials and geometry at welds has resulted in a conservative grouping of potentially-flawed locations to limit the number of flaw evaluations to a manageable number. Thus, the graphical acceptance standards included herein are intended to be conservative but need not serve as the only basis for performing Section XI flaw evaluations.

Section 2 of this report describes the methods of analysis and the assumptions that have been made in conducting the analysis. Reading and understanding the information included therein is important to understand the limitations inherent in conducting an evaluation of all possible flaws that might exist in the vessel. Section 3 presents an evaluation of the specific materials and welds for the CR-3 reactor vessel and shows how they were grouped to limit the number of evaluations conducted. The vessel inlet, outlet, and core flood nozzle evaluations are also presented. The design input (stresses, load cases, etc.) that forms the basis for the analysis is included. Section 4 presents and describes the results. Section 5 summarizes the findings and restates the limitations with respect to the results presented in this report.

2.0 EVALUATION METHODOLOGY

2.1 Overview of Section XI Evaluation Procedures

For purposes of this evaluation, the 1989 edition of Section XI of the ASME Boiler & Pressure Vessel Code [1] is generally used, modified with additional more conservative criteria, as discussed in Section 2.5. The rules for evaluation of flaws in reactor vessels are contained in IWA-3000, IWB-3500 and IWB-3600 of Section XI. Appendix A of Section XI provides specific methodology that may be used for detailed fracture mechanics evaluations. The following provides an overview of the Section XI evaluation approach.

In the first step of vessel flaw evaluation, the indications from vessel inspections must be characterized per the requirements of Section XI Article IWA-3000. This requires that the indications be bounded by a rectangular shape with depth (a for surface flaws and $2a$ for subsurface flaws) and length (ℓ) that will completely contain the suspected material flaws. Closely adjacent flaws must be linked together based on criteria contained in IWA-3000. Similarly, flaws closely adjacent to the base metal surface must be assumed to be surface flaws, based on criteria presented in the Code.

The next step in the vessel flaw evaluation is to compare the flaw with the evaluation standards included in Table IWB-3510-1. This table provides the size of allowable planar flaws that may be accepted without further evaluation. Table IWB-3510-1 defines allowable sizes for surface and subsurface flaws as a function of wall thickness, flaw aspect ratio (a/ℓ) and flaw depth ratio (a/t), where t is the base metal thickness.

If the indication is larger than may be accepted by IWB-3510-1, then additional analytical evaluation is allowed per IWA-3600. These evaluations are based on the total wall thickness including cladding. Again, flaws located closely adjacent to the surface must be evaluated as surface flaws based on

criteria in IWB-3000. Flaws located completely within the vessel cladding are acceptable with no further evaluation. Key points of the evaluation include:

- The criteria allow acceptance by specifying a factor of safety on either the size of the critical flaw, or a factor of safety on the stress intensity factor.

- Separate evaluations are required for Normal/Upset and Emergency/Faulted conditions, with different factors of safety for each.

- Additional consideration is given to areas near structural discontinuities (e.g., for welds near a flange) by allowing alternate factors of safety for low-pressure operating conditions, per IWB-3613.

Appendix A of Section XI provides a detailed procedure for vessel flaw evaluation. To perform the analysis, the following factors must be considered:

- The flaw must be characterized and resolved into a shape that can be evaluated. This includes determination of the depth ratio (a/t) and the aspect ratio (a/ℓ) of the flaw. For subsurface flaws, the eccentricity ratio (e/t) must be determined, where e is the distance from the center of the vessel wall (including cladding) to the center of the flaw.

- Stress and the temperature distributions at the location of the flaw must be determined for all loading conditions.

- The flaw stress intensity factor and critical crack size must be calculated, either by using the equations, charts, and tables of Appendix A of Section XI or through use of other, more sophisticated, documented analytical techniques.

- The material properties must be defined at the location of the flaw, including the effects of irradiation.

- The crack growth that can occur during the evaluation interval must be determined (e.g., to the next inspection or to end-of-life).

- The flaw size at the end-of-evaluation period must be less than that allowed by Section XI.

- The primary stress limits of the original Code of Design, Section III, (NB-3000) must also be met assuming a local area reduction of the pressure-retaining membrane that is equal to the area of the characterized flaws.

- For evaluation of flaws in shell-like structures (e.g., the reactor vessel wall), the methodology of Appendix A of Section XI is directly applicable. For the evaluation of more complex geometries or complex stress distributions, (e.g. for the inlet, outlet, and core flood nozzle corner flaws, more sophisticated techniques may be used as allowed by A-3300(c)).

2.2 Specific Details of Vessel Shell Evaluation Methodology

2.2.1 Stress Intensity Factors

Appendix A of Section XI provides a basic methodology for evaluating vessel flaws. However, there is limited guidance for the determination of stress intensity factors for cracks extending through cladding. In addition, the guidelines are very limited for determining the stress intensity at the surface for surface flaws. The following describes how the stress intensity factors were determined for the CR-3 RPV evaluation.

<u>Appendix A Methods</u>

For all stresses, except for those due to cladding for an internal surface flaw, the methods of Appendix A are used for the deepest point of surface flaws and for subsurface flaws.

Surface Stress Intensity Factors (except for cladding)

For surface stress intensity factors for surface flaws, M_m and M_b, as defined in Appendix A of Section XI, have been determined based on the Raju/Newman membrane and bending solutions [2] for the worst case of internal and external cracks for a vessel with thickness-to-radius ratio of 0.1. The so-determined surface stress intensity factor is applied at the cladding-to-base metal interface for the vessel inside surface. For flaws with an aspect ratio (a/ℓ) of zero, the surface stress intensity factor is assumed to be zero since an infinitely long crack does not have a surface point.

Cladding Stress Intensity Factor

For cladding stresses for a long inside-surface flaw, the stress intensity factor at the deepest point of the flaw is determined by integration of the stress over the crack face for an edge-cracked plate using the methods from Tada and Paris [3].

$$\overline{K_I} = \frac{2}{\sqrt{\pi a}} \int_o^a m(x) \cdot \sigma(x)\, dx \tag{1}$$

where: $\sigma(x)$ = cladding stress distribution in cladding and base metal as a function of distance (x) from clad surface

a = crack depth

$$m(x) = \frac{3.52(1-a^*)}{(1-t^*)^{1.5}} - \frac{4.35 - 5.28a^*}{(1-t^*)^{0.5}} + \left[\frac{1.3 - 0.3(a^*)^{1.5}}{(1-(a^*)^2)^{0.5}} + 0.83 - 1.76a^*\right] \cdot \left[1-(1-a^*)t^*\right] \tag{2}$$

where: a^* = x/a

t^* = a/t

t = wall thickness

As shown in a paper by Kuo, Deardorff, and Riccardella [4], this type of solution yields a stress intensity factor that shows a reasonable comparison to "exact" solutions, but is unrealistic and increases significantly for deep-wall cracks in a pressure vessel. Thus, it is assumed that the deep-wall stress intensity factor increases by no more than described by the following:

For $a \le a_{min}$,

$$K_I' = \overline{K}_I \tag{3}$$

For $a > a_{min}$

$$K_I' = lesser\ of\ \overline{K}_I$$

or

$$\overline{K}_{I_{min}} \sqrt{\frac{a}{a_{\min}}} \tag{4}$$

where: $\overline{K}_{I_{min}}$ = minimum $\overline{K}_I$ predicted in base material

a = crack depth size

a_{min} = a at $\overline{K}_{I_{min}}$

To account for the flaw aspect ratio, the stress intensity factor is corrected using the shape factor of Appendix A of Section XI for the crack.

$$K_I = K_I' \left(\frac{Q_o}{Q}\right)^{0.5} \tag{5}$$

where: Q_o = shape factor for flaw with aspect ratio of $(a/\ell) = 0$

Q = shape factor for flaw with aspect ratio (a/ℓ) being evaluated

The stress ratio (the other factor affecting Q) is determined based on membrane plus bending stress ($\sigma_m + \sigma_b$) for the flaw, exclusive of the cladding stresses at the crack. Since a ratio is being determined, this approach is reasonable.

ASME Section XI does not require that the stress intensity factor in the cladding be evaluated. However, the stress intensity factor for the cladding-to-base metal interface location is calculated based on determination of the surface stress intensity factor. To calculate the surface stress intensity factor, the cladding stress intensity factor (obtained by Equations 1 and 5 above) for a flaw depth equal to the thickness of the cladding (with the same aspect ratio as the deeper flaw being evaluated) is determined. It is then modified based on the ratio between the membrane stress intensity correction factors for the surface (using the Raju/Newman, M_m) and the crack tip (using the Appendix A, M_m). Although not rigorously derived, this formulation is believed to be conservative for this analysis.

For flaws with aspect ratio of zero ($a/\ell = 0$), there is no surface crack. Therefore, the stress intensity factor due to cladding at the "surface" is evaluated as zero.

2.2.2 Fracture Toughness

The fracture toughness, K_{Ia} or K_{Ic}, is obtained from Section XI Appendix A. The analyzed vessel wall local fracture toughness, at the location of the associated crack stress intensity factor, is determined with consideration of local temperature (as a function of wall depth), initial RT_{NDT}, local fluence, margins and chemistry factors in accordance with the methods of Regulatory Guide 1.99 Revision 2 [5]. The approach is as follows:

$$ART = RT_{NDT,i} + RT_{NDT}\,Shift + Margin \tag{6}$$

where:

ART = Adjusted Reference Temperature, °F
$RT_{NDT,i}$ = initial RT_{NDT}, °F
$Margin$ = required margin = $2\sqrt{\sigma_i^2 + \sigma_\Delta^2}$, °F
($RT_{NDT}\,Shift$, σ_i, and σ_Δ are defined below)

The margin is determined based on the standard deviation of the initial RT_{NDT} (σ_i) and that of the RT_{NDT} *shift* (σ_Δ). The standard σ_Δ is 28°F for welds and 17°F for base metal [5], except that σ_Δ need not exceed 0.5 times the computed shift in RT_{NDT}.

$$RT_{NDT}\,Shift = (CF) \cdot (FF) \tag{7}$$

where: CF = chemistry factor, °F

FF = fluence factor, dimensionless

$$FF = f^{(0.28 - 0.1\log_{10}(f))} \tag{8}$$

where: f = local fluence, neutrons/cm^2 x 10^{19} (E>1MeV)

The local fluence, f, at any position in the wall may be calculated from:

$$f = f_{surf}\, e^{-0.24x} \tag{9}$$

where: f_{surf} = fluence at inside surface, neutrons/cm^2 x 10^{19} (E>1MeV)

x = distance from inside surface, inches

The fluence at the surface is a function of the amount of irradiation exposure time:

$$f_{surf} = \frac{f_{ref}}{EFPY_{ref}} \times EFPY \tag{10}$$

where: f_{ref} = reference surface fluence, neutrons/cm^2 x 10^{19} (E>1MeV)

$EFPY_{ref}$ = effective full power years associated with f_{ref}

$EFPY$ = effective full power years for evaluation

This allows the adjusted reference temperature to be calculated for the beltline region at any depth, at any time, and for each specific weld or plate being evaluated. For regions not in the beltline region, there is no shift in RT_{NDT}.

2.2.3 Crack Growth Considerations

A conservative estimate of the crack growth for determining allowable subsurface and outside surface flaws is based on the crack-growth curve for air of Section XI Appendix A, using the latest formulations from the 1992 Edition with 1993 Addenda. A conservative estimate of the number of cycles to the end of the evaluation period is made. For inside surface flaws, the water crack-growth curve is used, conservatively based on $R \geq 0.65$, where R is the ratio of the minimum crack tip stress intensity factor to the maximum stress intensity factor (K_{min}/K_{max}). For subsurface flaws, the crack growth curve for air environment based on R=1 was used. The stress intensity factor at the allowable flaw size for each flaw is used in this evaluation. For flaws accepted by the evaluation standards of Table IWB-3500-1, there is no requirement to consider crack growth.

2.2.4 Subsurface Flaw Size Considerations

For subsurface flaws, the maximum allowable size that does not have to be considered as a surface flaw per the requirements of Table IWB-3510-1 or Figure IWB-3610-1, as applicable, is determined based on flaw eccentricity as follows:

$$\left(\frac{a}{t}\right)_{max} = \frac{0.5 - |e/t|}{1.4} \qquad (11)$$

where:

t = thickness of vessel base material (for IWB-3500 evaluation), or total thickness of vessel wall including cladding (for IWB-3600/Appendix A evaluation)

e = flaw eccentricity, measured from center of vessel wall, (determined with or without cladding as appropriate), negative if toward inner vessel wall

2.2.5 Definition of Allowable Flaw Size and Shape

In evaluating hypothetical flaws, such as evaluated herein, one is faced with the problem of determining the size of the allowable flaw. In some cases, larger flaws may be acceptable as compared to smaller flaws. This is especially true when there is a large bending component to the through-wall stress distribution, the fracture toughness through the wall is not constant due to irradiation embrittlement and/or if cladding stresses are a significant contribution to the stress intensity factor. Also, if the surface stress intensity factor is controlling, a flaw with a smaller aspect ratio (more extent of flaw length) may be acceptable when a similar depth flaw with less flaw length would not be acceptable. There are several choices that can be made in choosing the allowable flaw size at a location:

- **Option 1**: Accept the largest flaw with the smallest aspect ratio that is acceptable. In this case, a larger flaw (depth and/or length) may be acceptable whereas a smaller flaw would not be acceptable. This is analogous to evaluating an actual flaw by assuming a larger bounding flaw size or length.

- **Option 2**: The most conservative approach is to determine the minimum flaw size that is acceptable for the flaw aspect ratio being evaluated.

- **Option 3**: In some cases, the surface stress intensity factor may control the allowable flaw depth, especially when cladding stresses are being evaluated or if the surface fracture toughness is low. However, a longer flaw (e.g., $a/\ell = 0$) might be acceptable. For this approach, the acceptable flaw size would be based on the smallest acceptable flaw depth (as in Option 2) but, the aspect ratio can be assumed to be smaller (the flaw is assumed to be longer) than for the actual aspect ratio being evaluated.

In the evaluations performed in this report, the first option has been chosen since the stress intensity factor solutions for surface stresses and cladding are believed to be quite conservative. In most cases, more sophisticated analysis, as allowed by Appendix A, A-3300 (c), could result in lower values of stress intensity factors.

The stress intensity factor within the cladding does not have to be evaluated for acceptability. Thus, the allowable inside surface flaw size will always be at least equal to the cladding thickness plus that allowed by the acceptance standards of IWB-3500.

2.3 Vessel Shell Analysis Implementation

The flaw acceptance analysis for the vessel-shell, shell-to-flange, and shell-to-nozzle weld locations has been prepared using a computer program developed and verified by SI for this specific purpose. APPENDA (standing for Appendix A Analysis) [6] is a computer program written to perform reactor pressure vessel flaw evaluation in accordance with Appendix A of Section XI and Subarticle IWB-3600 of Section XI of the ASME Boiler and Pressure Vessel Code [1]. It uses the methodology described above, and determines allowable inside surface, outside surface and subsurface flaws. It is intended to provide a rapid assessment of all possible flaws so as to allow construction of flaw acceptance diagrams that may be used to provide guidance in reactor vessel inspections.

APPENDA performs an evaluation to determine the acceptable size of surface and subsurface flaws in accordance with the requirements of ASME Code, Section XI, Appendix A and Subarticle IWB-3600 [1]. In addition, the acceptability of relatively smaller flaws is evaluated in accordance with Section XI, Table IWB-3510-1 [1] for planar flaws. The program output includes the acceptable flaw size for the complete range of flaw aspect ratios and flaw eccentricities (for subsurface flaws). Key features include:

- ability to include an arbitrary stress distribution for pressure, bending, thermal, and residual stresses, including load multiplier factors for each

- evaluation of cladding stresses, with several methods to handle the effects of the cladding stresses at the surface for inside surface flaws

- ability to evaluate flaws based either on the maximum acceptable size, minimum acceptable size, or the minimum acceptable size assuming a smaller aspect ratio, a/ℓ

- consideration of Normal/Upset condition, Emergency/Faulted condition or regions near local discontinuities (per IWB-3613 (a))

- automatic determination of the wall fracture toughness distribution given initial material properties and accumulated surface fluence at the end of the evaluation period

- conservative assessment of flaw growth to the end of the evaluation period

A separate utility program MAPPA (standing for Multiple Appendix A analysis) provides an evaluation of multiple input cases for a location and determines the controlling loading condition (or combination of conditions) for a number of individual evaluations using APPENDA.

2.4 Nozzle Inner Corner Flaw Evaluation

For a postulated flaw at the inlet, outlet, and core flood nozzle inner corner, the methodology of Section XI, Appendix A is not directly applicable since it applies to shell-like structures. As allowed by A-3300(c) for complex geometries, the Structural Integrity Associates' computer program **pc-CRACK** [7] was used, employing the 3-D corner crack model. With this approach, the stress distributions for pressure, thermal and boltup loadings (as affected by proximity to the vessel flanges) are fit by cubic polynomial curves and the stress intensity factors are determined versus depth into the crack corner. For the cladding stresses, the stress intensity factor is assumed to be equal to that for the adjacent plate material.

For the corner crack, the evaluation considers only the deepest point of the crack. In addition, no parametric evaluation of flaw aspect ratio is required since corner cracking will almost always result in a "round" crack front that is simulated by the 3-D corner crack model. The crack depth will be reported as the smallest size that is not acceptable, unless larger flaws would be acceptable due to a decreasing cladding stress intensity factor. (For corner cracks, the pressure stresses are almost always dominant due to the large nozzle stress concentration factor at the inside corners.)

2.5 Section XI Code Editicn/Addenda for Flaw Evaluation

The current evaluation is generally based on Section XI Code methodology from the 1989 Code. This edition is the most recent of the ASME Code that is accepted by 10CFR50. It contains several revised approaches for flaw evaluation that are not contained in the 1983 edition of Section XI (with Summer 1983 Addenda), the edition applicable at CR-3. In addition, several steps of the evaluation contain more recent criteria. The following summarizes the differences.

1. In the 1983 Code, all flaw sizing for flaws at the clad surface was based on the depth from the cladding-to-base metal interface. In the mid 1980's, a conscious decision was made to revise the methodology such that the depth of the flaw should be based on the total dimension from the cladding wetted surface to the deepest point of the flaw. The guidance on flaw sizing provided by IWB-3610 of the current Code was not available in the earlier edition. For this evaluation, it has been conservatively assumed that flaw evaluation is based on the total flaw depth, including cladding, for inside surface flaws.

2. For this evaluation, the 1992 Code with 1993 Addenda was used as the basis for fatigue crack growth curves. This provides a slightly more conservative curve for an air environment (subsurface or outside surface flaws) that is dependent on the R ratio (K_{min}/K_{max}).

3. In this evaluation, the methodology of Reg. Guide 1.99, Rev. 2 is used for determining the total shift in RT_{NDT} as affected by uncertainties, fluence and material composition. Use of this approach is consistent with current regulatory requirements for the evaluation of reactor

vessel beltline materials. No guidance on determination on irradiation shift has been provided in Section XI since the Summer '83 Addenda of the 1983 Code. Prior to this time, there was a figure provided.

4. Section XI, A-3000 of the 1989 Code requires that the effects of cladding stresses on the calculated stress intensity factors be considered, whereas there was no mention of cladding in the 1983 version of Section XI. Thus, the 1989 Code approach is more conservative.

As shown above, the Code approach used in this evaluation reflects the currently accepted approach for evaluation of material properties, stresses, and stress intensity factors. It is more conservative than an evaluation based solely upon the 1983 Code with Summer 1983 Addenda that is applicable to CR-3, and more appropriate from a licensing viewpoint. Structural Integrity Associates' experience in the area of flaw evaluation has always shown that use of later Code editions and addenda for evaluation of flaws is acceptable.

3.0 EVALUATION OF VESSEL LOADINGS

3.1 Grouping of Locations

The reactor vessel plates, forgings, and welds at CR-3 are shown in Figure 3-1. Material properties for all the RPV plates and welds have been assembled in Reference 8 based on data collected during a site visit to CR-3. For the purpose of reducing the magnitude of the analytical computations, these locations have been combined to form the 10 regions for analysis (Regions A-J). For the ten reactor vessel shell welds, the region groupings have been selected based on similarities in geometry, material data, stresses or thicknesses in the surrounding plate and/or weld material, as shown in Table 3-1. Similarly, the grouping of the nozzle locations is shown in Table 3-2. The surrounding material has been examined for the worst case, i.e., irradiation effects, stresses and/or initial RT_{NDT} and used as bounding conditions for the entire region. The limiting component is chosen with respect to material properties such that the adjusted reference temperature at the vessel wall 1/4T point is maximized. A description of each vessel shell and nozzle region and the reasoning for their grouping is as follows:

Region A

Closure Head/Flange

This region includes the Closure Head Center Disc (MK #24) and Closure Head Flange materials. Material properties for the Closure Head Center Disc are used to represent all materials in this region. Stresses extracted from the Upper Head to Closure Flange Weld were conservatively used for this region.

Region B

Upper Head to Closure Flange Weld

This region includes the Upper Head to Closure Flange Weld only. (Because its material properties differ significantly from surrounding materials, this weld has been grouped separately.) Stresses extracted from the Upper Head to Closure Flange Weld were used for this region.

Region C

Vessel Flange and Adjacent Shells/Welds

This region represents the Upper Shell Flange, Vessel Flange to Nozzle Belt Weld, and Upper Nozzle Shell. The material properties for the Upper Shell Flange (or Upper Nozzle Shell, as they are identical) were selected as representative for this location. Stresses extracted from the Vessel Flange to Nozzle Belt Weld were used for this region.

Region D

Lower Nozzle Belt Shells

This region represents the Lower Nozzle Shells (unirradiated) only. (Because its material properties differ significantly from surrounding materials, this weld has been grouped separately.) Stresses for this grouping were taken from the 3-D stress analyses for the inlet and outlet nozzles due to interaction (bending) effects of the nozzles on the shell located between these nozzles.

Region E

Nozzle Belt to Nozzle Belt Weld/Nozzle Shells

This region represents the Nozzle Belt to Nozzle Belt Weld (unirradiated) and the Upper Nozzle Shells. Material properties for the Upper Nozzle Shell were selected as representative for this grouping. Stresses for this grouping were taken from the 3-D stress analyses for the inlet and outlet nozzles due to the interaction (bending) effect of the nozzles on the shell located between these nozzles.

Region F

Beltline Welds and Shells I

The region represents irradiated shell regions: Upper Shells (A1-207-1,-2), Lower Shell (A2-207-2), Nozzle Belt to Upper Shell Welds (WF-169-1 and SA1769) and Lower Nozzle Shells. The material properties for the Upper Shell (A1-207-2) were selected as representative for this grouping. The maximum through-wall stress distribution (i.e., maximum tensile stresses) along the length of the longitudinal welds in the upper and lower vessel shells was conservatively used for this region.

Region G

Beltline Welds and Shells II

This grouping represents irradiated (beltline) welds: Upper Shell Longitudinal Weld (WF8,18), Upper Shell to Lower Shell Weld (WF70), Lower Shell Longitudinal Weld (SA1580) and Lower Shell (A2-207-1). The material properties for Upper Shell Longitudinal Weld (WF8,18) were selected as representative for this grouping. The maximum through-wall stress distribution (i.e., maximum tensile stresses) for all of the welds analyzed in this grouping was conservatively used for this region.

Region H

Transition Region I

This grouping represents the shells located in the vicinity of the transition region between the lower shell and bottom head, Lower Shells (A2-207-1, A2-207-2). It was selected due to the high stresses associated with the thickness transition. This grouping includes lower portion (thinner than 8.4375 in.) of the Lower Shell (material located adjacent to the transition weld). The lower fluence reported in Reference 8 at the Lower Shell to Head Transition Weld was used for this grouping. The material properties of the Lower Shell (A2-207-1) shall be selected as representative for this grouping. The stress distribution for the Lower Shell to Head Transition Weld was conservatively used for this region.

Region I

Transition Region II

This grouping represents the shells located in the vicinity of the transition region between the lower shell and bottom head and includes the Head Transition Piece, Lower Shell Longitudinal Weld (SA1580), and Lower Shell to Head Transition Weld (WF154). The material properties of the Head Transition Piece were selected as representative for this grouping. The stress distribution for the Lower Shell to Head Transition Weld (WF154) was conservatively used for this region. This grouping includes lower portions (with thickness less than 8.4375 in.) of the Lower Shell Longitudinal Weld, Lower Shell to Head Transition Weld, and upper portions of Head Transition Piece (and material located adjacent to the Transition Weld).

Region J

Bottom Head Region

This Region includes the Head Transition Piece (unirradiated), Head Transition to Bottom Head Weld, and Bottom Head Shell (MK #6). (Flaw indications found in Head Transition Piece must be evaluated as both Region J and Region H). The material properties for the Head Transition Piece and Bottom Head Shell have been selected as representative for this grouping. The stress distribution for the Head Transition to Bottom Head Weld was conservatively used for this region.

Region K

Inlet Nozzle to Shell Weld

This region includes the inlet nozzles (MK #18), the welds between these nozzles and the adjacent shell materials. The region is further divided into two sub-regions because of variable stresses around the nozzle due to the hoop versus radial stress field in the inlet nozzle forging and due to interaction between the nozzles and the upper flange region. The material properties chosen as being representative are for inlet nozzle forging (MK #18).

Region L

Outlet Nozzle to Shell Weld

This region includes the outlet nozzles (MK #19), the welds between these nozzles and the adjacent shell materials. Two sub-regions are included because of variability of stresses around the nozzle. The material properties chosen as being representative are for outlet nozzle forging (MK #19).

Region M

Core Flood Nozzle to Shell Weld

This region includes the core flood nozzles (MK #17), the welds between these nozzles and the adjacent shell materials. Two sub-regions are included because of variability of stresses around the nozzle. The material properties chosen as being representative are for core flood nozzle forging (MK #17).

Region N

Inlet Nozzle Corner Crack

This region includes only the inlet nozzle inner corner forging (MK #18) and is defined for a postulated inner corner crack, since pressure stresses at the region are high. The material properties for inlet nozzle forging are used.

Region O

Outlet Nozzle Corner Crack

This region is similar to Region N and includes only the outlet nozzle inner corner forging (MK #19). The material properties for outlet nozzle forging are used.

Region P

Core Flood Nozzle Corner Crack

This region is similar to Regions N & O and includes only the core flood nozzle inner corner forging (MK #17). The material properties for core flood nozzle forging are used.

3.2 Vessel Geometry and Materials

To determine stress distributions in the vessel and nozzles, finite element stress analysis was conducted. The geometric details of the CR-3 vessel are shown in Figures 3-2 through 3-4. The dimensions in these figures are based on information contained in the drawings from References 9 through 16. If minor discrepancies were found in the vessel wall thicknesses in these drawings, the as-fabricated thickness at a given location was used. The geometric details of the nozzles are shown in Figures 3-5 through 3-7. The dimensions were developed from References 17 through 19.

The vessel plate material is SA-533, Class 1, Grade B (modified). The vessel flange and nozzle forgings material is SA-508, Class 2. The vessel stud bolts were fabricated from SA-540, Grade B23 steel [20]. The reactor pressure vessel at CR-3 was constructed in accordance with the 1965 ASME Code, Section III, with Summer 1967 Addenda [21]. Material properties for purposes of the updated stress analysis were obtained from the 1989 version of the Code and are presented in Table 3-3 [22].

3.3 Loadings and Loading Combinations

To determine the stresses in the vessel shell and nozzle regions, several load cases were evaluated based on current operating pressure and temperature (P-T) limits at CR-3 (for in-service leak tests) as defined in Reference 23. Based upon the limit line shown on Figure 3-8, several loading conditions have been identified to be the most limiting from a fracture mechanics standpoint, as shown in Table 3-4. Each case represents a point on the P-T curve, whereby the lowest temperature, highest pressure, and maximum heatup or cooldown rate was conservatively used. For each load combination, thermal stresses will be computed assuming a "quasi" steady-state temperature distribution associated with the heatup rate with the fluid temperature being at the stated temperature on the P-T curve and the existence of bolt-up stresses. Load Combinations (LC) 1 through 5 represent heatup conditions. Load Combinations 6 through 12 represent cooldown conditions. For the core flood nozzle to shell weld location, cooldown load cases have been derived from Reference 36 as the nozzle is exposed to a different transient than the vessel, (i.e., decay heat removal test). For this location, cooldown load cases are identified in Table 3-4. Heatup load cases were taken from the reactor vessel locations, LC1-LC5.

Use of the loadings from Figure 3-8 will be especially conservative at end-of-life, since the operating limits will probably shift to the right (higher temperatures) after EFPY=20, (explained later in the report, all evaluations are based on the vessel fluence at EFPY=32).

To conservatively assess cyclic crack growth (assumed to be due to startup/shutdown cycles), the number of heatups/cooldowns has been determined. Two hundred and forty (240) cycles are allowed for the CR-3 plant. Seventy-seven heatup and cooldown cycles will have occurred at the time of the vessel inspections, leaving 167 cycles remaining [24]. This number has been used for purposes of assessing potential future growth of flaw indications.

3.4 Vessel Stresses and Stress Evaluation

3.4.1 Operating Stresses

An axisymmetric finite element model of the reactor pressure vessel (RPV) was developed for the purpose of determining the operating stresses, as shown in Figure 3-9 [26]. The model was developed using the ANSYS computer software [25]. The model was generated using isoparametric finite elements for the vessel. No cladding material was included in the model consistent with the original vessel stress analysis [10,27]. The contact surface between the vessel shell flange and the closure head were not physically connected in the model, but rather they shared common coincident nodal locations. In the thermal analysis, the coincident nodes were coupled such that they had the same temperature. For stress analysis, the upper head is connected to the flange by a number of gap elements which started from the inner diameter and ran approximately to the end of the raised seating face between the flange and the head. The bolt holes in the flange were not modeled but were accounted for by modifying the properties of the material at that location based on area reduction of the holes [26]. The materials properties used for the model are shown in Table 3-3 [22].

The following basic loading conditions were determined from the closure stress report [27]:

- Gasket loads of 400 and 407.6 kips were applied to the mating flange surfaces at the inner and outer gasket grooves.

- A spring load of 3×10^3 kips was applied to the closure region (head flange to shell flange) during cooldown. A value of 6×10^3 kips was applied during heatup.

- A total bolt load (for a total of 60 bolts) of 84×10^3 kips was applied for 70°F isothermal conditions.

Five basic load stress cases were run using this model to determine the stress response. Several other load cases can be derived from these basic load cases and will be discussed in Section 3.4.4.

Bolt-up at 70°F - Basic Load Case 1

In this load case, the cold bolt-up load was applied to the flange. In addition to the bolt-up load, the spring and gasket loads were applied. The bolt load was applied to the model by the use of a 2-D spar element available in the ANSYS library. By adjustment of the spar length, the required bolt load was iteratively obtained.

Bolt-up at 604°F - Basic Load Case 2

This case is similar to Basic Load Case 1 above except the vessel was maintained at 604°F. This case was run to determine the effect of temperature on the bending stress due to bolt-up.

Bolt-up Plus Pressure at 604°F - Basic Load Case 3

This case simulates the maximum pressure at normal operating conditions. It is similar to Basic Load Cases 1 and 2 except that a pressure of 2240 psig was applied to the inside surface of the vessel. The pressure force was also applied between the top head and the upper shell flange to the first gasket.

Heatup Transient - Basic Load Case 4

The initial temperature of the transient was 70°F with a heatup rate of 50°F per hour to a temperature of 604°F. Stress analysis was performed at the time 604°F was reached. No internal pressure was assumed for this case, however, the bolt, gasket and spring ledge loads used in Basic Load Cases 1 through 3 were applied.

Cooldown Transient - Basic Load Case 5

This case is similar to Basic Load Case 4 except that it initiates at the operating (hot) conditions and simulates the cooldown transient. The initial temperature of the transient was 604°F with a cooldown rate of 50°F per hour to a temperature of 70°F. Stress analysis was performed at a temperature of

280°F to assess the maximum effects of temperature dependency on the modulus of elasticity and coefficient of thermal expansion.

3.4.2 Weld Residual Stresses

For purposes of the fracture mechanics analysis, it was also assumed that weld residual stresses could be present at all locations. A cosine-shaped distribution was assumed in the base metal with a maximum surface tensile stress of 8 ksi [28] at the inside and outside surface. The 8 ksi stress was conservatively extended into the cladding for purposes of evaluation. Since residual stresses may be beneficial in reducing the stress intensity factors, evaluations were also conducted without residual stresses so that the controlling condition could be determined.

3.4.3 Cladding Stresses

Following PWHT of the vessel, the vessel cools to ambient. Because of the relative coefficients of thermal expansion, the cladding will yield in tension. A cladding stress of 35 ksi in the axial and circumferential directions is assumed at 70°F. This compares to 30 ksi minimum yield strength for most austenitic stainless steels in Reference 22.

To calculate the reduction in cladding stress due to temperature, the mean metal temperature is needed. The through-wall temperature distributions for each of heatup/cooldown rates defined in the twelve load cases discussed in Section 3.3, can be found with the following algorithm:

$$T_{i,modified} = R \times [T_{i,input} - T_{reactor,input}] + T_{reactor,new} \quad (12)$$

where: $T_{i,modified}$ = computed temperatures at each location, i, through the wall for modified conditions.

R = reactor temperature heatup/cooldown rate multiplier

= rate(modified)/rate (+50°F/hr and -50°F/hr)

$T_{reactor,input}$ = reactor temperature used in ANSYS model, 604°F or 280°F (for Basic Load Cases 4 and 5)

$T_{i,input}$ = through-wall temperature distribution as determined from Basic Load Cases 4 and 5 in ANSYS model

$T_{reactor,new}$ = Load Combinations 1 through 12 reactor temperature.

Using the resulting through-wall temperature distributions for the various heatup/cooldown rates, the mean metal temperature (T_{mean}) can be found. Using the mean metal temperature, the reduction of cladding stress is determined with the following equation [29]:

$$\sigma_{clad} = \sigma_{clad,yield} - \frac{E_{clad}\,(\alpha_{clad} - \alpha_{base})\,(T-70)}{(1-\nu)\,(1 + (E_{clad}\cdot t_{clad})/(E_{base}\cdot t_{base}))} \tag{13}$$

where: ν = Poissons Ratio, 0.3

E_{clad}, E_{base} = modulus of elasticity, ksi at T_{mean}

$\alpha_{clad}, \alpha_{base}$ = coefficient of thermal expansion, in/in-°F, (mean from 70°F to T_{mean})

$\sigma_{clad,yield}$ = assumed cladding stress at 70°F (35 ksi)

t_{clad}, t_{base} = thickness of cladding and base materials

For use in computing the flaw shape factor, Q, the reactor vessel material, A533 Class 1 Grade B has a specific minimum yield strength of 50 ksi [22] at ambient conditions. For the twelve load cases, the yield strength was determined based upon the maximum metal temperature existing at the region being analyzed.

3.4.4 Determination of Stresses for Various Regions

The results of the RPV stress analysis were reviewed to determine the bounding stress distributions in the welds included in each region. To assure conservatism, the stresses for each loading case may not have been taken from exactly the same position. In addition, vessel wall thicknesses vary slightly for different vessel locations. (Vessel wall thicknesses do not include cladding.) The resulting "unit

load" stress distributions for each of the regions of the vessel for pressure (2240 psig), boltup, and thermal (heatup +50°F/hr) and (cooldown -50°F/hr) are given in Tables 3-5 through 3-11. Stress distributions for Regions D and E (Table 3-7) were obtained from finite element stress analysis of the inlet and outlet nozzles as described in Section 3.6. Special treatment of these regions was necessary due to the interaction (bending) effects of the nozzles on the shell located between these nozzles. These tables also show the temperature distribution in the vessel wall. Load multipliers were used to ratio these stresses to reflect the specific conditions for each load case in question.

3.5 Loading Multipliers

Because the stress analysis was linear, the basic loading conditions described in Section 3.4.1 can be recombined using factored loads to define the state of stress for other loading conditions shown in Table 3-4. The multiplying factors were derived to reflect the actual stress and temperature distributions for all of the other loading cases.

3.5.1 Pressure Stress Load Multiplier

The stated pressure (in ksi) for each load case divided by 2240 psig was used as a load multiplier. For example, Load Combination 1 is evaluated at 391 psig, therefore; the load multiplier is 0.17; 0.49 for Load Combination 3; and 1.1 for Load Combination 5 and Load Combination 6.

3.5.2 Bending Stress Load Multiplier

Although temperature has a minimal effect on the bolt load bending stress, the stresses decrease by about 10% at normal operating temperature. The resulting decrease in bending stress at the fluid temperature for each of the eight loading cases was then interpolated and used as the load multiplier for the specific load case.

3.5.3 Thermal Stress Load Multiplier

For the thermal stresses, the stated heatup/cooldown rate for each load combination (divided by 50 or -50) was used as the load multiplier. For example, for Load Combination 1, the heatup rate is 30°F per hour. Therefore, the load multiplier for this case was 0.1. For Load Combination 11, the load multiplier is 0.2.

3.5.4 Weld Residual Stress Load Multiplier

The weld residual stress is input as unit load cosine distribution with a load multiplier of 8, corresponding to the 8 ksi weld residual stress, as discussed in Section 3.4.2. A load multiplier of zero is used to simulate the absence of weld residual stresses.

3.5.5 Cladding Stress Load Multiplier

The temperature dependant cladding stress can be determined with the use of the equation discussed in Section 3.4.3. The ratio between this value and the cladding stress at 70°F (35 ksi) was used as the cladding stress load multiplier for each load combination.

3.6 Vessel Nozzle and Upper Shell Stress Analysis

An ANSYS 3-D finite element model was developed for determining stresses around the inlet, outlet, and core flood nozzles. A model was developed for each of the nozzles as shown in Figures 3-5 through 3-7, assuming symmetry conditions between the nozzles. (For simplicity, the weld build-up area at the inside of the outlet nozzle was not included.) This was quite conservative for the outlet nozzle since the model was constructed with an adjacent outlet nozzle and it was assumed that no build-up area reinforcement existed. No cladding was included for either nozzle. A simplified upper flange model was included with loadings applied to simulate boltup, pressure, heatup, and cooldown loadings, with the resulting shell stresses comparing quite well to those from the 2-D model discussed in Section 3.4 [30, 31, 32]. During cooldown, flow to the nozzles (from the reactor coolant pumps)

terminates at 280°F, and decay heat removal starts with flow through the core flood nozzle [36,37]. Therefore, two distinct cooldown rates exist for the inlet and outlet nozzles. For the core flood nozzle, four distinct cooldown rates exist. Material properties and loading conditions were identical to that for the 2-D model [30,31,32]. Bounding stress output for each of the nozzle-related regions is included in Tables 3-11 through 3-16. For purposes of running the various load combinations, the same loading multipliers discussed in Section 3.5 were utilized.

For the inlet, outlet and core flood nozzle regions, there was considerable variation of the boltup and pressure stresses around the nozzle, especially in the hoop direction relative to the nozzle centerline. For these regions, the state of stress was determined for two subregions, with the hoop stresses being highest near the top and bottom of the nozzle (aligned with the hoop direction of the vessel). Thus, one set of stresses will represent the top and bottom 90° portions of the nozzles while another will represent the lateral 90° portions of the nozzles.

For the clad stresses at the nozzle inner corners, it was assumed that the stress and stress intensity factors in the cladding and in the adjacent base metal would be identical to that for the adjacent 12-inch thick plate. For these locations, no weld residual stresses were applied.

Table 3-1

Grouping of Vessel Locations

Type	Description	ID	t in. [3]	Initial RTNDT °F	Fluence N/cm2 [2]	Chemistry Factor	Margin σ_Δ °F (4)	 σ_i °F	Adjusted RT_{NDT} (1/4t) °F
Region A	**Closure Head Flange**		6.625	30	NA	NA	NA	0	30
Shell	Closure Head Center Disc	MK#24	6.625	30	NA	NA	NA	0	30
Shell	Closure Head Flange		12	10	NA	NA	NA	0	10
Region B	**Upper Head to Closure Flange Weld**		6.625	-27	NA	NA	NA	0	-27
Weld	Upper Head to Closure Flange		6.625	-27	NA	NA	NA	0	-27
Region C	**Vessel Flange & Adjacent Shells/Welds**		12	10	NA	NA	NA	0	10
Shell	Upper Shell Flange		12	10	NA	NA	NA	0	10
Weld	Vessel Flange to Nozzle Belt		12	-27	NA	NA	NA	0	-27
Shell	Upper Nozzle Shell		12	10	NA	NA	NA	0	10
Region D	**Lower Nozzle Shell**		12	3	NA	NA	NA	31	65
Shell	Lower Nozzle Shell (1)		12	3	NA	NA	NA	31	65
Region E	**Nozzle to Nozzle Belt Welds & Adjacent Shells**		12	10	NA	NA	NA	0	10
Shell	Upper Nozzle Shell		12	10	NA	NA	NA	0	10
Weld	Nozzle Belt to Nozzle Belt		12	-27	NA	NA	NA	0	-27
Region F	**Beltline Welds & Shells I**		8.4375	20	5.16E+18	141.8	17	0	169.6
Shell	Lower Nozzle Shell		8.4375	3	4.54E+18	94	17	31	147
Weld	Nozzle Belt to Upper Shell	WF 169-1	8.4375	-27	4.54E+18	159	12.5	0	122
Weld	Nozzle Belt to Upper Shell	SA 1769	8.4375	-27	4.54E+18	173.6	12.5	0	133.4
Shell	Upper Shell	A1-207-1	8.4375	20	5.16E+18	118.7	17	0	150.8
Shell	Upper Shell	A1-207-2	8.4375	20	5.16E+18	141.8	17	0	169.6
Shell	Lower Shell	A2-207-2	8.4375	45	4.96E+18	82.6	17	0	145.4
Region G	**Beltline Welds & Shells II**		8.4375	-27	4.8E+18	152.2	12.5	0	119
Shell	Lower Shell	A2-207-1	8.4375	-10	4.96E+18	82.6	17	0	90.4
Weld	Upper Shell Longitudinal	WF 8,18	8.4375	-27	4.8E+18	152.2	12.5	0	119
Weld	Upper Shell to Lower Shell	WF 70	8.4375	-27	4.96E+18	142.2	12.5	0	112.3
Weld	Lower Shell Longitudinal	SA 1580	8.4375	-27	4.21E+18	152.2	12.5	0	113.71
Region H	**Transition Region I**		5	45	3.55E+16	82.6	17	0	83.3
Shell	Lower Shell @ Transition	A2-207-1	5	-10	3.55E+16	82.6	17	0	28.3
Shell	Lower Shell @ Transition	A2-207-2	5	45	3.55E+16	82.6	17	0	83.3
Region I	**Transition Region II**		5	10	3.55E+16	67	17	0	47.5
Weld	Lower Shell Longitudinal	SA 1580	5	-27	3.55E+16	152.2	12.5	0	5.9
Weld	Lower Shell to Head Transition	WF 154	5	-27	3.55E+16	196.7	5.1	0	-6.6
Shell	Head Transition Piece		5	10	3.55E+16	67	17	0	47.5
Region J	**Bottom Head**		5	10	NA	NA	NA	0	10
Shell	Head Transition Piece (1)		5	10	NA	NA	NA	0	10
Weld	Head Transition to Bottom Head		5	-27	NA	NA	NA	0	-27
Shell	Bottom Head	Mk #6	5	10	NA	NA	NA	0	10

Notes:

1. Unirradiated portions of shells and wel s.
2. Fluence terms are taken from "Materia Evaluation and Estimation of Reference Temperature for Crystal River Unit 3", SI File: FPC-01Q-301, Rev.0 and are reported at the cladding-to-base metal interface. For APPENDA analysis, fluence values must be attenuated through the cladding.
3. Taken from "RPV Finite Element Stress Analysis", SI File: FPC-01Q-302, Rev.0.
4. σ_Δ terms are the minimum of either the recommended values in Reg. Guide 1.99 for welds and base material or 1/2 ΔRTNDT. For APPENDA analyses, 28° (for welds) and 17° (for base material) is used.

Table 3-2

Grouping of Nozzle and Upper Shell Weld Locations

Type *	Description	ID	t in. [2]	Initial RTNDT °F	Fluence N/cm2 [3]	Chemistry Factor	Margin σ_Δ °F [4]	Margin σ_i °F	Adjusted RT_{NDT} (1/4t) °F
Region K	**Inlet Nozzle to Shell Weld**		**12.125**	**10**	**NA**	**NA**	**NA**	**0**	**10**
Shell	Upper Nozzle Shell		12.125	10	NA	NA	NA	0	10
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Weld	Nozzle/Shell		12.125	-27	NA	NA	NA	0	-27
Region L	**Outlet Nozzle to Shell Weld**		**12.125**	**10**	**2.78E+16**	**241**	**5.2**	**0**	**30.6**
Shell	Upper Nozzle Shell		12.125	10	NA	NA	NA	0	10
Forging	Outlet Nozzle (1)	MK#19	NA	10	2.78E+16	241	5.2	0	30.6
Weld	Nozzle/Shell		12.125	-27	NA	NA	NA	0	-27
Region M	**Core Flood Nozzle to Shell Weld**		**12**	**30**	**NA**	**NA**	**NA**	**0**	**30**
Shell	Upper Nozzle Shell		12.125	10	NA	NA	NA	0	10
Forging	Core Flood Nozzle (1)	MK#17	NA	30	NA	NA	NA	0	30
Forging	Core Flood Nozzle	MK#17	NA	30	NA	NA	NA	0	30
Weld	Nozzle/Shell		12.125	-27	NA	NA	NA	0	-27
Region N	**Inlet Nozzle Corner Crack**		**NA**	**10**	**NA**	**NA**	**NA**	**0**	**10**
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Forging	Inlet Nozzle	MK #18	NA	10	NA	NA	NA	0	10
Region O	**Outlet Nozzle Corner Crack**		**NA**	**10**	**2.78E+16**	**241**	**5.2**	**0**	**30.6**
Forging	Outlet Nozzle (1)	MK#19	NA	10	2.78E+16	241	5.2	0	30.6
Region P	**Core Flood Nozzle Corner Crack**		**NA**	**30**	**NA**	**NA**	**NA**	**0**	**30**
Forging	Core Flood Nozzle (1)	MK#17	NA	30	NA	NA	NA	0	30
Forging	Core Flood Nozzle	MK#17	NA	30	NA	NA	NA	0	30

Notes:

1. Represents the "worst" material properties found in "Materials Evaluation and Estimation of Reference Temperature for Crystal River Unit 3", SI File: FPC-01Q-301, Rev.0.
2. Fluence terms are taken from above reference (in Note 1) and are reported at the cladding-to-base metal interface. For APPENDA analysis, fluence values must be attenuated through the cladding.
3. Taken from "RPV Finite Element Stress Analysis", SI File: FPC-01Q-302, Rev.0.
4. σ_Δ terms are the minimum of either the recommended values in Reg. Guide 1.99 for welds and base material or 1/2 ΔRTNDT. For APPENDA analyses, 28° (for welds) and 17° (for base material) is used.

Table 3-3

Material Properties of CR-3 Vessel

Vessel Material - A-533-Gr. B

Material Property	Temperature, °F											
	70	100	150	200	250	300	350	400	450	500	550	600
ex, psi (1E6)	29.2	29.0	28.8	28.5	28.2	28.0	27.7	27.4	27.2	27.0	26.7	26.4
alpx, in/in (1E-6)	7.06	7.06	7.16	7.25	7.34	7.43	7.50	7.58	7.63	7.70	7.77	7.83
kxx, Btu/hr-ft^2	22.3	22.6	23.1	23.4	23.7	23.8	23.8	23.8	23.7	23.5	23.2	23.0
d, ft2/hr	0.429	0.427	0.424	0.420	0.415	0.408	0.399	0.389	0.378	0.366	0.354	0.342
c, Btu/lb-°F	0.1063	0.1082	0.1114	0.1139	0.1168	0.1193	0.1220	0.1251	0.1282	0.1313	0.1340	0.1375
dens, lb/ft^3	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024
nuxy	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333

Flange Material - A-508-64-Cl 2

Material Property	Temperature, °F											
	70	100	150	200	250	300	350	400	450	500	550	600
ex, psi (1E6)	29.2	29.0	28.8	28.5	28.2	28.0	27.7	27.4	27.2	27.0	26.7	26.4
alpx, in/in (1E-6)	6.50	6.50	6.57	6.67	6.77	6.87	6.98	7.07	7.15	7.25	7.34	7.42
kxx, Btu/hr-ft^2	23.60	23.70	23.90	24.00	24.00	23.90	23.70	23.60	23.30	23.10	22.70	22.40
d, ft2/hr	0.4540	0.4470	0.4370	0.4270	0.4160	0.4060	0.3960	0.3850	0.3740	0.3620	0.3500	0.3390
c, Btu/lb-°F	0.1063	0.1084	0.1118	0.1149	0.1180	0.1204	0.1224	0.1253	0.1274	0.1305	0.1326	0.1351
dens, lb/ft^3	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024
nuxy	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333

Type 304 Stainless Steel (SA240 Plate)

Material Property	Temperature, °F											
	70	100	150	200	250	300	350	400	450	500	550	600
ex, psi (1E6)	28.3	28.2	27.9	27.7	27.4	27.1	26.9	26.6	26.4	26.1	25.8	25.4
alpx, in/in (1E-6)	9.11	9.16	9.25	9.34	9.41	9.47	9.53	9.59	9.65	9.70	9.76	9.82
kxx, Btu/hr-ft^2	8.35	8.40	8.67	8.90	9.12	9.35	9.56	9.80	10.00	10.23	10.45	10.70
d, ft2/hr	0.150	0.150	0.153	0.155	0.157	0.159	0.160	0.163	0.164	0.166	0.168	0.171
c, Btu/lb-°F	0.1140	0.1149	0.1163	0.1176	0.1189	0.1203	0.1221	0.1229	0.1248	0.1261	0.1269	0.1282
dens, lb/ft^3	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024	489.024
nuxy	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333

Note: To simulate the bolt in the hole reduction in stiffness the value of 0.517 was multplieds into ex, kxx and c for Bolt Material.

Table 3-4

Appenda Load Cases

Reactor Vessel Locations

Load Combination I.D.	Temperature (°F)	Pressure (psig)	Heatup/Cooldown Rate (°F/hr)
LC1 [1]	160	391	50
LC2 [1]	215	500	50
LC3	290	1107	50
LC4	330	1659	50
LC5	369	2500	50
LC6	369	2500	-100
LC7	330	1659	-100
LC8	280	1015	-100
LC9	215	500	-50
LC10 [1]	150	391	-50
LC11 [1]	70	391	-10
LC12 [1]	70	391	0

Core Flood Nozzle to Shell Weld

LC6	385	2240	-100
LC7	278	993	-50
LC8 [1]	150	391	-50
LC9 [1]	70	391	-10

Notes: (1) Represents approximately 20% of Design Pressure Conditions (low temperature, depressurized conditions). For these cases (in regions near local discontinuities), the "L" option is utilized in the APPENDA program which gives lower safety factors than normal operating conditions ("N" option).

Table 3-5

Stresses for Regions A and B
Closure Head/Flange Welds

Distance	Bolt-up @ 70°F		Bolt-up* @ 604°F		Pressure (2240 psi)		Heatup 50°F/hr			Cooldown 50°F/hr		
							Stress			Stress		
	Axial	Hoop	Axial	Hoop	Axial	Hoop	Axial	Hoop	Temp	Axial	Hoop	Temp
0.000	-15.08	6.80	-14.66	6.09	8.728	11.127	-9.03	-16.21	593.0	8.55	17.53	295.5
0.636	-11.83	7.63	-11.50	6.91	9.908	11.502	-6.85	-14.10	585.1	6.53	15.46	300.4
1.276	-8.52	8.45	-8.28	7.72	11.046	11.869	-4.77	-12.05	578.0	4.60	13.45	304.9
1.920	-5.20	9.26	-5.06	8.52	12.147	12.23	-2.92	-10.20	571.5	2.91	11.62	309.0
2.566	-1.89	10.06	-1.85	9.31	13.223	12.587	-1.30	-8.54	565.7	1.41	9.97	312.5
3.216	1.42	10.86	1.35	10.10	14.308	12.96	0.13	-7.08	560.6	0.08	8.50	315.4
3.973	5.33	12.09	5.10	11.17	15.399	13.03	1.39	-6.01	556.2	-0.25	7.02	317.9
4.628	10.13	13.59	9.70	12.62	15.657	12.78	1.06	-4.79	552.6	-0.45	5.79	319.8
5.287	15.50	15.17	14.86	14.16	17.17	12.76	1.24	-3.80	549.7	-0.41	4.80	321.1
5.950	21.98	17.07	21.07	15.98	19.24	13.41	1.20	-3.06	547.7	-0.04	4.09	321.8
6.616	31.90	20.05	30.56	18.84	23.8	14.84	1.13	-2.81	546.8	0.50	3.73	322.1

Table 3-6

Stresses for Region C
Vessel Flange and Adjacent Shells/Welds

Distance	Bolt-up @ 70°F		Bolt-up @ 604°F		Pressure (2240 psi)		Heatup 50°F/hr			Cooldown 50°F/hr		
							Stress			Stress		
	Axial	Hoop	Axial	Hoop	Axial	Hoop	Axial	Hoop	Temp	Axial	Hoop	Temp
0.000	-10.50	1.02	-10.38	0.84	9.245	15.4722	-16.40	-18.43	589.1	16.88	18.77	302.9
1.213	-8.50	1.60	-8.38	1.41	8.8787	15.122	-11.87	-13.72	571.8	12.35	14.16	317.1
2.425	-6.45	2.17	-6.36	1.98	8.498	14.773	-7.73	-9.44	557.5	8.18	9.94	329.8
3.638	-4.36	2.74	-4.30	2.54	8.097	14.437	-4.12	-5.74	545.3	4.49	6.24	341.0
4.850	-2.26	3.31	-2.23	3.10	7.686	14.106	-1.01	-2.59	534.8	1.25	3.06	350.7
6.063	-0.17	3.86	-0.16	3.65	7.2777	13.797	1.69	0.05	525.9	-1.00	0.38	358.9
7.275	2.59	4.40	2.54	4.19	6.475	13.488	3.54	2.18	518.6	-3.86	-1.80	365.6
8.488	5.59	4.94	5.48	4.72	5.925	13.20	4.73	3.82	512.7	-5.13	-3.50	370.8
9.700	8.98	5.57	8.79	5.29	5.208	12.857	5.81	5.31	508.3	-6.02	-4.75	374.5
10.913	13.27	6.48	12.99	6.17	4.52	12.292	6.11	6.27	505.4	-6.39	-5.84	376.7
12.125	20.39	8.41	19.95	8.04	4.64	12.19	6.58	6.67	504.3	-7.42	-6.05	377.4

Table 3-7

Stresses for Regions D and E
Lower Nozzle Belt Shells

Distance (in)	Boltup Hoop (ksi)	Boltup Axial (ksi)	Pressure Hoop (ksi)	Pressure Axial (ksi)	Heatup Hoop (ksi)	Heatup Axial (ksi)	Heatup Temp °F	Cooldown 1 Hoop (ksi)	Cooldown 1 Axial (ksi)	Cooldown 1 Temp °F	Cooldown 2 Hoop (ksi)	Cooldown 2 Axial (ksi)	Cooldown 2 Temp °F
0	1.764	1.984	8.742	7.716	-11.964	-14.073	598.5	13.727	13.756	285.9	10.764	10.757	88.8
1	1.653	1.691	9.730	8.558	-8.546	-10.664	587.3	10.397	10.544	296.1	8.146	8.119	97.3
2	1.542	1.399	10.718	9.399	-5.128	-7.295	576.1	7.285	7.412	306.3	5.662	5.627	105.7
3	1.447	1.120	11.648	10.138	-3.236	-4.730	567.2	4.702	4.770	314.6	3.675	3.752	112.5
4	1.358	0.842	12.578	10.877	-1.319	-1.948	558.3	2.120	2.615	323.0	1.688	2.149	119.4
5	1.317	0.568	13.466	11.585	0.595	0.308	551.5	0.165	1.038	329.4	0.186	0.913	124.7
6	1.301	0.315	14.355	12.293	2.508	2.564	544.7	-1.207	-0.539	335.9	-0.892	-0.324	130.0
7	1.366	0.166	15.340	13.089	3.767	4.201	539.9	-2.193	-1.746	340.4	-1.650	-1.279	133.7
8	1.431	0.016	16.587	13.949	5.164	5.838	535.1	-3.179	-2.952	345.0	-2.408	-2.234	137.5
9	1.572	-0.134	17.849	15.483	6.001	6.865	532.3	-3.964	-3.862	347.8	-3.006	-2.963	139.7
10	1.714	-0.179	19.112	17.017	6.637	7.892	529.5	-4.749	-4.773	350.5	-3.607	-3.693	142.0
11	1.995	-0.103	20.697	18.663	7.179	8.321	528.6	-5.523	-5.811	351.4	-4.241	-4.511	142.7
12	2.279	-0.028	22.283	20.308	7.814	8.751	527.6	-5.537	-6.850	352.3	-4.267	-5.329	143.4

Table 3-8

Stresses for Regions F and G
Beltline Welds and Shells (I,II)

			Heatup 50°F/hr			Cooldown 50°F/hr		
	Pressure (2240 psi)		Stress			Stress		
Distance	Axial	Hoop	Axial	Hoop	Temp	Axial	Hoop	Temp
0.000	10.96	24.06	-5.85	-6.06	599.9	8.68	6.80	294.3
0.844	10.94	23.9	-4.10	-4.17	592.9	6.38	4.86	300.5
1.688	10.91	23.6	-2.61	-2.37	586.7	4.26	3.10	306.1
2.531	10.88	23.39	-1.15	-0.82	581.3	2.38	1.58	311.0
3.375	10.85	23.18	-0.02	0.49	576.7	0.70	0.27	315.2
4.219	10.76	22.97	0.88	1.56	572.8	0.00	0.02	318.7
5.063	11.19	22.77	2.23	2.62	569.6	0.03	0.02	321.6
5.906	11.64	22.58	3.35	3.47	567.1	0.05	0.02	323.9
6.750	12.13	22.5	4.25	4.10	565.4	0.08	0.02	325.4
7.594	12.65	22.3	4.94	4.49	564.3	0.11	0.03	326.4
8.438	13.22	22.20	5.42	4.66	564.0	0.14	0.03	326.7

Table 3-9

Stresses for Regions H and I
Transition Regions (I,II)

Distance	Pressure (2240 psi)		Stress			Stress		
	Axial	Hoop	Axial	Hoop	Temp	Axial	Hoop	Temp
0.000	20.36	17.68	-13.58	-7.98	600.8	13.42	7.81	291.5
0.640	17.78	16.93	-9.12	-5.75	597.1	9.00	5.67	294.7
1.164	17.2	16.79	-6.15	-4.20	594.1	6.10	4.23	297.5
1.687	16.91	16.66	-3.56	-2.81	591.4	3.55	2.92	299.8
2.211	16.81	16.58	-1.26	-1.58	589.1	1.29	1.77	301.9
2.735	16.82	16.51	0.82	-0.49	587.2	-0.77	0.73	303.6
3.259	16.9	16.47	2.72	0.47	585.7	-2.66	-0.18	305.0
3.782	17.01	16.43	4.43	1.30	584.5	-4.37	-0.99	306.1
4.306	17.13	16.41	5.98	2.02	583.6	-5.93	-1.68	306.9
4.830	17.25	16.38	7.37	2.62	583.0	-7.34	-2.28	307.4
5.354	17.46	16.38	8.73	3.12	582.8	-8.74	-2.79	307.6

Table 3-10

Stresses for Region J
Bottom Head Region

Distance	Pressure (2240 psi)		Heatup 50°F/hr			Cooldown 50°F/hr		
			Stress		Temp	Stress		Temp
	Axial	Hoop	Axial	Hoop		Axial	Hoop	
0.000	19.67	15.73	2.31	-8.39	601.5	1.042	9.08	289.2
0.500	19.5	15.78	1.95	-7.66	599.1	0.704	8.31	291.5
1.000	19.29	15.85	1.53	-6.86	596.9	0.413	7.63	293.6
1.500	19.08	15.92	1.06	-6.16	595.0	0.2613	7.24	295.4
2.000	18.86	15.99	0.50	-5.55	593.4	0.2012	6.94	297.0
2.500	18.88	16.06	-0.06	-5.03	592.0	0.2999	6.74	298.3
3.001	19.07	16.13	0.04	-4.60	590.8	1.355	6.63	299.4
3.501	19.25	16.20	0.08	-4.26	590.0	2.474	6.62	300.3
4.001	19.41	16.28	0.08	-3.99	589.3	3.642	6.70	300.9
4.501	19.54	16.35	0.05	-3.79	588.9	4.84	6.89	301.3
5.001	19.64	16.40	-0.08	-3.68	588.8	5.978	7.12	301.4

Table 3-11

Stresses for Region K
Inlet Nozzle Weld

Inlet Radial

	(0-45°,135°-180°)		(45°-135°)							
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2	
	Stress	Stress	Stress	Stress	Stress	Temp	Stress	Temp	Stress	Temp
Distance	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	°F	(ksi)	°F	(ksi)	°F
0	5.577	1.220	0.546	1.818	-10.165	599.2	11.374	284.6	9.290	85.4
1.165	5.471	1.060	1.640	1.679	-7.348	586.0	8.178	296.1	6.717	95.3
2.038	5.621	0.946	2.461	1.574	-5.049	580.6	6.059	300.6	4.954	99.1
3.494	5.946	0.792	3.578	1.524	-2.641	572.3	3.469	307.7	2.855	105.1
4.658	5.866	1.107	4.422	1.508	-1.011	564.7	1.585	314.2	1.343	110.6
5.240	6.085	1.155	4.837	1.493	-0.443	561.5	0.879	317.0	0.772	112.9
6.114	6.413	1.228	5.459	1.470	0.409	557.6	0.018	320.3	0.048	115.7
6.495	6.523	1.252	5.666	1.463	0.745	556.3	-0.199	321.4	-0.120	116.6
7.569	6.851	1.376	6.526	1.373	2.034	551.6	-0.933	325.4	-0.680	120.0
8.734	7.512	1.218	7.445	1.169	3.135	550.0	-1.540	328.0	-1.154	122.2
9.025	7.677	1.179	7.725	1.153	3.413	547.7	-1.692	328.6	-1.272	122.7
10.481	7.744	0.535	8.476	0.924	4.225	545.5	-2.345	330.3	-1.780	124.2
11.645	7.645	-0.069	9.233	0.840	4.749	544.4	-2.847	331.3	-2.170	125.0
12.227	7.231	-0.615	9.329	0.807	4.946	543.9	-3.081	331.5	-2.348	125.2

Inlet Hoop

	(0-45°,135°-180°)		(45°-135°)							
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2	
	Stress	Stress	Stress	Stress	Stress	Temp	Stress	Temp	Stress	Temp
Distance	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	°F	(ksi)	°F	(ksi)	°F
0	31.503	10.170	18.131	4.009	-12.352	599.2	14.146	284.6	11.362	85.4
1.1645	30.080	9.534	18.248	3.827	-9.103	586.0	10.974	296.1	8.837	95.3
2.0379	29.013	9.057	18.336	3.691	-6.559	580.6	8.667	300.6	6.974	99.1
3.4935	27.016	8.245	18.235	3.437	-3.148	572.3	5.525	307.7	4.499	105.1
4.658	25.374	7.592	18.105	3.229	-0.636	564.7	3.149	314.2	2.636	110.6
5.240	24.572	7.257	17.972	3.109	0.330	561.5	2.222	317.0	1.904	112.9
6.114	23.370	6.756	17.772	2.930	1.833	557.6	0.831	320.3	0.806	115.7
6.405	22.969	6.588	17.705	2.870	2.333	556.3	0.368	321.4	0.440	116.6
7.569	21.313	5.865	17.353	2.591	4.011	551.6	-1.285	325.4	-0.871	120.0
8.734	19.606	5.087	16.917	2.271	5.362	550.0	-2.736	328.0	-2.027	122.2
9.025	19.179	4.892	16.807	2.191	5.700	547.7	-3.099	328.6	-2.316	122.7
10.481	16.785	3.650	16.004	1.605	6.767	545.5	-4.508	330.3	-3.429	124.2
11.645	14.818	2.602	15.309	1.099	7.497	544.4	-5.496	331.3	-4.204	125.0
12.227	13.437	1.787	14.805	0.676	7.618	543.9	-5.684	331.5	-4.346	125.2

Note: Hoop, radial stresses taken from nozzle centerline. Hoop stresses are applicable to a radially-oriented flaw; radial stresses are applicable to a circumferential flaw.

Table 3-12

Stresses for Region L
Outlet Nozzle Weld

Outlet Radial										
	(0-45°,135°-180°)		(45°-135°)							
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2	
	Stress	Stress	Stress	Stress	Stress	Temp	Stress	Temp	Stress	Temp
Distance	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	°F	(ksi)	°F	(ksi)	°F
0	6.215	1.056	0.018	1.940	-12.907	598.6	15.560	285.2	12.662	87.0
0.611	6.289	1.004	0.771	1.897	-11.119	592.6	13.341	290.4	10.853	91.5
1.529	6.400	0.926	1.900	1.832	-8.410	583.5	10.211	297.9	8.343	97.8
2.140	6.474	0.873	2.653	1.789	-6.487	577.4	8.263	302.8	6.734	101.9
3.057	6.599	0.802	3.576	1.787	-4.347	569.9	5.923	309.1	4.834	107.1
4.586	6.820	0.690	4.941	1.837	-1.526	558.8	2.508	318.6	2.096	114.9
5.198	6.138	1.596	5.465	1.850	-0.582	555.0	1.329	321.9	1.148	117.6
6.420	6.839	1.740	6.467	1.862	0.942	548.8	-0.494	327.4	-0.349	122.1
7.643	7.552	1.828	7.481	1.836	2.807	543.0	-1.617	332.3	-1.208	126.2
8.561	8.113	1.767	8.409	1.574	3.893	540.0	-2.175	334.9	-1.641	128.4
9.172	8.487	1.727	9.055	1.543	4.631	538.0	-2.547	336.7	-1.930	129.9
10.089	8.869	1.532	9.852	1.447	5.489	535.5	-3.002	338.9	-2.283	131.7
11.618	8.915	0.764	10.541	1.156	6.006	533.0	-3.420	341.1	-2.607	133.6
12.229	8.933	0.456	10.911	1.141	6.213	532.0	-3.588	341.9	-2.736	134.3

Outlet Hoop										
	(0-45°,135°-180°)		(45°-135°)							
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2	
	Stress		Stress		Stress	Temp	Stress	Temp	Stress	Temp
Distance	(ksi)		(ksi)		(ksi)	°F	(ksi)	°F	(ksi)	°F
0	28.981	10.522	16.228	3.602	-12.829	598.6	14.255	285.2	11.281	87.0
0.611	28.398	10.204	16.396	3.561	-11.036	592.6	12.526	290.4	9.917	91.5
1.529	27.525	9.728	16.648	3.499	-8.348	583.5	9.931	297.9	7.870	97.8
2.140	26.942	9.411	16.817	3.457	-6.427	577.4	8.201	302.8	6.505	101.9
3.057	25.991	8.949	16.949	3.385	-4.113	569.9	6.095	309.1	4.846	107.1
4.586	24.342	8.189	17.071	3.255	-0.771	558.8	2.923	318.6	2.402	114.9
5.198	23.691	7.883	17.084	3.196	0.367	555.0	1.807	321.9	1.535	117.6
6.420	22.403	7.265	17.036	3.060	2.281	548.8	-0.105	327.4	0.028	122.1
7.643	21.094	6.618	16.950	2.900	4.186	543.0	-1.873	332.3	-1.344	126.2
8.561	20.065	6.066	16.800	2.725	5.254	540.0	-2.905	334.9	-2.151	128.4
9.172	19.379	5.698	16.699	2.608	5.966	538.0	-3.593	336.7	-2.689	129.9
10.089	18.292	5.077	16.504	2.375	6.853	535.5	-4.471	338.9	-3.370	131.7
11.618	16.289	3.814	16.025	1.792	7.733	533.0	-5.524	341.1	-4.194	133.6
12.229	15.488	2.309	15.833	1.559	8.084	532.0	-5.928	341.9	-4.507	134.3

Note: Hoop, radial stresses taken from nozzle centerline. Hoop stresses are applicable to a radially-oriented flaw; radial stresses are applicable to a circumferential flaw.

Table 3-13
Stresses for Region M
Core Flood Nozzle Weld

Core Flood Radial														
	(0-45°,135°-180°)		(45°-135°)											
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2		Cooldown 3		Cooldown 4	
Distance	Stress (ksi)	Stress (ksi)	Stress (ksi)	Stress (ksi)	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F
0.00	6.829	2.906	2.415	6.929	-11.236	570.4	27.617	389.6	22.200	297.8	15.083	159.7	17.622	72.614
1.58	6.659	2.543	2.678	7.429	-7.164	556.1	20.423	403.8	13.768	314.9	10.714	167.2	10.099	74.392
2.37	6.614	2.377	2.786	7.607	-5.309	549.6	17.000	410.5	10.055	321.7	8.768	170.7	6.864	75.126
3.42	6.660	2.198	2.870	7.647	-3.374	542.5	12.519	418.1	6.436	330.8	6.774	174.5	3.969	76.001
3.68	6.672	2.154	2.890	7.657	-2.888	540.7	11.399	420.0	5.532	333.1	6.275	175.4	3.247	76.220
4.21	6.695	2.064	2.932	7.677	-1.918	537.1	9.159	423.8	3.722	337.7	5.278	177.3	1.805	76.587
5.52	6.738	1.837	3.047	7.721	-0.301	530.9	5.305	430.9	0.895	346.2	3.315	180.5	0.352	77.328
6.57	6.988	2.695	3.151	7.779	0.888	526.5	2.592	435.7	-1.041	352.3	1.838	182.7	0.115	77.781
7.62	7.029	3.415	3.291	7.911	2.014	523.6	1.343	437.8	-1.583	356.1	0.998	183.8	-0.021	78.094
8.15	7.050	3.774	3.360	7.976	2.704	522.1	0.719	438.9	-1.854	357.9	0.578	184.3	-0.089	78.230
9.73	7.317	4.714	3.696	8.452	4.565	520.2	1.108	435.7	-1.992	359.1	-0.551	183.8	-0.270	78.287
10.52	7.473	5.169	3.878	8.721	5.475	519.5	1.529	433.4	-1.994	359.1	-1.103	183.2	-0.358	78.218
11.57	8.294	5.865	4.753	10.288	7.426	520.7	0.891	423.3	1.060	354.4	-2.217	179.6	-0.319	77.869
12.36	8.918	6.392	5.432	11.508	8.889	521.5	0.412	414.5	3.351	350.4	-3.018	177.0	1.249	77.585

Core Flood Hoop														
	(0-45°,135°-180°)		(45°-135°)											
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2		Cooldown 3		Cooldown 4	
Distance	Stress (ksi)	Stress (ksi)	Stress (ksi)	Stress (ksi)	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F	Stress (ksi)	Temp °F
0.00	21.321	9.3546	14.597	3.4449	-14.077	570.4	32.743	389.6	19.057	297.8	17.492	159.7	2.8099	72.3
1.58	20.227	9.390	14.456	3.235	-8.974	568.0	24.659	392.0	12.223	300.5	13.177	161.0	2.035	72.6
2.37	19.723	9.436	14.383	3.136	-6.586	553.7	20.441	406.2	8.952	316.7	11.098	168.5	1.666	74.4
3.42	19.165	9.571	14.290	3.018	-3.839	547.8	14.275	412.4	4.949	324.0	8.52	171.6	1.221	75.1
3.68	19.025	9.604	14.266	2.988	-3.152	540.7	12.761	420.0	3.949	333.1	7.8759	175.4	1.110	76.0
4.21	18.746	9.672	14.218	2.929	-1.778	538.9	9.742	421.9	1.950	335.4	6.5881	176.4	0.887	76.2
5.52	18.191	9.784	13.730	3.530	0.315	535.9	4.133	425.2	-1.093	339.4	4.2426	178.0	0.503	76.6
6.57	17.473	9.897	13.523	4.365	2.780	529.7	-2.523	432.4	-4.547	347.9	1.4068	181.2	0.044	77.3
7.62	16.822	9.897	13.319	5.004	4.263	525.8	-6.684	436.3	-6.456	353.2	-0.65773	183.0	-0.274	77.8
8.15	16.496	9.897	13.218	5.324	5.005	522.9	-8.763	438.4	-7.350	357.0	-1.6617	184.1	-0.425	78.1
9.73	15.175	9.546	12.775	6.081	6.953	521.4	-12.085	439.4	-9.219	358.9	-4.0669	184.6	-0.760	78.3
10.52	14.480	9.336	12.540	6.440	8.085	520.0	-13.099	434.9	-9.686	359.1	-5.0112	183.6	-0.881	78.3
11.57	12.946	8.463	12.148	6.530	9.196	519.8	-14.569	431.0	-8.839	358.0	-5.8086	182.3	-0.981	78.2
12.36	11.796	7.808	11.864	6.603	10.029	521.0	-15.671	420.3	-8.205	353.0	-6.4067	178.7	-1.056	77.9

Note: Hoop, radial stresses taken from nozzle centerline. Hoop stresses are applicable to a radially-oriented flaw; radial stresses are applicable to a circumferential flaw.

Table 3-14

Stresses for Region N
Inlet Nozzle Inner Corner

Inlet Corner Crack										
	(0-45°,135°-180°)		(45°-135°)							
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2	
	Stress	Stress	Stress	Stress	Stress	Temp	Stress	Temp	Stress	Temp
Distance	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	°F	(ksi)	°F	(ksi)	°F
0.000	46.884	12.285	25.579	3.668	-10.405	598.7	15.377	284.8	12.847	83.6
0.889	43.229	11.226	24.459	3.550	-8.941	594.4	13.548	289.1	11.275	87.6
1.185	42.037	10.881	24.098	3.513	-8.463	592.8	12.957	290.5	10.764	89.0
2.073	38.552	9.874	23.056	3.406	-7.063	588.0	11.244	294.5	9.280	93.0
3.258	34.720	8.763	21.881	3.205	-4.930	581.3	8.854	300.0	7.292	98.0
4.147	32.138	8.015	21.083	3.040	-3.232	576.2	7.041	304.2	5.811	101.7
5.035	29.652	7.293	20.321	2.875	-1.595	571.2	5.276	308.2	4.368	105.3
6.220	26.793	6.429	19.329	2.593	0.362	565.5	3.099	313.0	2.622	109.4
7.108	24.714	5.804	18.641	2.392	1.873	561.1	1.479	316.6	1.321	112.6
8.293	22.099	4.963	17.653	2.075	3.452	556.4	-0.396	320.5	-0.179	115.9
9.182	20.236	4.353	16.922	1.831	4.538	553.2	-1.681	323.2	-1.199	118.2
10.070	18.444	3.762	16.252	1.589	5.547	550.2	-2.954	325.8	-2.211	120.3
11.255	15.901	2.766	15.173	1.080	6.361	547.9	-4.267	327.7	-3.248	122.0
12.143	14.527	2.016	16.054	0.710	7.005	546.1	-5.245	329.2	-4.017	123.2
13.032	13.737	0.965	16.733	0.320	7.348	545.8	-5.662	329.6	-4.330	123.6
14.217	13.293	-0.507	18.896	0.557	8.531	545.6	-5.739	329.8	-4.370	123.7

Note: Hoop, radial stresses taken from nozzle centerline. Hoop stresses are applicable to a radially-oriented flaw; radial stresses are applicable to a circumferential flaw.

Table 3-15

Stresses for Region O
Outlet Nozzle Inner Corner

Outlet Corner Crack										
	(0-45°,135°-180°)		(45°-135°)							
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2	
	Stress	Stress	Stress	Stress	Stress	Temp	Stress	Temp	Stress	Temp
Distance	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	°F	(ksi)	°F	(ksi)	°F
0	48.477	14.126	25.756	4.1	-11.358	600.88	13.696	282.03	11.846	79.28
1.0766	44.842	12.989	24.557	3.9619	-10.254	596.32	12.49	286.39	10.666	83.979
2.1532	41.318	11.888	23.403	3.8176	-9.0643	591.46	11.21	291	9.447	88.837
3.2298	37.924	10.829	22.301	3.666	-7.7754	586.24	9.8478	295.92	8.1833	93.88
4.3064	35.136	9.9407	21.443	3.5038	-6.0135	580.56	8.0921	301.72	6.7097	99.252
5.0241	33.414	9.3875	20.929	3.3957	-4.7696	576.21	6.8753	305.49	5.7076	102.79
6.1007	30.899	8.5806	20.18	3.2358	-2.9242	569.62	5.0849	310.85	4.2462	107.7
7.1773	28.556	7.823	19.464	3.0667	-1.1808	563.27	3.3881	315.99	2.8701	112.18
8.2539	26.439	7.1242	18.789	2.874	0.4409	557.54	1.7952	320.64	1.5967	116.18
9.3305	24.419	6.4532	18.185	2.6817	2.1136	551.98	0.20317	325.17	0.32816	120.08
10.048	23.108	6.0138	17.803	2.5549	3.2197	548.3	-0.82289	328.08	-0.4921	122.58
11.125	21.213	5.3146	17.149	2.2961	4.4098	544.23	-2.0701	331.48	-1.4757	125.47
12.201	19.369	4.6256	16.551	2.0436	5.6235	540.15	-3.3358	334.89	-2.4733	128.36
13.278	17.537	3.9003	15.945	1.7441	6.6036	536.76	-4.3954	337.66	-3.3054	130.71
14.355	15.639	3.0522	16.438	1.3348	7.187	534.52	-5.2251	339.67	-3.9556	132.41
15.072	15.077	2.4993	17.325	1.0768	7.6099	533	-5.7618	341.02	-4.3786	133.55
16.149	14.649	1.384	18.416	0.81801	7.8661	531.97	-6.0627	341.98	-4.6175	134.37
17.226	14.939	0.14301	20.735	1.0568	8.5462	531.36	-6.1301	342.59	-4.6679	134.89

Note: Hoop, radial stresses taken from nozzle centerline. Hoop stresses are applicable to a radially-oriented flaw; radial stresses are applicable to a circumferential flaw.

Table 3-16

Stresses for Region P
Core Flood Nozzle Inner Corner

Core Flood Corner Crack														
	(0-45°,135°-180°)		(45°-135°)											
	Pressure	Boltup	Pressure	Boltup	Heatup		Cooldown 1		Cooldown 2		Cooldown 3		Cooldown 4	
	Stress	Stress	Stress	Stress	Stress	Temp	Stress	Temp	Stress	Temp	Stress	Temp	Stress	Temp
Distance	(ksi)	(ksi)	(ksi)	(ksi)	(ksi)	°F	(ksi)	°F	(ksi)	°F	(ksi)	°F	(ksi)	°F
0.000	45.273	23.598	26.365	6.842	-14.282	565.7	79.631	220.1	47.625	211.9	34.142	124.5	4.387	70.8
0.799	39.937	20.179	24.181	6.080	-11.661	561.2	65.157	252.2	39.465	229.8	28.868	131.4	3.682	71.5
1.065	38.268	19.182	23.502	5.844	-10.799	559.6	60.825	262.6	36.957	235.8	27.229	133.7	3.461	71.7
1.597	35.087	17.391	22.204	5.397	-9.094	556.6	52.886	282.9	32.252	247.8	24.128	138.4	3.041	72.2
2.130	32.869	16.149	21.225	5.080	-7.649	553.8	45.959	299.2	27.877	258.4	21.431	142.4	2.678	72.7
3.195	29.260	14.178	19.581	4.561	-4.881	548.0	33.918	325.8	19.672	277.6	16.547	149.6	2.013	73.6
3.461	28.423	13.748	19.195	4.441	-4.173	546.5	31.256	332.0	17.742	282.3	15.391	151.3	1.853	73.8
4.260	26.249	12.711	18.159	4.313	-2.289	542.5	24.812	347.8	12.614	294.5	12.263	155.8	1.416	74.5
5.058	24.521	11.967	17.327	4.494	-0.712	539.2	19.989	360.7	8.200	304.6	9.506	159.5	1.038	75.0
6.123	22.412	11.144	16.301	4.770	1.445	534.6	14.491	377.6	2.550	318.0	5.962	164.4	0.545	75.7
7.188	20.593	10.500	15.403	5.046	2.972	531.4	10.154	387.8	-1.433	326.8	3.096	167.7	0.153	76.2
8.253	18.975	9.998	14.608	5.370	4.470	528.2	4.893	397.7	-4.996	335.1	0.409	170.9	-0.216	76.7
9.052	17.722	9.562	14.017	5.571	5.407	526.4	0.925	402.4	-7.010	339.6	-1.368	172.7	-0.449	77.0
10.117	16.137	9.017	13.294	5.852	6.773	524.5	-3.772	407.4	-8.892	344.3	-3.394	174.6	-0.698	77.3
11.182	14.438	8.377	12.632	6.089	8.210	523.1	-8.723	410.3	-9.568	347.3	-4.921	175.7	-0.874	77.5
12.513	12.285	7.602	12.211	6.442	9.914	522.2	-14.748	410.6	-8.371	348.3	-6.340	175.8	-1.046	77.5

Note: Hoop, radial stresses taken from nozzle centerline. Hoop stresses are applicable to a radially-oriented flaw; radial stresses are applicable to a circumferential flaw.

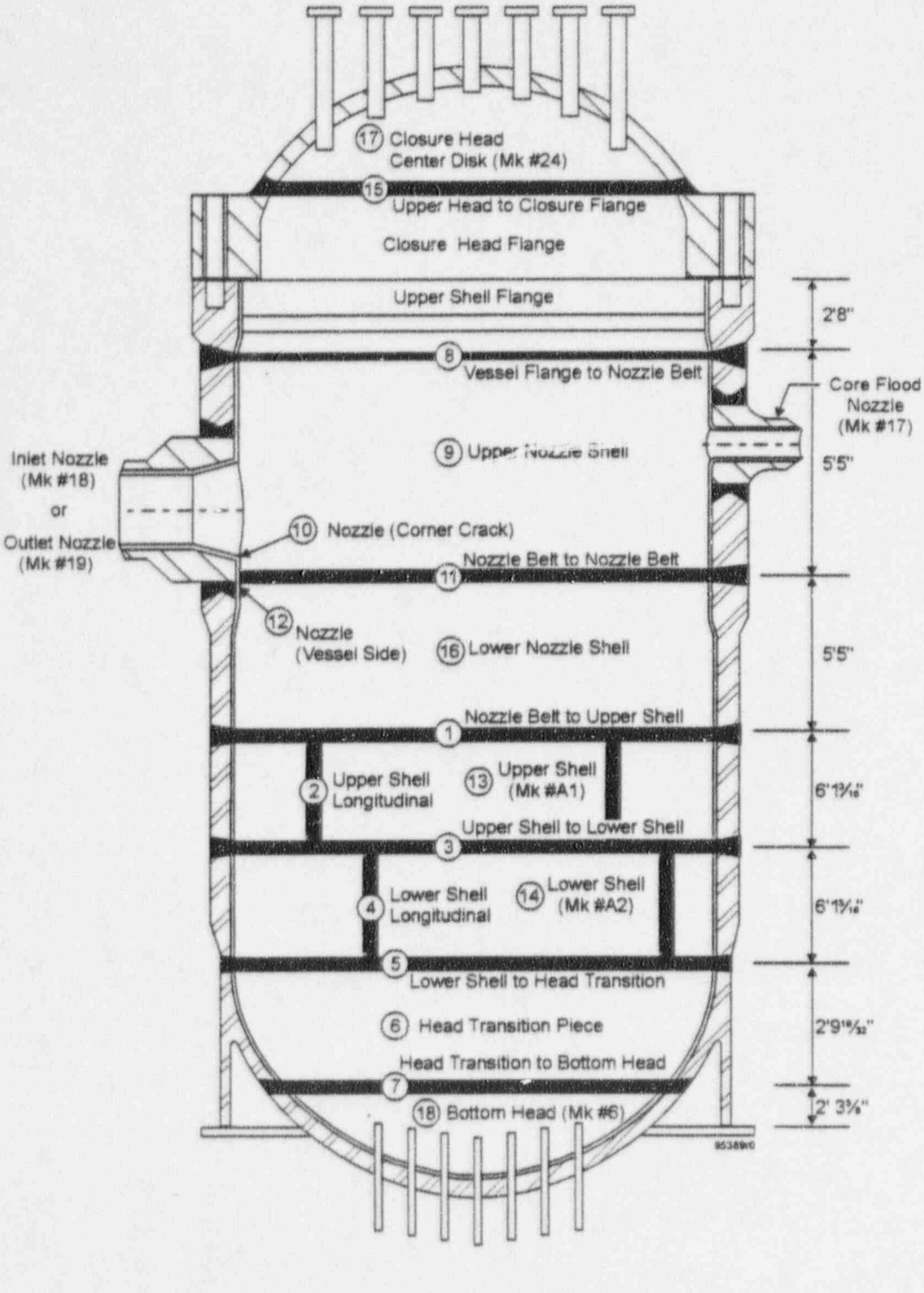


Figure 3-1. Plates and Weld Locations of CR-3 Vessel

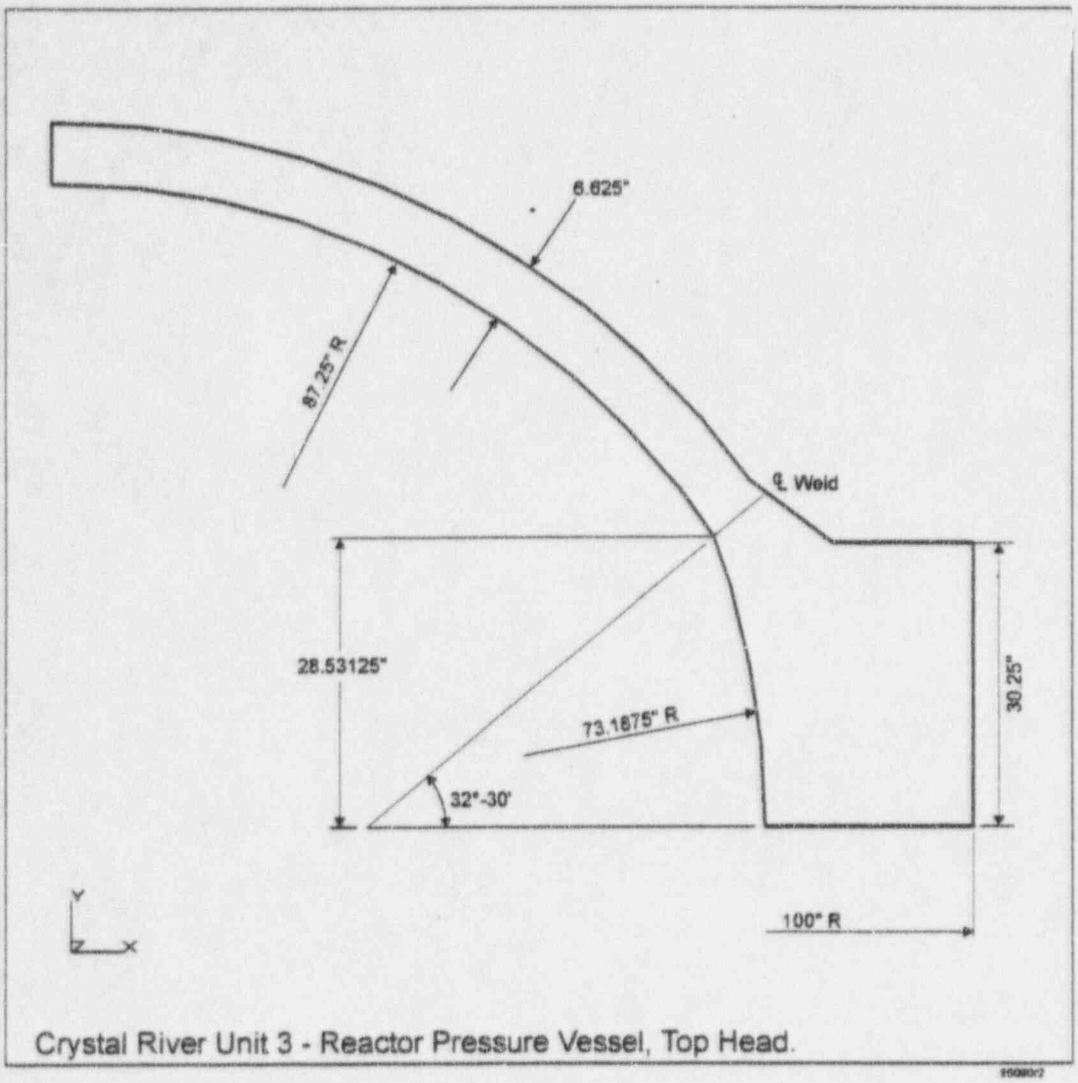


Figure 3-2. Vessel Geometry at CR-3 - Top Head Region

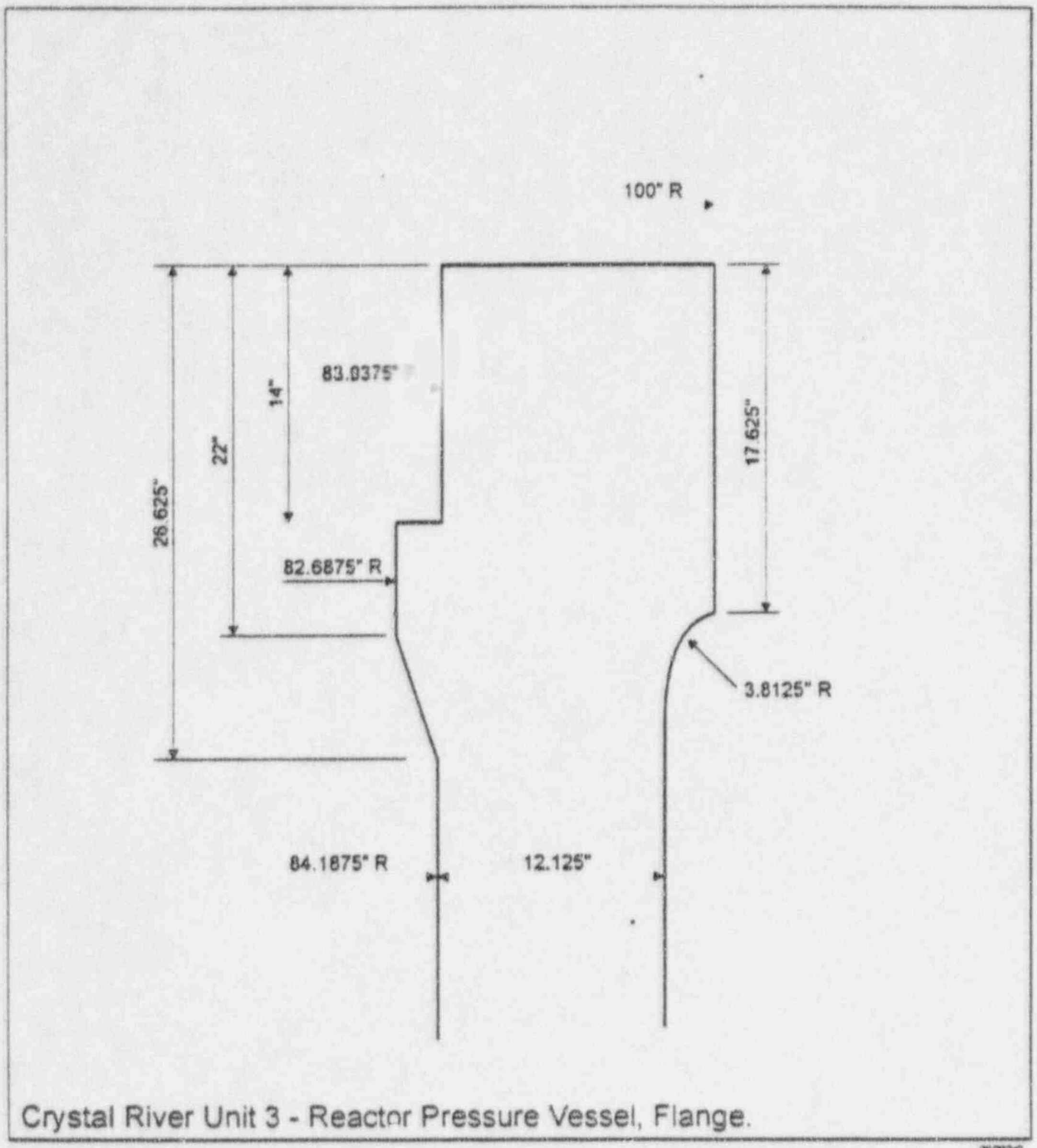


Figure 3-3. Vessel Geometry at CR-3 - Flange Region

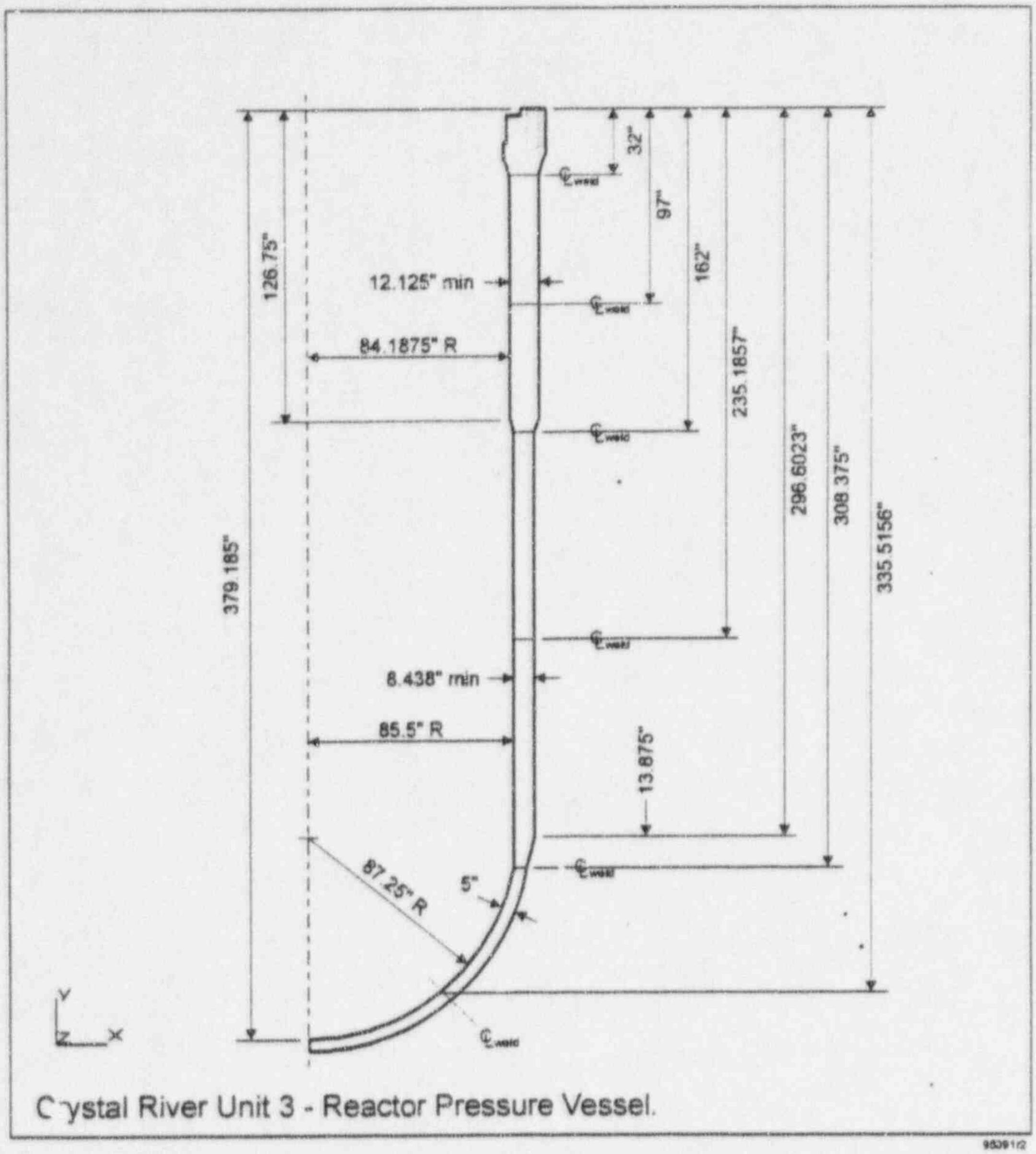


Figure 3-4. Vessel Geometry at CR-3 - Beltline and Bottom Head Regions

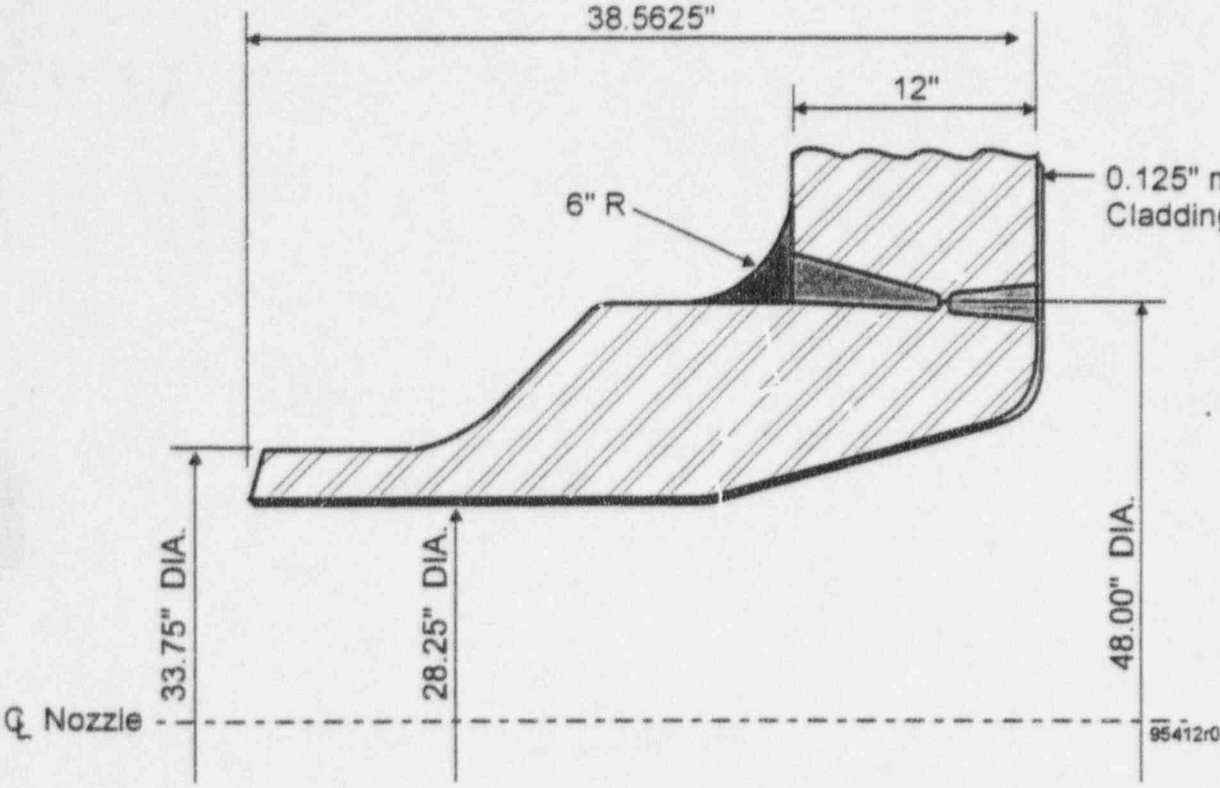


Figure 3-5. CR-3 Vessel Inlet Nozzle Geometry

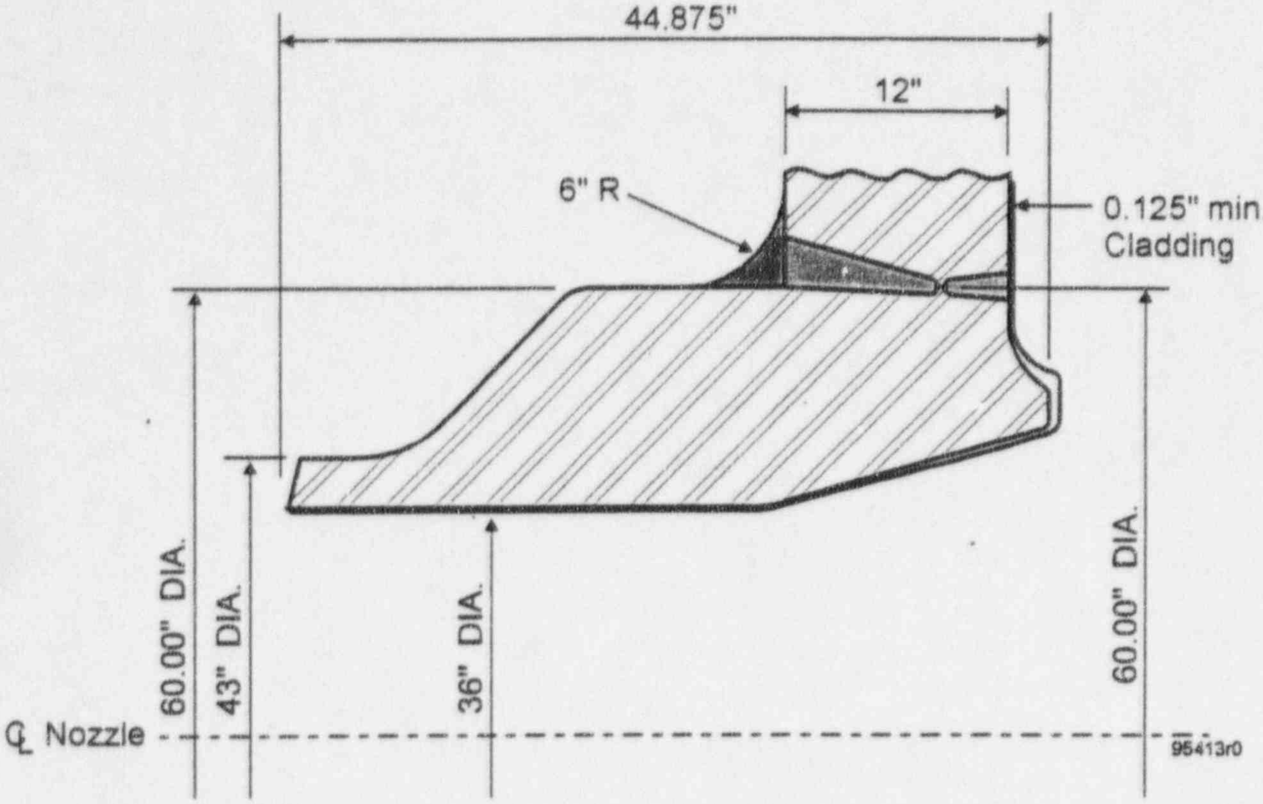


Figure 3-6. CR-3 Vessel Outlet Nozzle Geometry

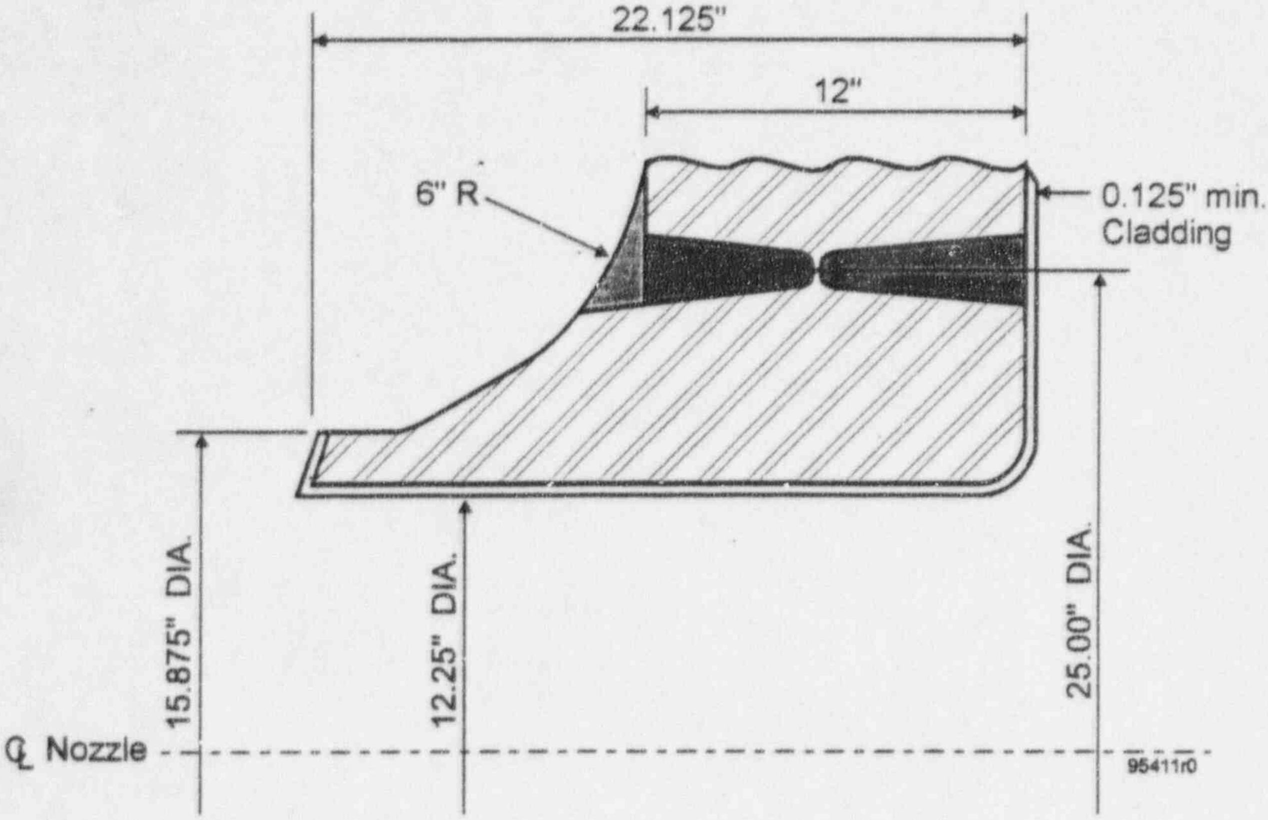
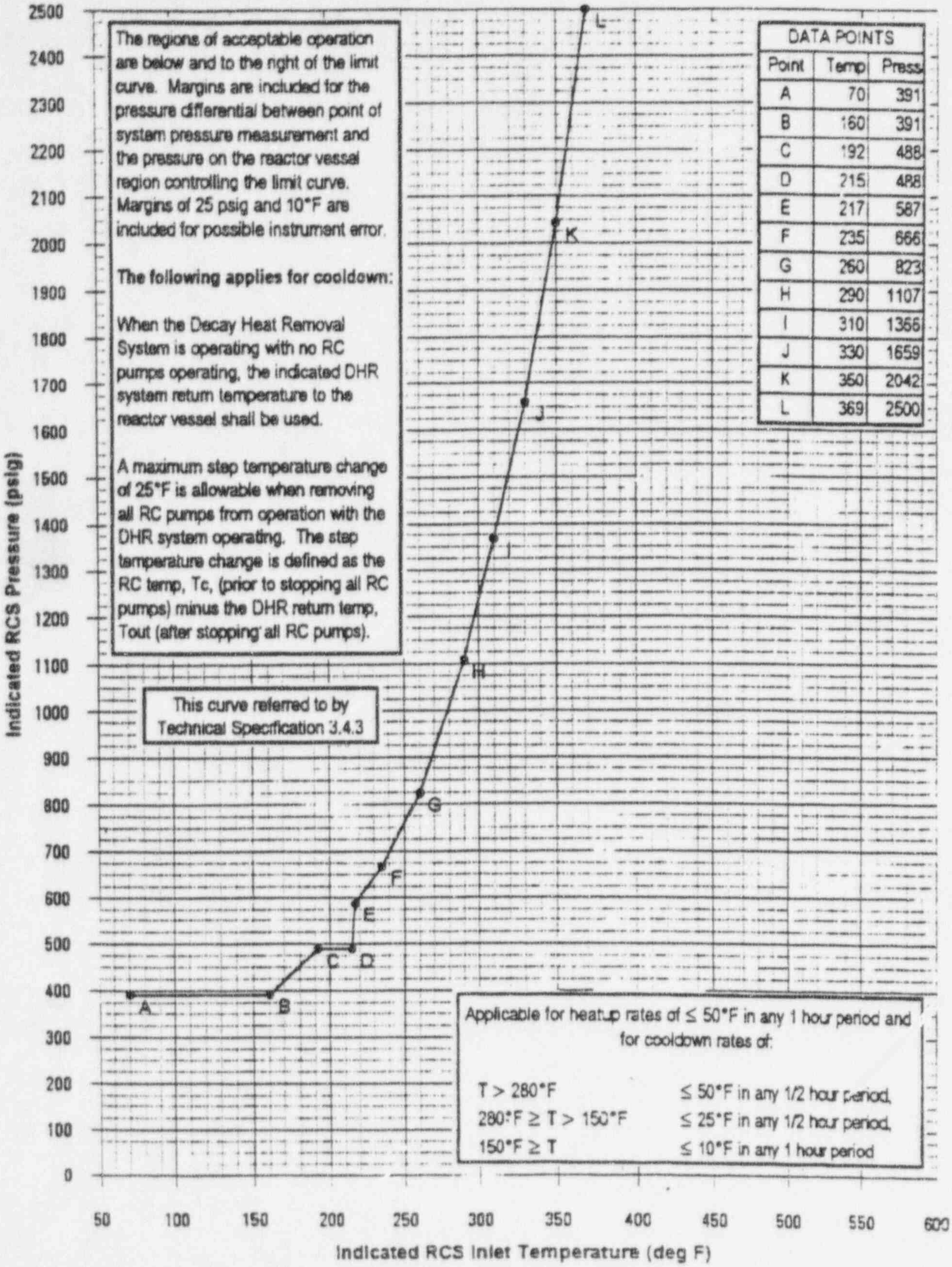


Figure 3-7. CR-3 Core Flood Nozzle Geometry



0-15 EFPY

Curve Basis: Peak Surface Fluence = 2.29×10^{19} n/cm^2 @ 20 EFPY

Figure 3-8. CR-3 Inservice Leak Test Pressure-Temperature Limits [23]

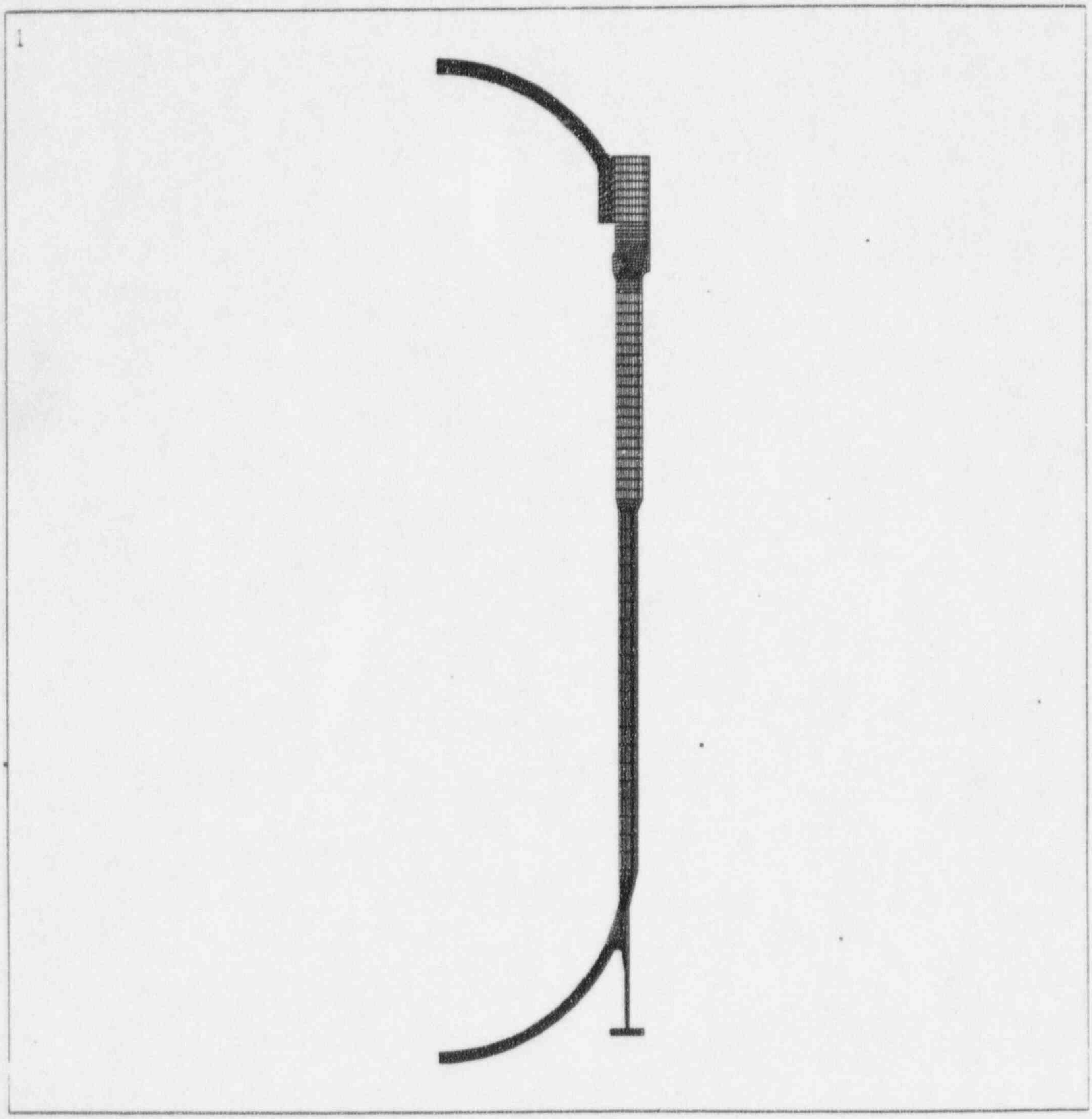


Figure 3-9. Reactor Vessel Axisymmetric Finite Element Model

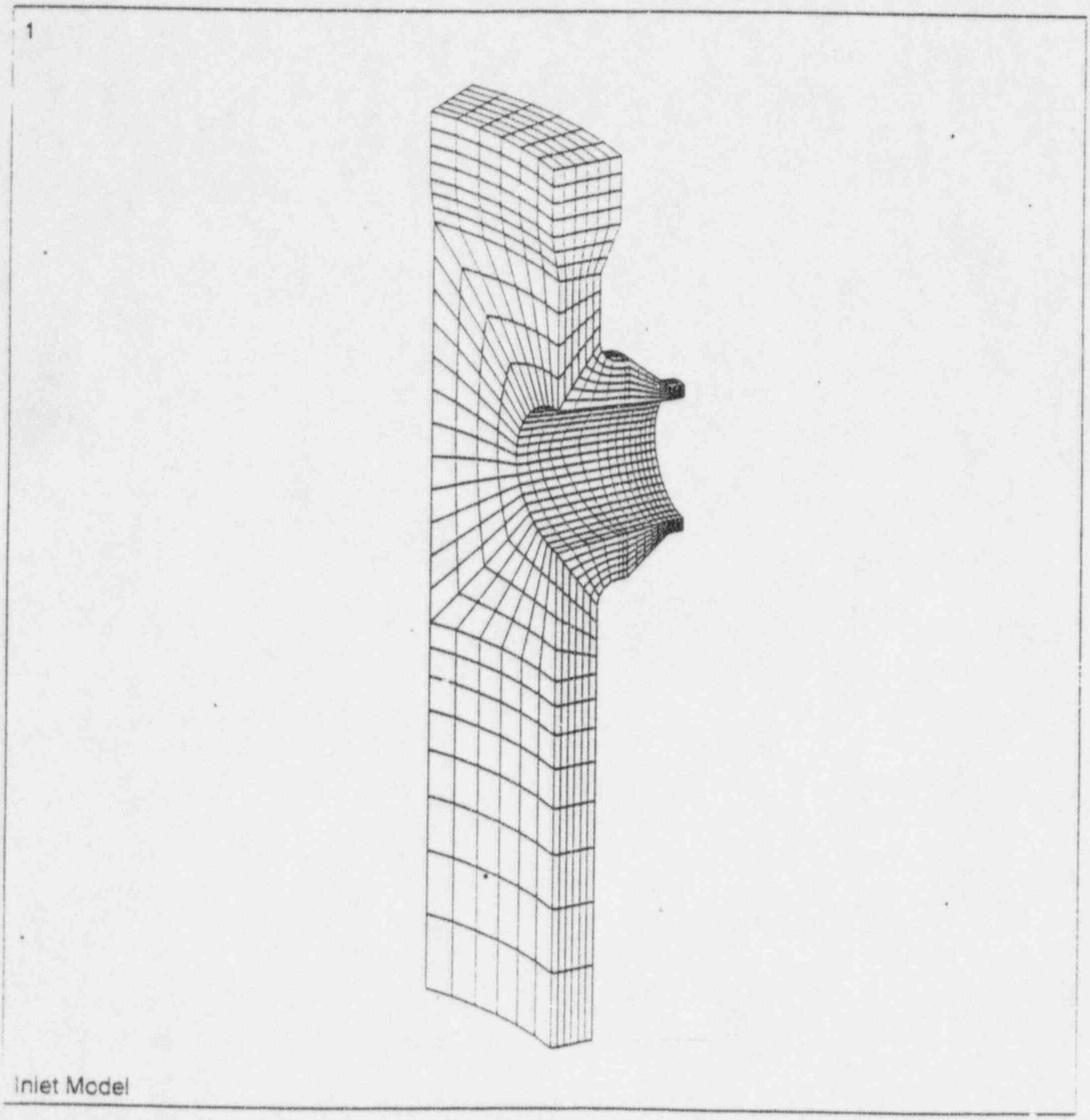


Figure 3-10. Inlet Nozzle 3-D Finite Element Model

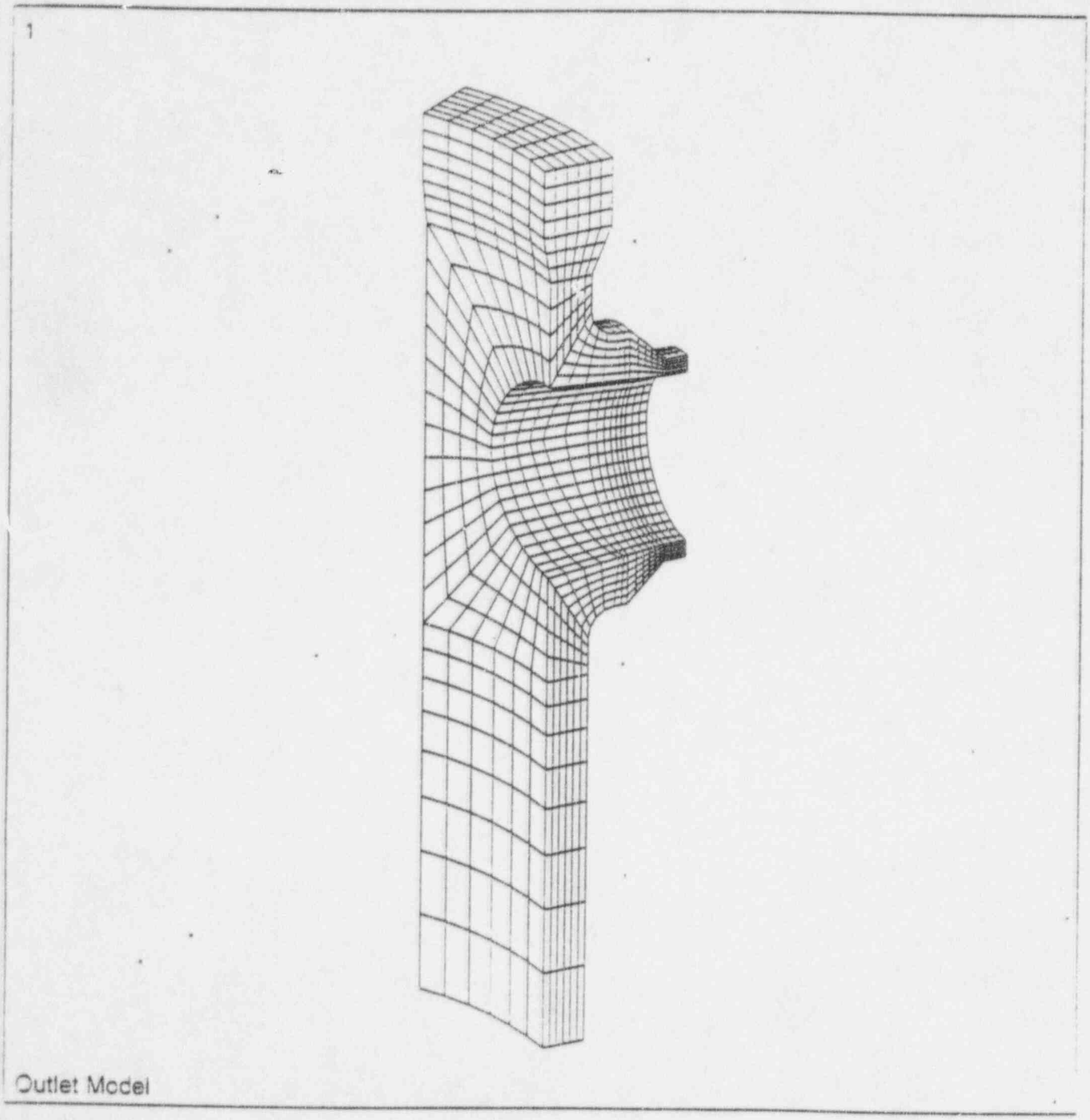


Figure 3-11. Outlet Nozzle 3-D Finite Element Model

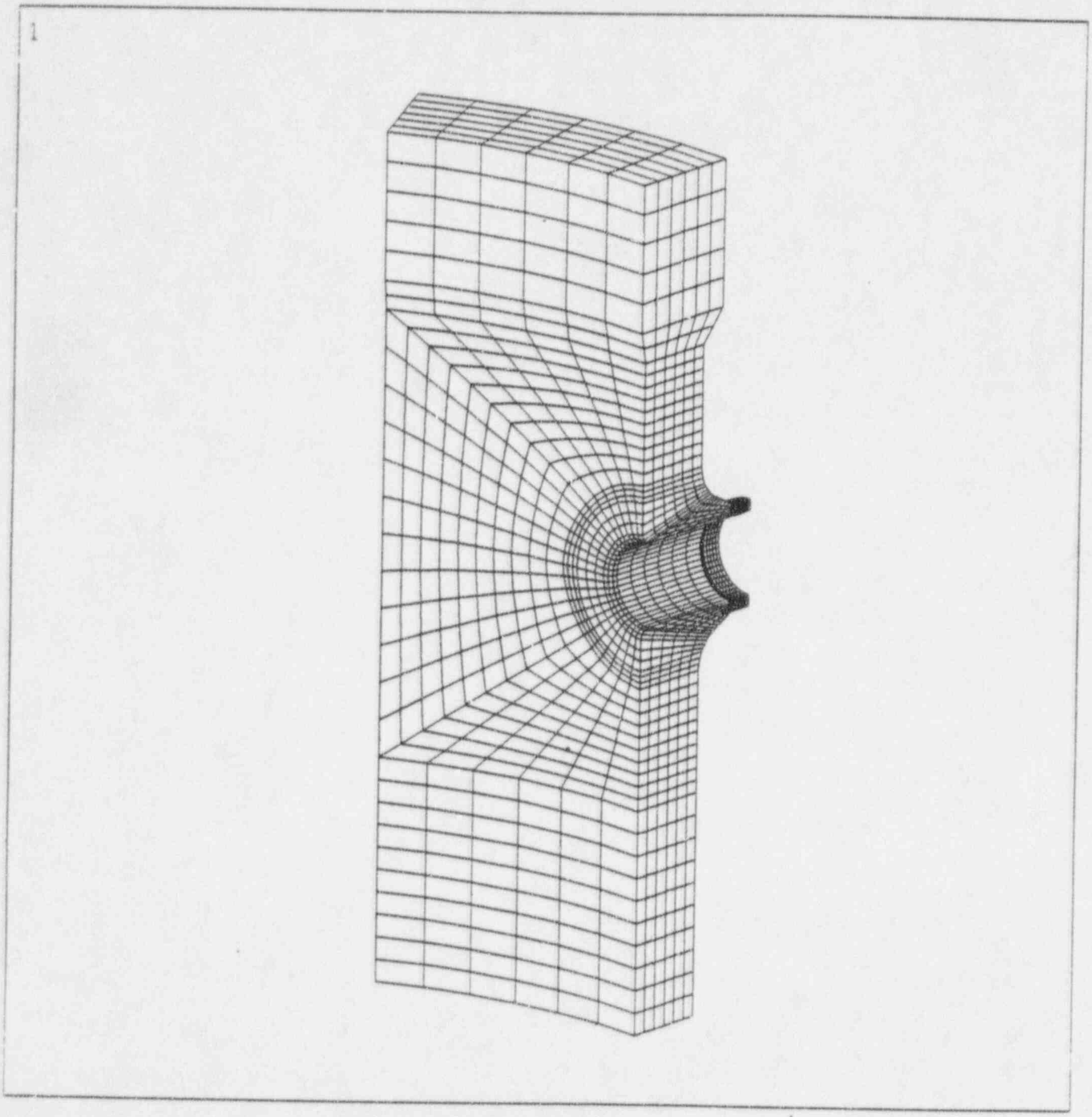


Figure 3-12. Core Flood Nozzle 3-D Finite Element Model

4.0 RESULTS

Graphs which define acceptable flaw sizes are included in Appendices A through M of this report for the corresponding vessel material and nozzle regions shown in Tables 3-1 and 3-2 [33, 34]. There are also provided on EXCEL spreadsheets on the diskette that accompanies this report. For the nozzle inner corners, the results are rather simple such that a single Appendix N contains the results for corner cracks of inlet, outlet, and core flood nozzles [35].

4.1 IWB-3500 Evaluation Standards

For completeness, each of the evaluations also considered the IWB-3500 evaluation standards from Table IWB-3500-1. For subsurface flaws, the limitations of proximity to the surface of the base metal are shown for rapid evaluation. Flaw acceptance diagrams for subsurface flaws give allowable flaw depth of 2(a) while surface flaws give allowable depth of (a). Linear interpolation may be used for intermediate flaw eccentricities.

The evaluation standards of IWB-3500 are also included for reference as the lower bound in the location-specific flaw acceptance graphs in Appendices A through M. In these sets of curves, the acceptable inside surface flaw is the depth of the cladding plus the acceptance standards. In all graphs, it has been assumed that the cladding thickness is 7/32 inch [13].

4.2 IWB-3600 Evaluations

The graphs of Appendices A through M show the acceptable flaw sizes based on this evaluation. Graphs are shown for all surface and subsurface flaws. Flaw acceptance diagrams for subsurface flaws give allowable flaw depth of two times it depth (2a) while surface flaws give allowable depth of (a). The minimum allowable flaw size for all cases evaluated is shown and considers the effects of crack growth to end-of-life (32 EFPY). Each appendix has two evaluations with one being for axially-oriented flaws and the other for circumferentially-oriented flaws. The general scheme is to show the allowables for inside surface flaws, outside surface flaws and a range of subsurface flaws

for various values of flaw eccentricity. For subsurface flaws with intermediate values of flaw eccentricity, linear interpolation can be used.

For all graphs and tables presented in Appendices A through M, a default maximum flaw size was determined such that the nominal stress would increase to approximately 1.5 times the nominal stress if a long flaw existed at the location. This was done because IWB-3610(d)(1) requires that the primary stress limits of NB-3000 (of ASME Section III) be satisfied for the size of the evaluated flaw. For actual flaws found in a reactor pressure vessel, this should never become limiting because NB-3000 allows local primary membrane stresses to approach 1.5 S_m provided that the extent of the region with stress exceeding 1.1 S_m does not exceed $\sqrt{Rt}$ (where R is the mean vessel radius and t is the thickness). This compares to the requirement for the design equations for pressure sizing where the stress must be maintained below S_m. Based on this ratio, the additional primary stress criterion might become governing for axial flaws with depths approaching one-third of the wall thickness that have any significant extent, provided that the pressure stress is near the allowable stress. Since the stresses acting on circumferential flaws are about one half of that for axial flaws, greater flaw depths would be allowed for flaws with a circumferential orientation, assumed in this evaluation to be limited to 50% of the wall thickness, except at regions near discontinuities where the one-third of wall thickness default maximum size is used.

It should be noted that most of the allowable flaw sizes for near-surface subsurface flaws are governed by proximity requirements at the surface and not by crack tip stress intensity factor. In these cases, the flaws may be acceptable when evaluated as surface flaws [22].

5.0 CONCLUSIONS AND DISCUSSION

A comprehensive evaluation of potential flaws in the CR-3 RPV shell welds, plate material, and nozzles has been completed. To limit the number of evaluations (and pages of this report) to a manageable size, a limiting set of regions was determined (welds) and flaw acceptance diagrams were developed for these regions. As in all engineering evaluations, a number of assumptions were built into these evaluations, including:

- The grouping of locations into a limited number of regions for this evaluation results in very conservative material properties (initial RT_{NDT}) and stresses for all locations in a particular group (region).

- A conservative assessment of pressure, boltup, heatup/cooldown, weld residual, and cladding stresses was included. The stresses included are bounding in the vicinity of the locations covered by each region.

- The effects of both deepest point and surface stress intensity factors were included for all vessel wall flaws.

- The largest acceptable flaw size was determined. There may be smaller flaw sizes (mainly for surface flaws) that would be unacceptable if evaluated without consideration of larger acceptable sizes. However, it is believed that more sophisticated evaluation methodology could be used to show acceptability of flaws up to and possibly greater than those presented in this report.

- The assessments were computed for hydrotest, heatup/cooldown and other normal operating conditions consistent with the vessel pressure/temperature limits for the current technical specifications [23]. The effects of boltup stresses were considered for all regions but were significant for the upper flange welds and the adjoining reactor vessel nozzle regions.

- A conservative assessment of cyclic crack growth was included for all plant transients that can affect overall vessel heatup and cooldown to end-of-life. The 167 cycles assumed in this evaluation exceed the experience to date at the plant. The conservatisms in the analysis and the fact that fatigue crack growth is insignificant would allow the use of the flaw acceptance results in this report, even if a reasonable number of additional cycles were experienced.

- The analyses were conducted both with and without the effects of weld residual stresses.

- For the beltline region, the maximum effects of shift in the reference temperature were considered to end-of-life. This is conservative since the P-T limitations of Reference 23 are for EFPY=20 years.

- A separate analysis was included to determine the allowable size for inlet and outlet nozzle inner corner cracks.

- The flaw evaluation methodology is based on methods from the 1989 edition of Section XI of the ASME Code, supplemented by more recent fatigue crack growth curves (1992 Code with 1993 Addenda) and by using materials evaluation methodology from Reg. Guide 1.99, Rev. 2 [5]. The evaluations are generally more conservative than would be required by the 1983 Section XI Code with Summer 1983 Addenda and reflect currently accepted flaw methodologies.

Based on the above, it is believed that the results of the evaluations are correct and conservative and can be used to the end-of-life for the CR-3 reactor vessel. However, because of the number of evaluations, every possible flaw location could not be studied in detail to quantify and understand the conservatisms. Thus, these results by themselves should not serve as the sole basis for accepting flaws that significantly exceed the acceptance standards of IWB-3500 or are near the limits for acceptable flaw size as determined by this report. The reactor vessel at CR-3 displays numerous geometric discontinuities and material property variation. Because of this, the flaw acceptance diagrams are quite conservative in nature with significant margin for most locations.

If flaws are found during inspections, location-unique flaws can be evaluated on a case-by-case basis, which will result in more realistic results, that could be used to justify the presence of larger flaws. In this case, alternate analysis can probably be conducted, removing some of the conservatisms to show acceptability of larger flaws, by using tools like SI's fracture mechanics computer program **pc-CRACK** [7], or by conducting additional analysis based on flaw-specific stresses, materials, and other parameters that have been bounded by the current analysis. In addition, the requirements of NB-3000 for primary stress limits must be checked.

The information presented in the Appendices of this report should allow FPC engineers to perform rapid assessment of any indications reported during RPV in-service examinations.

6.0 REFERENCES

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14. Dwg. No. 135552E, Rev. 5, "Closure Head Assembly", SI File: FPC-01Q-226.

15. Dwg. No. 135547E, Rev. 1, "Closure Head Flange," SI File: FPC-01Q-226.

16. Dwg. No. 135549E, Rev. 8, "Closure Head Sub-Assembly," SI File: FPC-01Q-226.

17. B&W Drawing 135541E, Rev. 3, "Detail and Sub-Assembly Inlet Nozzle", SI File FPC-01Q-230.

18. B&W Drawing 135540E, Rev. 2, "Detail and Sub-Assembly Outlet Nozzle", SI File FPC-01Q-231.

19. B&W Drawing 135539E, Rev. 7, "Core Flood Nozzle", SI File, FPC-01Q-229.

20. Dwg. No. 135559E, "Material List Head & Vessel," Rev. 10, SI File: FPC-01Q-228.

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22. ASME Boiler and Pressure Vessel Code, 1989 Edition, Section III Appendices.

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27. Stress Report #3, "Closure Analysis", Customer Order PR3-1000, Babcock & Wilcox Contract No. 620-0007-51, Feb. 1971, SI File: FPC-01Q-210.

28. EPRI-TR-100251, "White Paper on Reactor Vessel Integrity Requirements for Level A and B Conditions," Electric Power Research Institute, January 1993.

29. "Derivation of Clad Stress Equation", Rev. 0, SI File FPC-01Q-238.

30. SI Calculation FPC-01Q-303, "Inlet Nozzle Finite Element Stress Analysis," Rev. 0.

31. SI Calculation FPC-01Q-304, "Outlet Nozzle Finite Element Stress Analysis", Rev. 0.

32. SI Calculation FPC-01Q-305, "Core Flood Nozzle Finite Element Stress Analysis", Rev. 0.

33. SI Calculation FPC-01Q-308, "Development of Flaw Tolerance Diagrams for Inlet/Outlet/Core Flood Nozzle-to-Shell Weld Locations", Rev. 0.

34. SI Calculation FPC-01Q-307, "Development of Flaw Tolerance Diagrams for Reactor Pressure Vessel Using APPENDA Program," Rev. 0.

35. SI Calculation FPC-01Q-309, "Fracture Mechanics Analysis and Development of Flaw Tolerance for Corner Crack of Inlet/Outlet Nozzles at CR-3 Using **pc-CRACK** Program", Rev. 0.

36. Report #5, "Thermal/Mechanical Analysis of the Core Flood Nozzle for RV", B&W Contract No. 620-0007-51, February, 1971, SI File: FPL-01Q-211.

37. Report #4, "Thermal/Mechanical Analysis of Primary Inlet & Outlet Nozzles," B&W Contract No. 620-0007-51, February, 1971, SI File: FPC-01Q-212.

APPENDICES

Flaw Size Acceptance Graphs

APPENDIX A

Flaw Acceptance Diagrams for Region A Materials

Region A includes:

- Closure Head Center Disc (Mk #24)
- Closure Head Flange

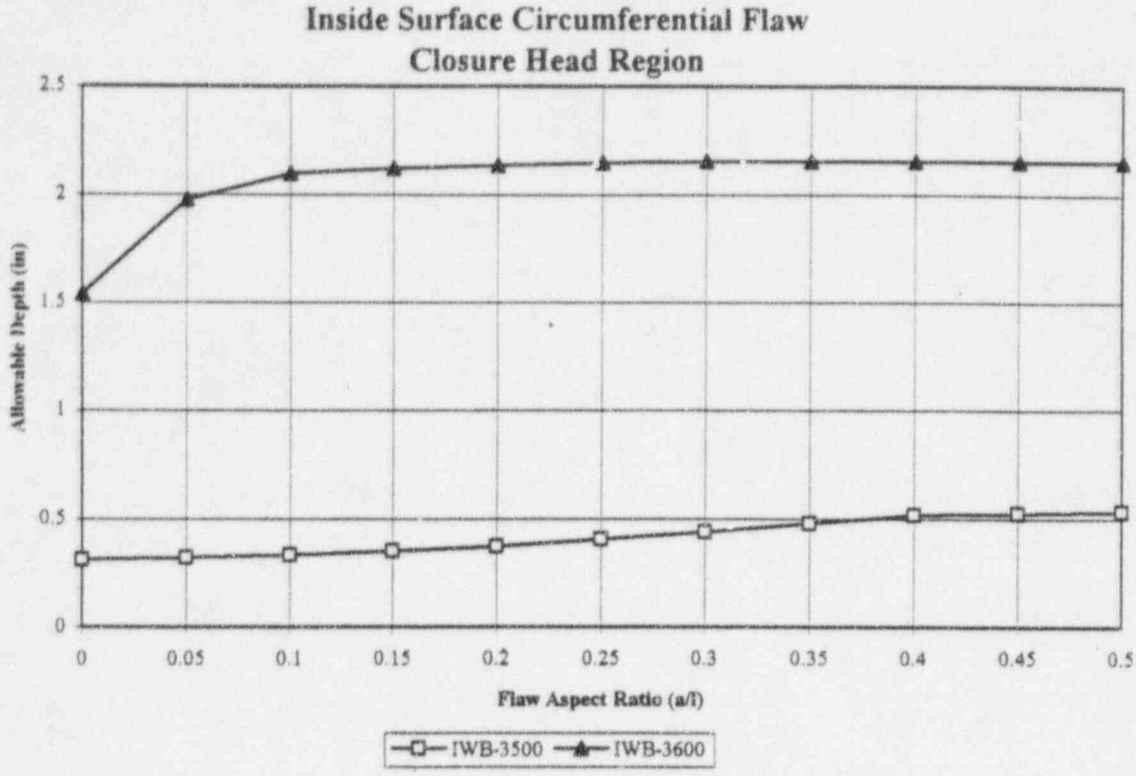
Based on Minimum Thickness = 6.625"

Default Maximum Allowable Flaw Sizes for All Charts:

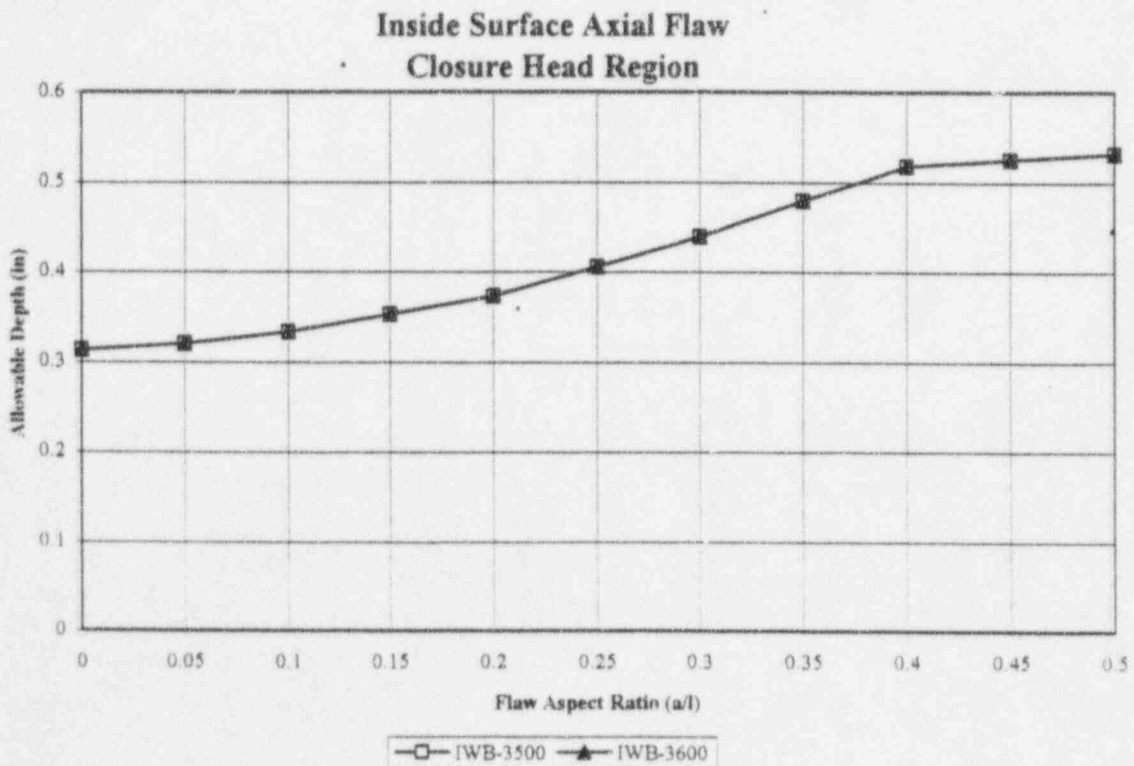
Axially-Oriented Flaws = 2.2"
Circumferentially-Oriented Flaws = 2.2"

General Notes:

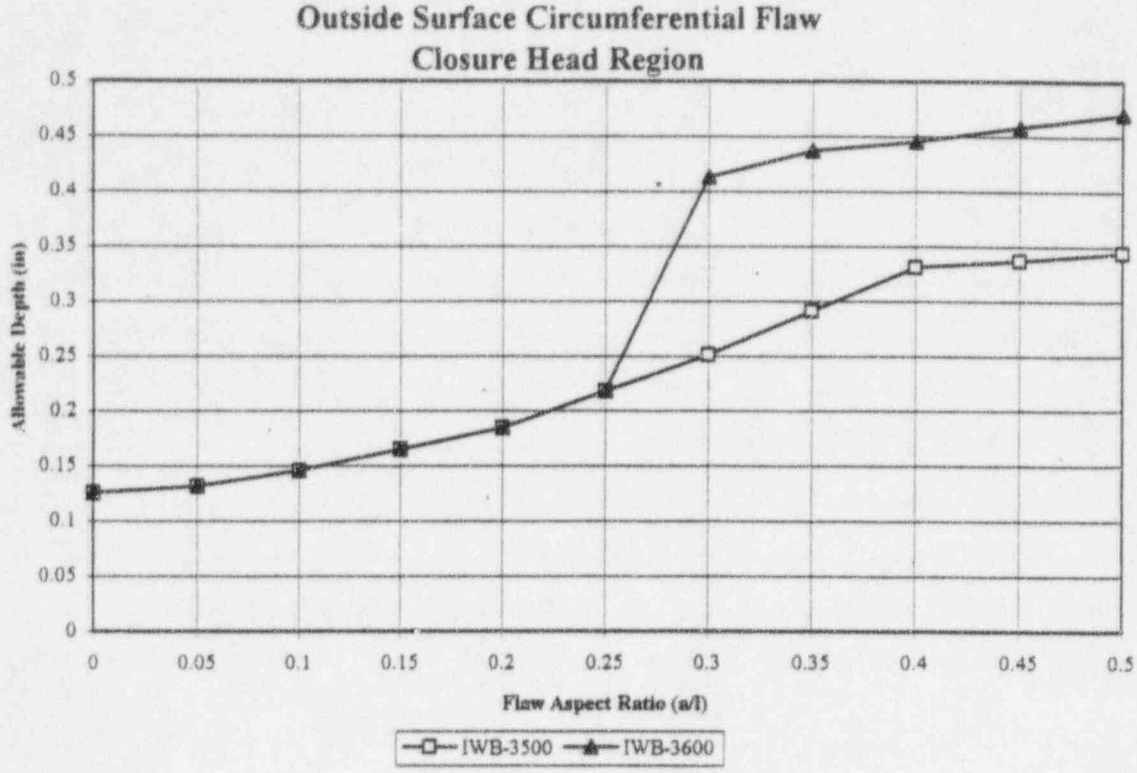
1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

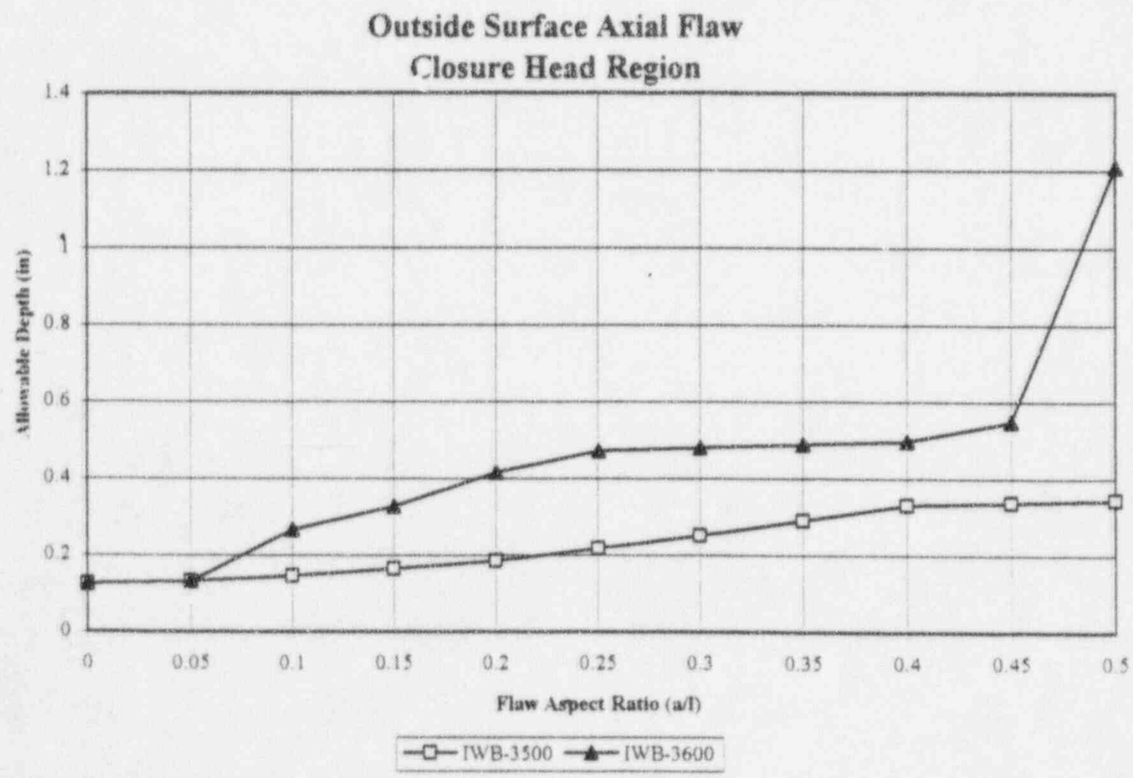


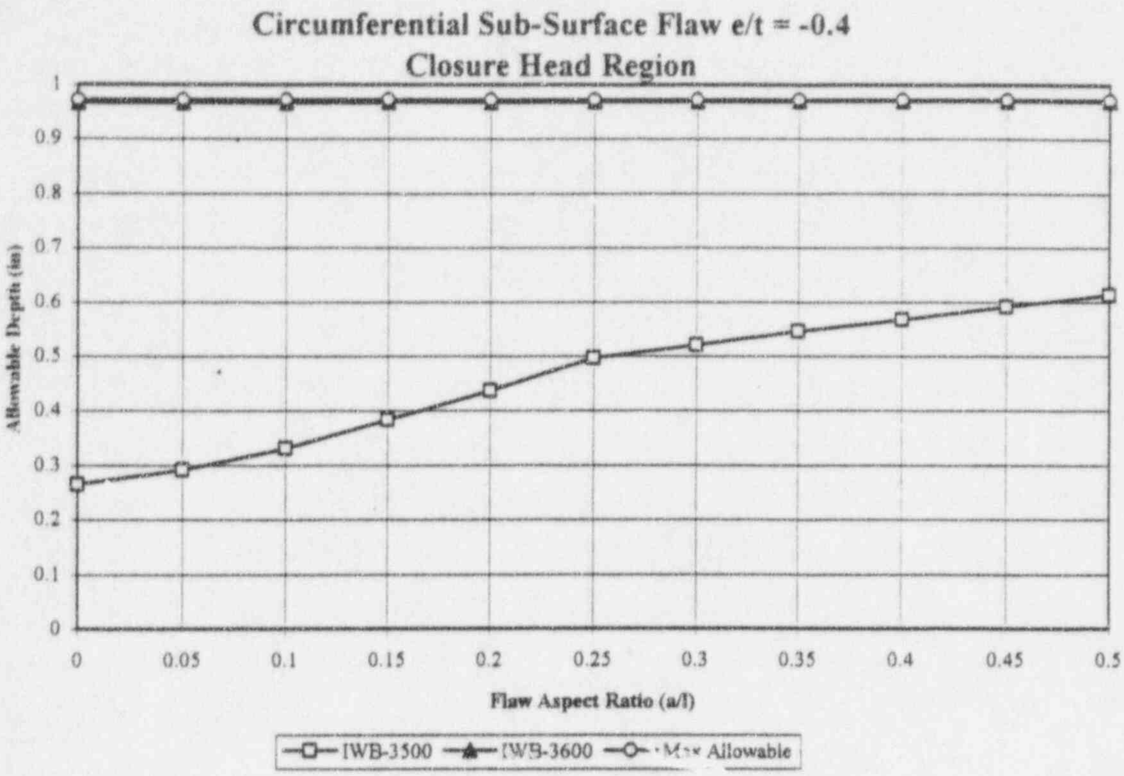
Inside Surface Circumferential Flaw
Closure Head Region
Allowable Depth (in)
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600



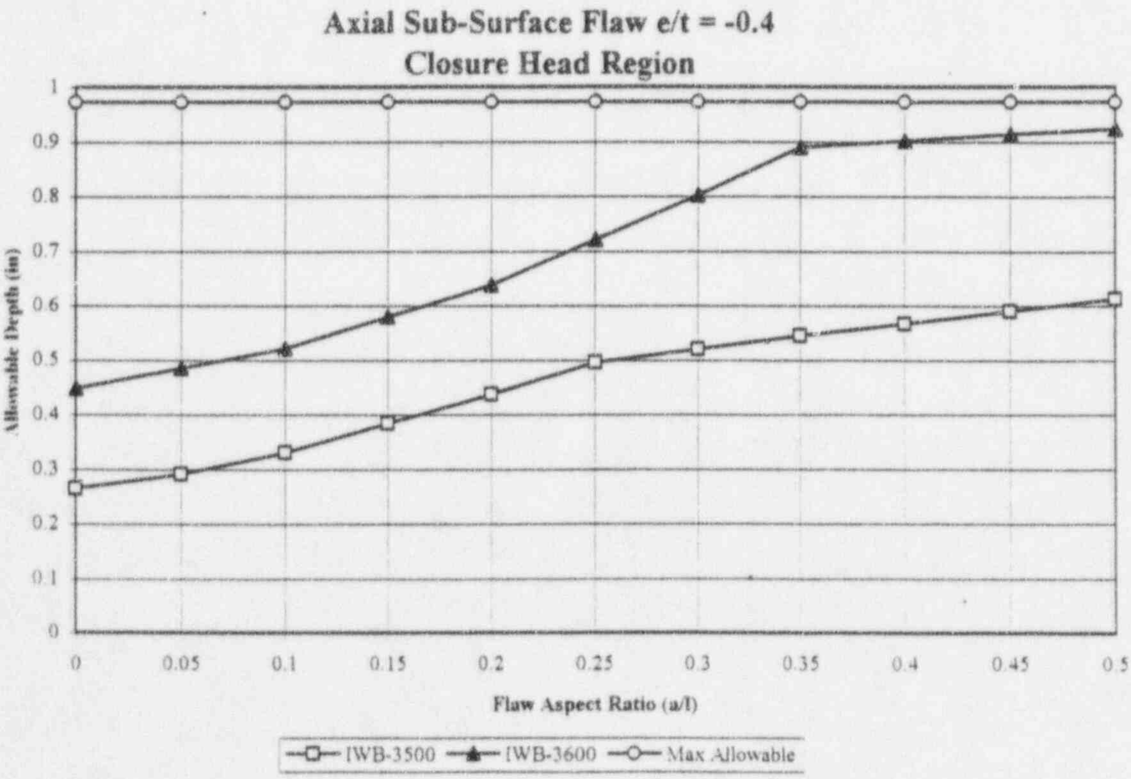
Inside Surface Axial Flaw
Closure Head Region
Allowable Depth (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600


Outside Surface Circumferential Flaw
Closure Head Region
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600


Outside Surface Axial Flaw
Closure Head Region
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

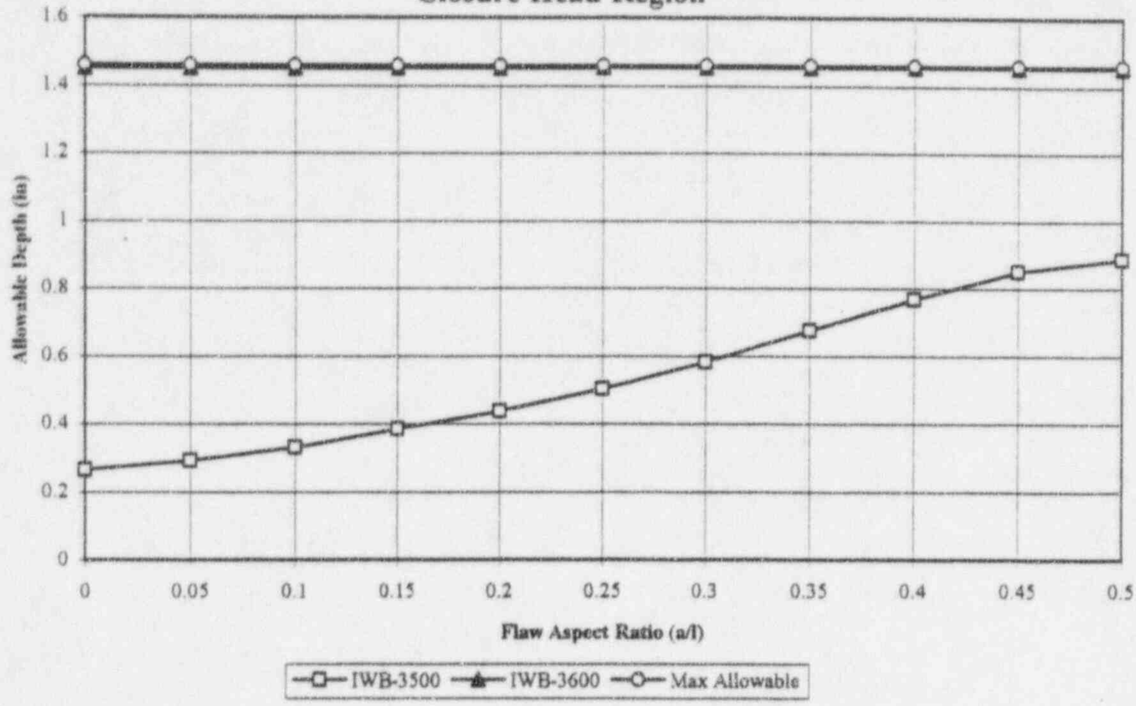


Circumferential Sub-Surface Flaw e/t = -0.4
Closure Head Region
Allowable Depth (in)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

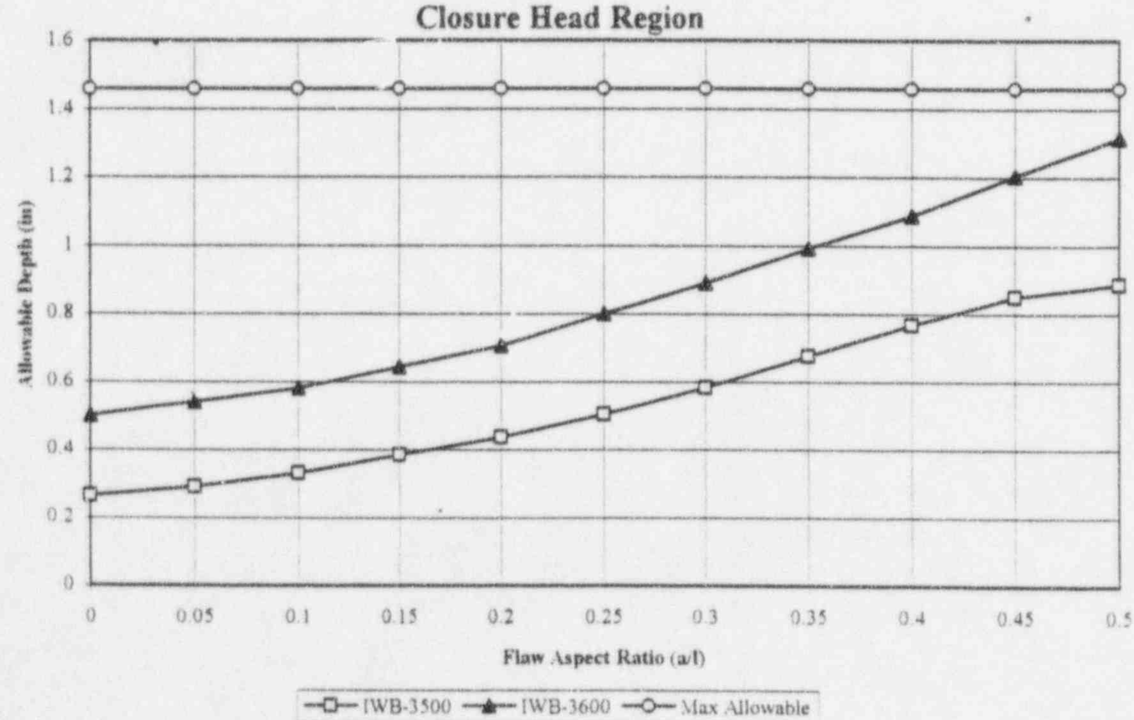


Axial Sub-Surface Flaw e/t = -0.4
Closure Head Region
Allowable Depth (in)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

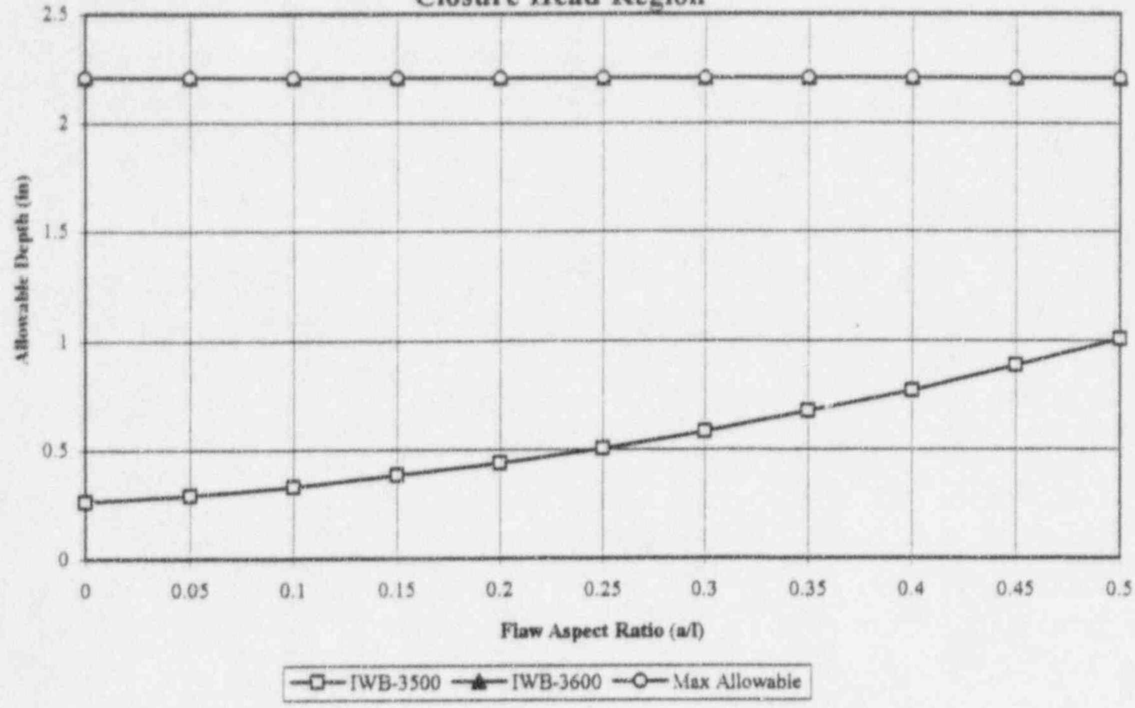
Circumferential Sub-Surface Flaw e/t = -0.35
Closure Head Region



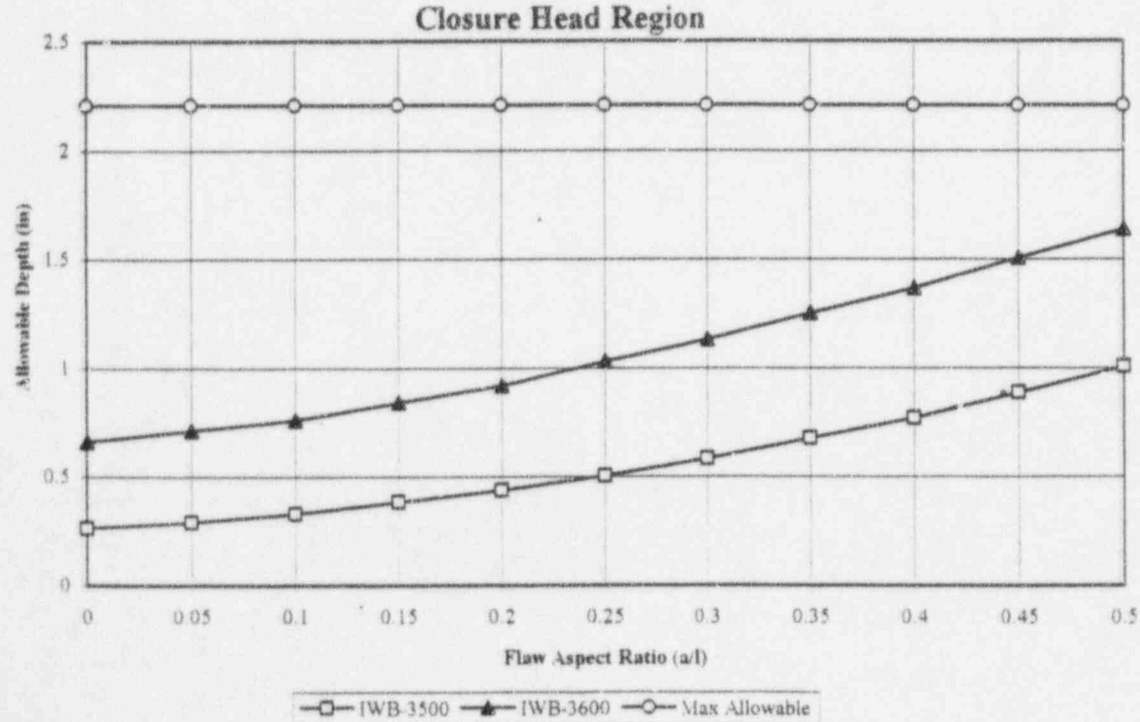
Axial Sub-Surface Flaw e/t = -0.35
Closure Head Region



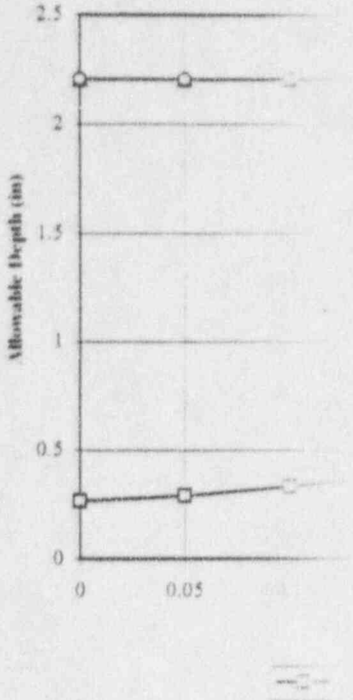
Circumferential Sub-Surface Flaw e/t = -0.25
Closure Head Region



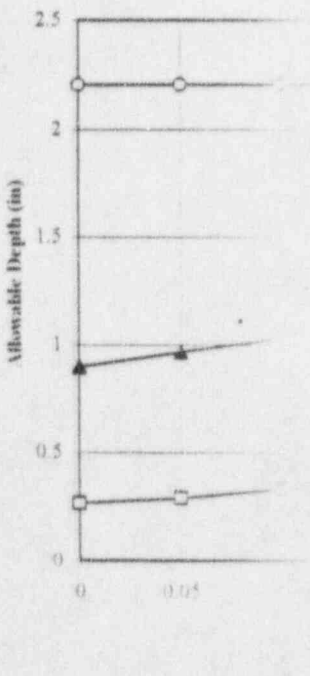
Axial Sub-Surface Flaw e/t = -0.25
Closure Head Region



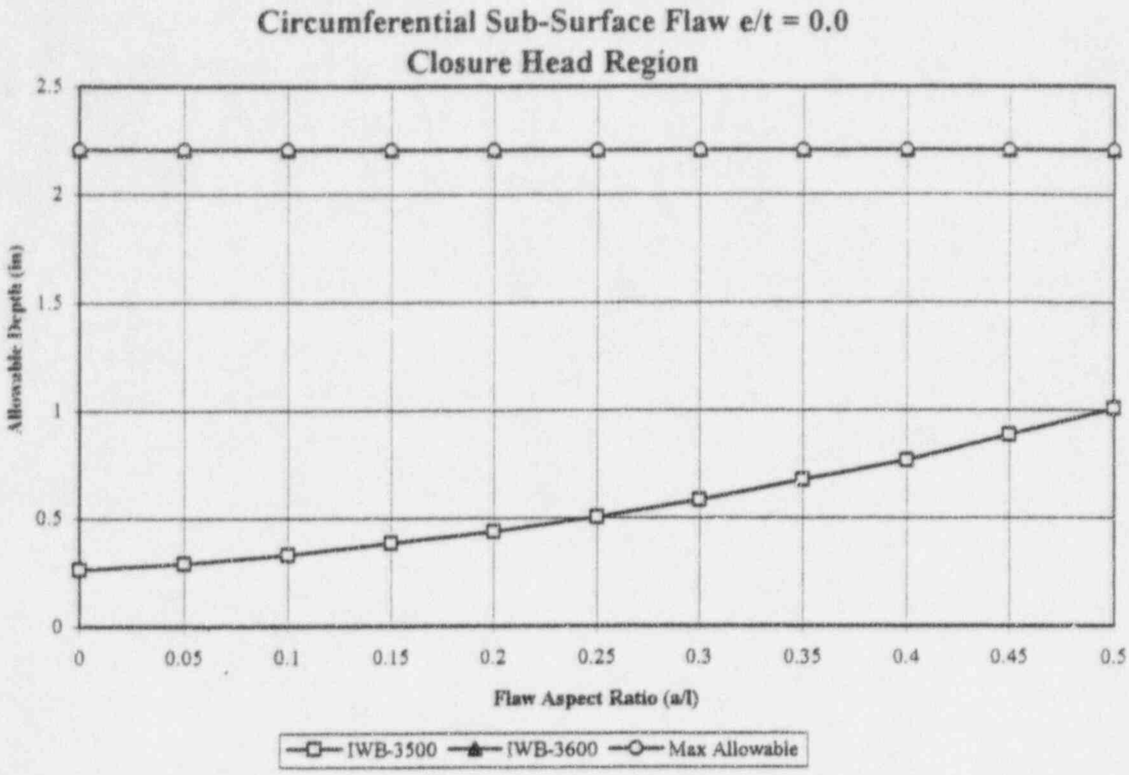
Cl

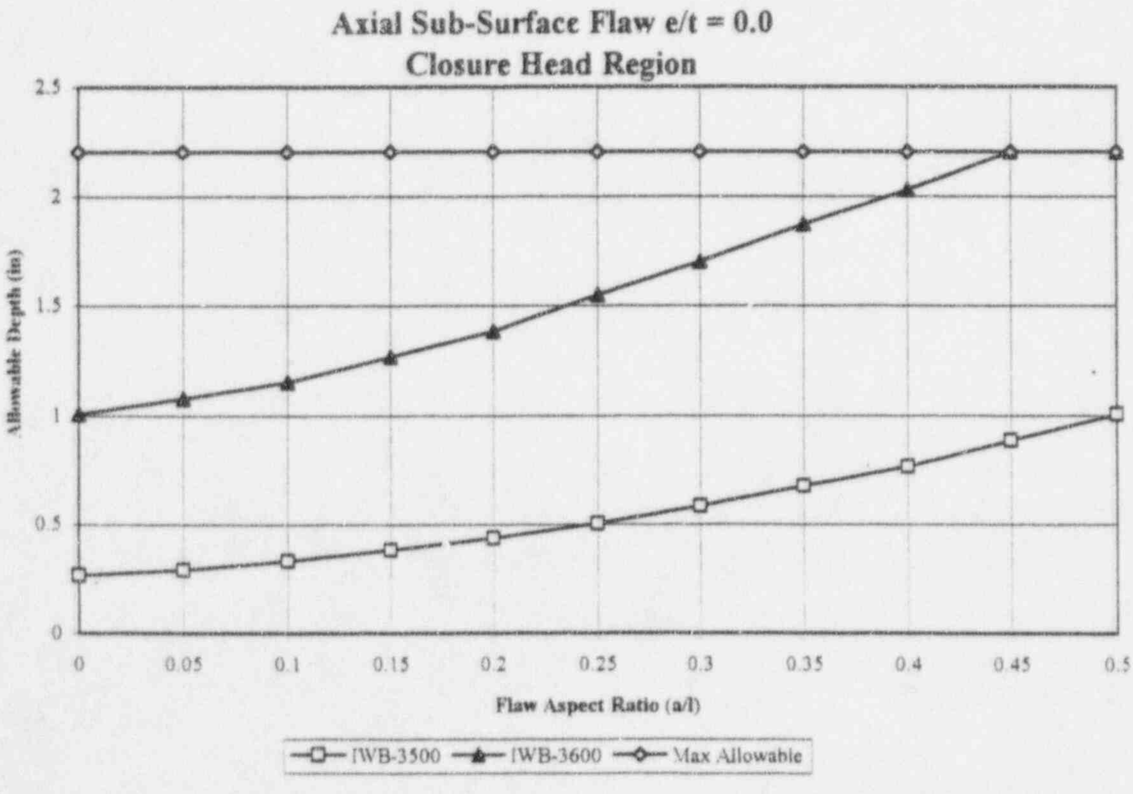


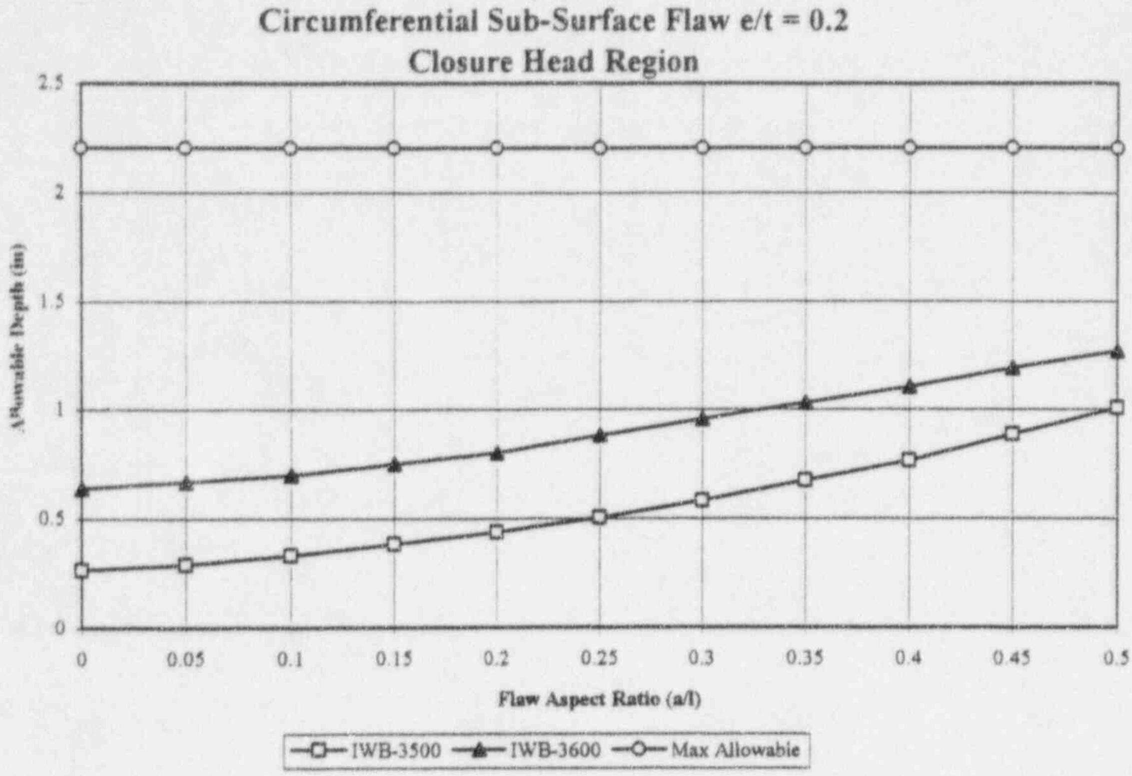
2.5
2
1.5
1
0.5
0
Allowable Depth (in)
0
0.05

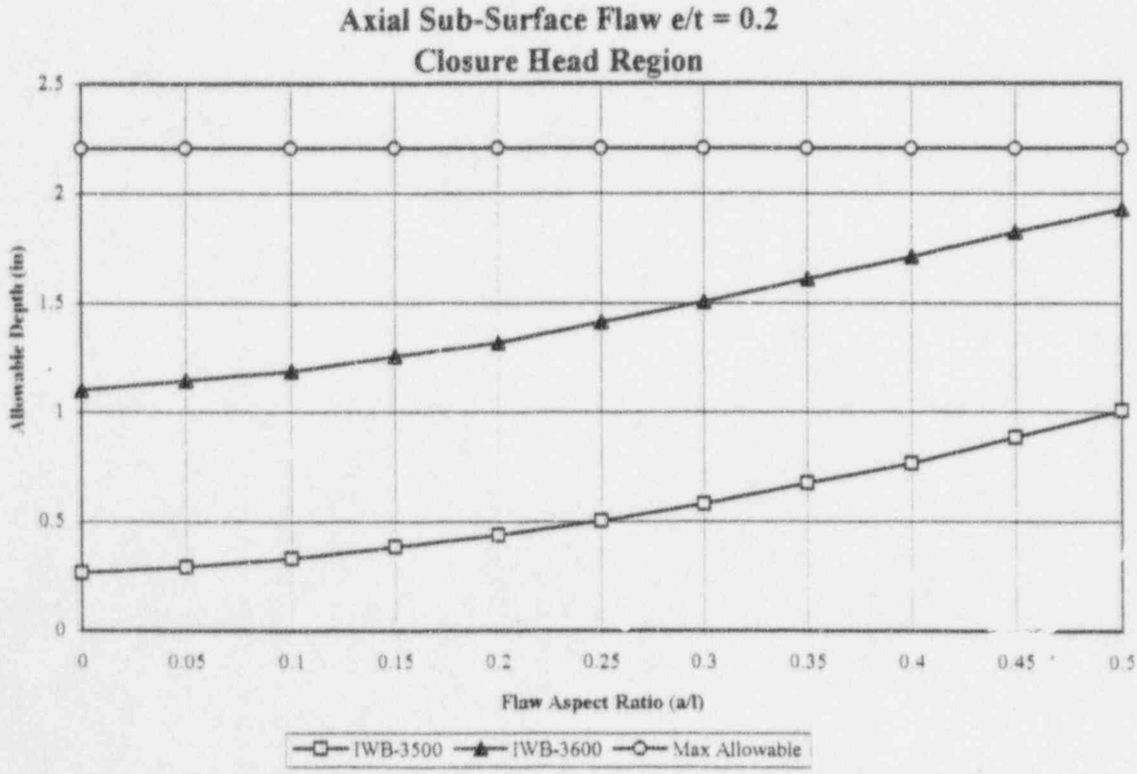


2.5
2
1.5
1
0.5
0
Allowable Depth (in)
0
0.05

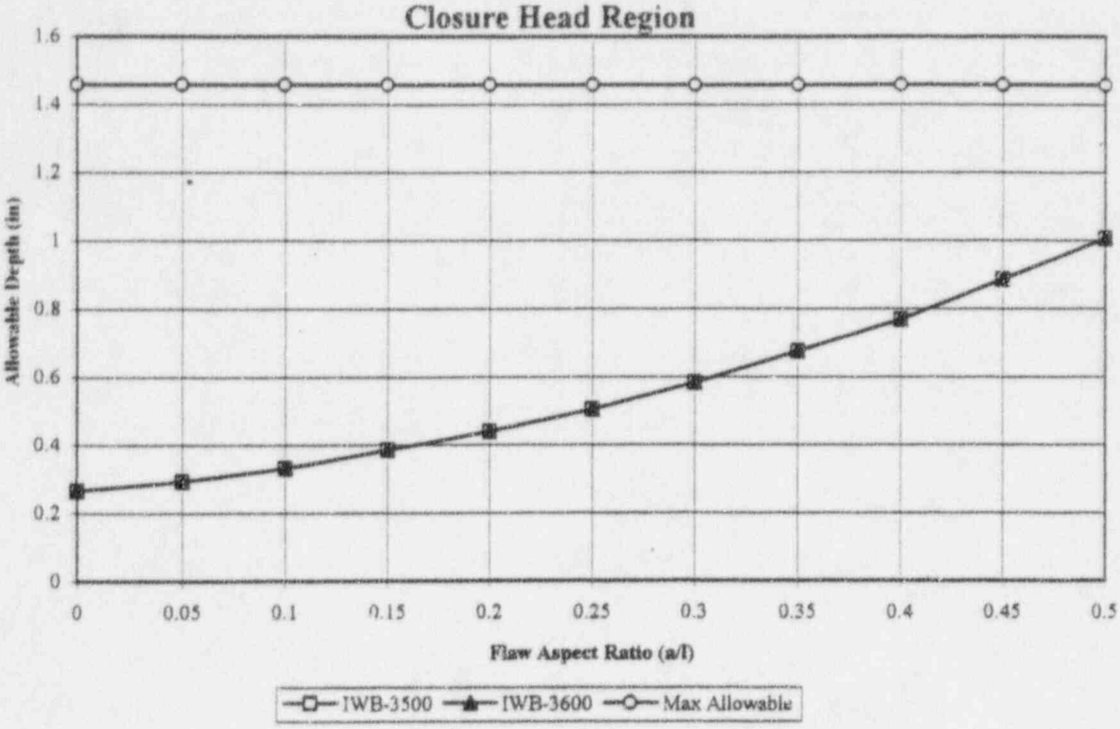

Circumferential Sub-Surface Flaw e/t = 0.0
Closure Head Region
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.0
Closure Head Region
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
IWB-3500
IWB-3600
Max Allowable

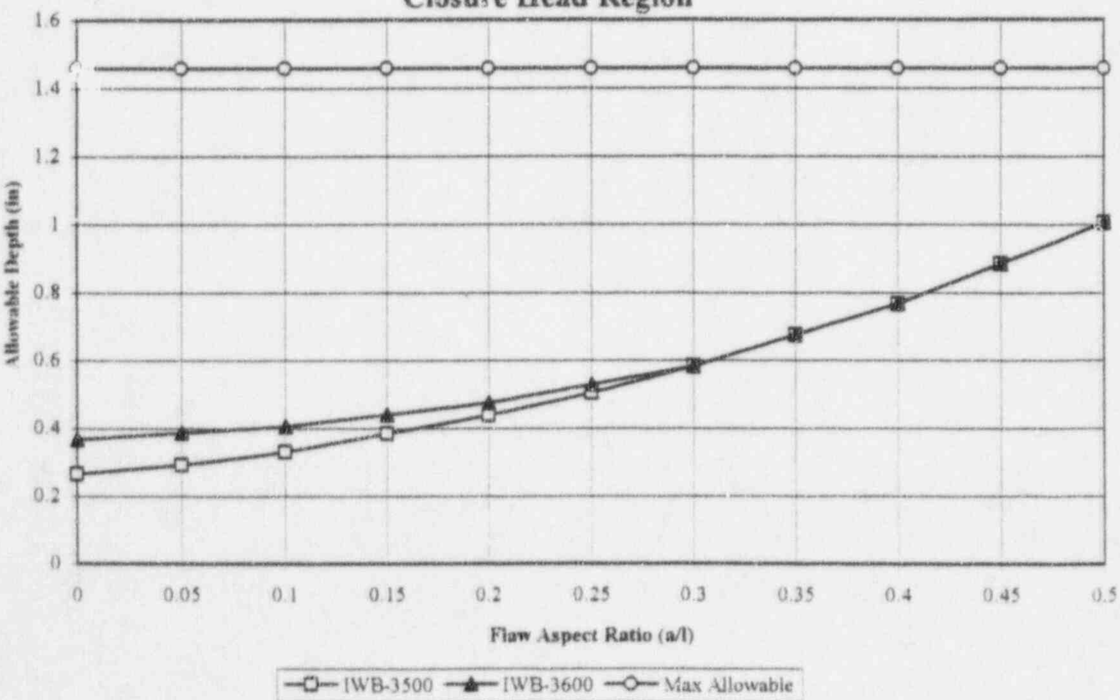

Circumferential Sub-Surface Flaw e/t = 0.2
Closure Head Region
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

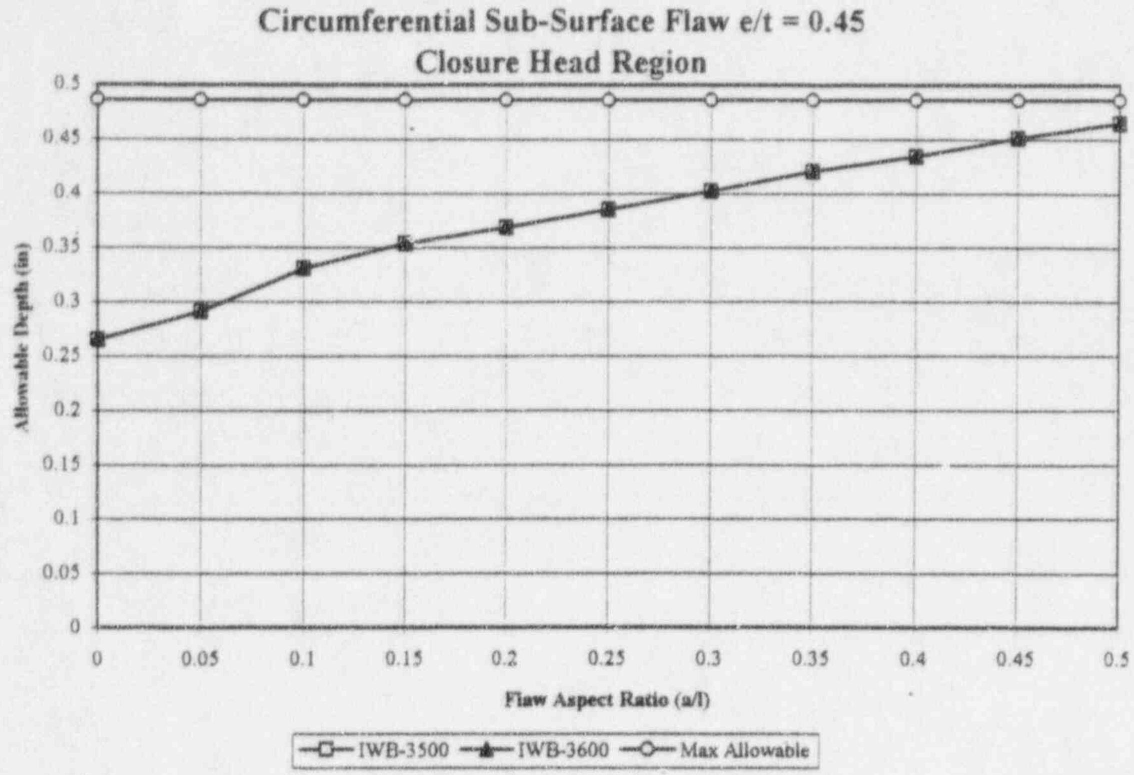

Axial Sub-Surface Flaw e/t = 0.2
Closure Head Region
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

Circumferential Sub-Surface Flaw e/t = 0.35
Closure Head Region

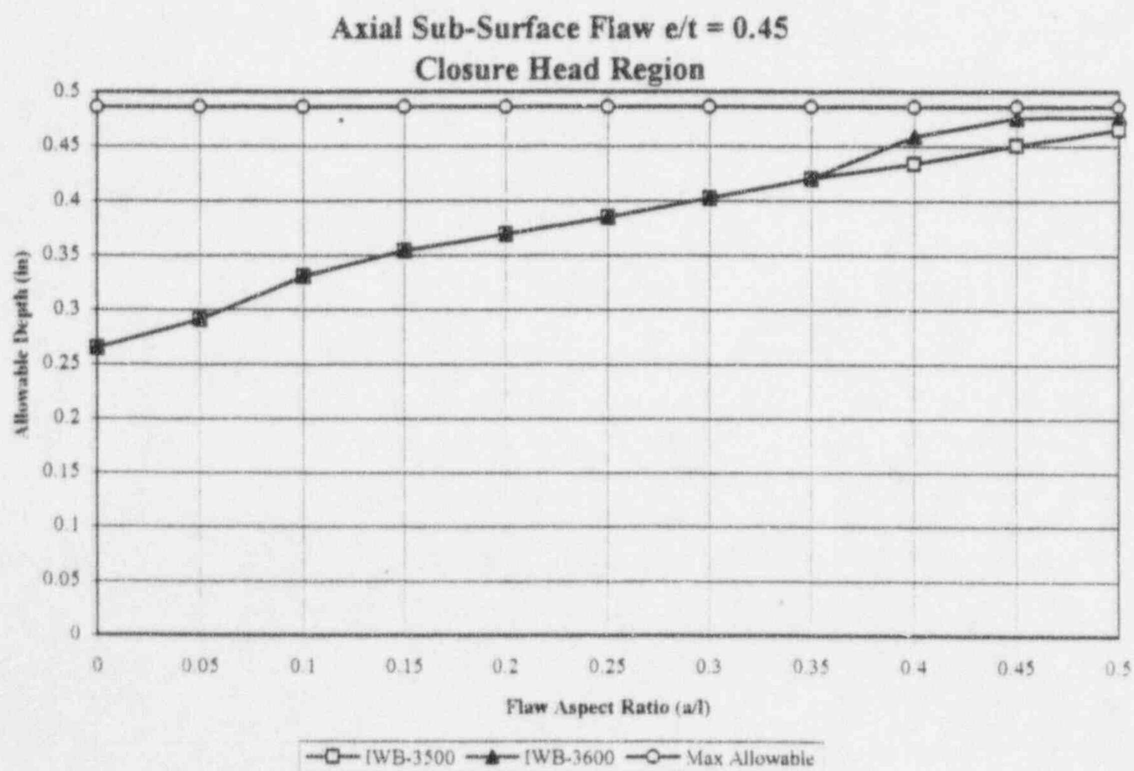


Axial Sub-Surface Flaw e/t = 0.35
Closure Head Region





Circumferential Sub-Surface Flaw e/t = 0.45
Closure Head Region
Allowable Depth (in)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable



Axial Sub-Surface Flaw e/t = 0.45
Closure Head Region
Allowable Depth (in)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

APPENDIX B

Flaw Acceptance Diagrams for Region B Materials

Region B includes:

- Upper Head to Closure Flange Weld

Based on Minimum Thickness = 6.625"

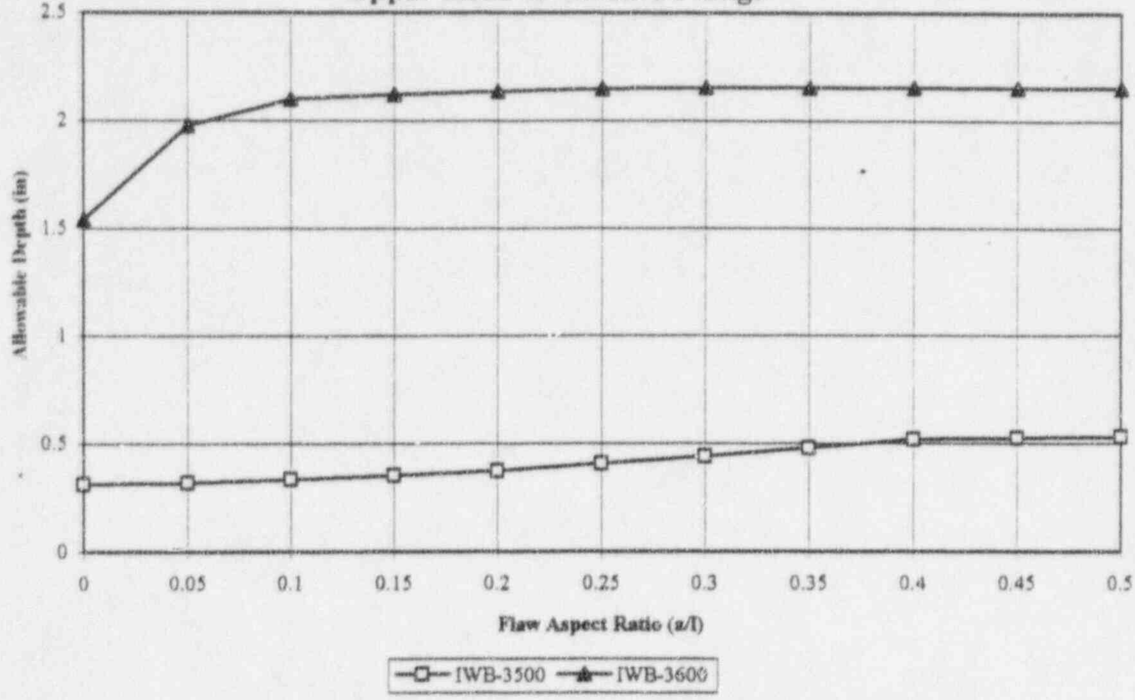
Default Maximum Allowable Flaw Sizes for All Charts:

Axially-Oriented Flaws = 2.2"
Circumferentially-Oriented Flaws = 2.2"

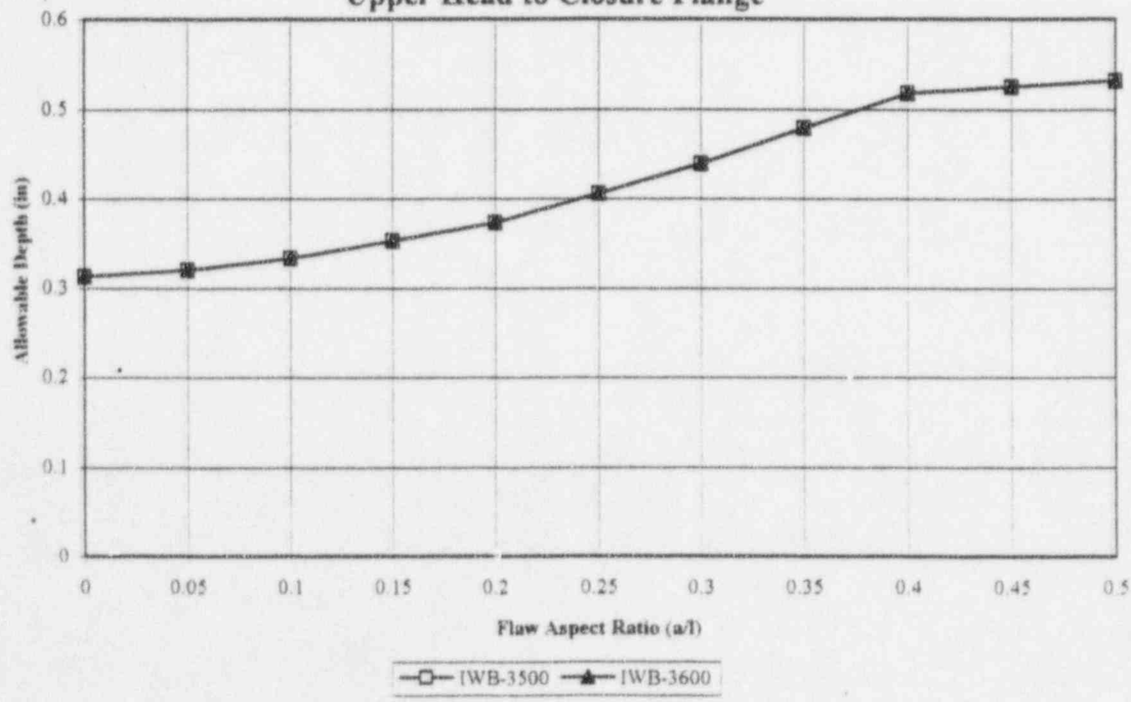
General Notes:

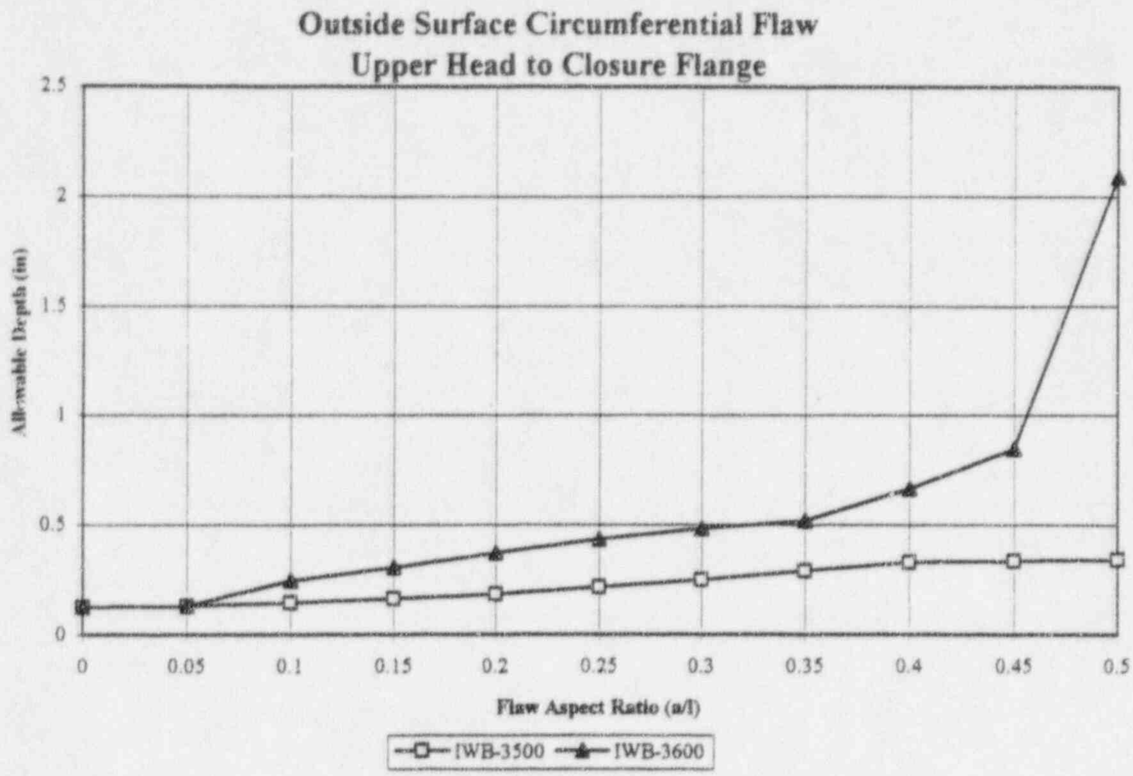
1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

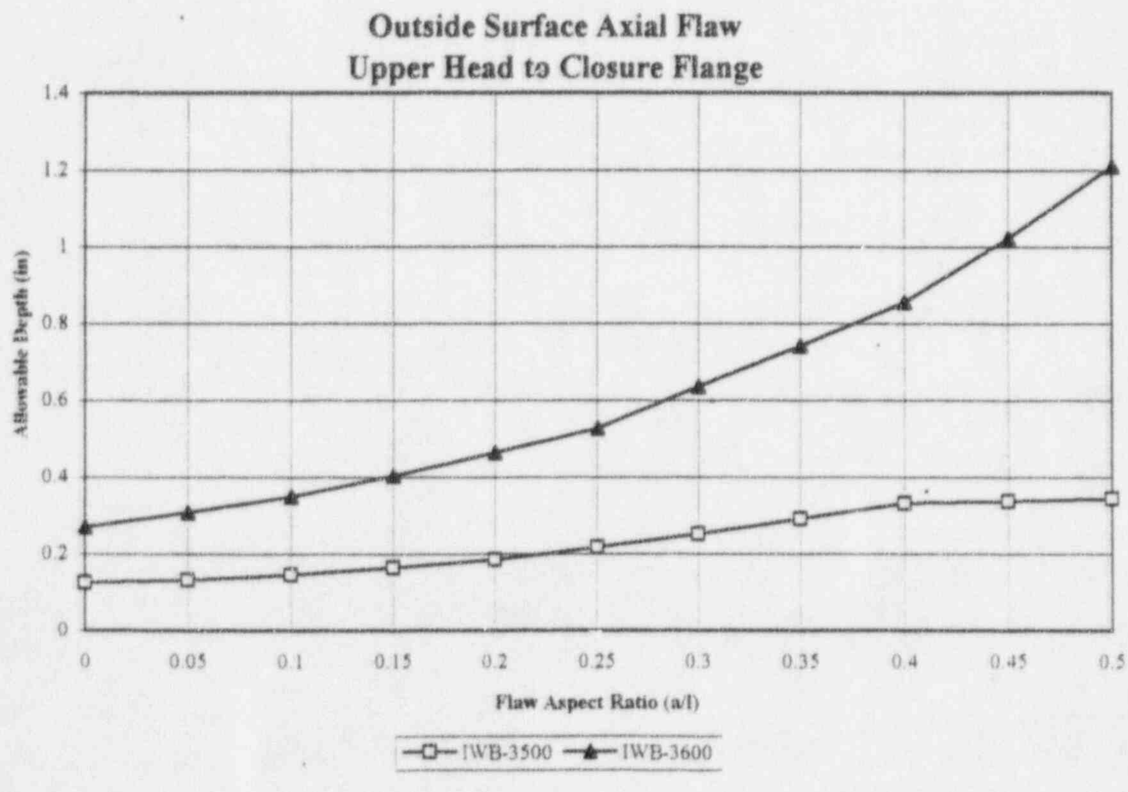
Inside Surface Circumferential Flaw
Upper Head to Closure Flange



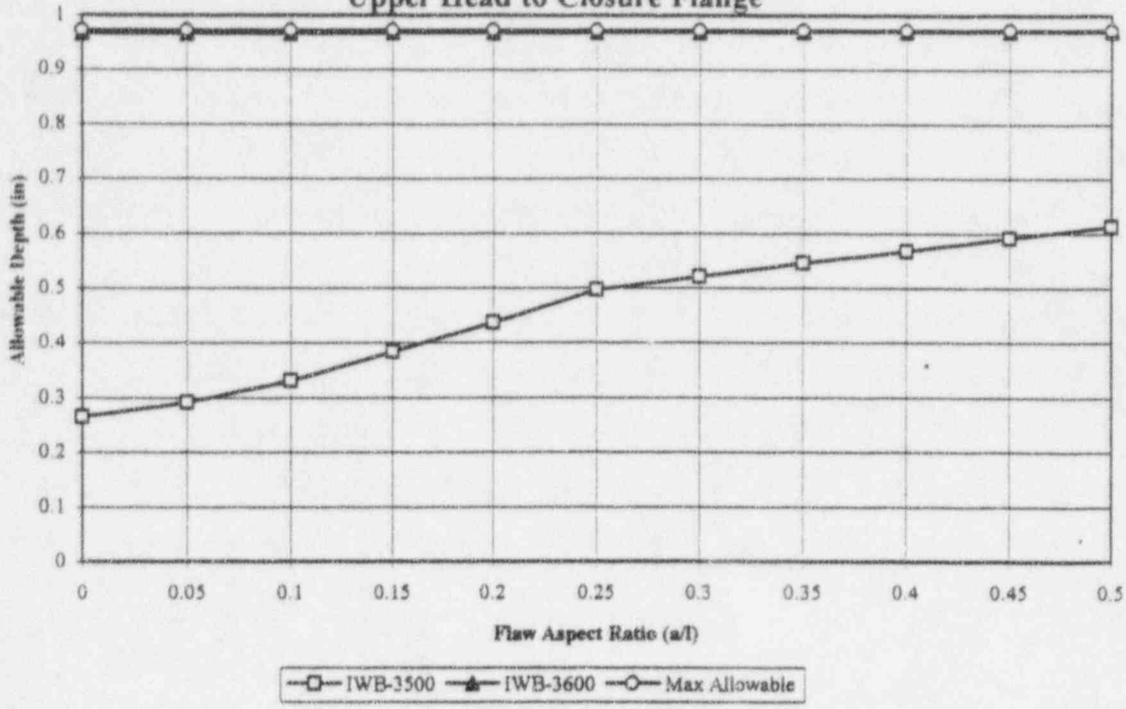
Inside Surface Axial Flaw
Upper Head to Closure Flange



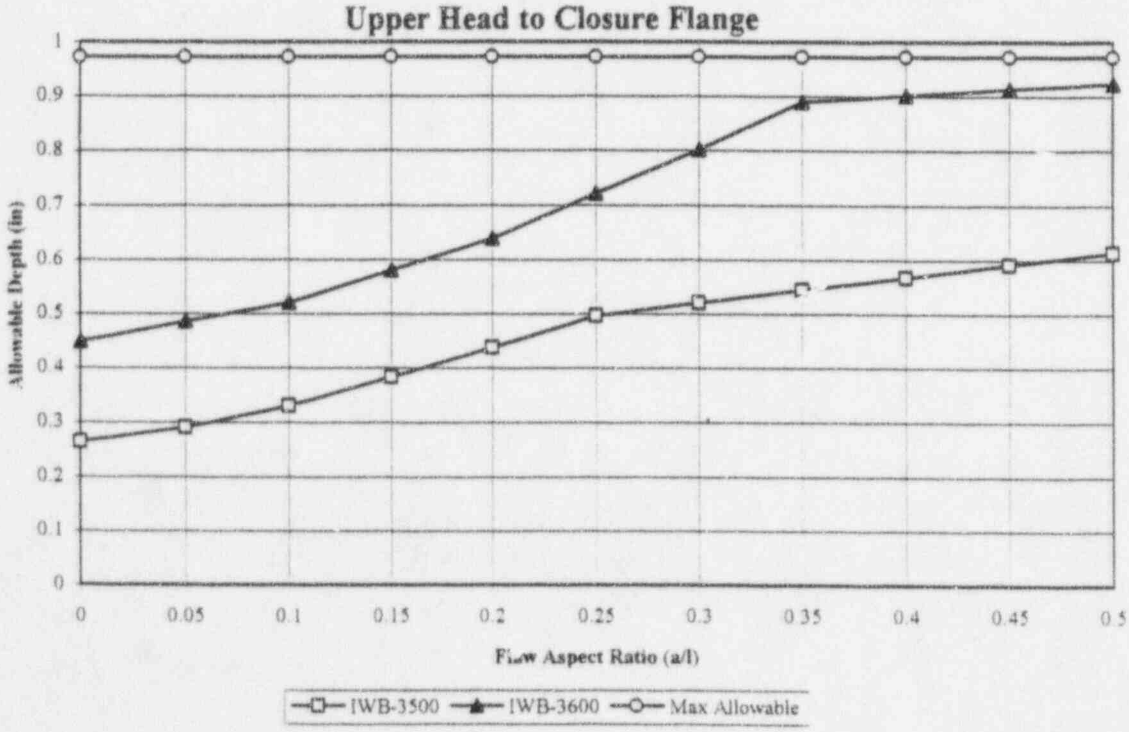

Outside Surface Circumferential Flaw
Upper Head to Closure Flange
2.5
2
1.5
1
0.5
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600


Outside Surface Axial Flaw
Upper Head to Closure Flange
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

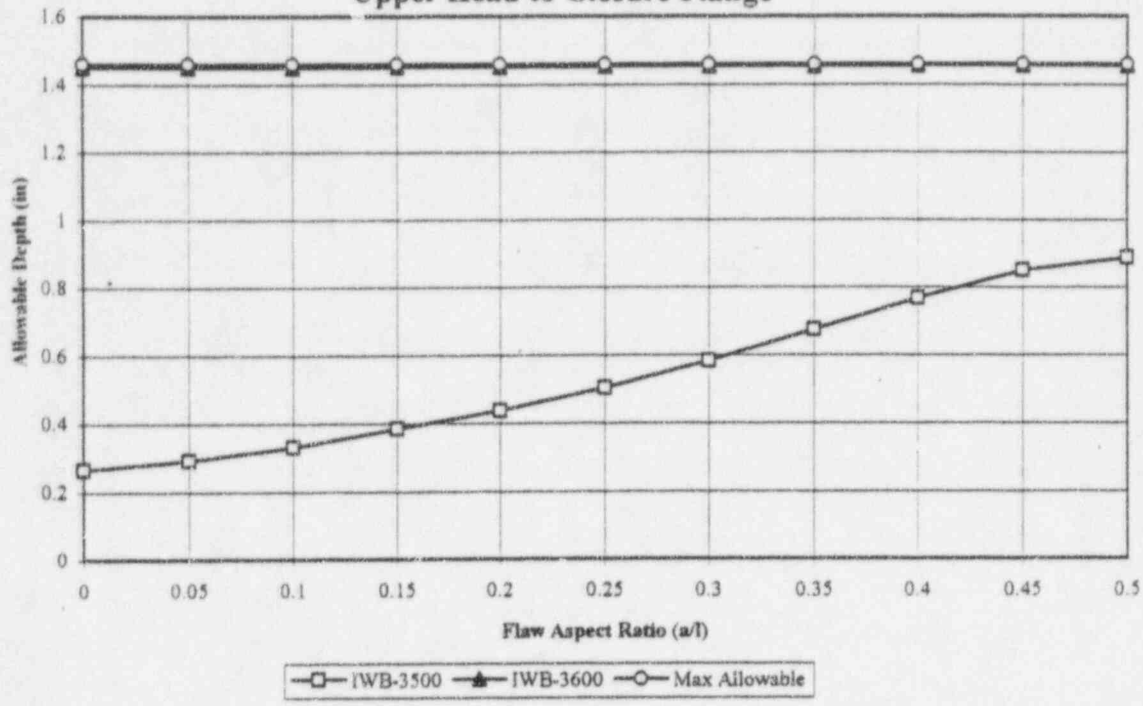
Circumferential Sub-Surface Flaw e/t = -0.4
Upper Head to Closure Flange



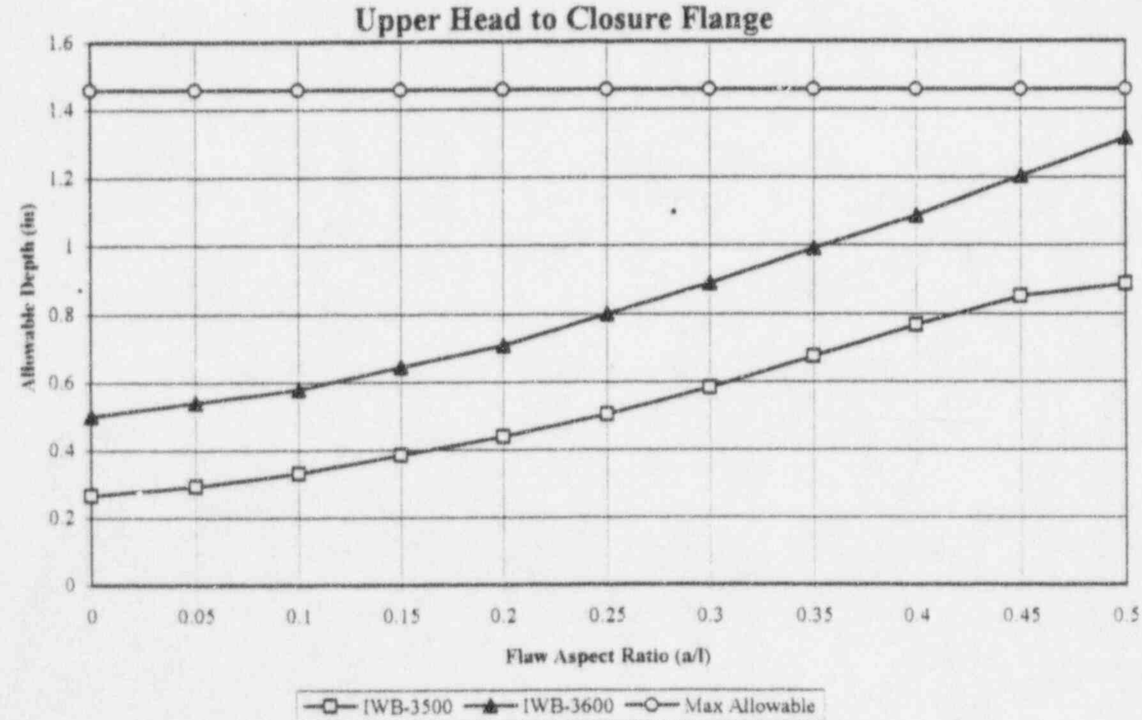
Axial Sub-Surface Flaw e/t = -0.4
Upper Head to Closure Flange



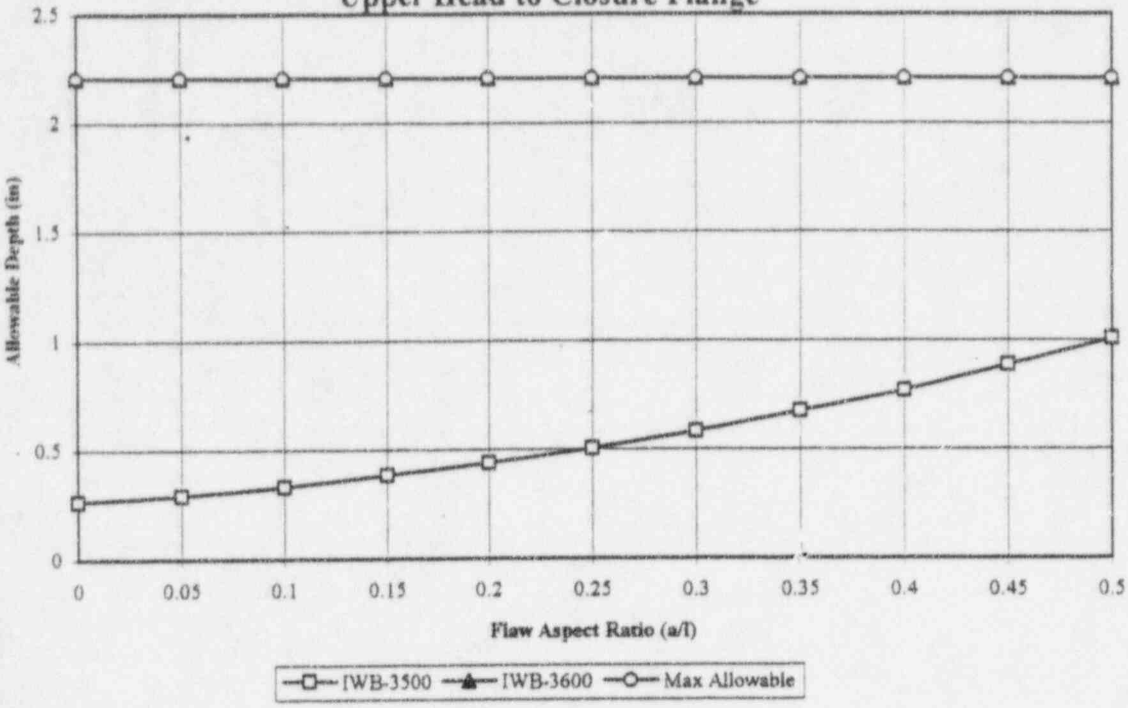
Circumferential Sub-Surface Flaw e/t = -0.35
Upper Head to Closure Flange



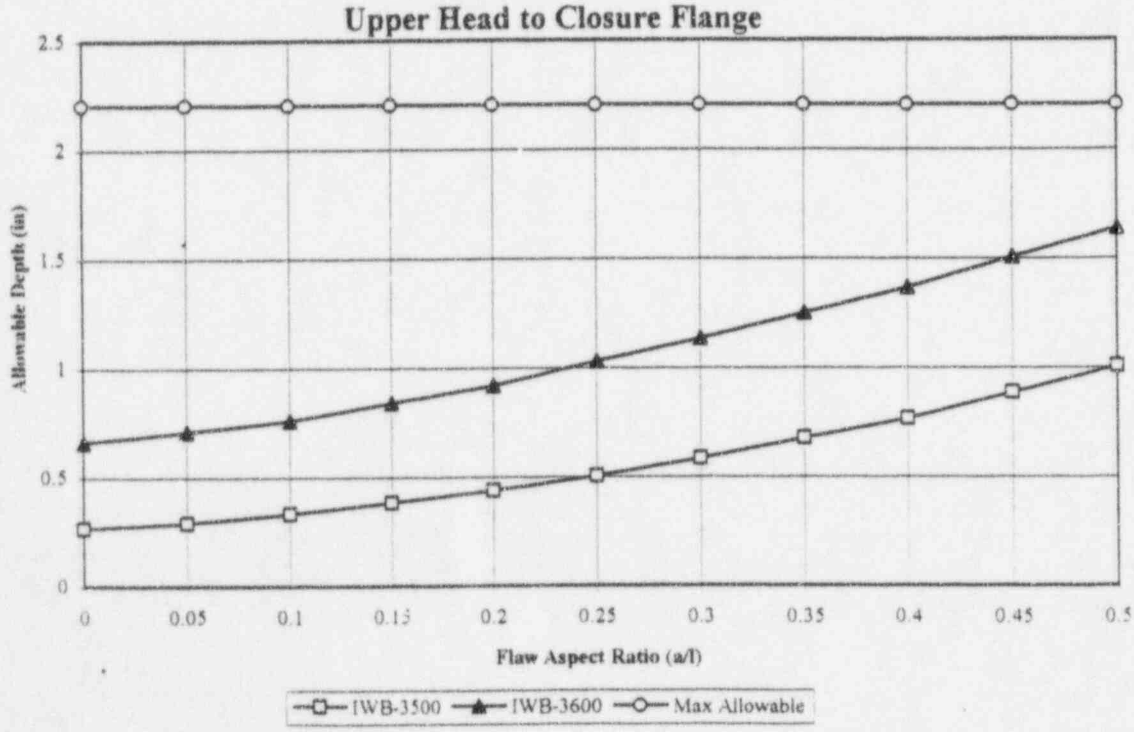
Axial Sub-Surface Flaw e/t = -0.35
Upper Head to Closure Flange



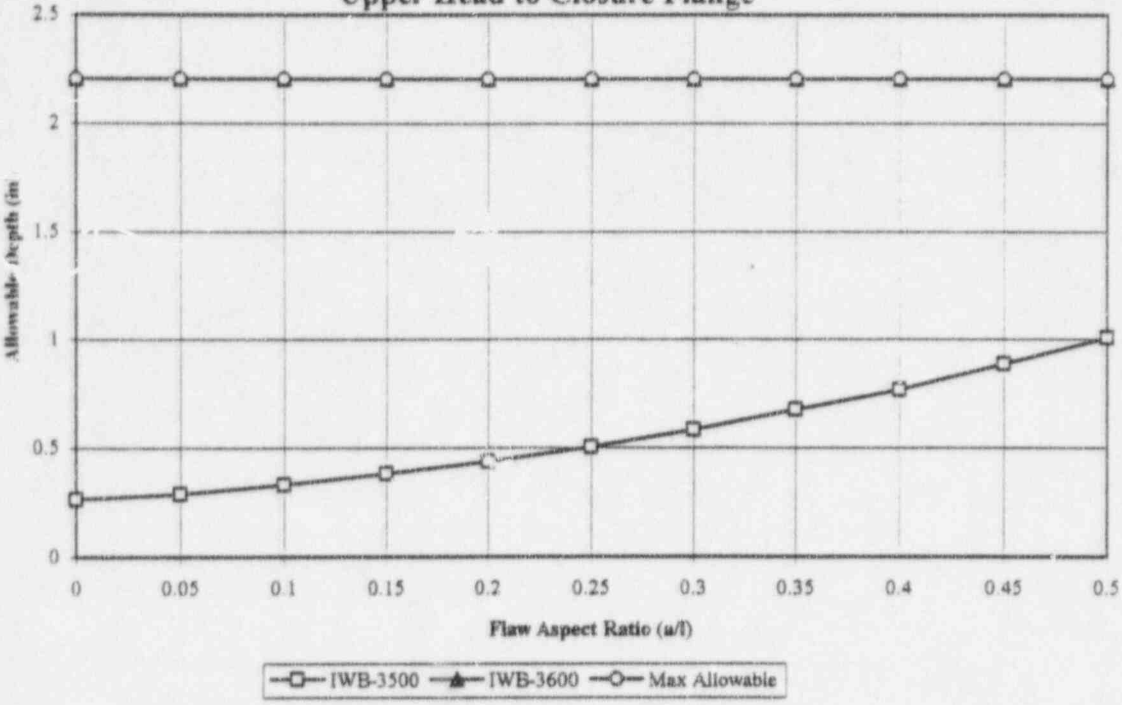
Circumferential Sub-Surface Flaw e/t = -0.25
Upper Head to Closure Flange



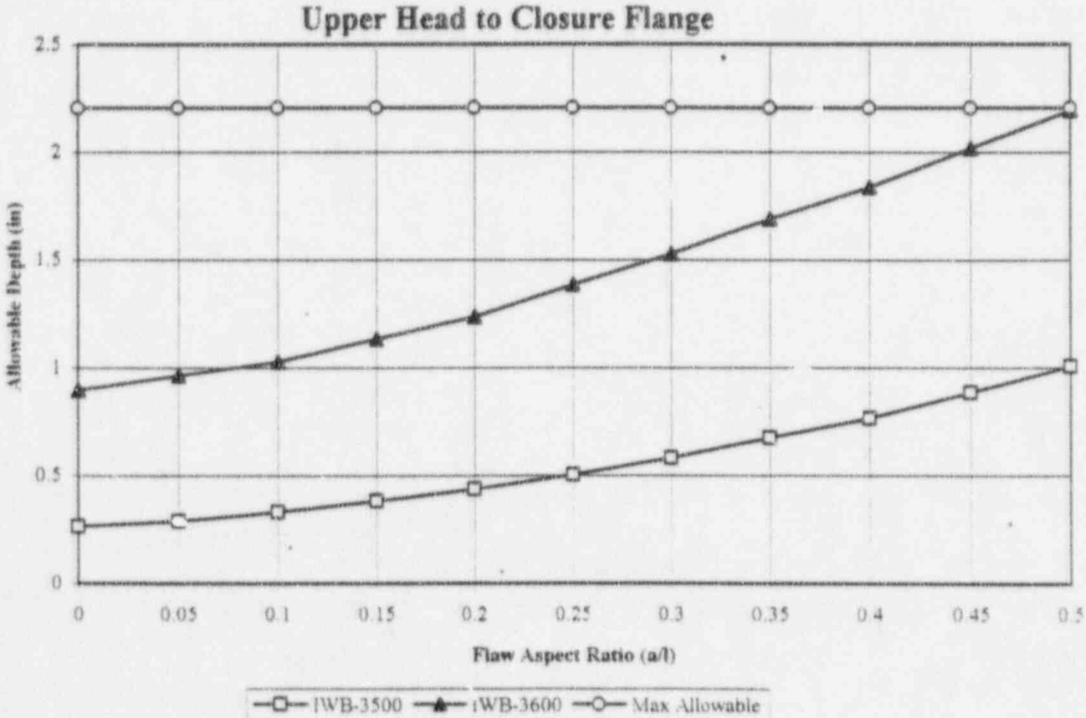
Axial Sub-Surface Flaw e/t = -0.25
Upper Head to Closure Flange



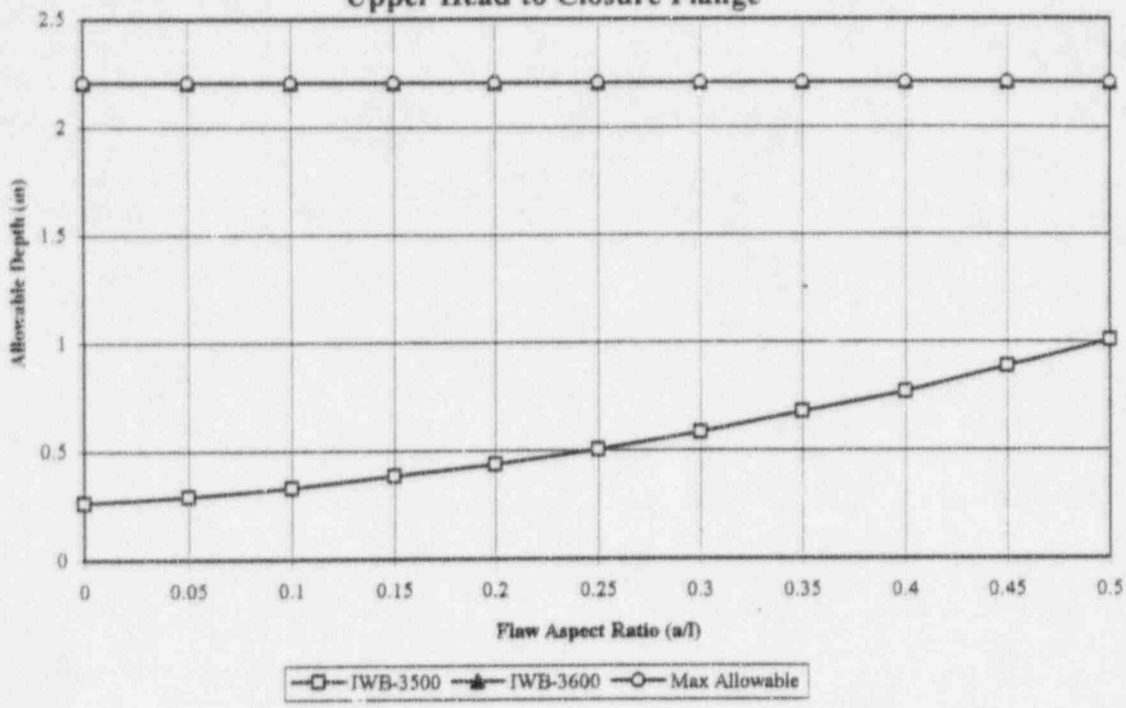
Circumferential Sub-Surface Flaw e/t = -0.1
Upper Head to Closure Flange



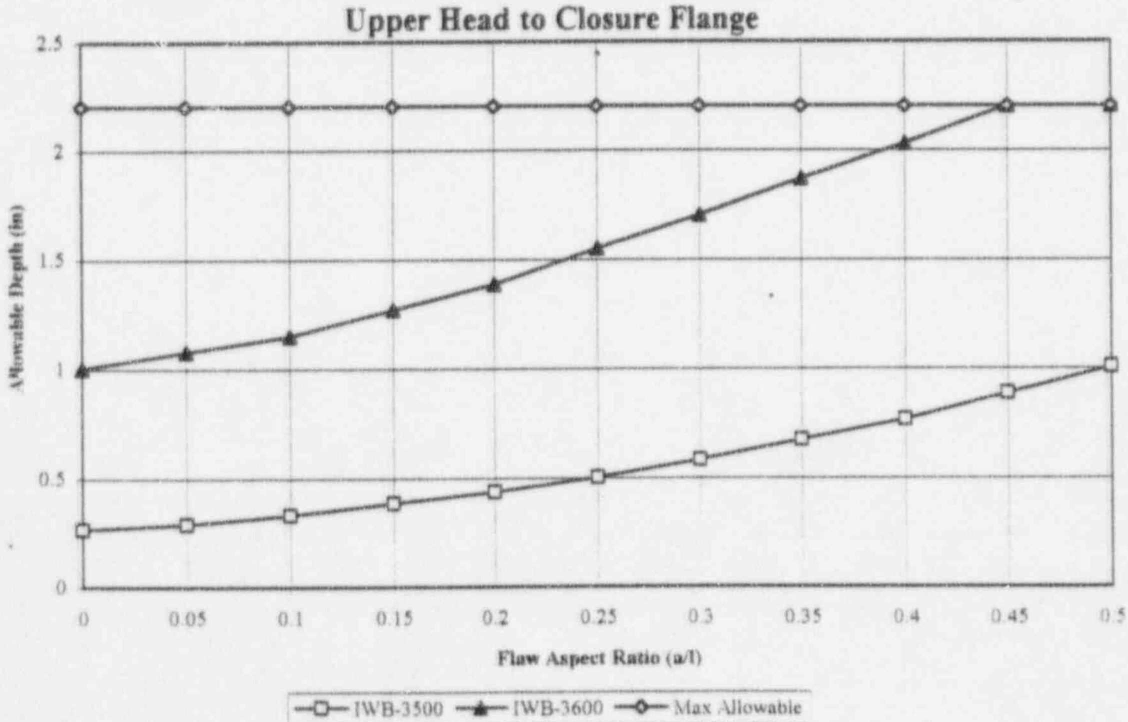
Axial Sub-Surface Flaw e/t = -0.1
Upper Head to Closure Flange



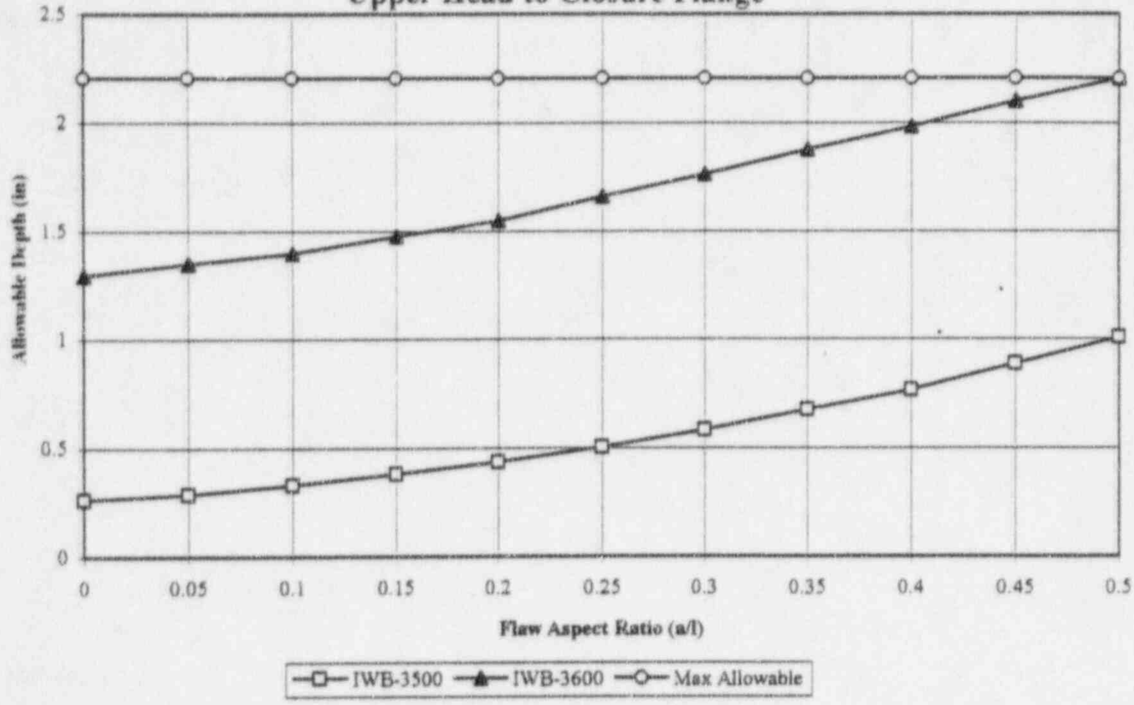
Circumferential Sub-Surface Flaw e/t = 0.0
Upper Head to Closure Flange



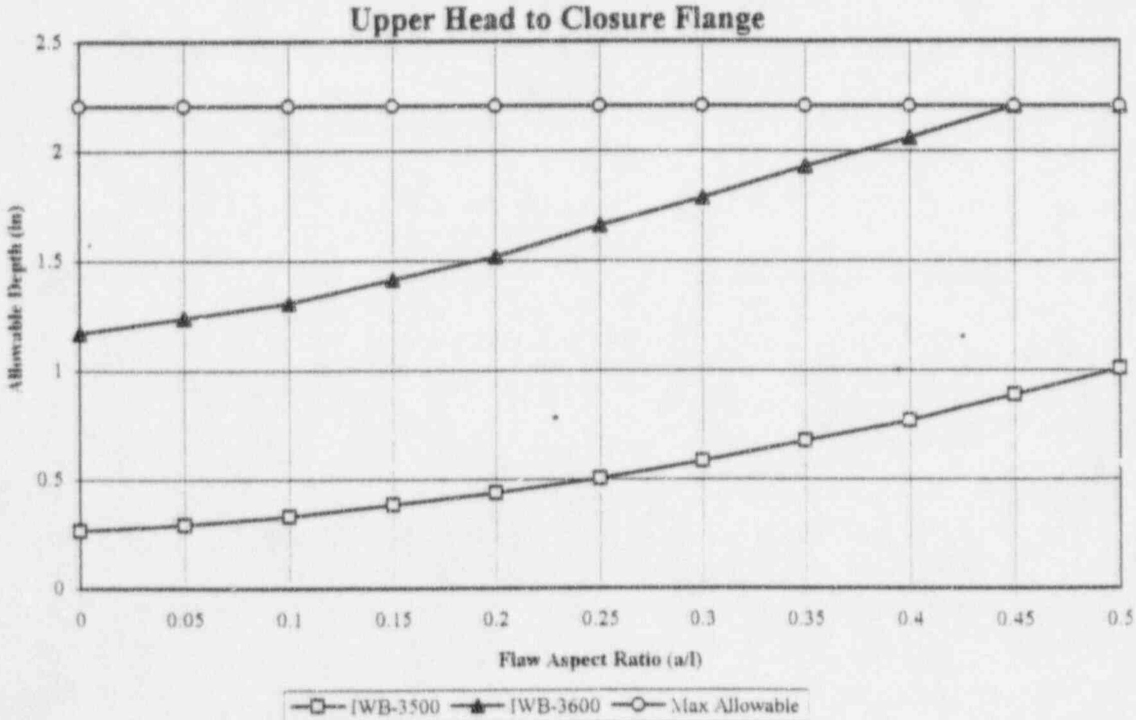
Axial Sub-Surface Flaw e/t = 0.0
Upper Head to Closure Flange



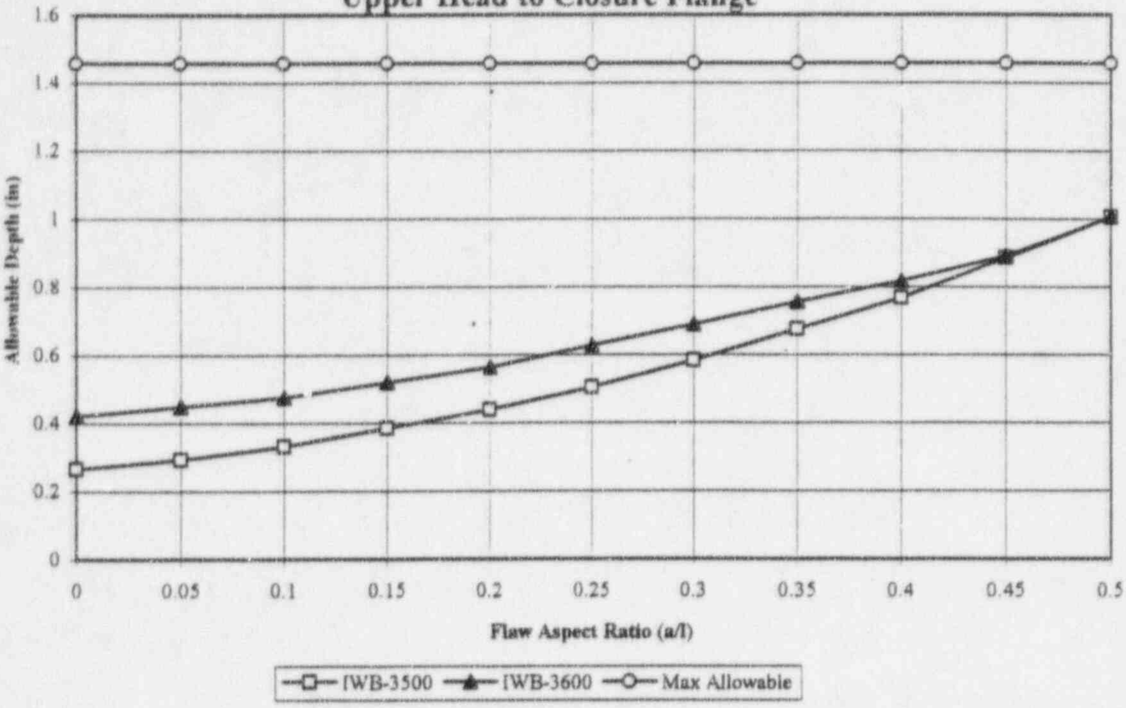
Circumferential Sub-Surface Flaw e/t = 0.2
Upper Head to Closure Flange



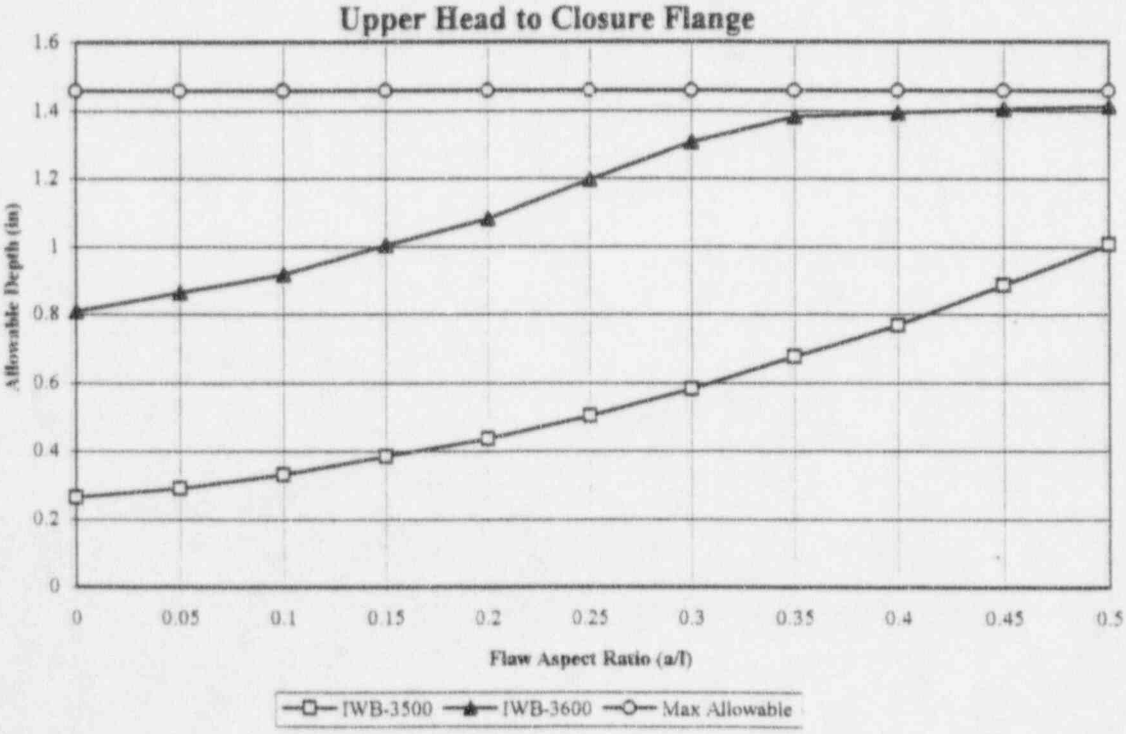
Axial Sub-Surface Flaw e/t = 0.2
Upper Head to Closure Flange



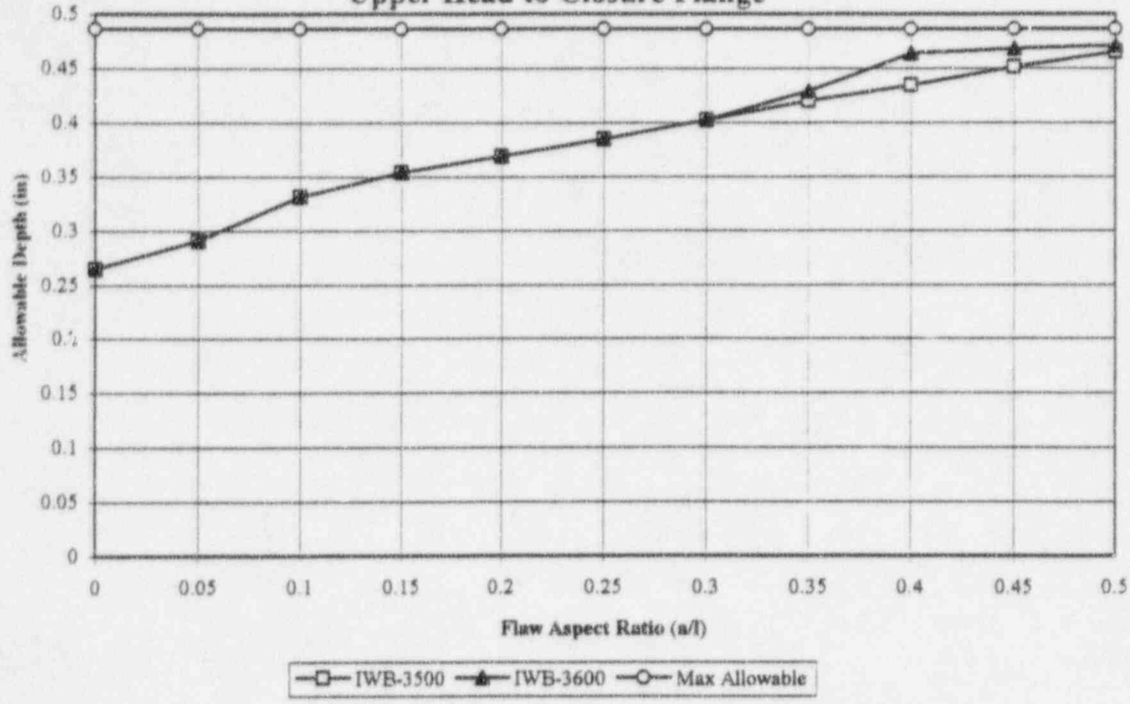
Circumferential Sub-Surface Flaw e/t = 0.35
Upper Head to Closure Flange



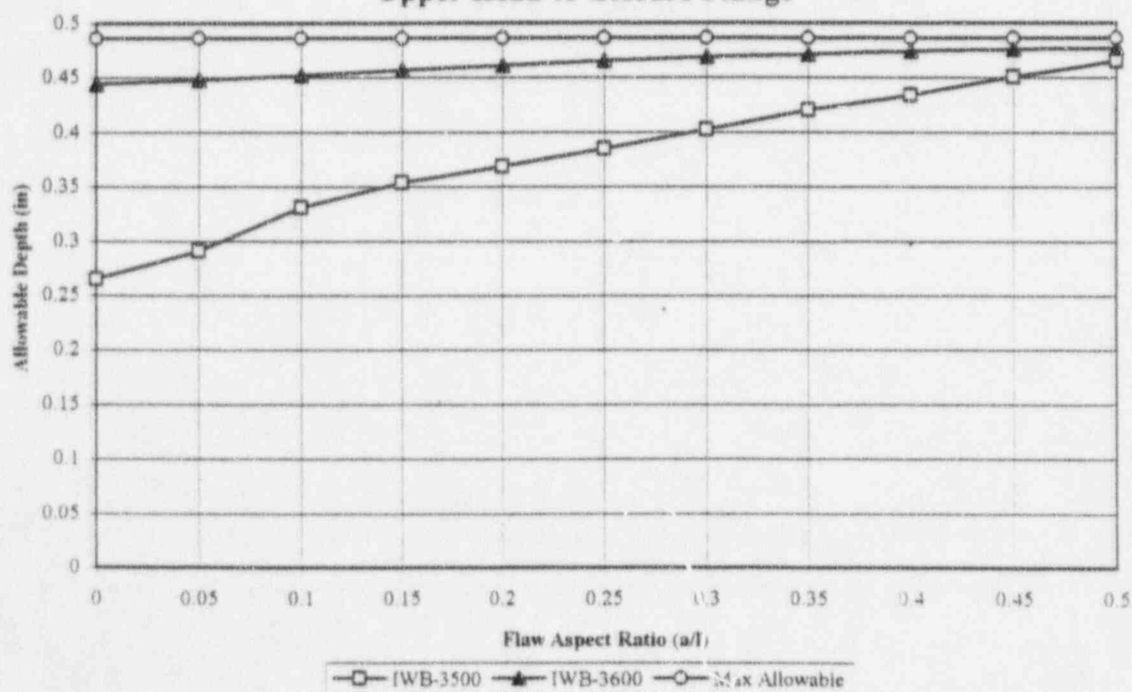
Axial Sub-Surface Flaw e/t = 0.35
Upper Head to Closure Flange



Circumferential Sub-Surface Flaw e/t = 0.45
Upper Head to Closure Flange



Axial Sub-Surface Flaw e/t = 0.45
Upper Head to Closure Flange



APPENDIX C

Flaw Acceptance Diagrams for Region C Materials

Region C includes:

- Upper Shell Flange
- Vessel Flange to Nozzle Belt Weld
- Upper Nozzle Shell *

Based on Minimum Thickness = 12"

Default Maximum Allowable Flaw Sizes for All Charts:

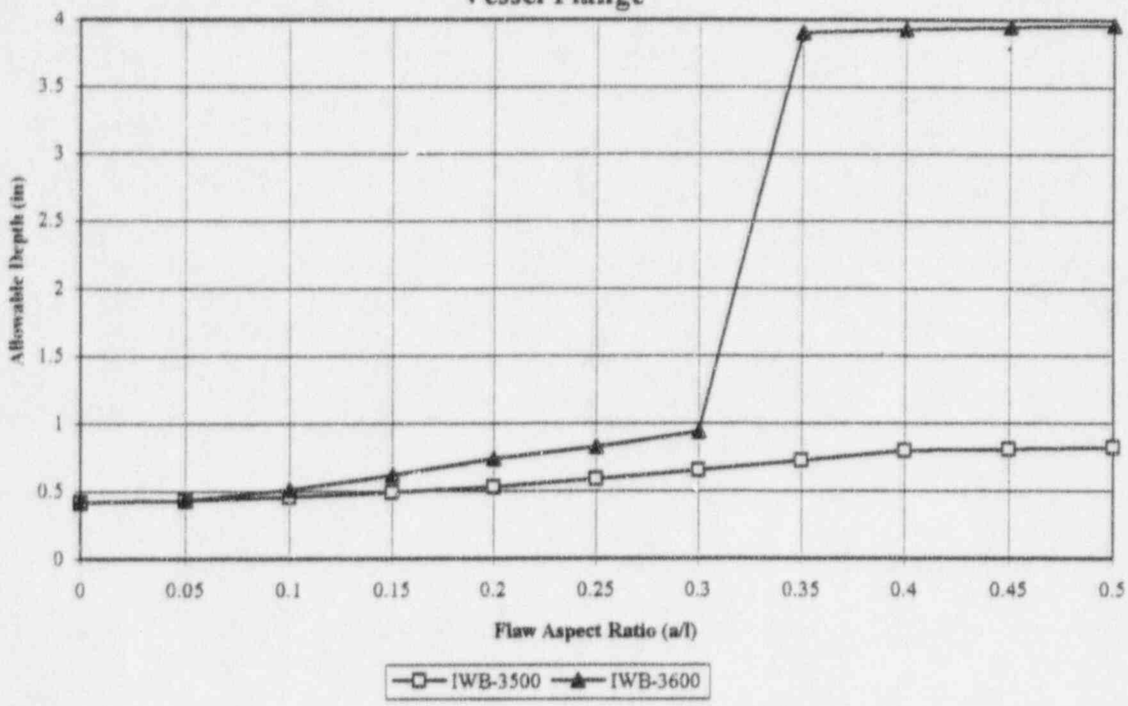
Axially-Oriented Flaws = 4"
Circumferentially-Oriented Flaws = 4"

* Note: For flaw indications found in Upper Nozzle Shell, need to also check Region E.

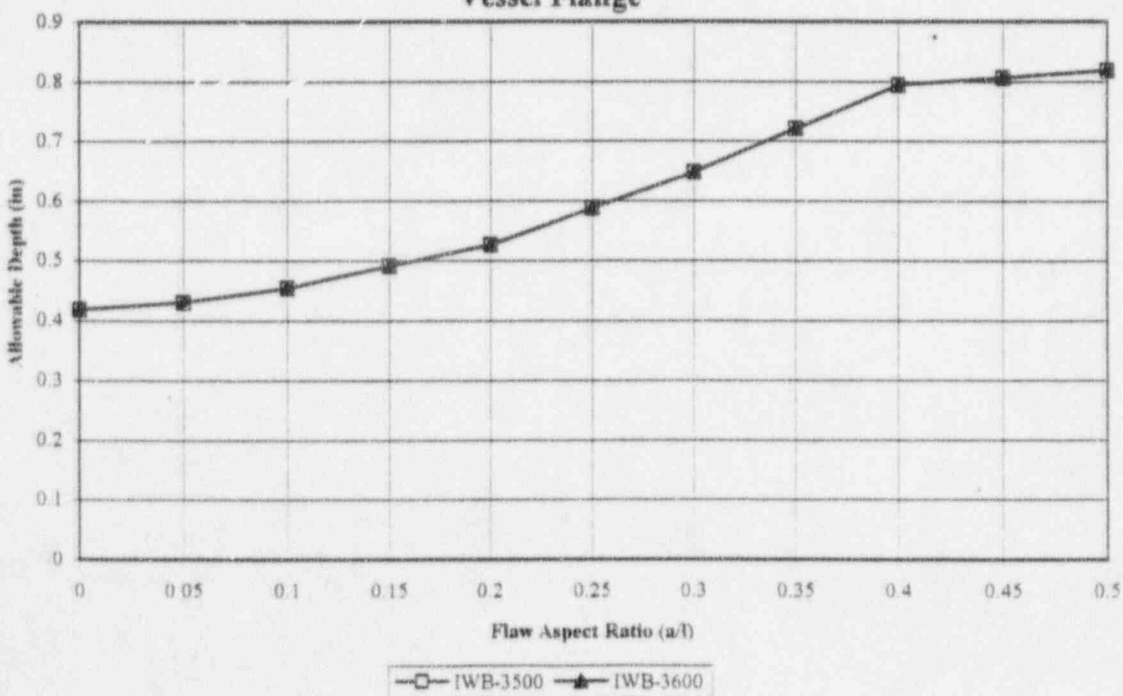
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

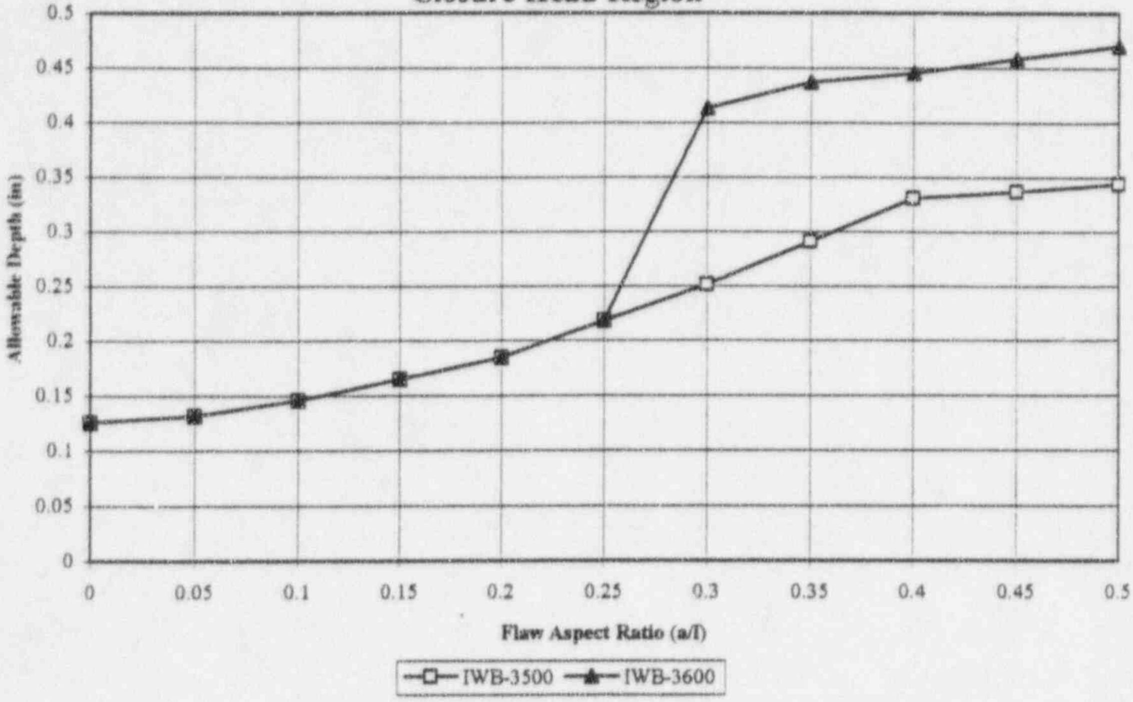
Inside Surface Circumferential Flaw
Vessel Flange



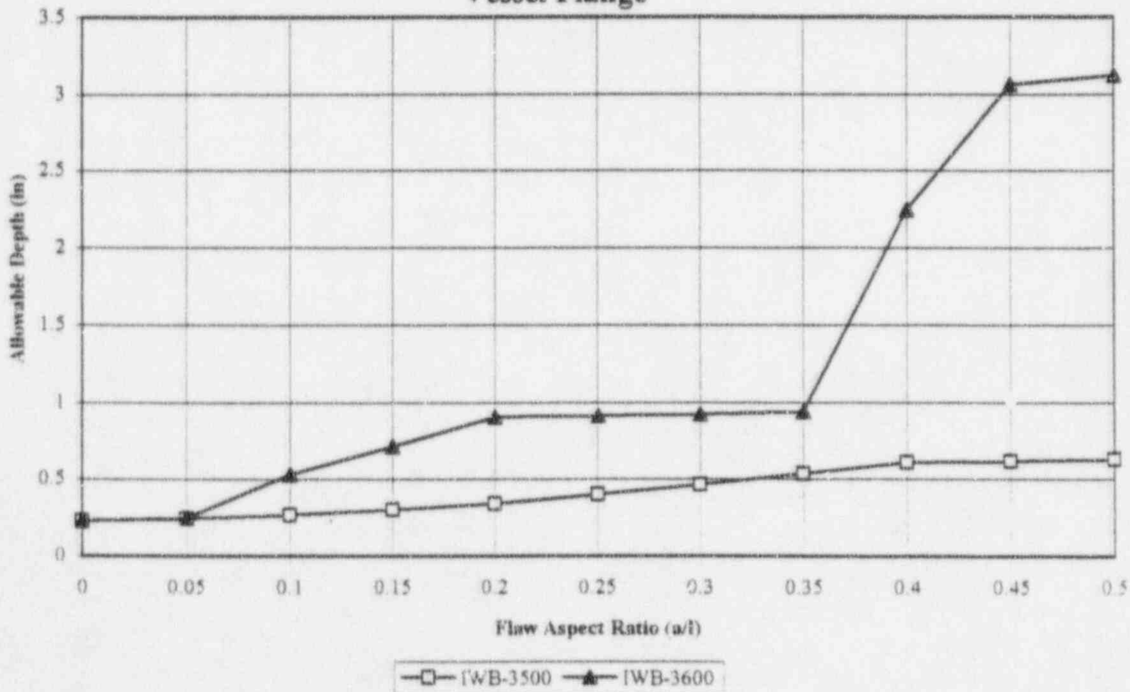
Inside Surface Axial Flaw
Vessel Flange



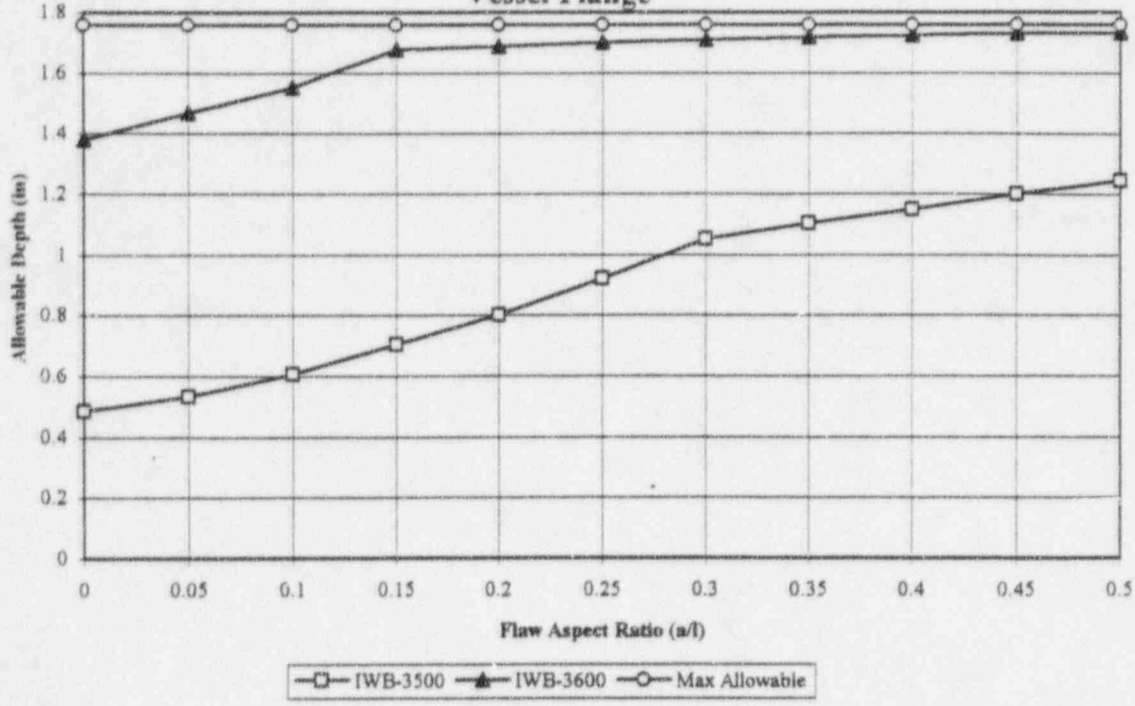
Outside Surface Circumferential Flaw
Closure Head Region



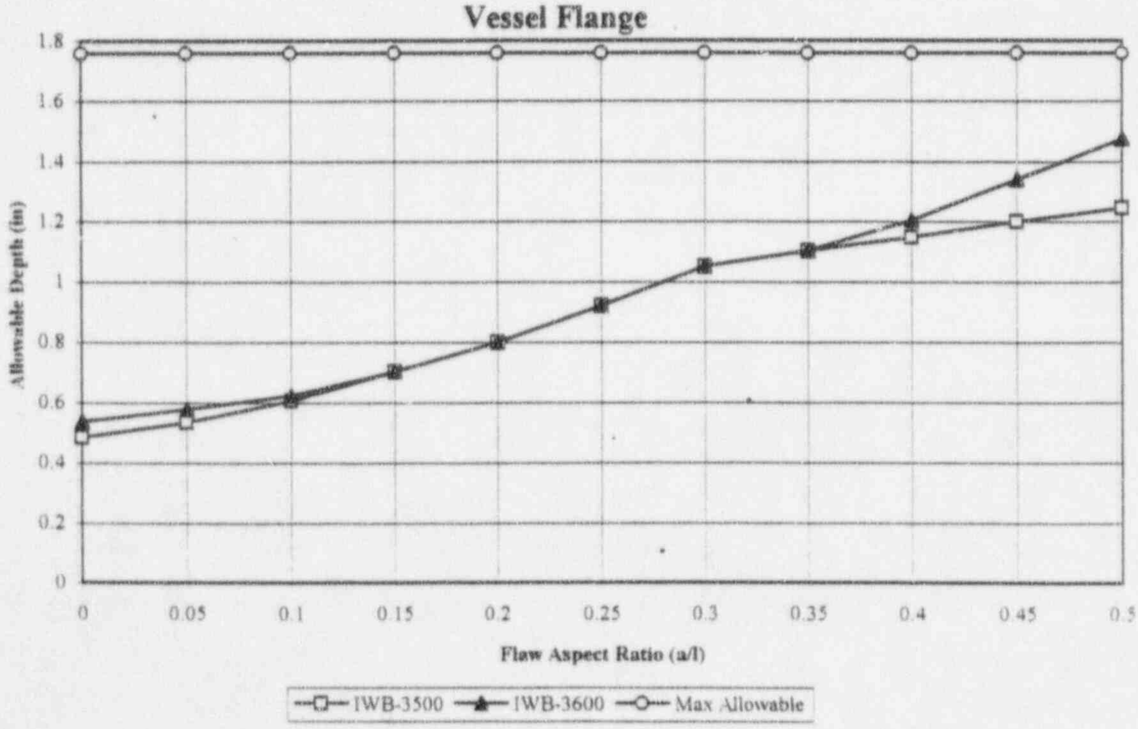
Outside Surface Axial Flaw
Vessel Flange

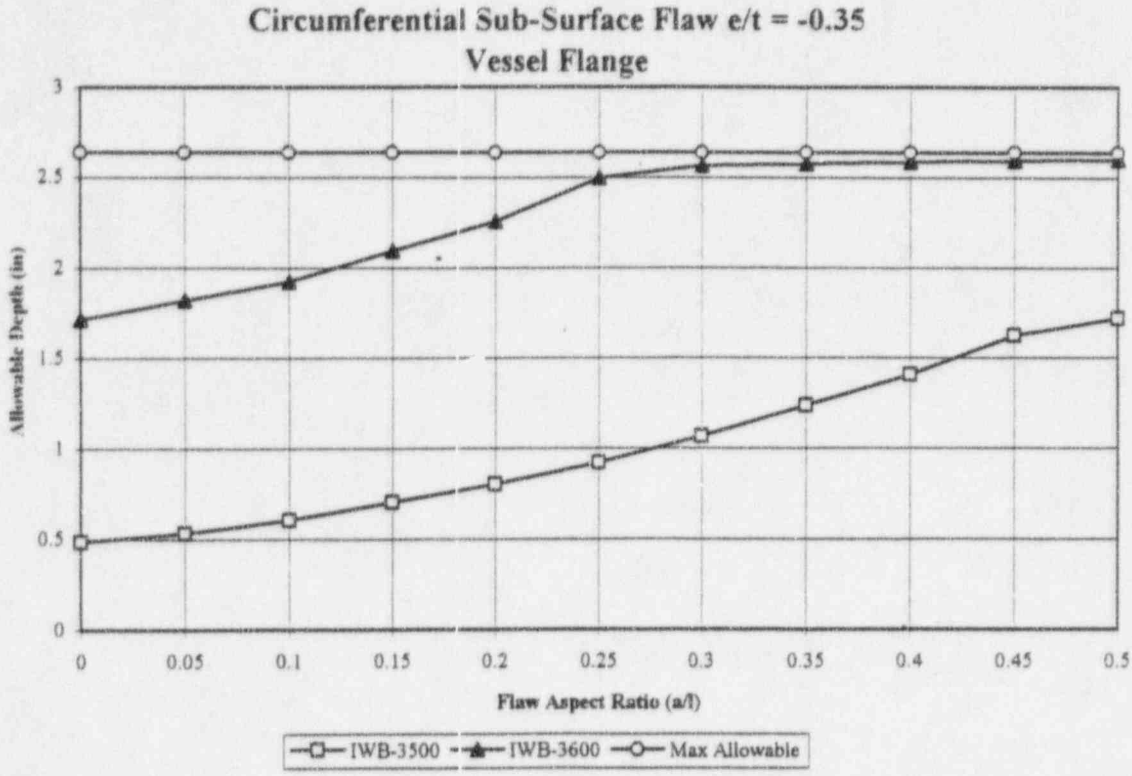


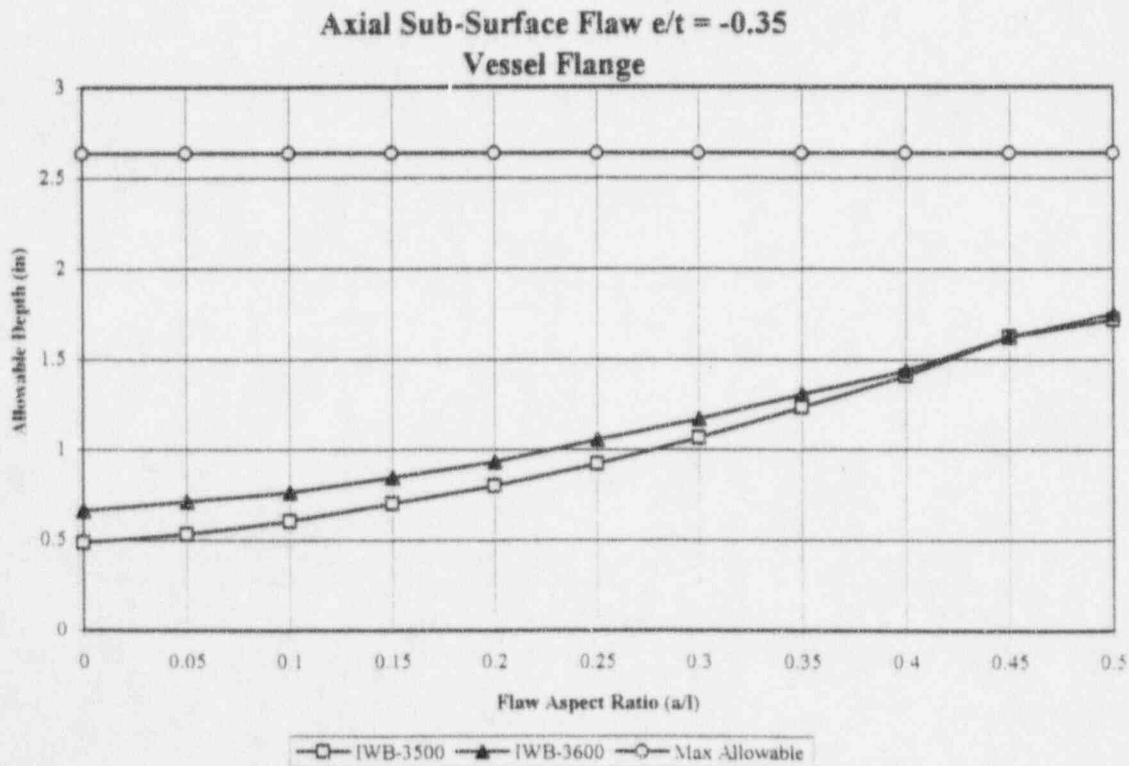
Circumferential Sub-Surface Flaw e/t = -0.4
Vessel Flange

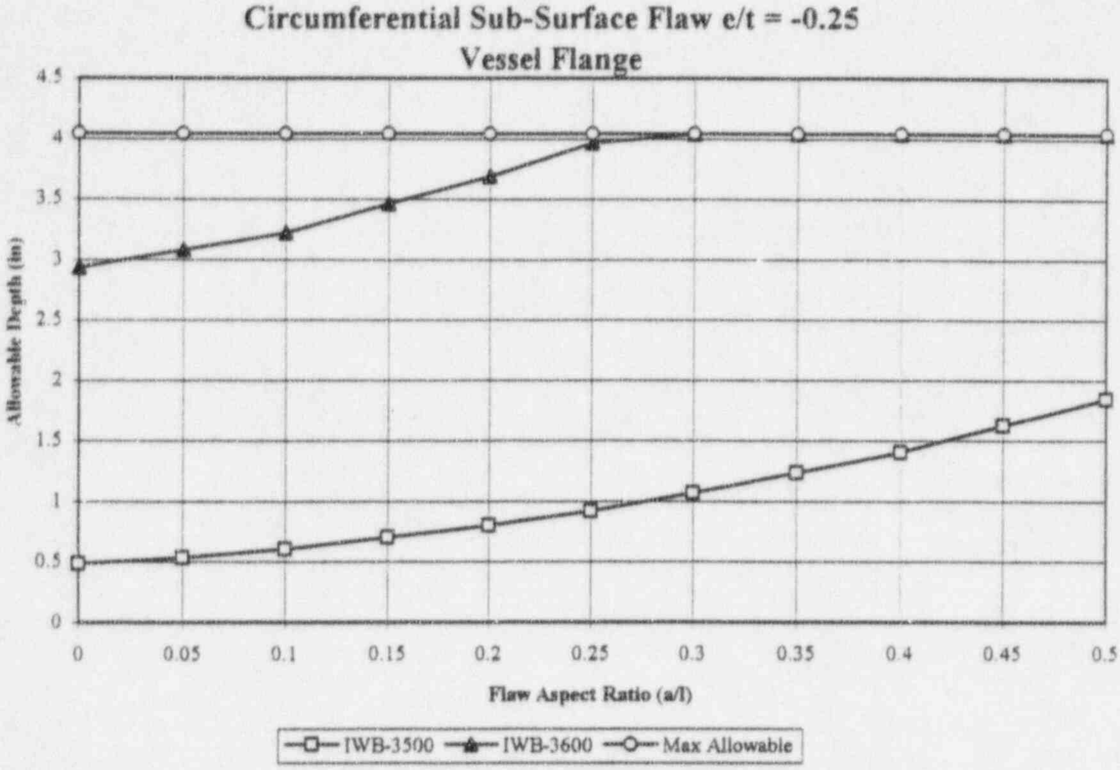


Axial Sub-Surface Flaw e/t = -0.4
Vessel Flange

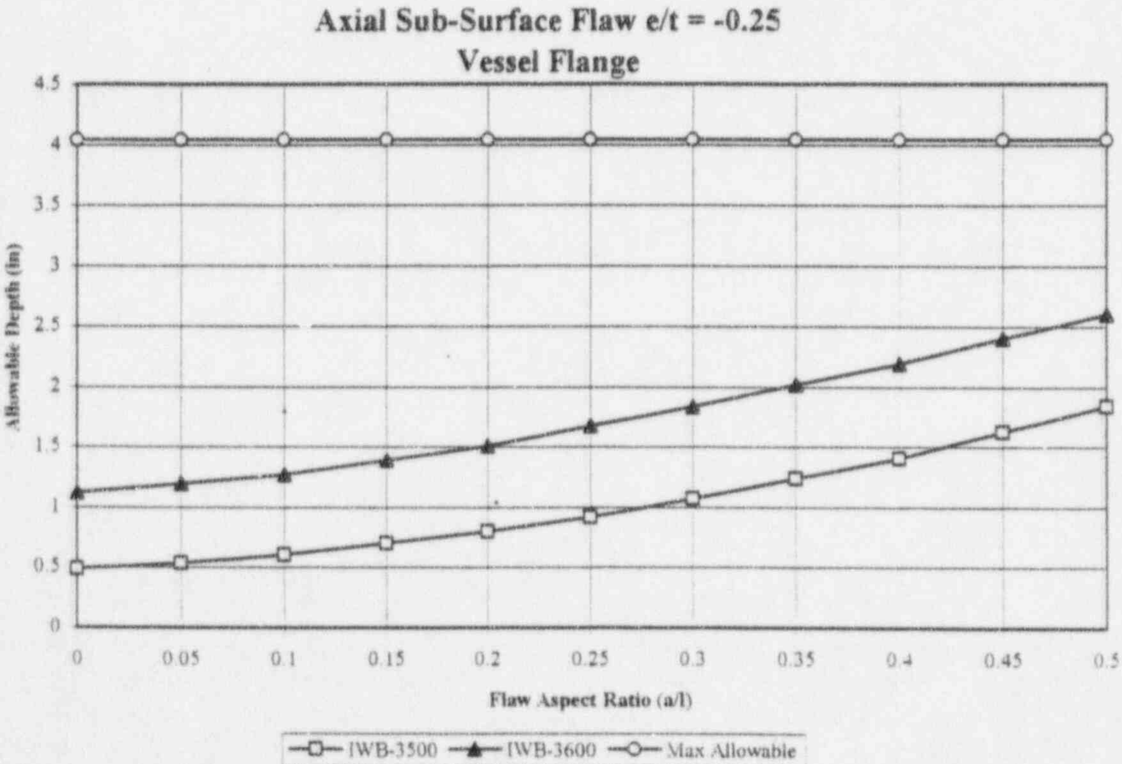



Circumferential Sub-Surface Flaw e/t = -0.35
Vessel Flange
Allowable Depth (in)
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

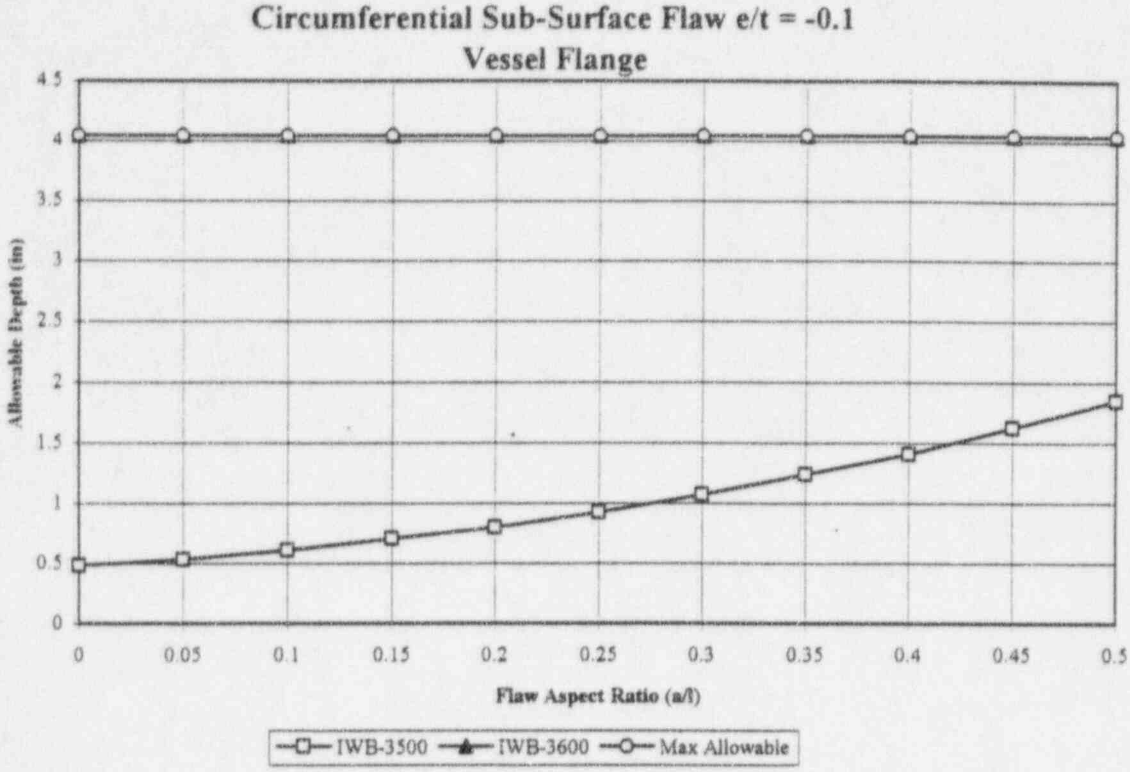

Axial Sub-Surface Flaw e/t = -0.35
Vessel Flange
Allowable Depth (in)
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable



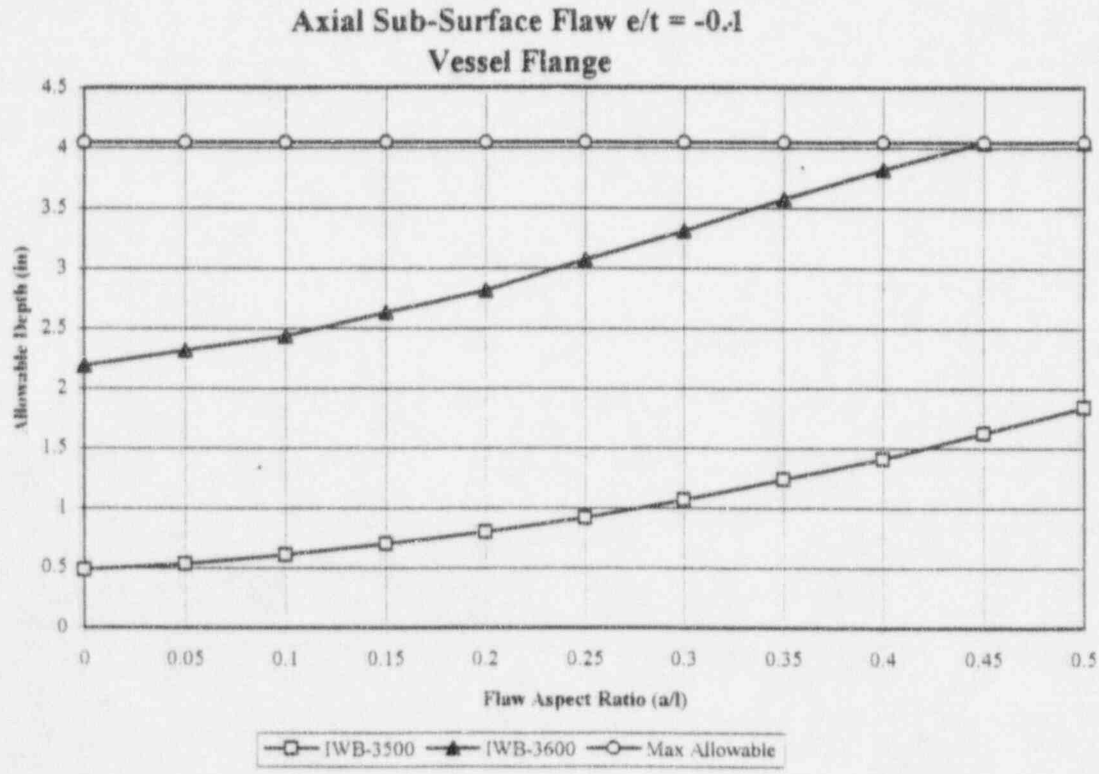
Circumferential Sub-Surface Flaw e/t = -0.25
Vessel Flange
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable



Axial Sub-Surface Flaw e/t = -0.25
Vessel Flange
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

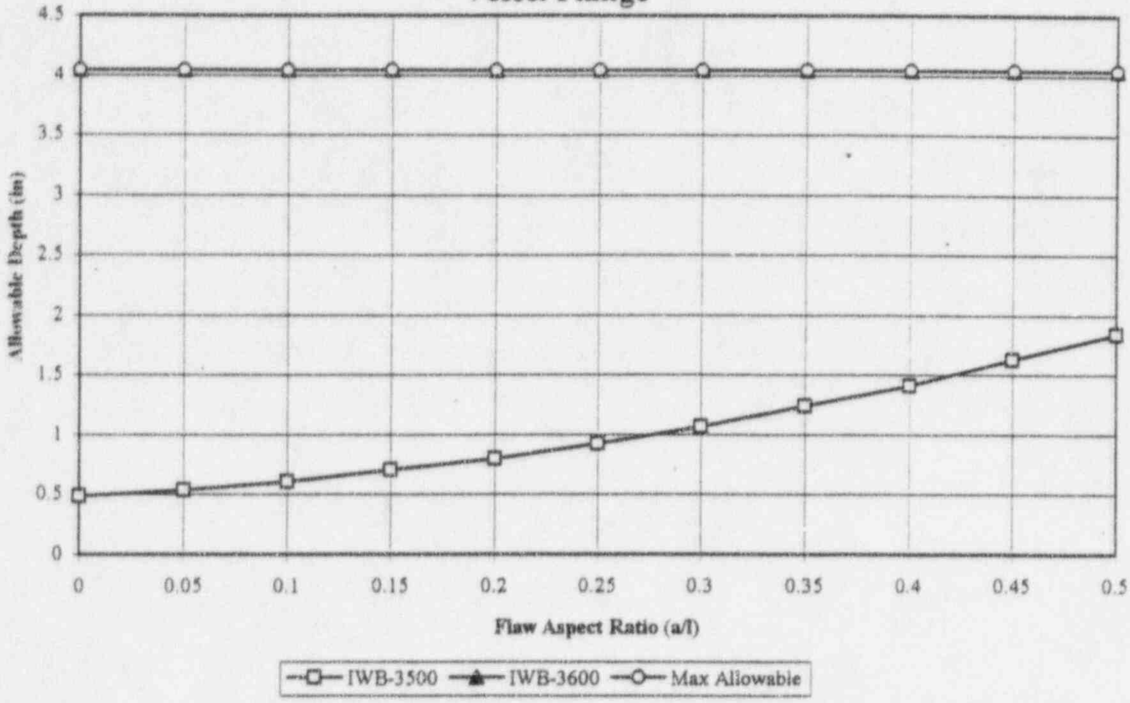


Circumferential Sub-Surface Flaw e/t = -0.1
Vessel Flange
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

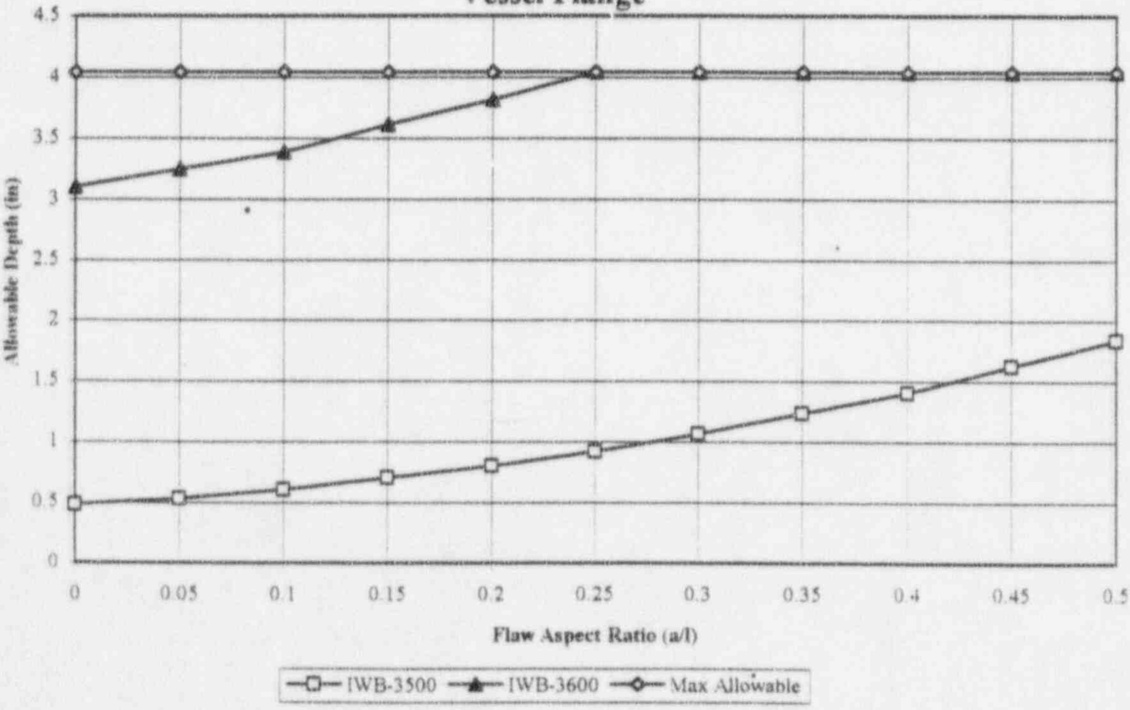


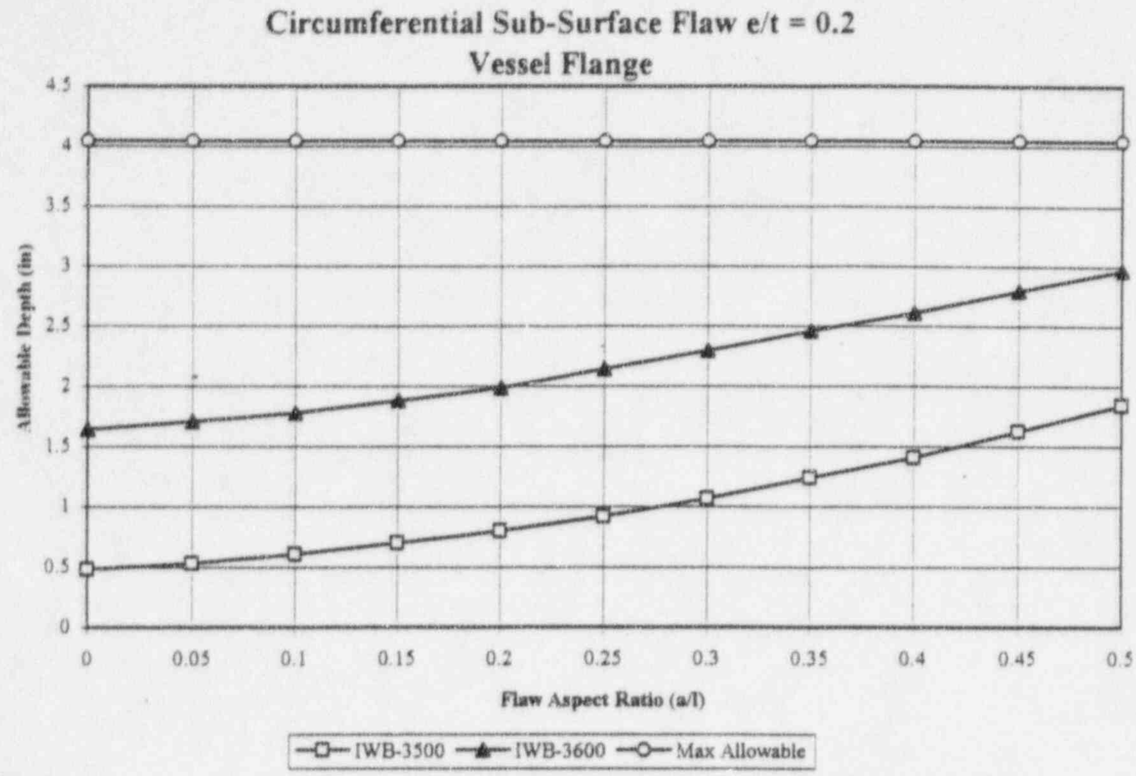
Axial Sub-Surface Flaw e/t = -0.1
Vessel Flange
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

Circumferential Sub-Surface Flaw e/t = 0.0
Vessel Flange

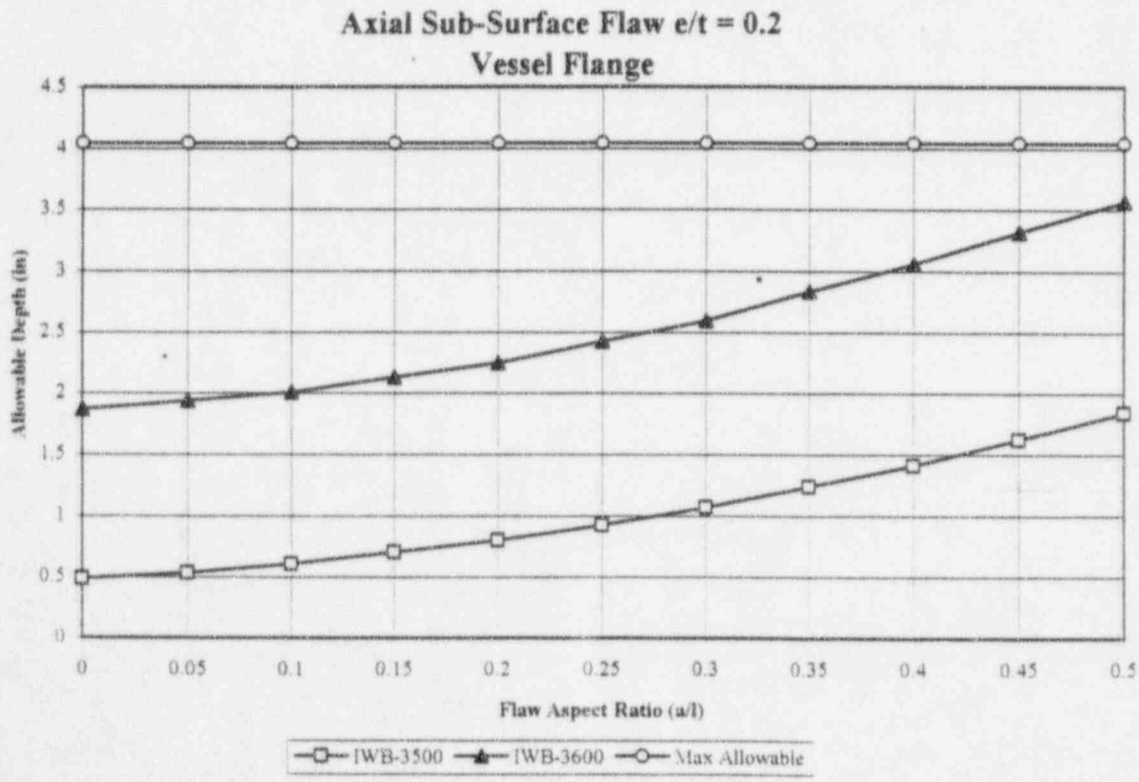


Axial Sub-Surface Flaw e/t = 0.0
Vessel Flange



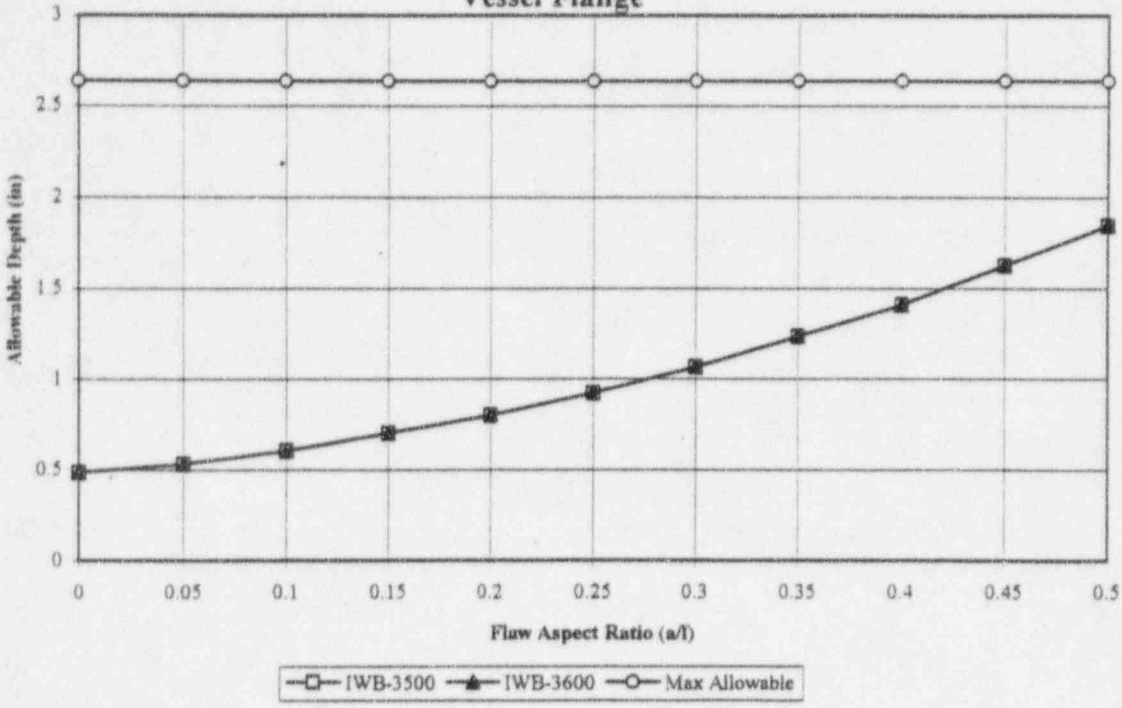


Circumferential Sub-Surface Flaw e/t = 0.2
Vessel Flange
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

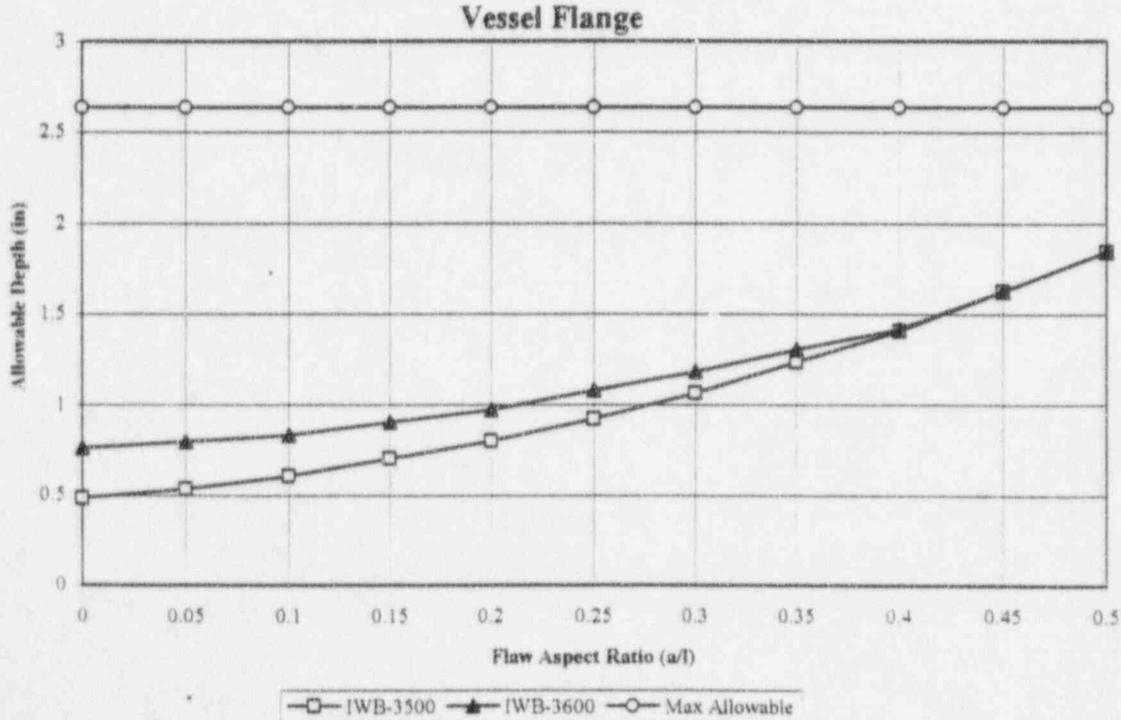


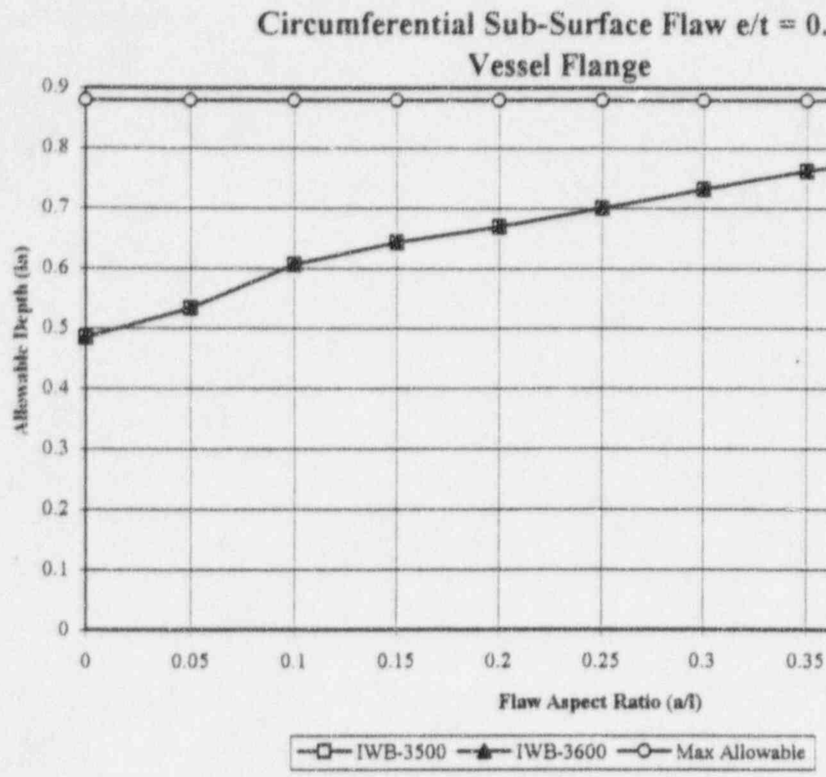
Axial Sub-Surface Flaw e/t = 0.2
Vessel Flange
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

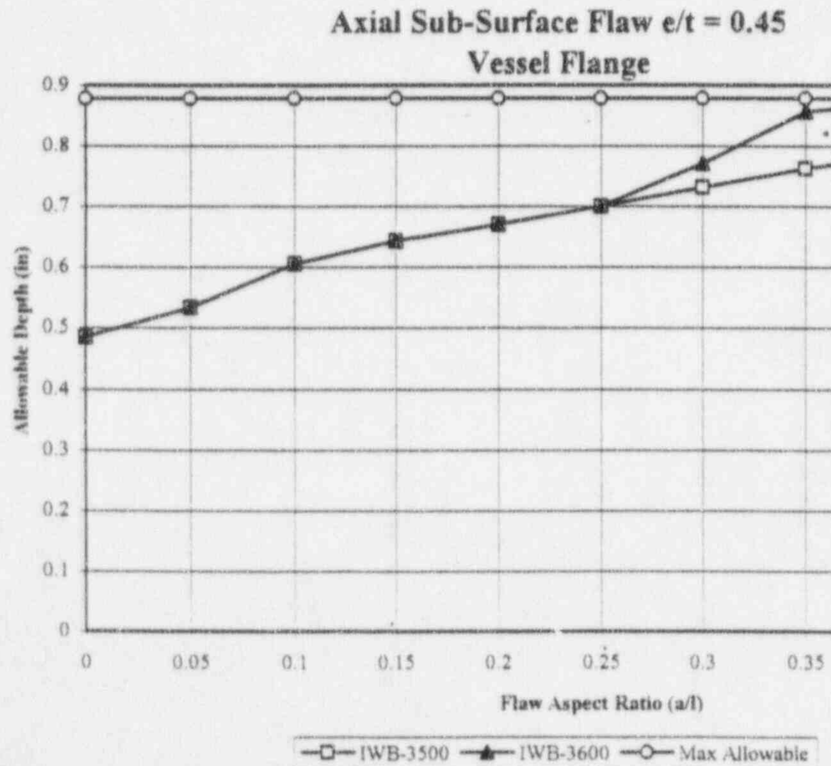
Circumferential Sub-Surface Flaw e/t = 0.35
Vessel Flange



Axial Sub-Surface Flaw e/t = 0.35
Vessel Flange




Circumferential Sub-Surface Flaw e/t = 0.45
Vessel Flange
Allowable Depth (in)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.45
Vessel Flange
Allowable Depth (in)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

APPENDIX D

Flaw Acceptance Diagrams for Region D Materials

Region D includes:

- Lower Nozzle Shell *

Based on Minimum Thickness = 12"

Default Maximum Allowable Flaw Sizes for All Charts:

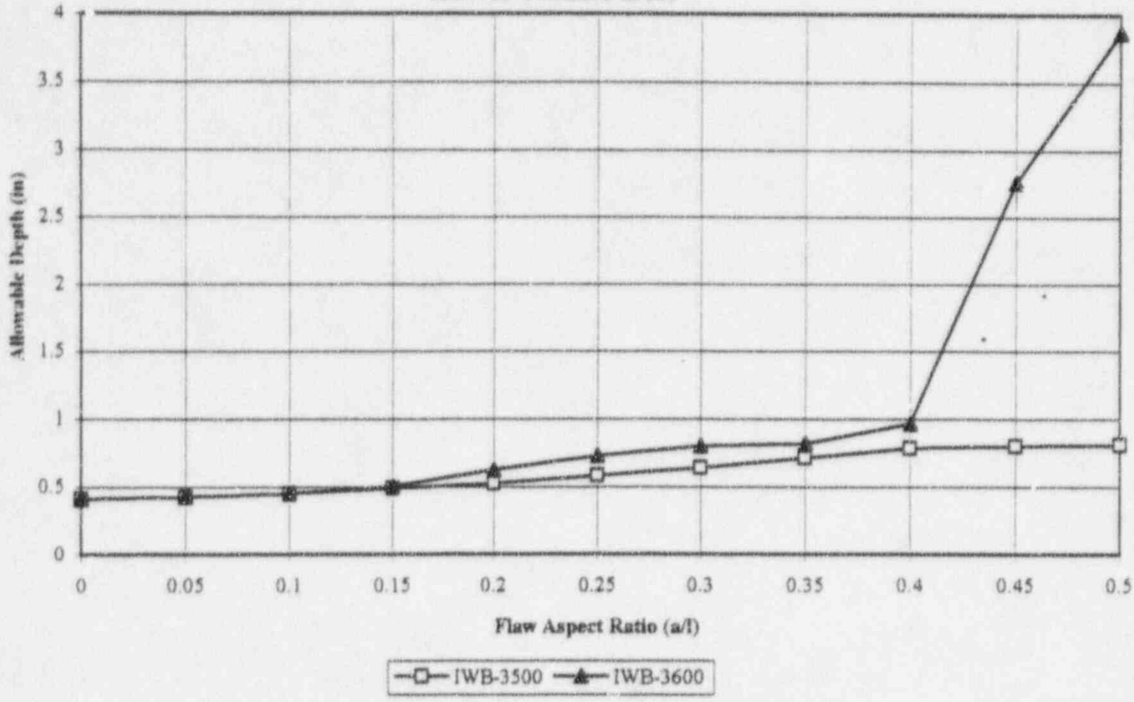
Axially-Oriented Flaws = 4"
Circumferentially-Oriented Flaws = 6"

* Note: Includes all unirradiated portions of Lower Nozzle Shell. For irradiated portions, see Region F.

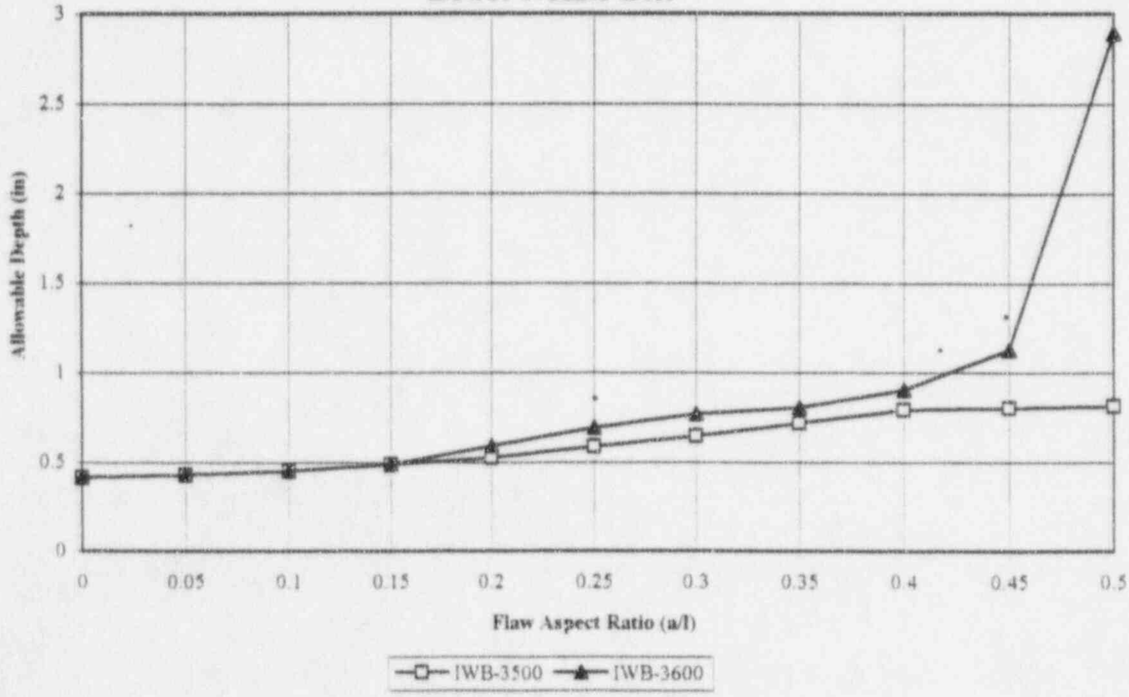
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

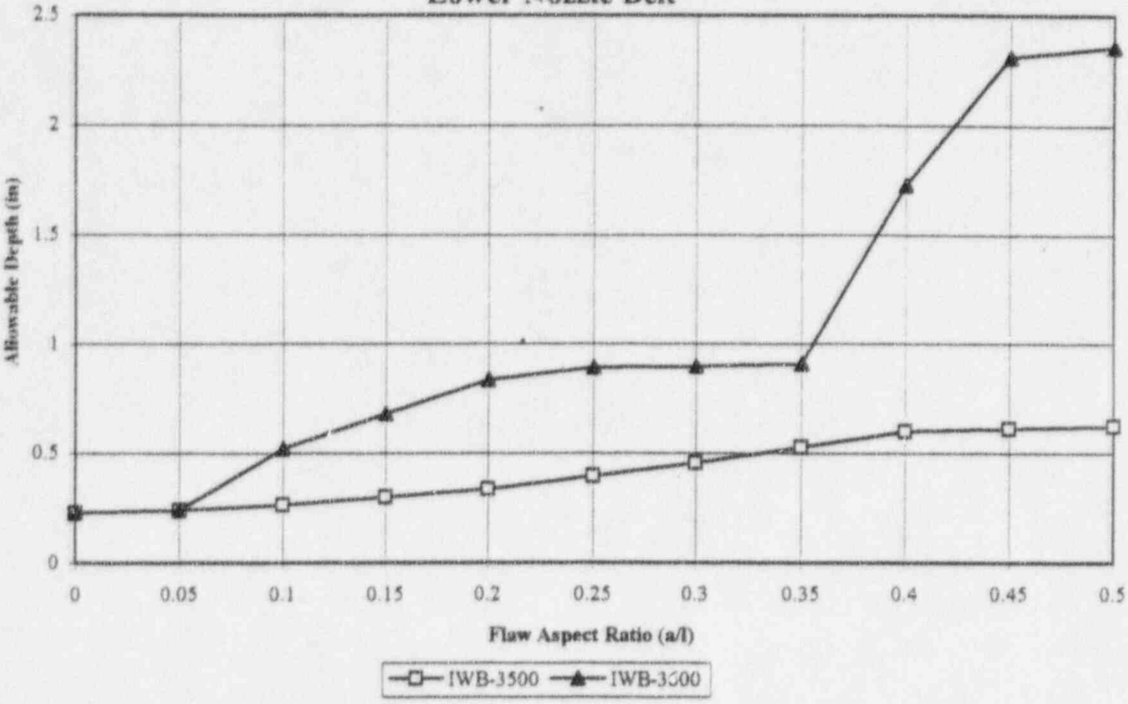
Inside Surface Circumferential Flaw
Lower Nozzle Belt



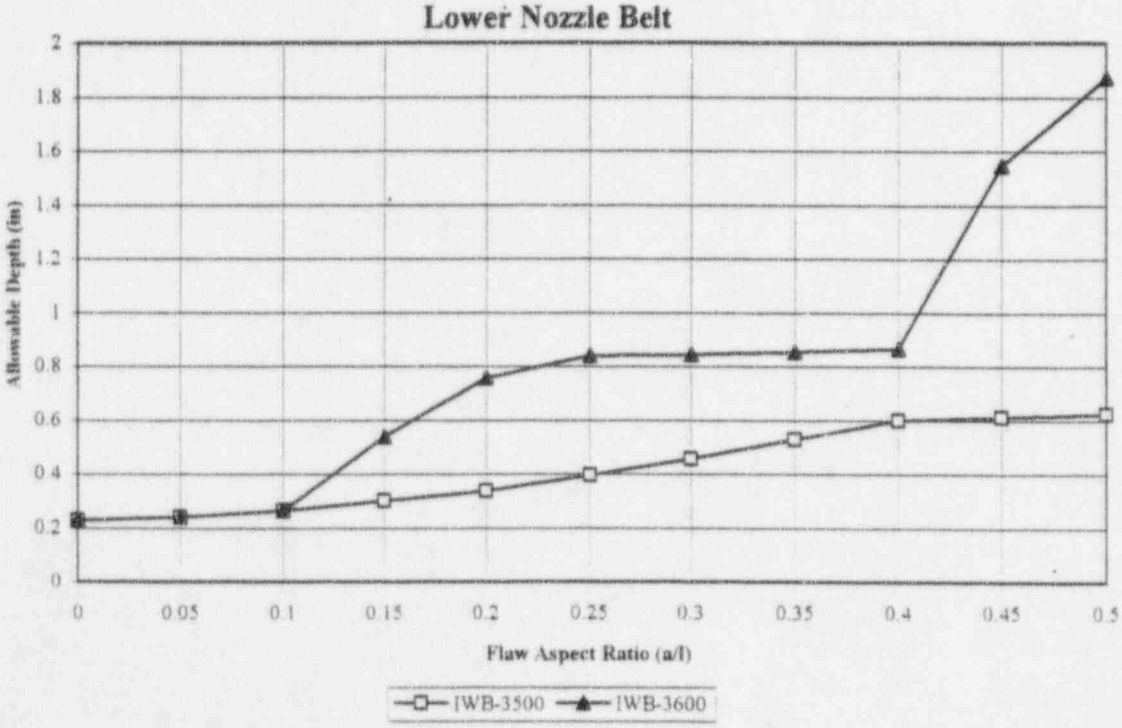
Inside Surface Axial Flaw
Lower Nozzle Belt



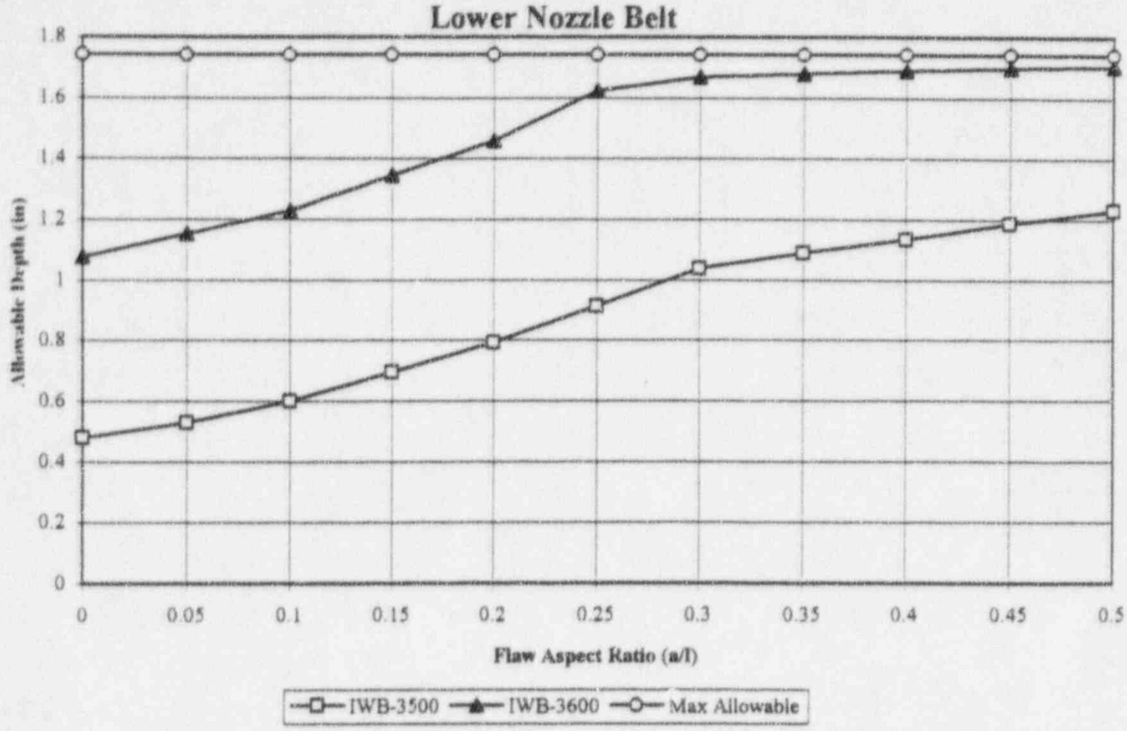
Outside Surface Circumferential Flaw
Lower Nozzle Belt



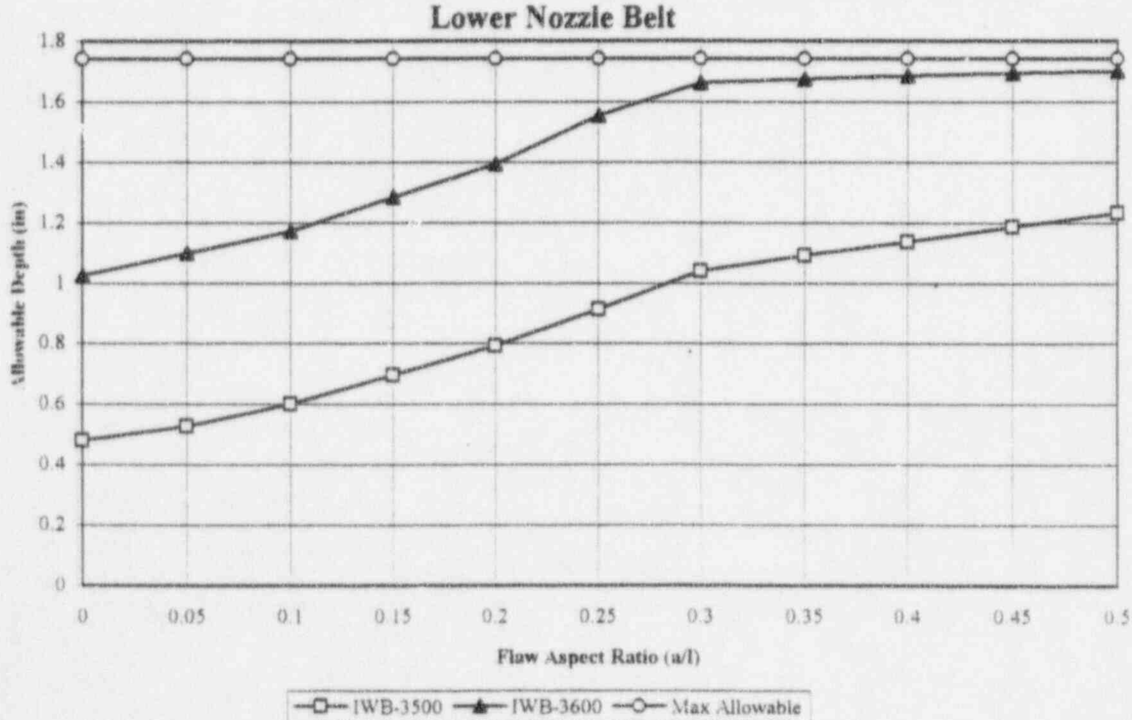
Outside Surface Axial Flaw
Lower Nozzle Belt



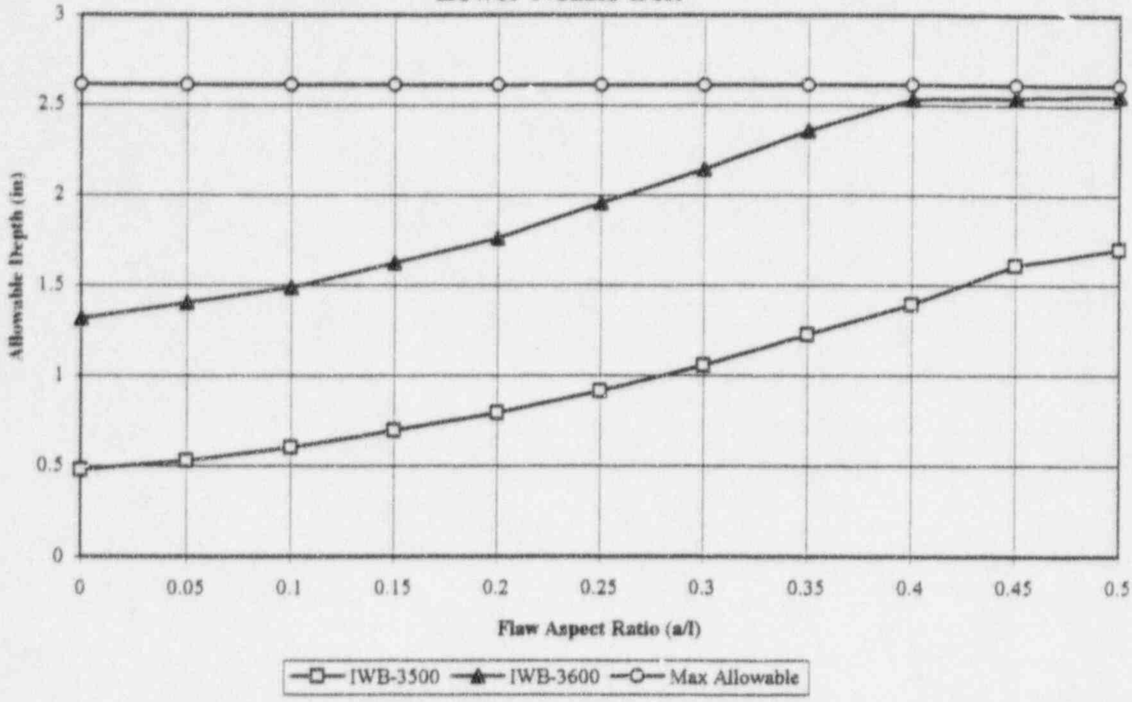
Circumferential Sub-Surface Flaw e/t = -0.4
Lower Nozzle Belt



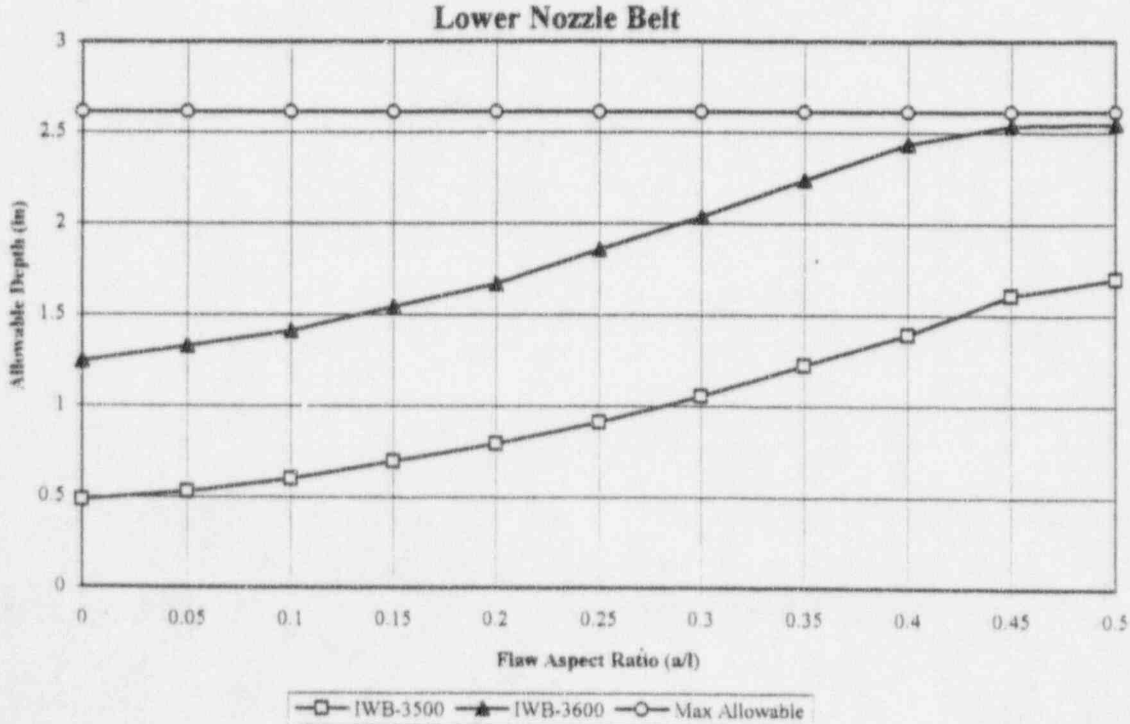
Axial Sub-Surface Flaw e/t = -0.4
Lower Nozzle Belt



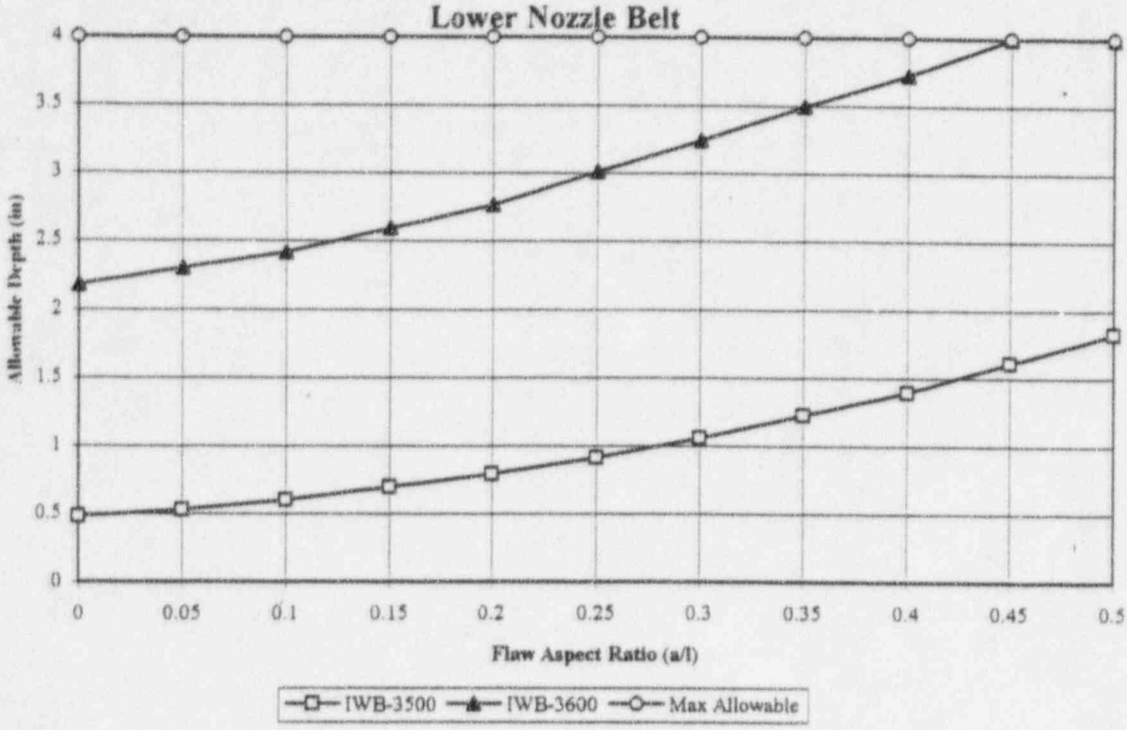
Circumferential Sub-Surface Flaw e/t = -0.35
Lower Nozzle Belt



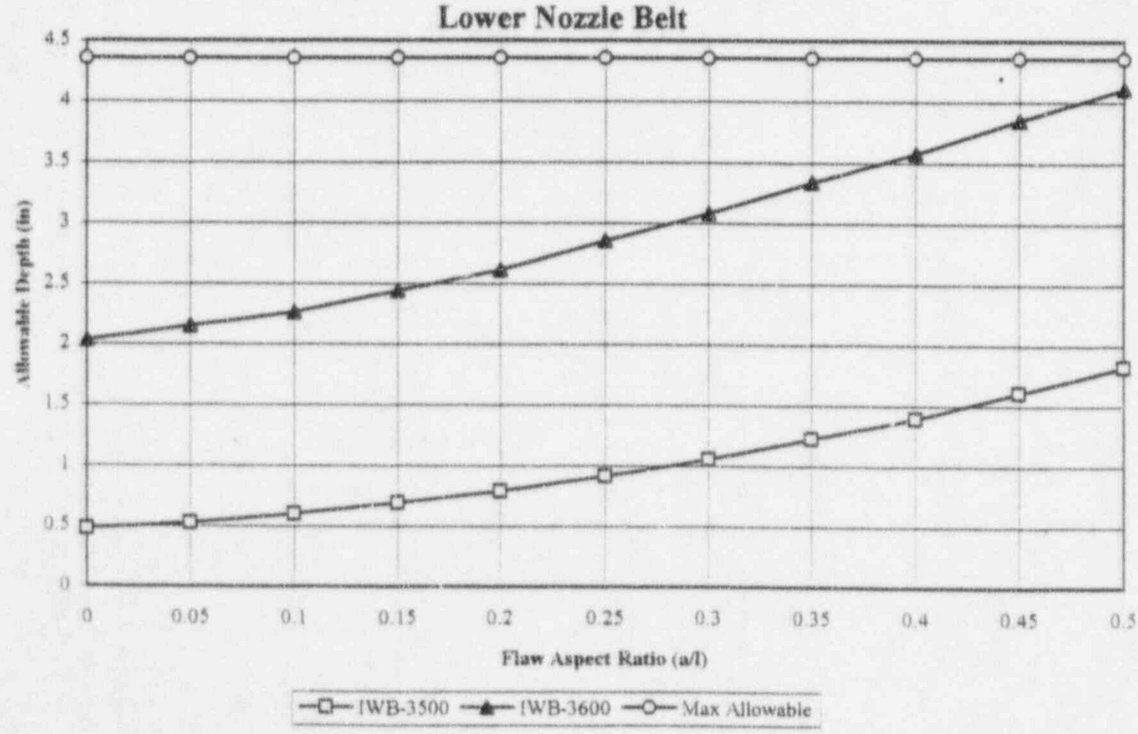
Axial Sub-Surface Flaw e/t = -0.35
Lower Nozzle Belt

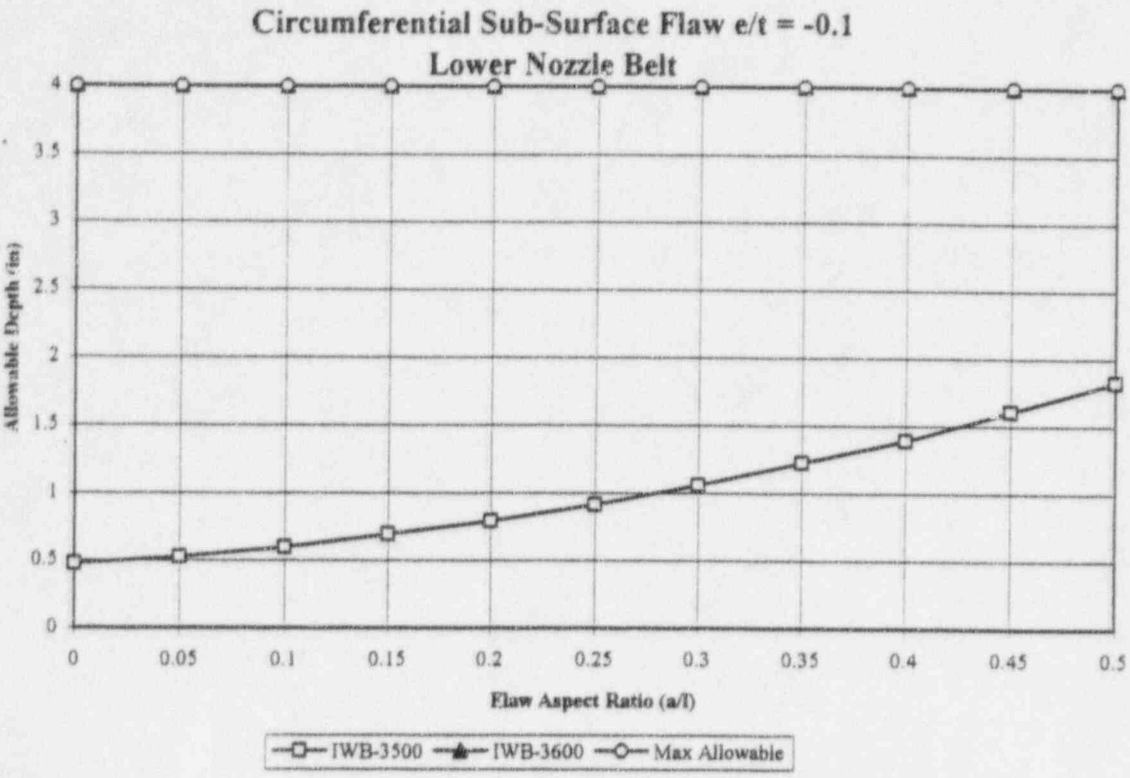


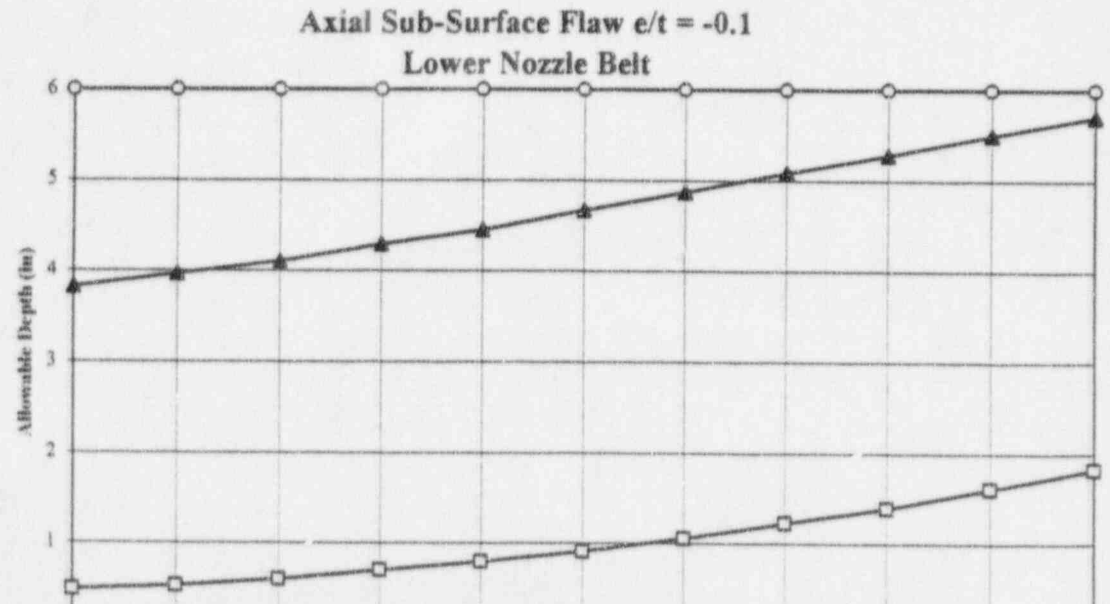
Circumferential Sub-Surface Flaw e/t = -0.25
Lower Nozzle Belt

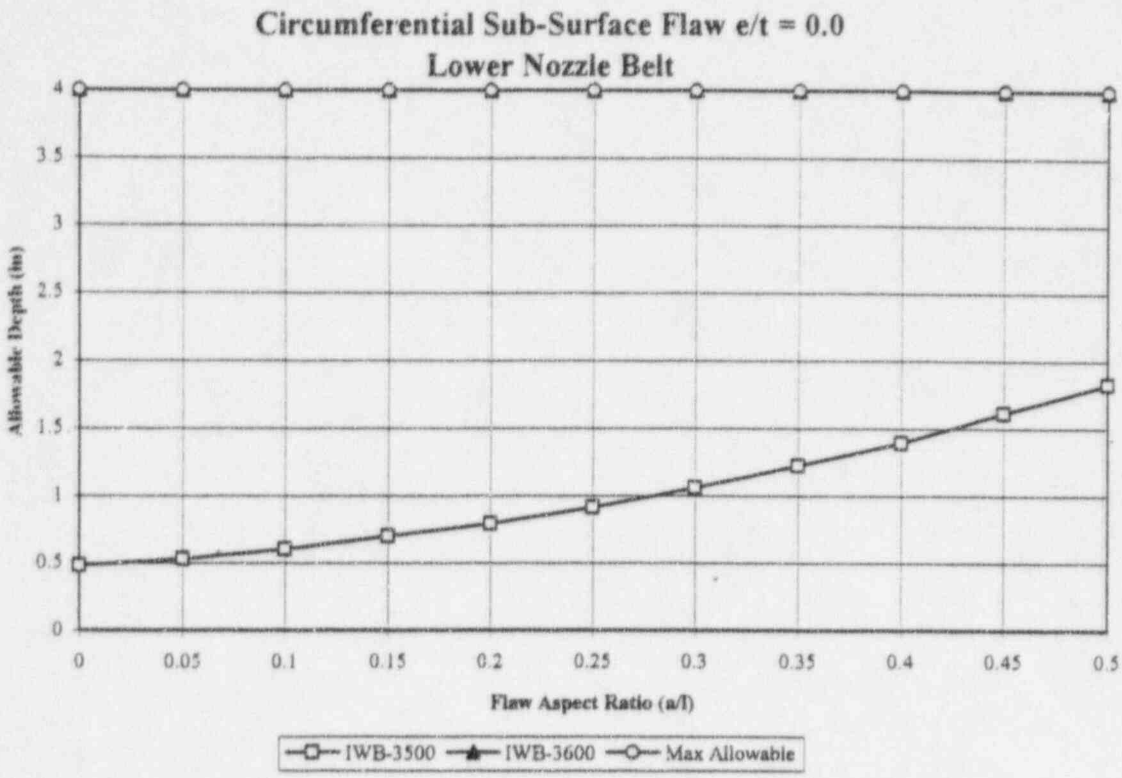


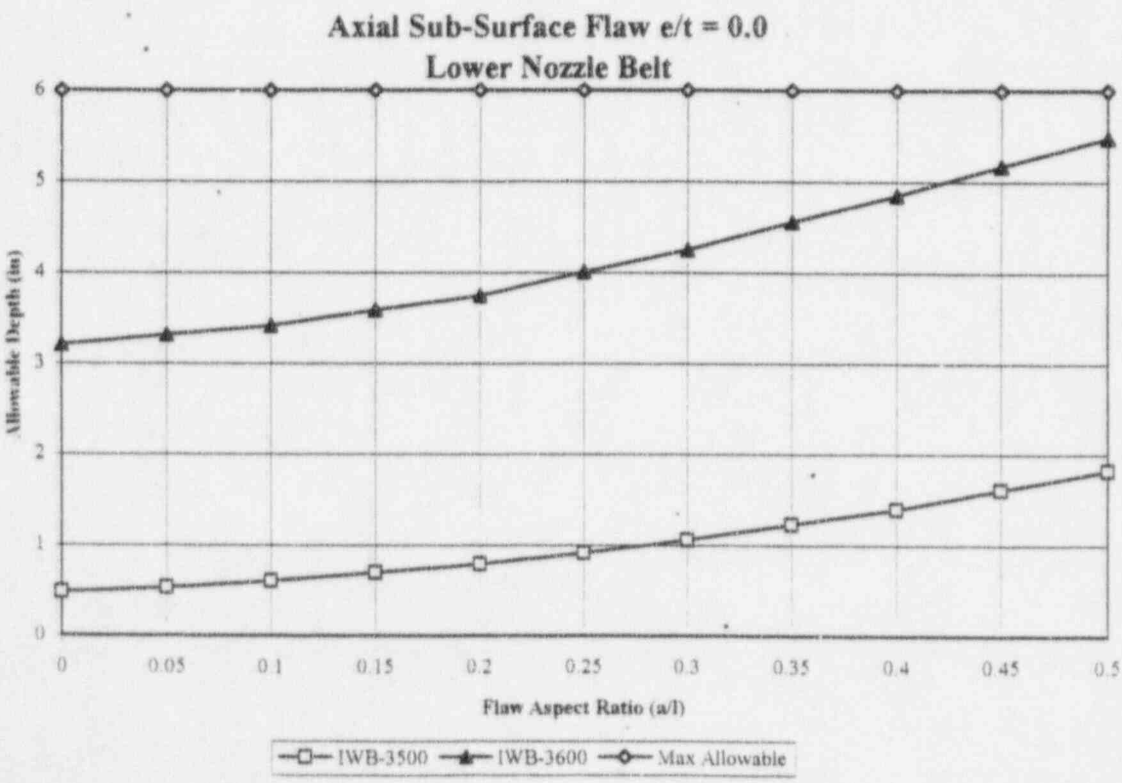
Axial Sub-Surface Flaw e/t = -0.25
Lower Nozzle Belt



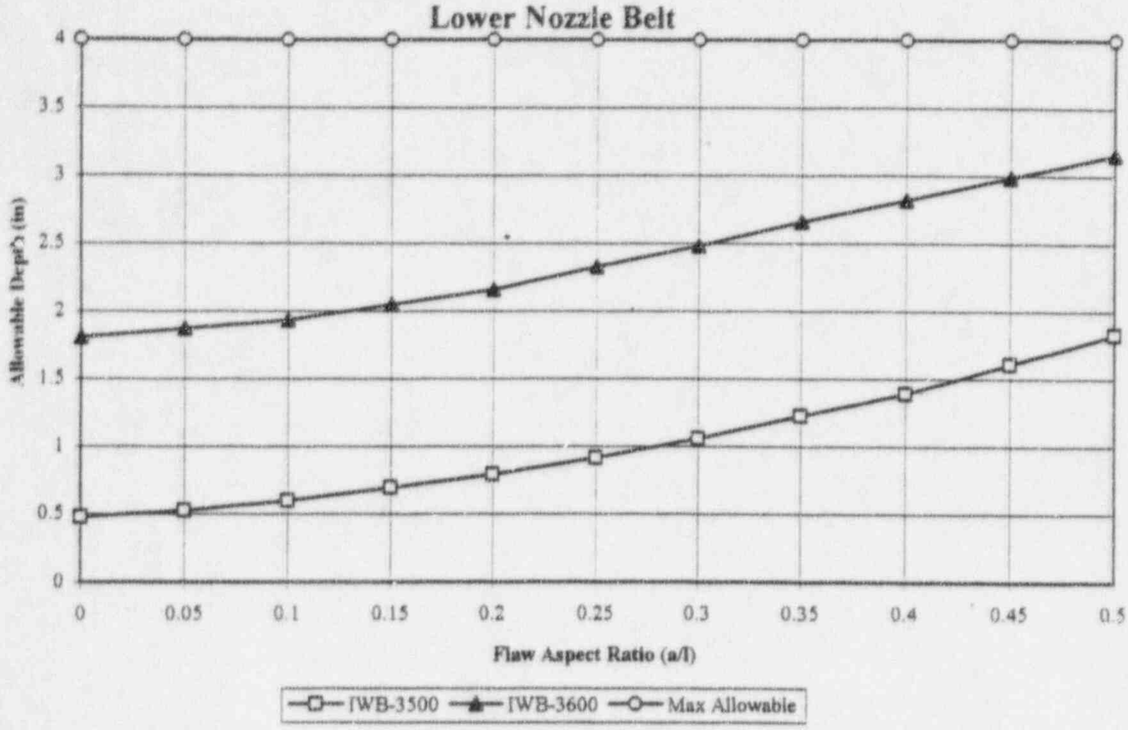

Circumferential Sub-Surface Flaw e/t = -0.1
Lower Nozzle Belt
Allowable Depth (in)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.1
Lower Nozzle Belt
Allowable Depth (in)
6
5
4
3
2
1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

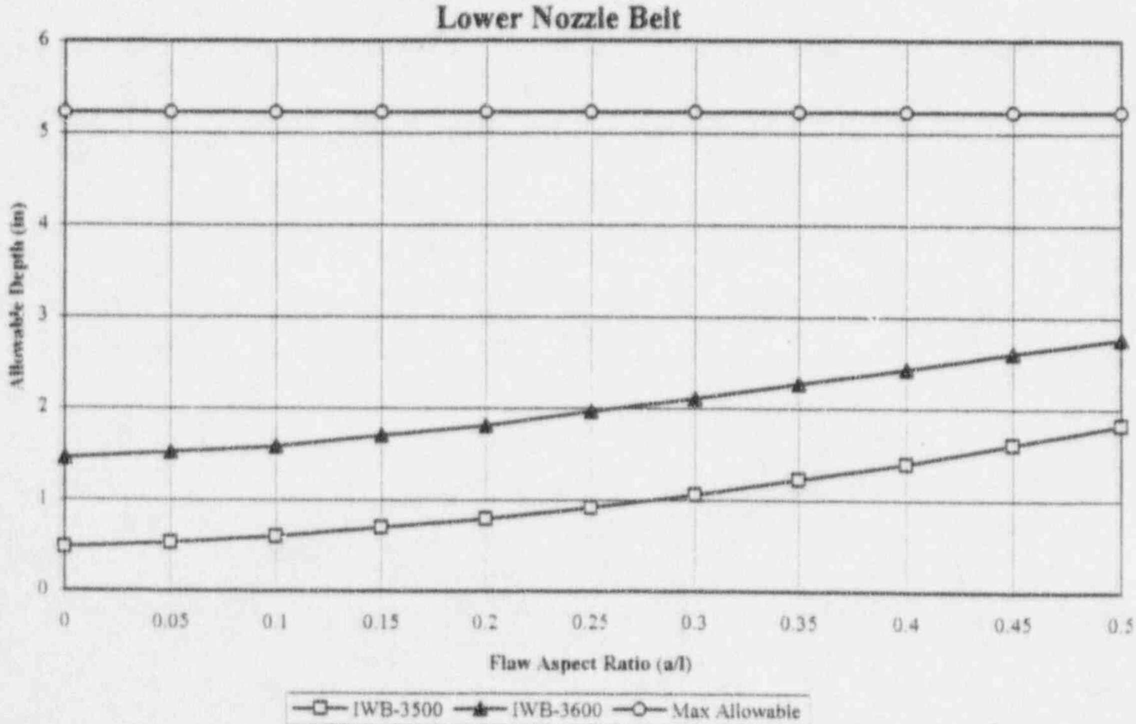

Circumferential Sub-Surface Flaw e/t = 0.0
Lower Nozzle Belt
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

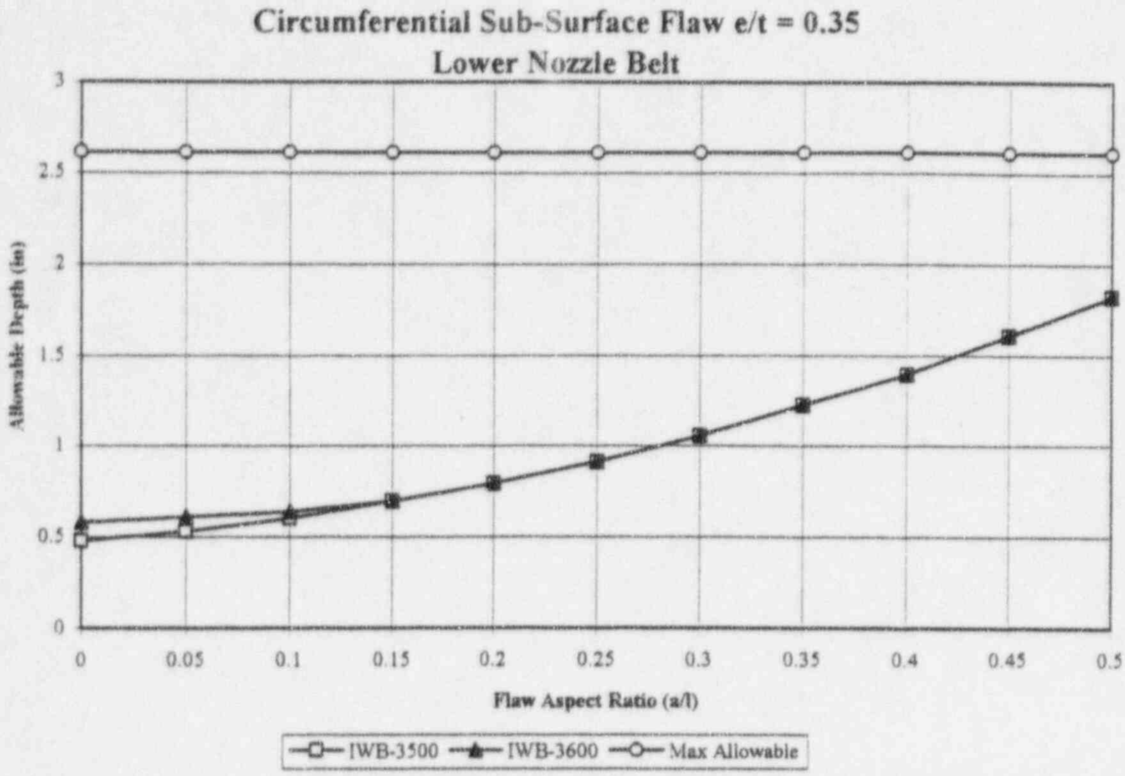

Axial Sub-Surface Flaw e/t = 0.0
Lower Nozzle Belt
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

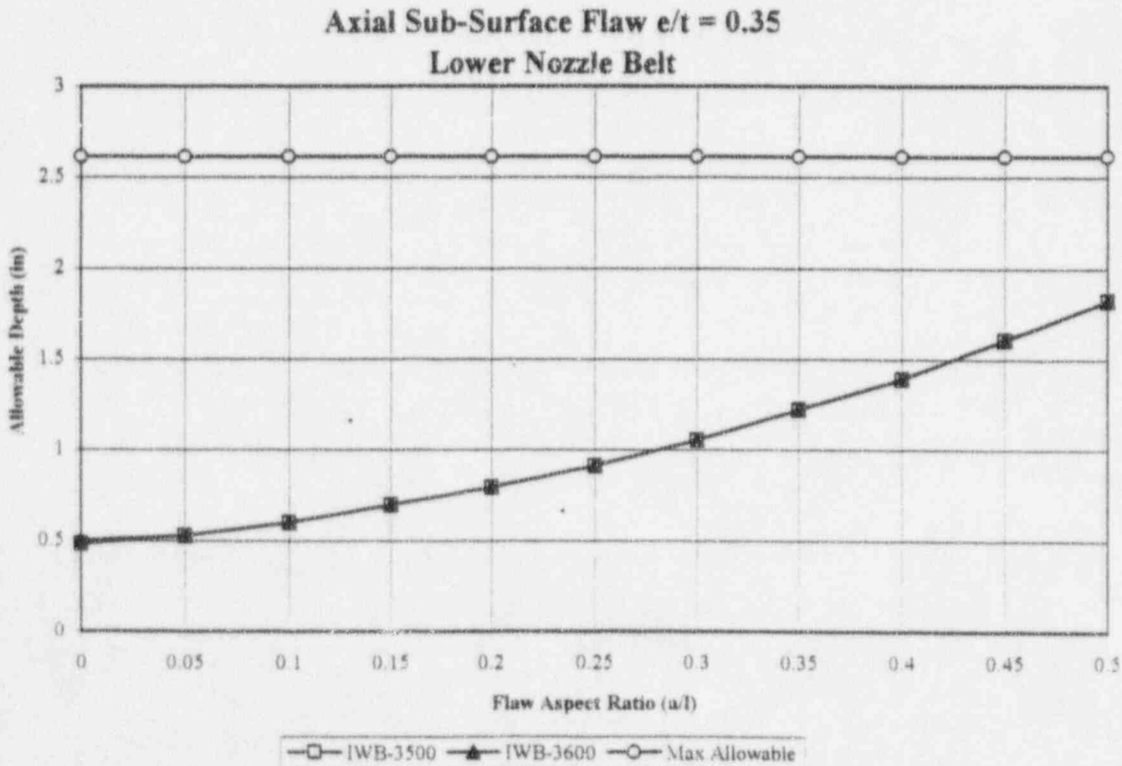
Circumferential Sub-Surface Flaw e/t = 0.2
Lower Nozzle Belt

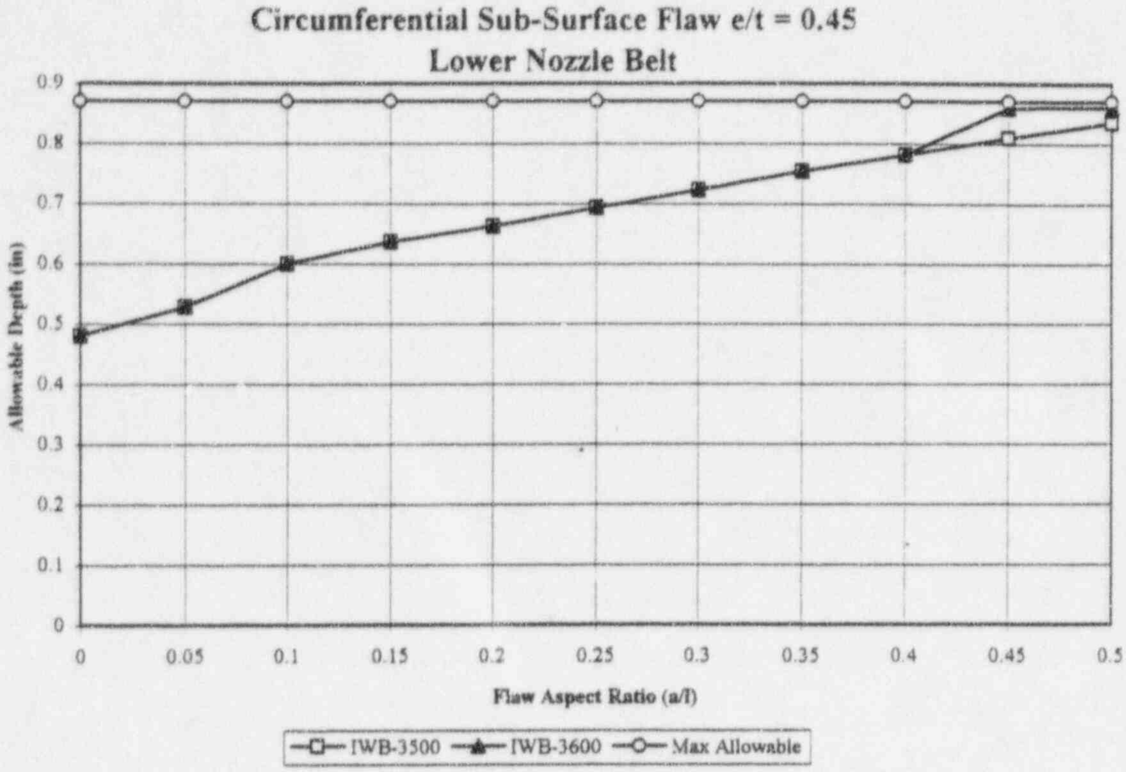


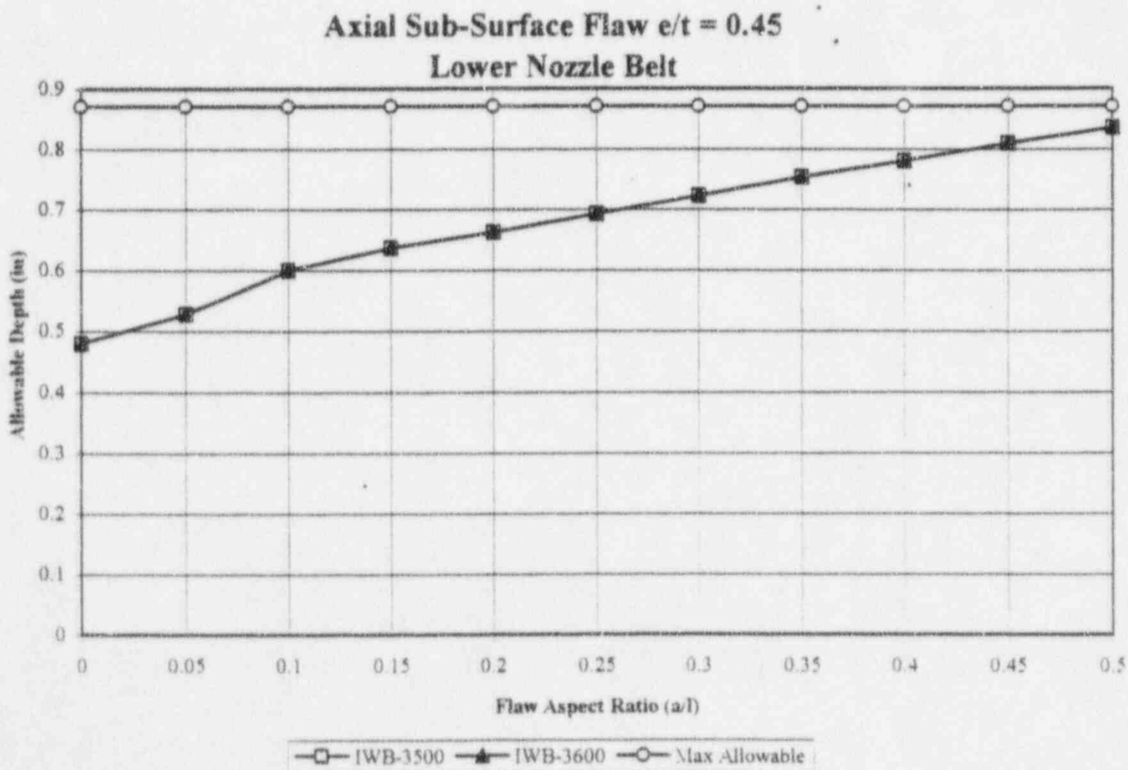
Axial Sub-Surface Flaw e/t = 0.2
Lower Nozzle Belt




Circumferential Sub-Surface Flaw e/t = 0.35
Lower Nozzle Belt
Allowable Depth (in)
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.35
Lower Nozzle Belt
Allowable Depth (in)
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Circumferential Sub-Surface Flaw e/t = 0.45
Lower Nozzle Belt
Allowable Depth (in)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.45
Lower Nozzle Belt
Allowable Depth (in)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

APPENDIX E

Flaw Acceptance Diagrams for Region E Materials

Region E includes:

- Upper Nozzle Shell *
- Nozzle Belt to Nozzle Belt Weld

Based on Minimum Thickness = 12"

Default Maximum Allowable Flaw Sizes for All Charts:

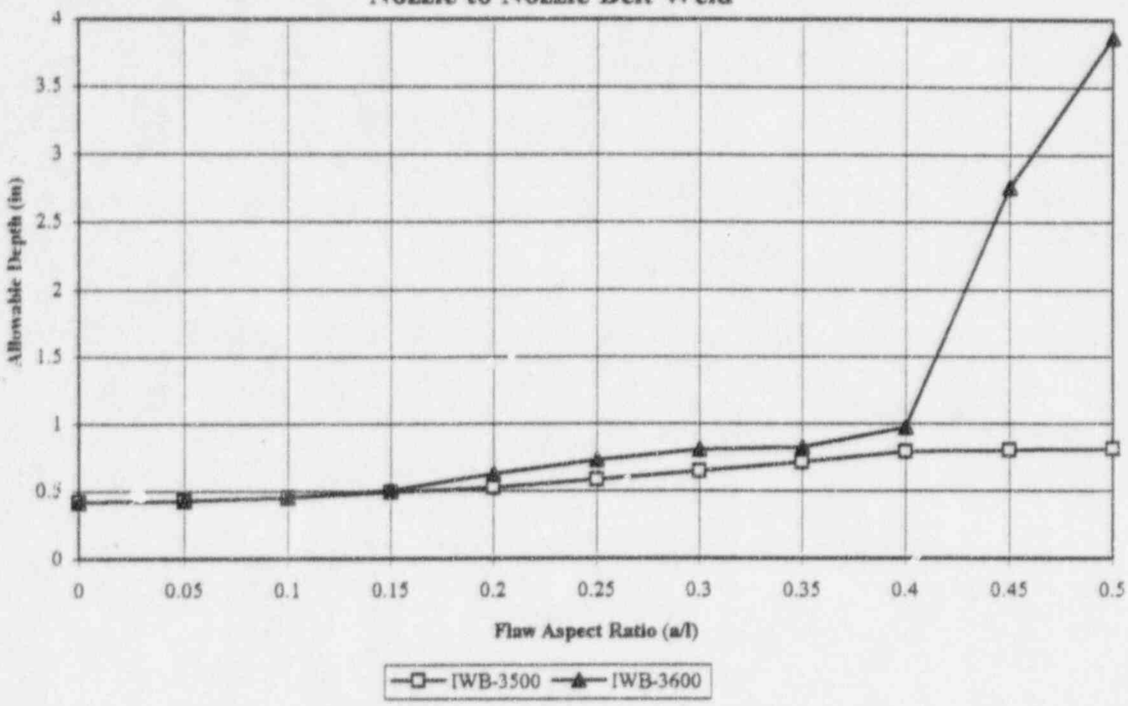
Axially-Oriented Flaws = 4"
Circumferentially-Oriented Flaws = 6"

* Note: For flaw indications found in Upper Nozzle Shell, need to also check Region C.

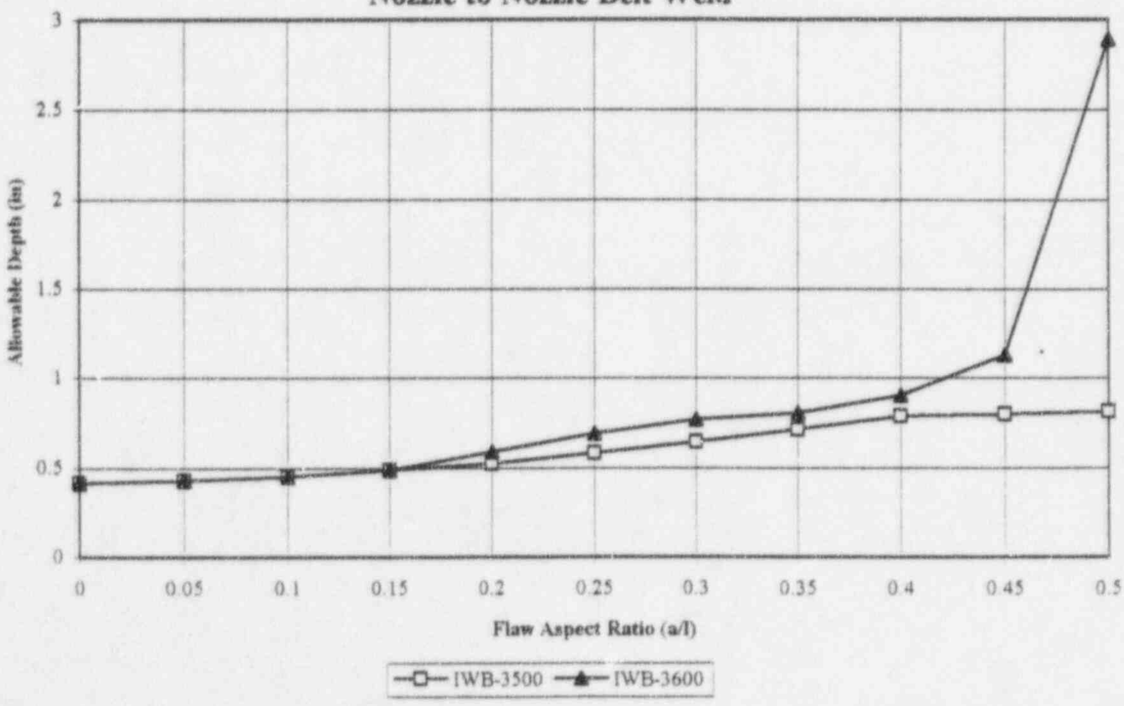
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

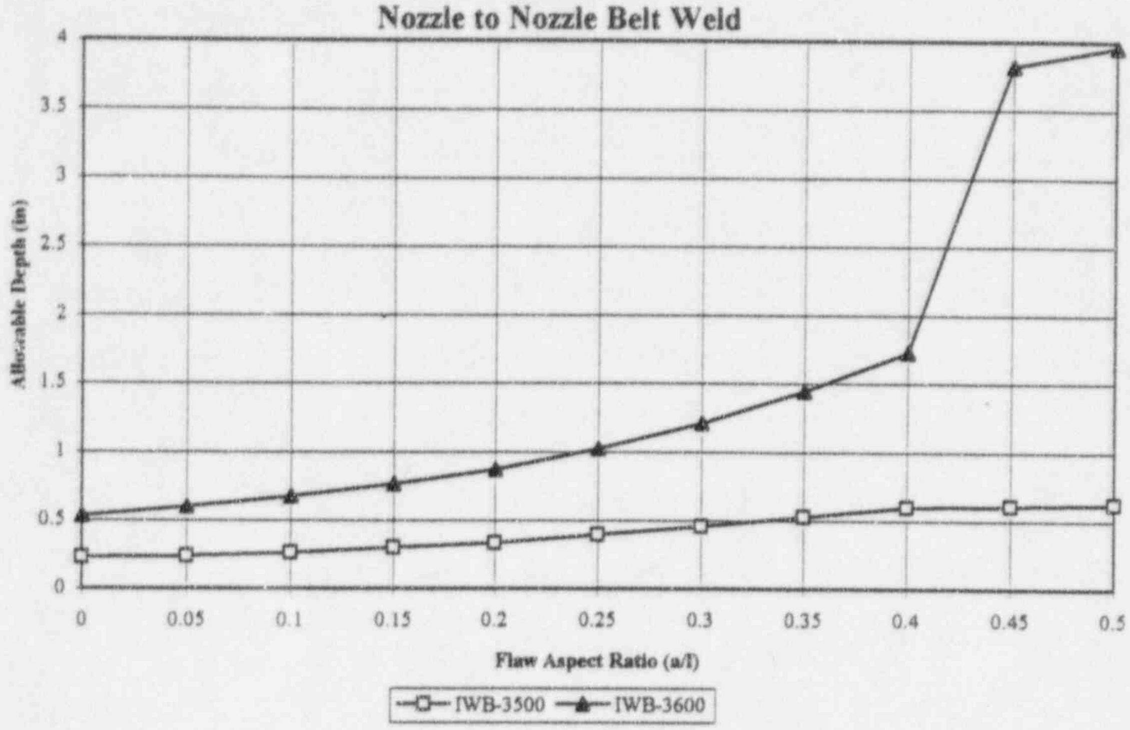
Inside Surface Circumferential Flaw
Nozzle to Nozzle Belt Weld



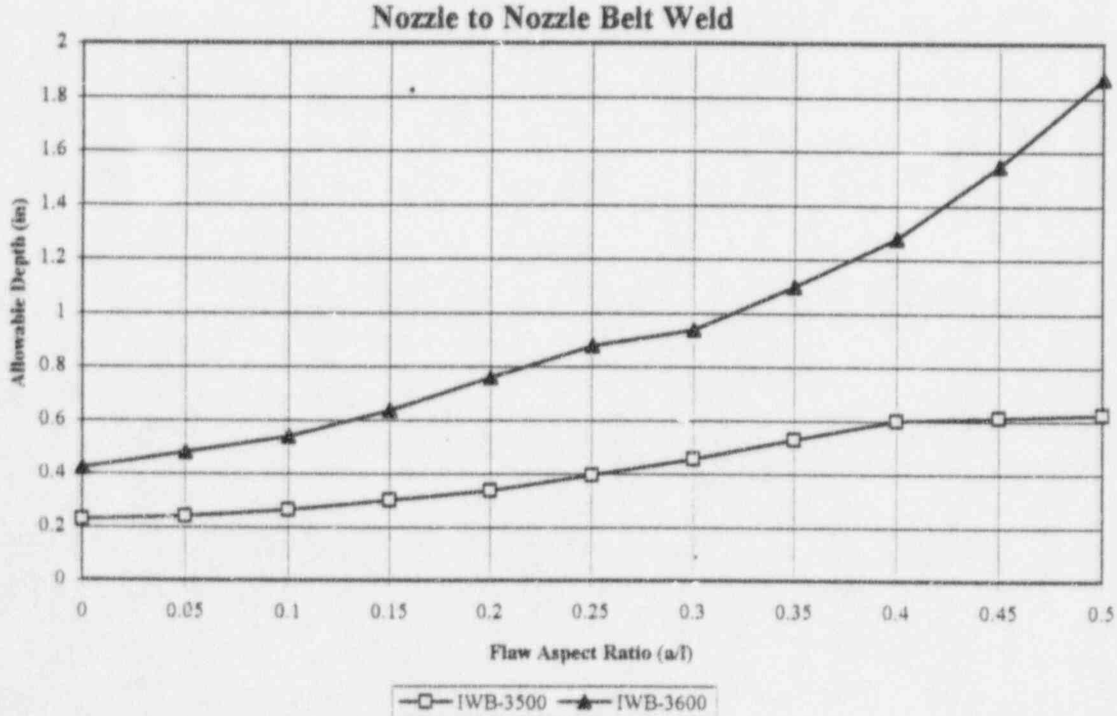
Inside Surface Axial Flaw
Nozzle to Nozzle Belt Weld

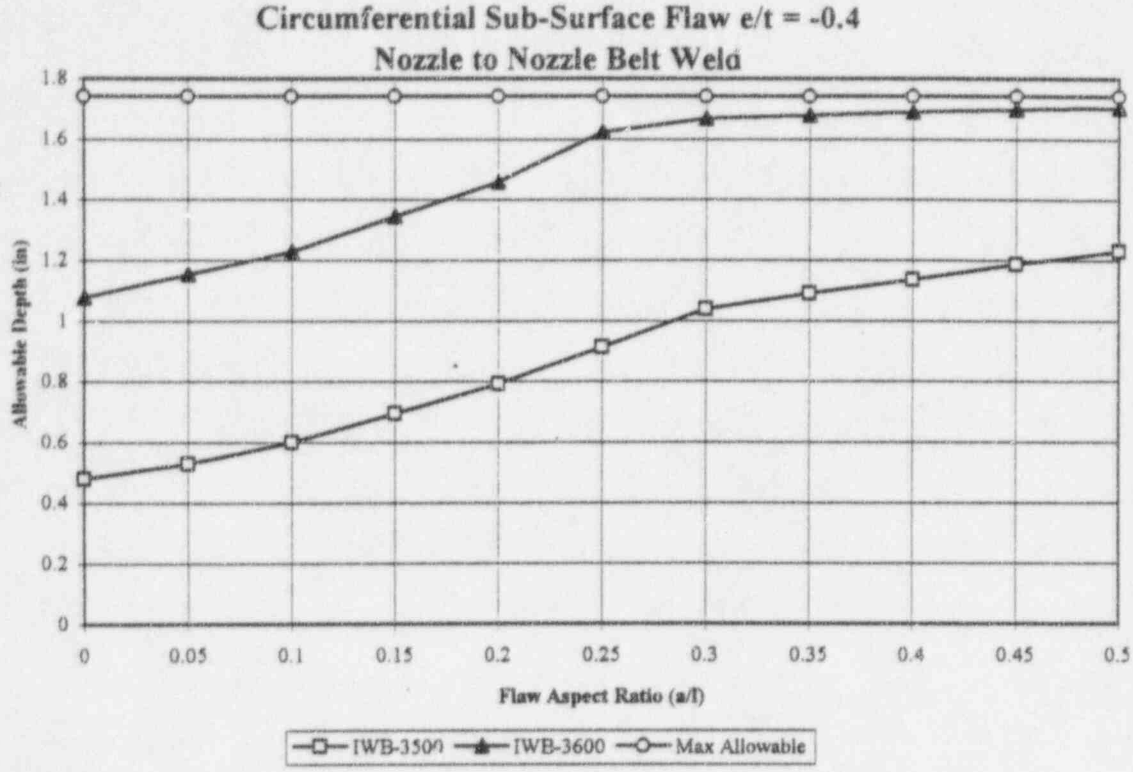


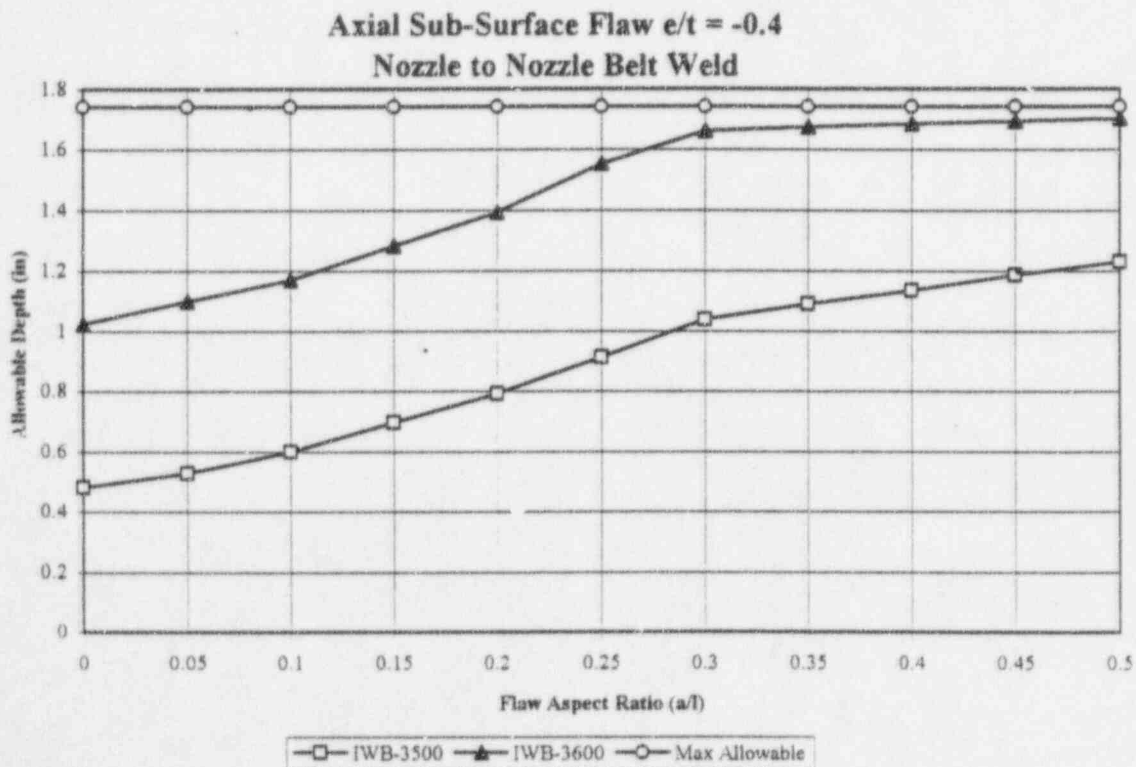
Outside Surface Circumferential Flaw
Nozzle to Nozzle Belt Weld



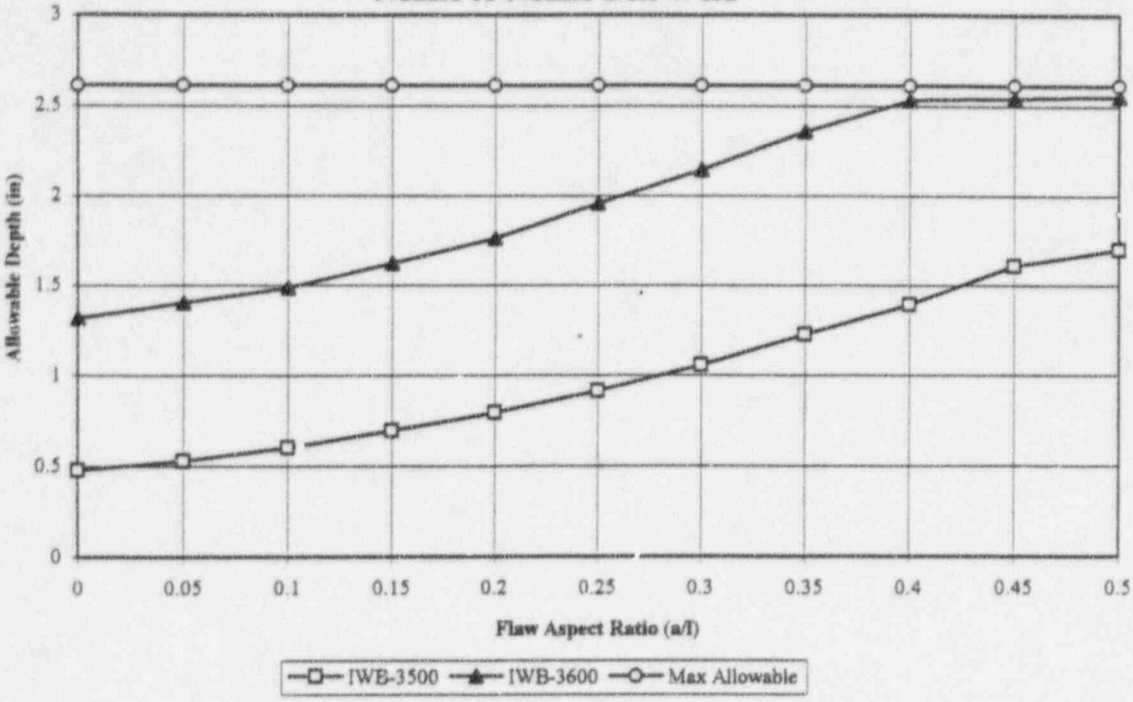
Outside Surface Axial Flaw
Nozzle to Nozzle Belt Weld



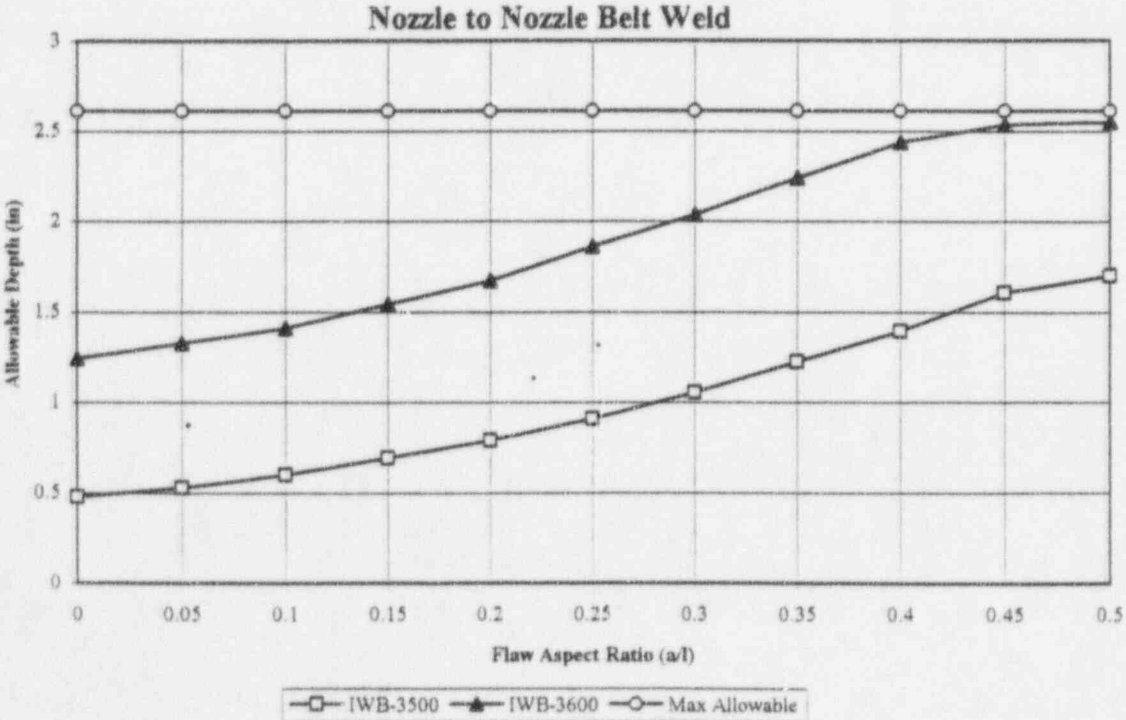

Circumferential Sub-Surface Flaw e/t = -0.4
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

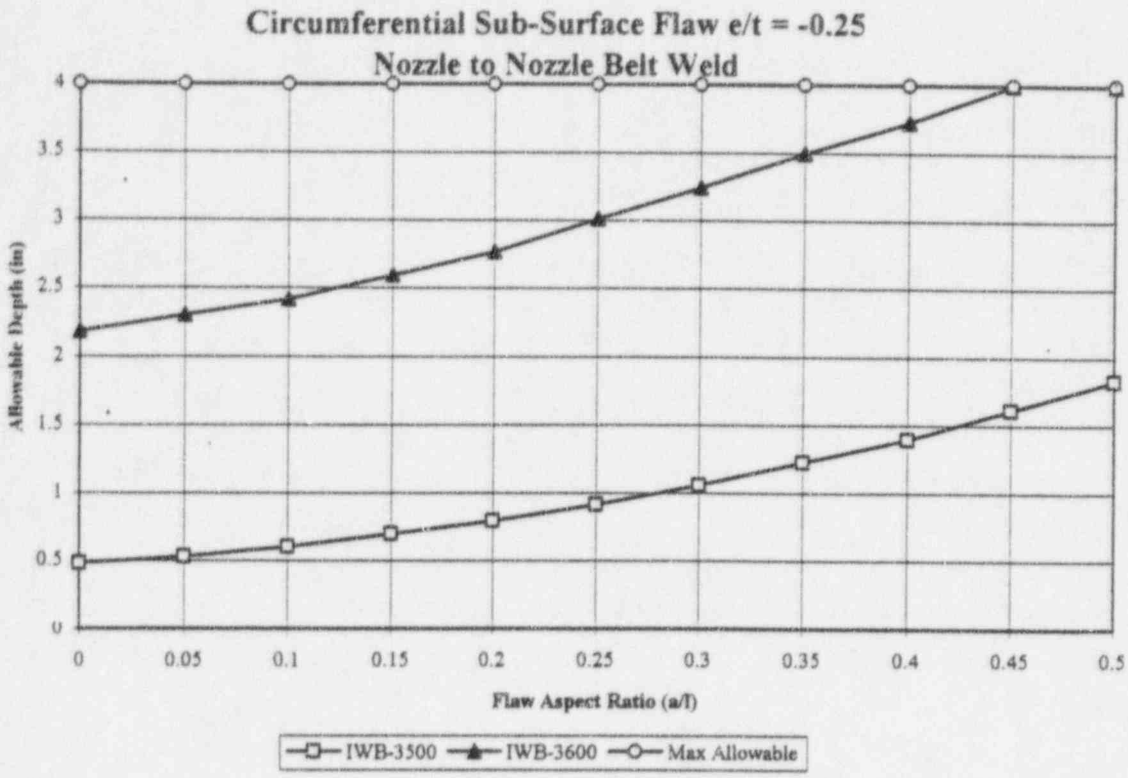

Axial Sub-Surface Flaw e/t = -0.4
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

Circumferential Sub-Surface Flaw e/t = -0.35
Nozzle to Nozzle Belt Weld

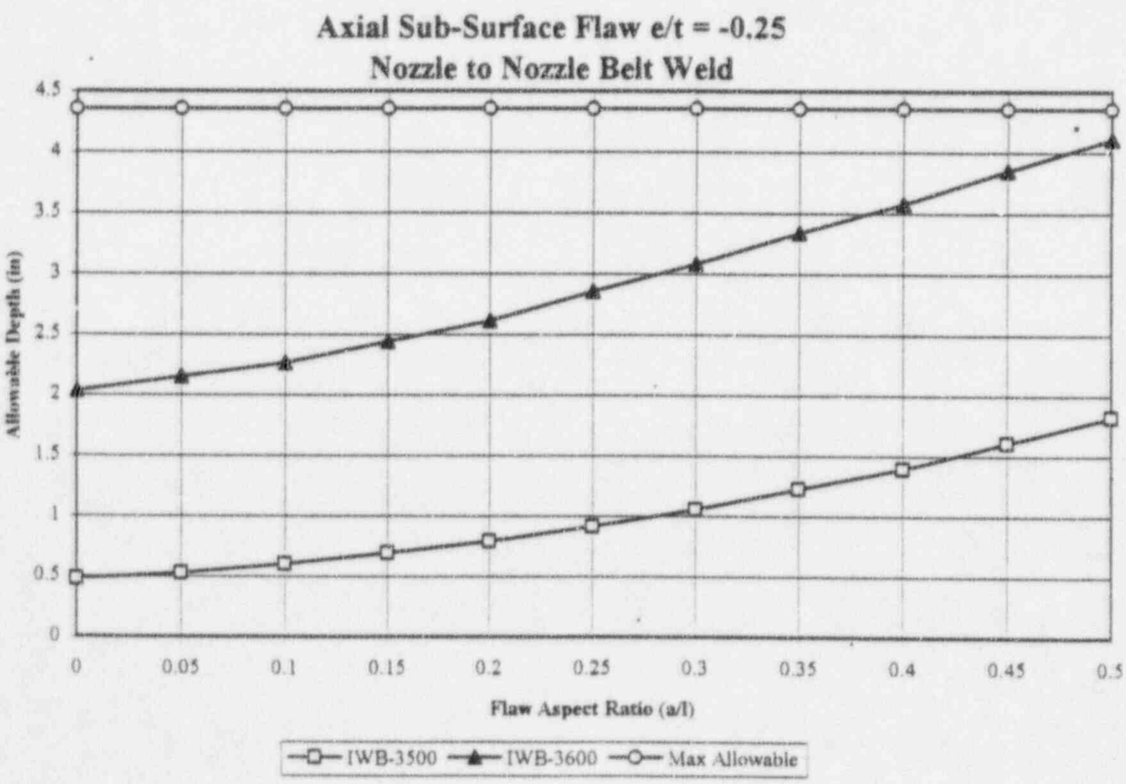


Axial Sub-Surface Flaw e/t = -0.35
Nozzle to Nozzle Belt Weld

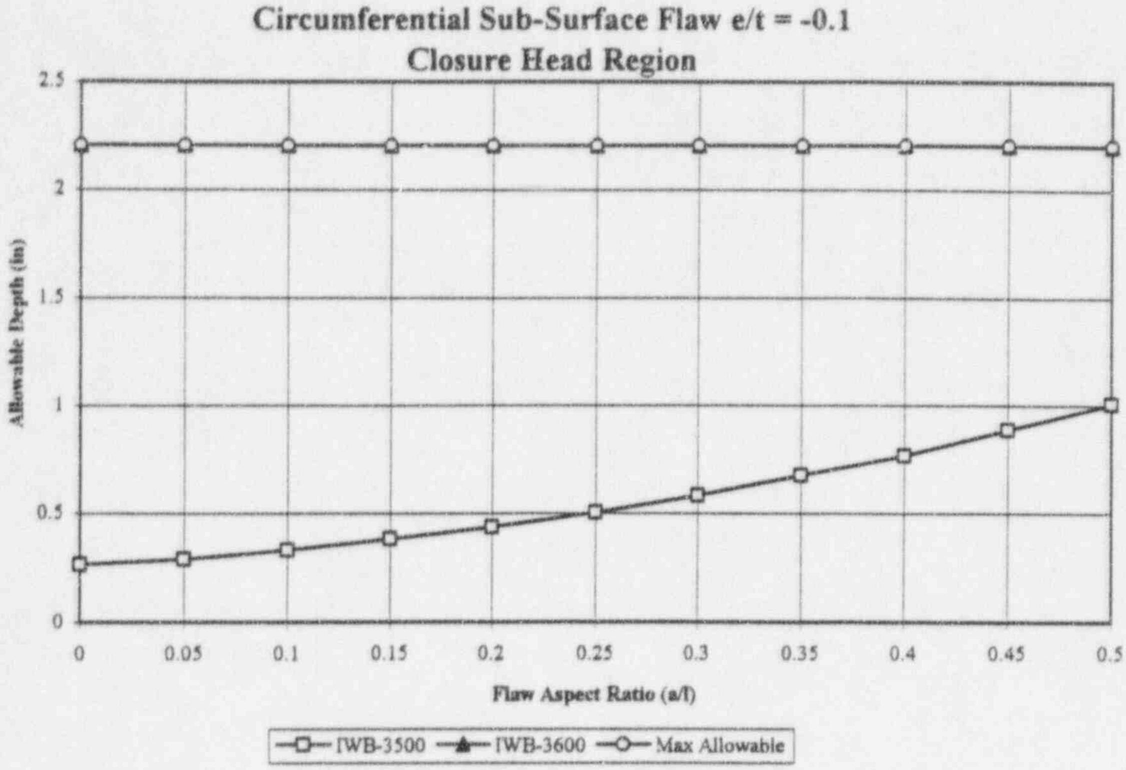


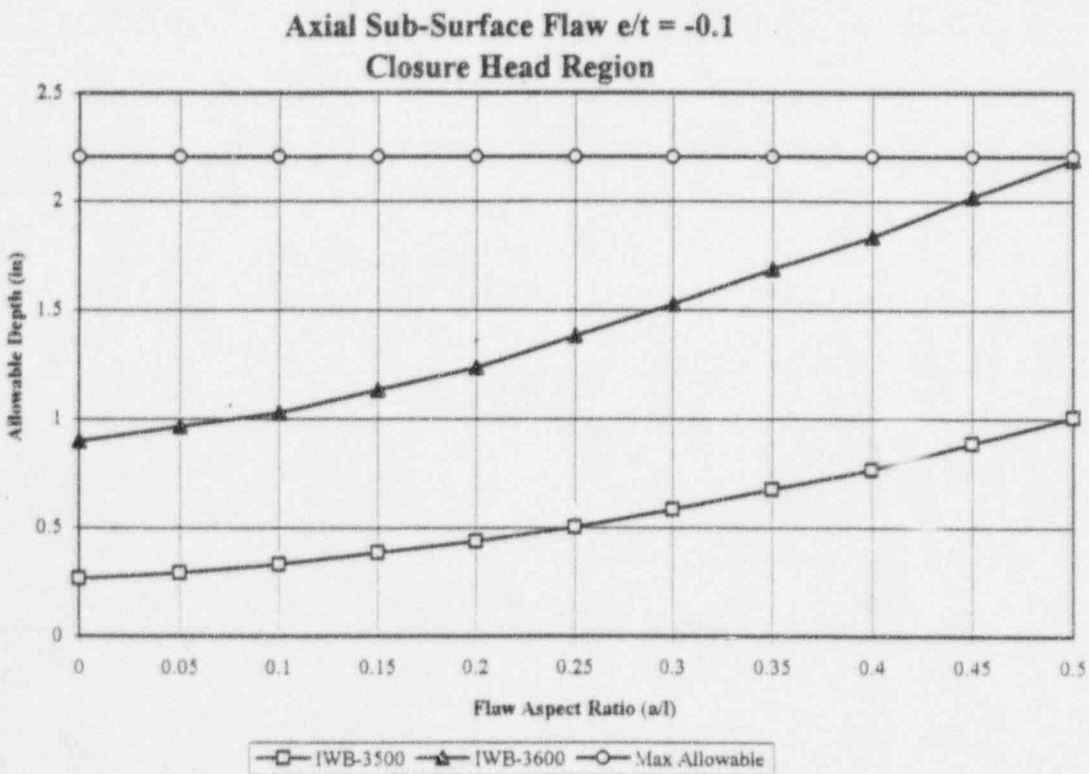


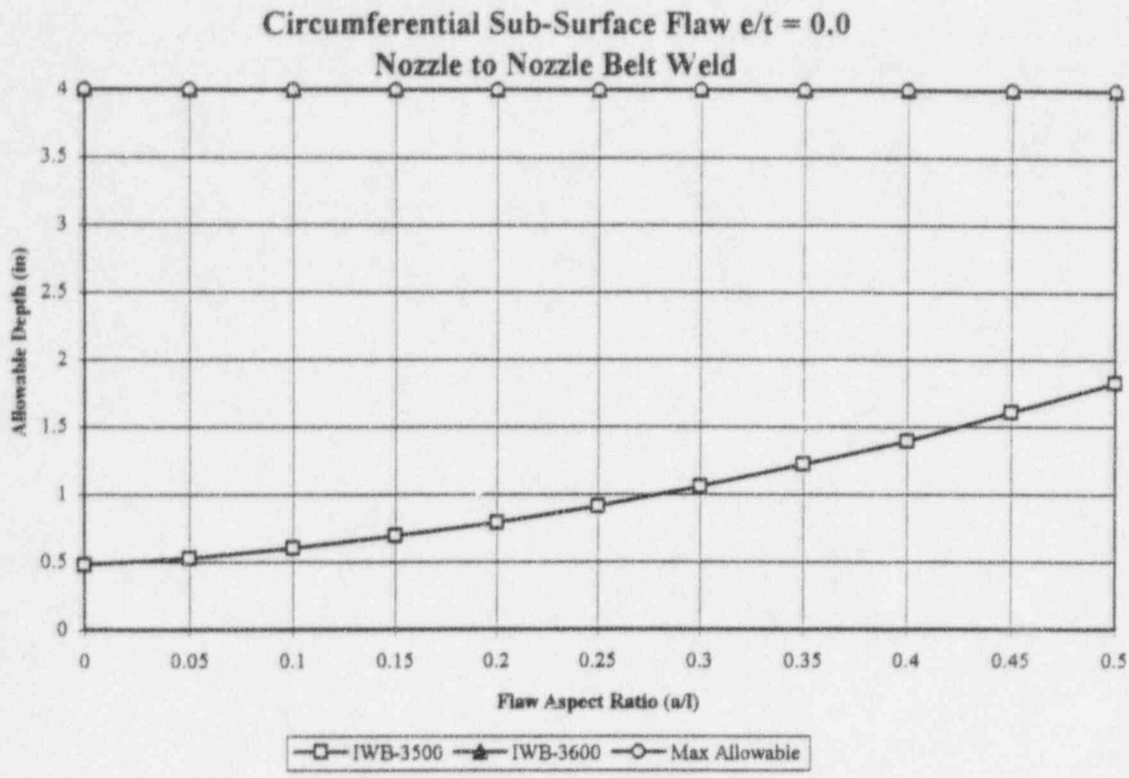
Circumferential Sub-Surface Flaw e/t = -0.25
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

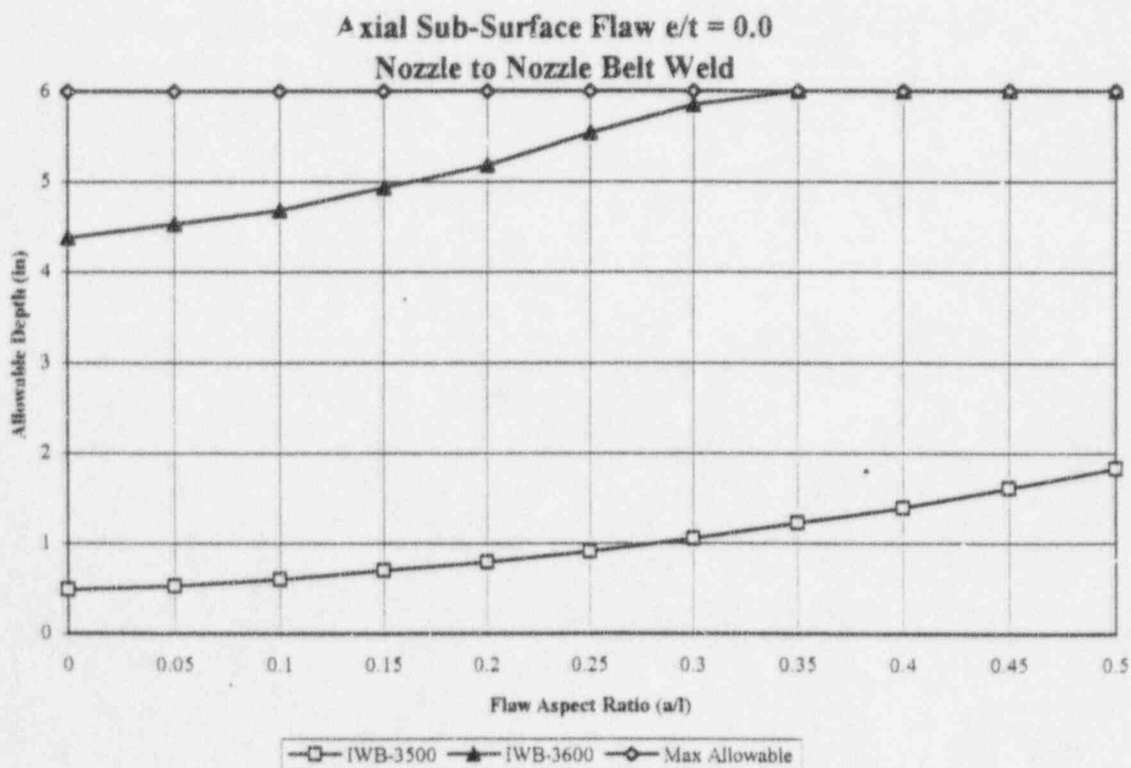


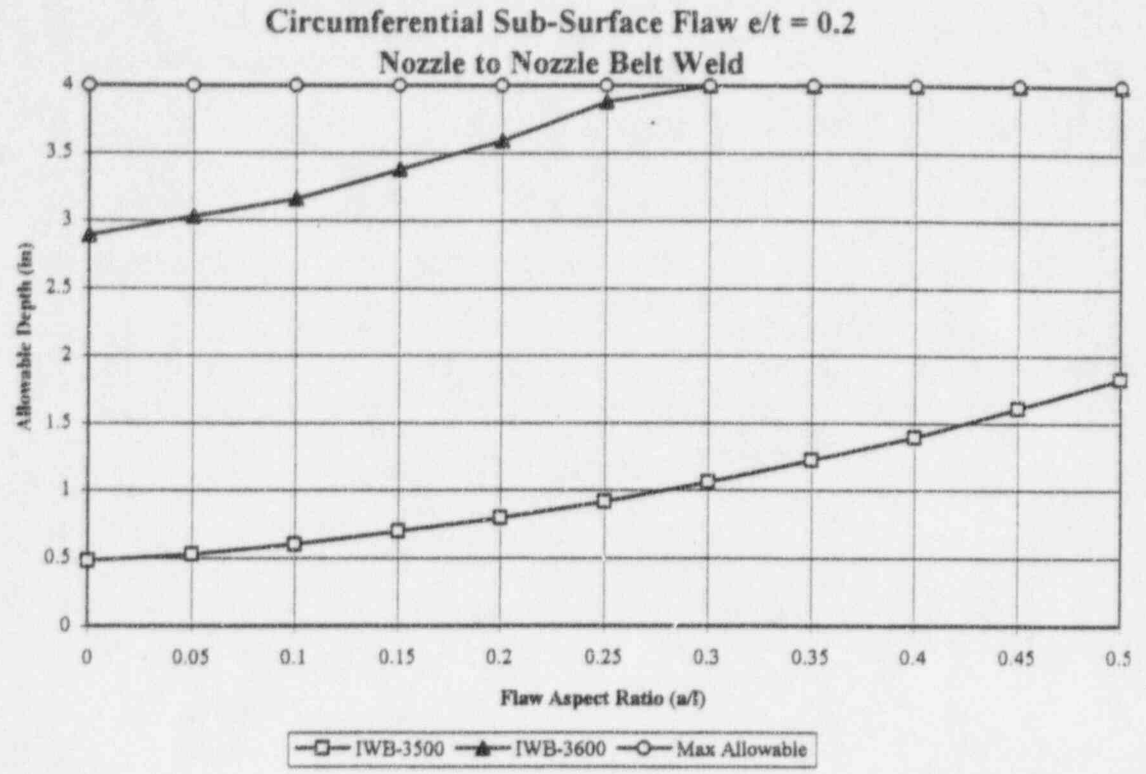
Axial Sub-Surface Flaw e/t = -0.25
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Circumferential Sub-Surface Flaw e/t = -0.1
Closure Head Region
Allowable Depth (in)
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

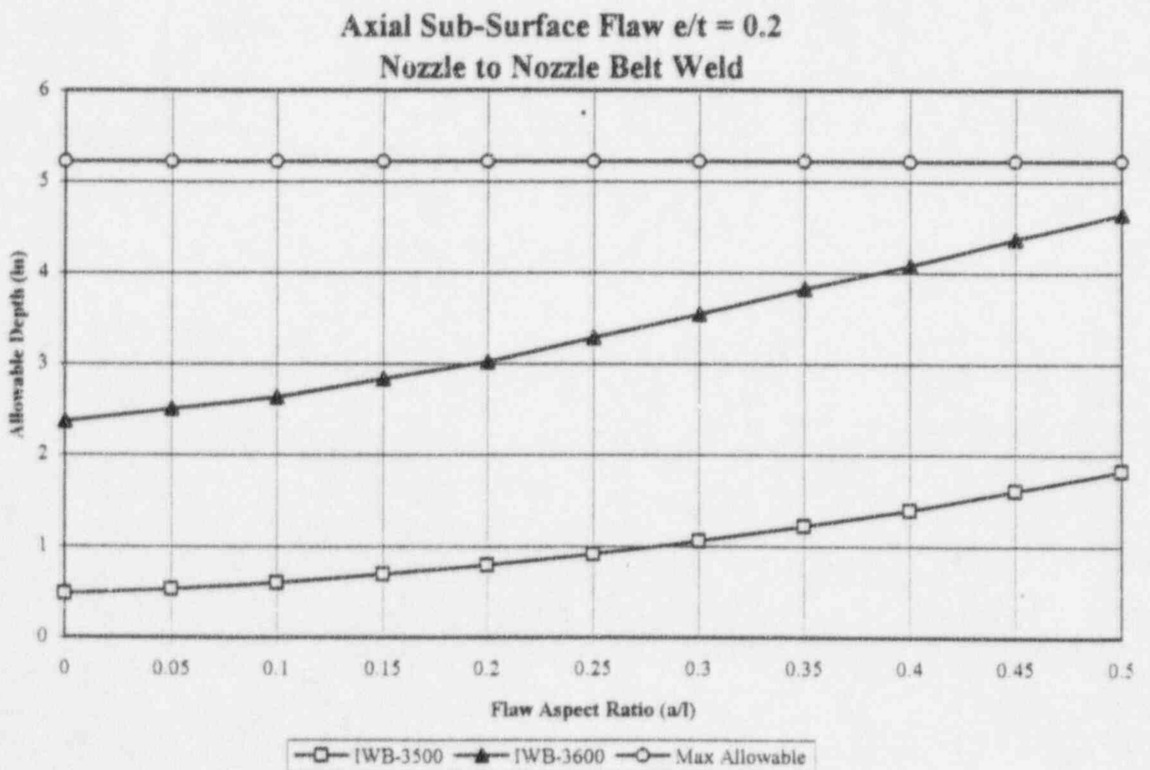

Axial Sub-Surface Flaw e/t = -0.1
Closure Head Region
Allowable Depth (in)
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Circumferential Sub-Surface Flaw e/t = 0.0
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

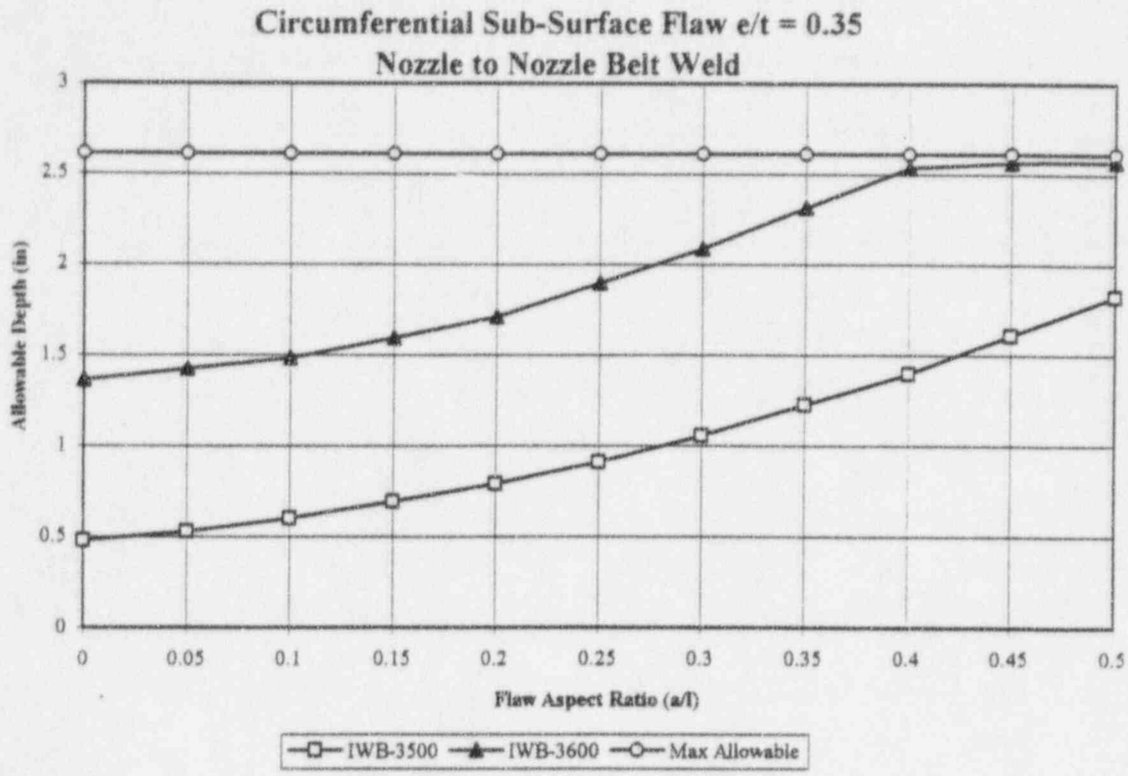

Axial Sub-Surface Flaw e/t = 0.0
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
0
1
2
3
4
5
6
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

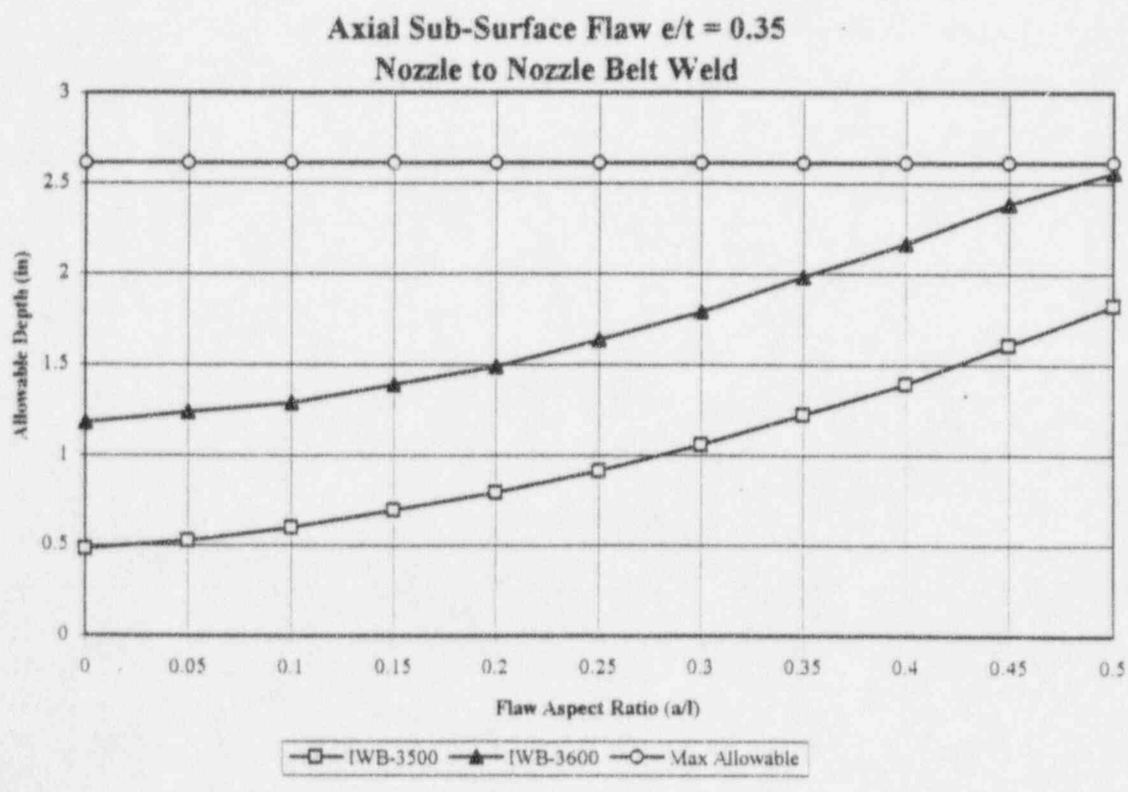


Circumferential Sub-Surface Flaw e/t = 0.2
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

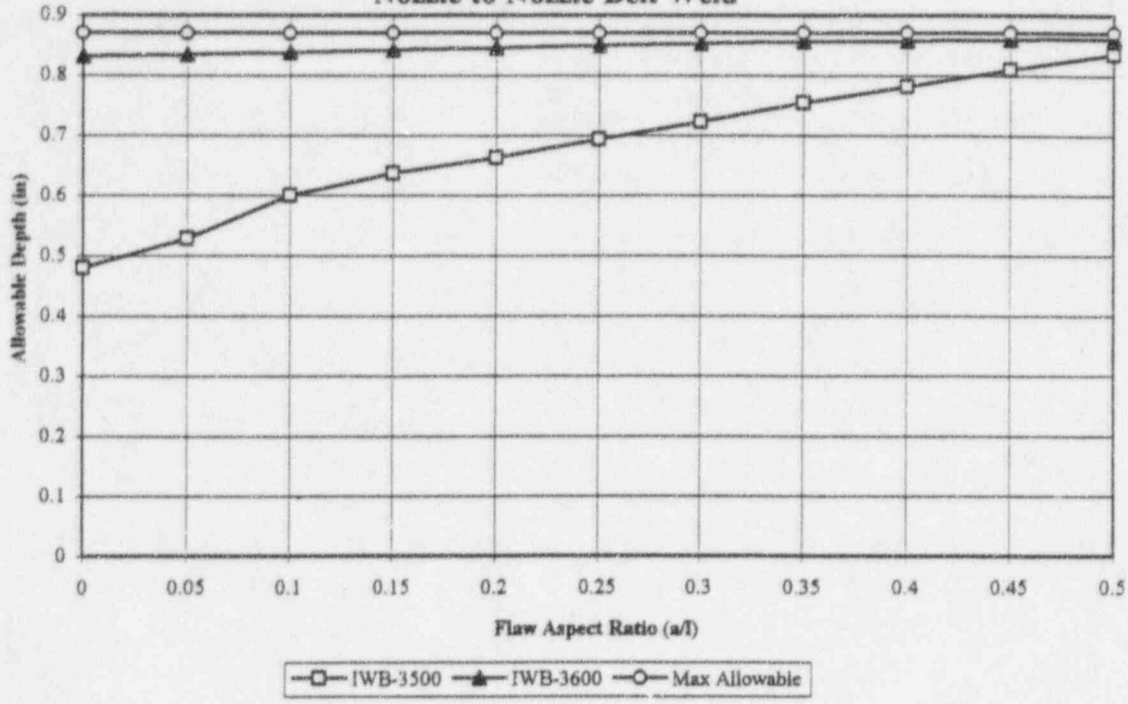


Axial Sub-Surface Flaw e/t = 0.2
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
6
5
4
3
2
1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

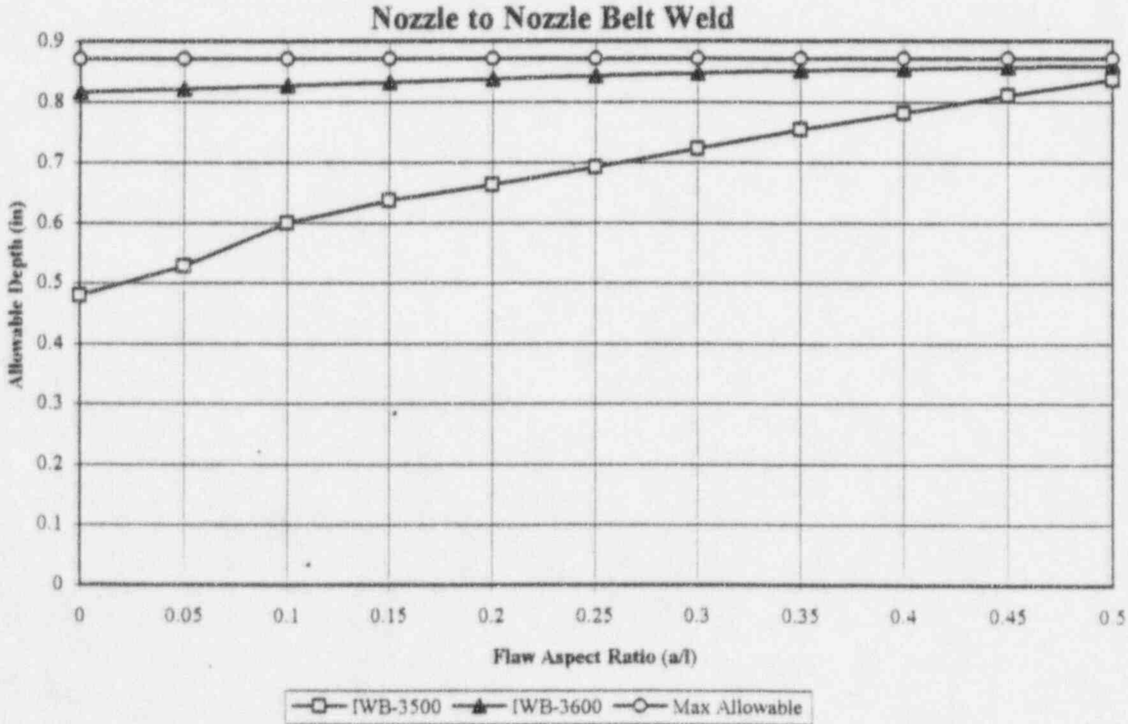

Circumferential Sub-Surface Flaw e/t = 0.35
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.35
Nozzle to Nozzle Belt Weld
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

Circumferential Sub-Surface Flaw e/t = 0.45
Nozzle to Nozzle Belt Weld



Axial Sub-Surface Flaw e/t = 0.45
Nozzle to Nozzle Belt Weld



APPENDIX F

Flaw Acceptance Diagrams for Region F Materials

Region F includes:

- Lower Nozzle Shell *
- Nozzle Belt to Upper Shell Welds (WF169-1, SA1769)
- Upper Shells (A1-207-1, 2)
- Lower Shell (A2-207-1)**

Based on Minimum Thickness = 8.4375"

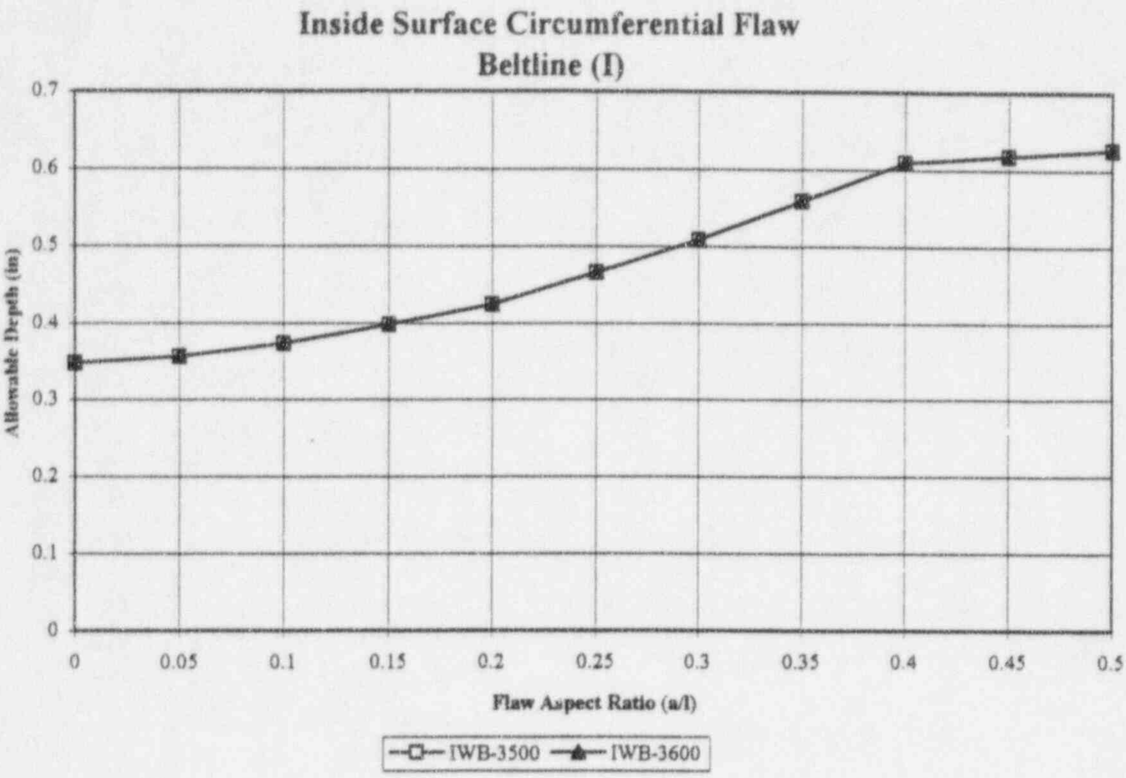
Default Maximum Allowable Flaw Sizes for All Charts:

Axially-Oriented Flaws = 2.8"
Circumferentially-Oriented Flaws = 4.2"

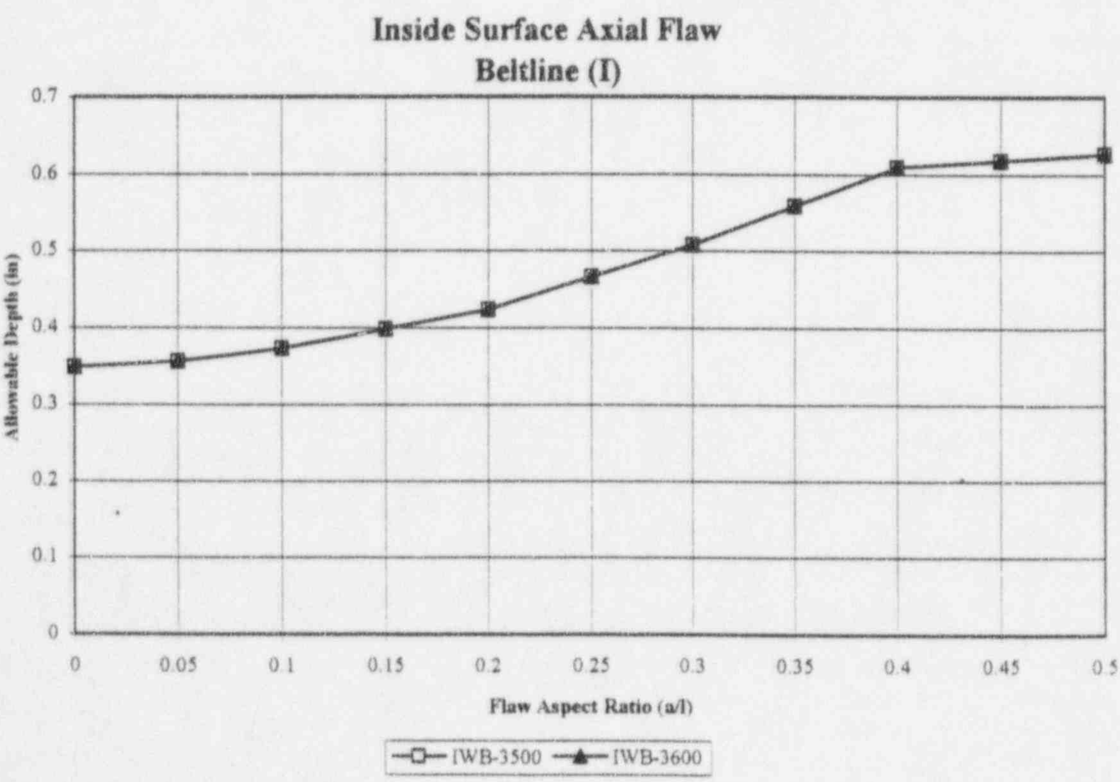
Notes: * Includes all irradiated portions of Lower Nozzle Shell. For unirradiated portions, see Region D.
** For flaw indications found in Lower Shell, need to also check Region H.

General Notes:

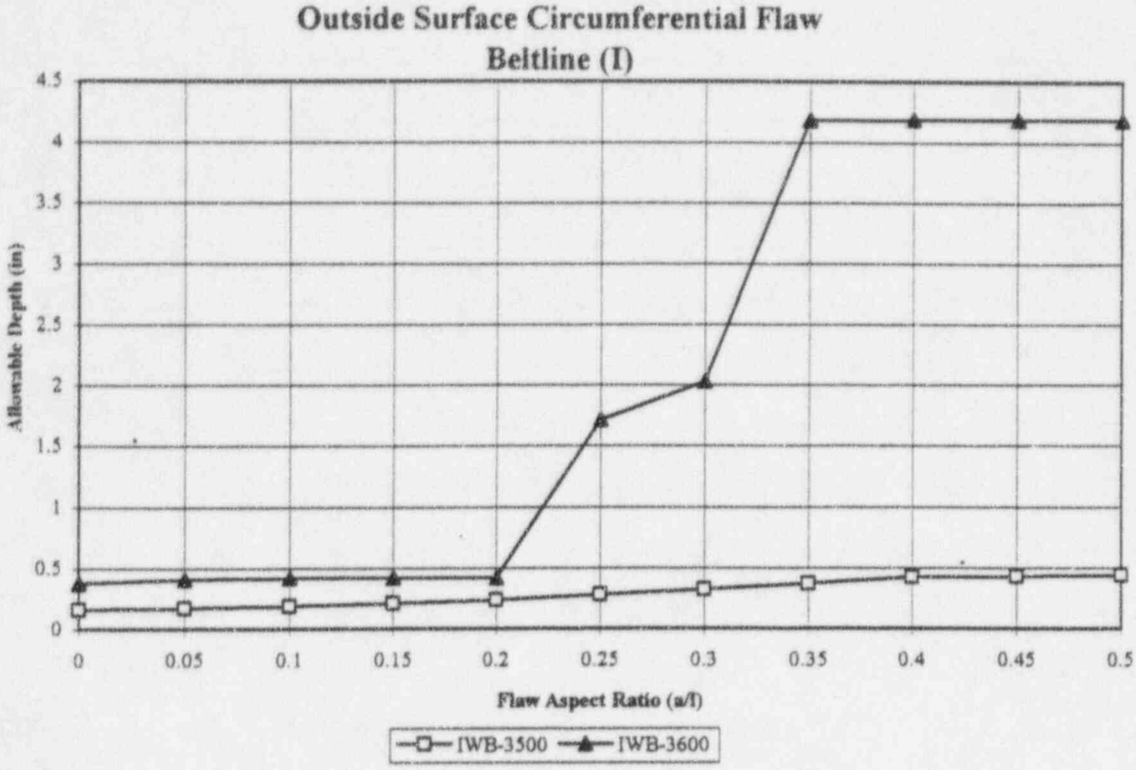
1.	t	=	vessel wall thickness (including cladding thickness of 3/16").
2.	e	=	distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3.	a	=	total radial depth of flaw, for surface flaws.
4.	2a	=	total radial depth of flaw, for subsurface flaws.
5.	ℓ	=	length of flaw parallel to vessel wall.



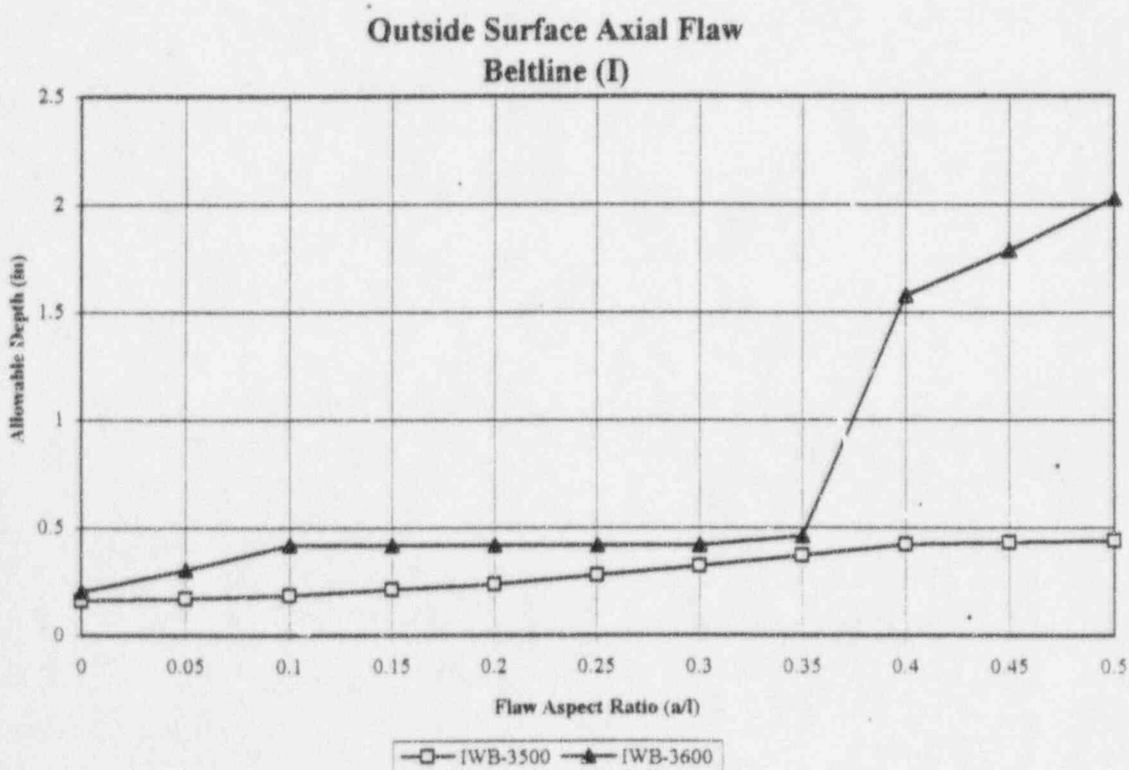
Inside Surface Circumferential Flaw
Beltline (I)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600



Inside Surface Axial Flaw
Beltline (I)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

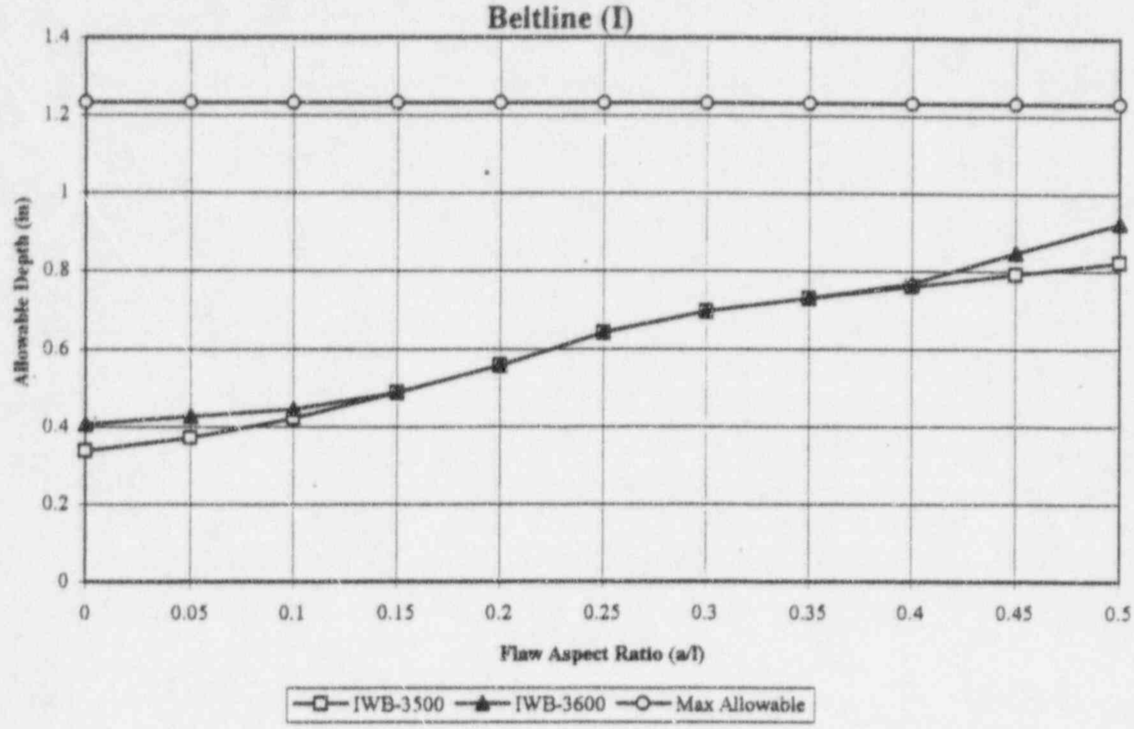


Outside Surface Circumferential Flaw
Beltline (I)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

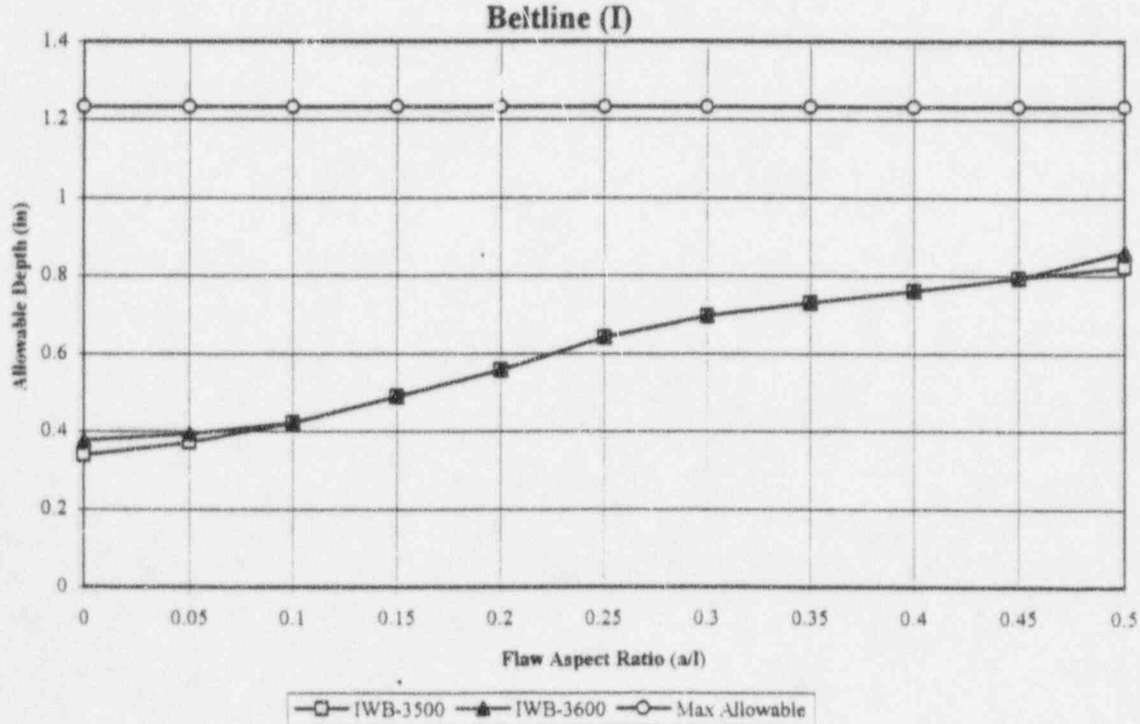


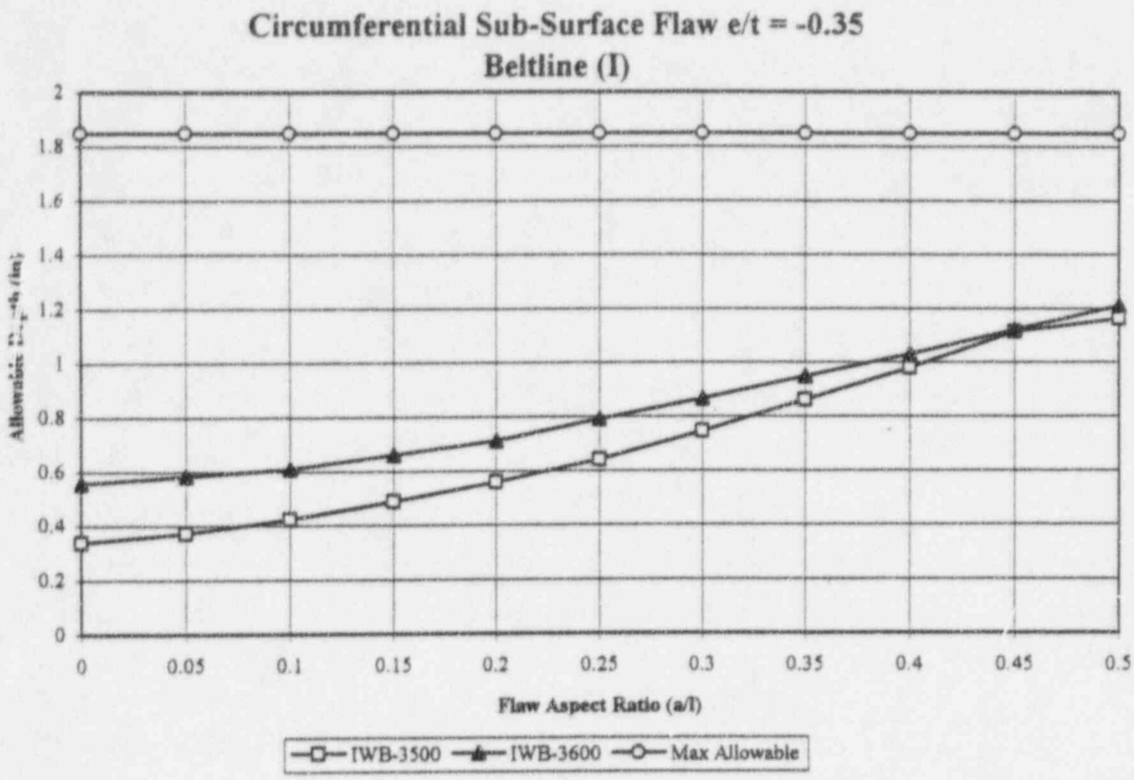
Outside Surface Axial Flaw
Beltline (I)
2.5
2
1.5
1
0.5
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

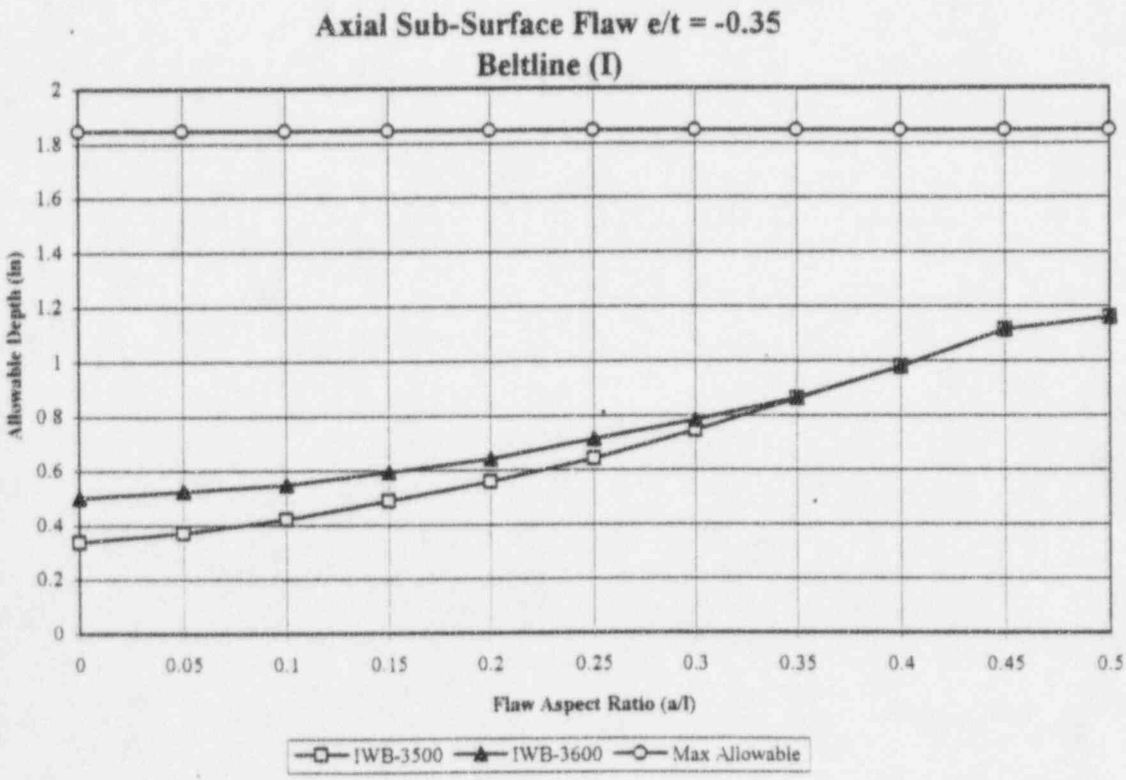
Circumferential Sub-Surface Flaw e/t = -0.4
Beltline (I)

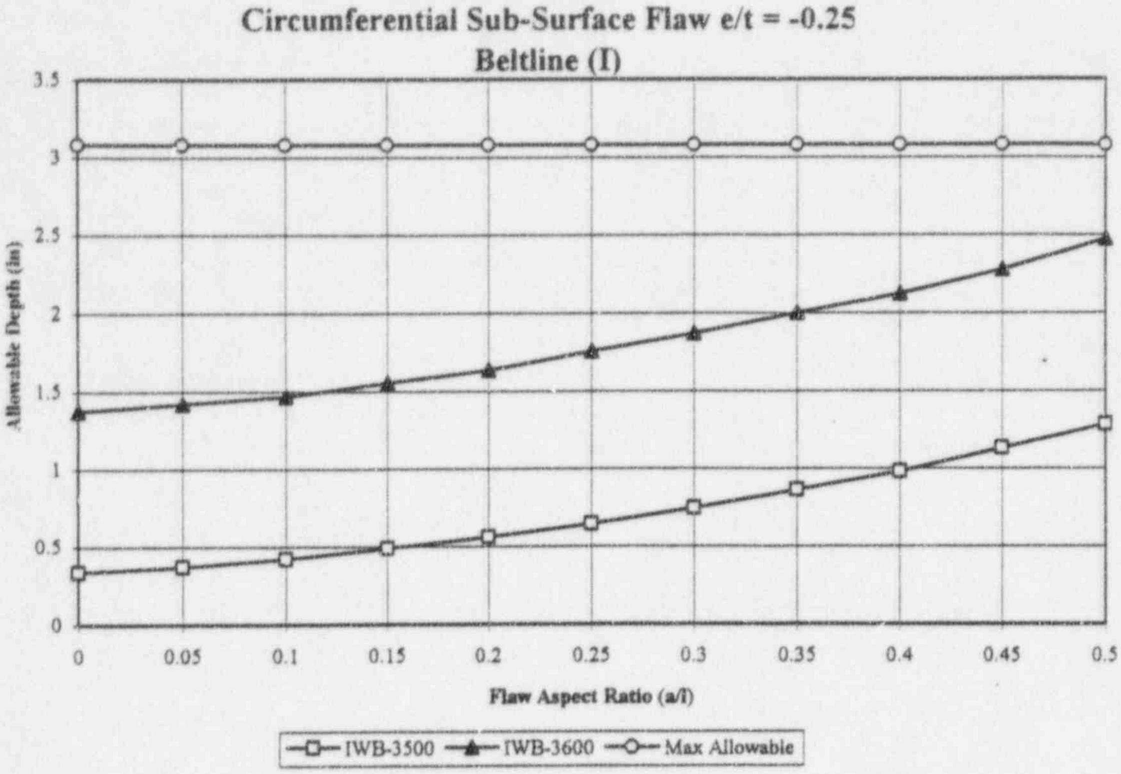


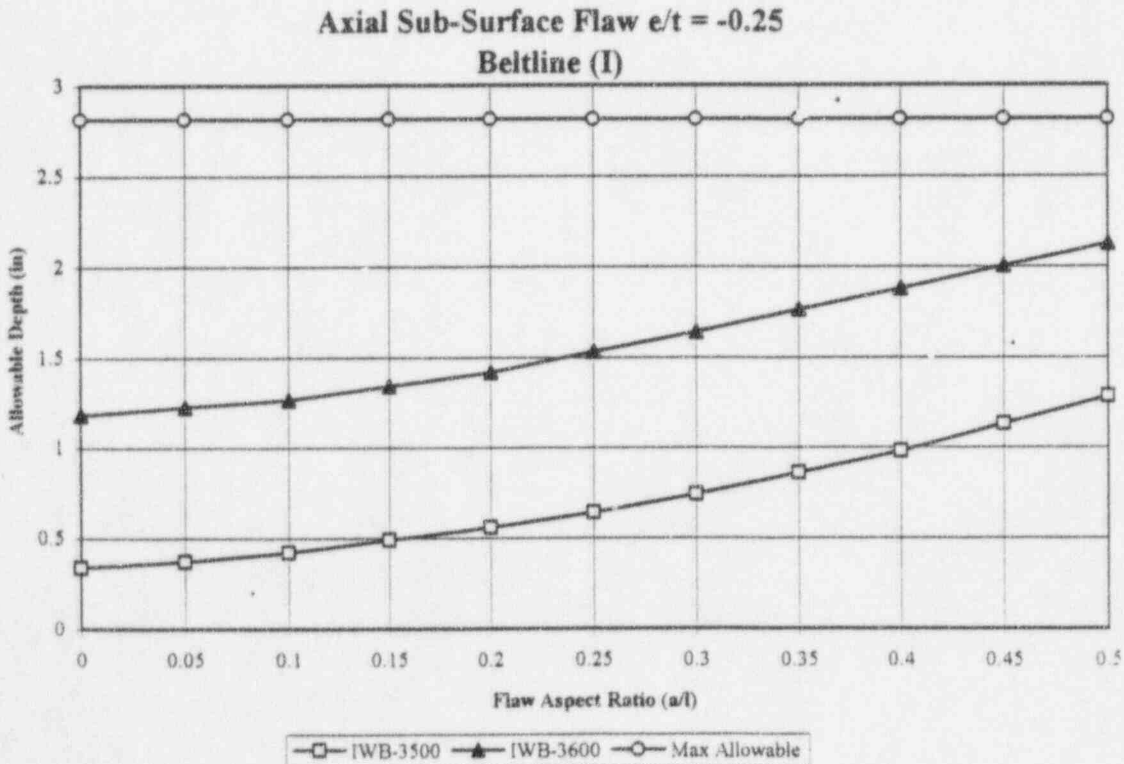
Axial Sub-Surface Flaw e/t = -0.4
Beltline (I)



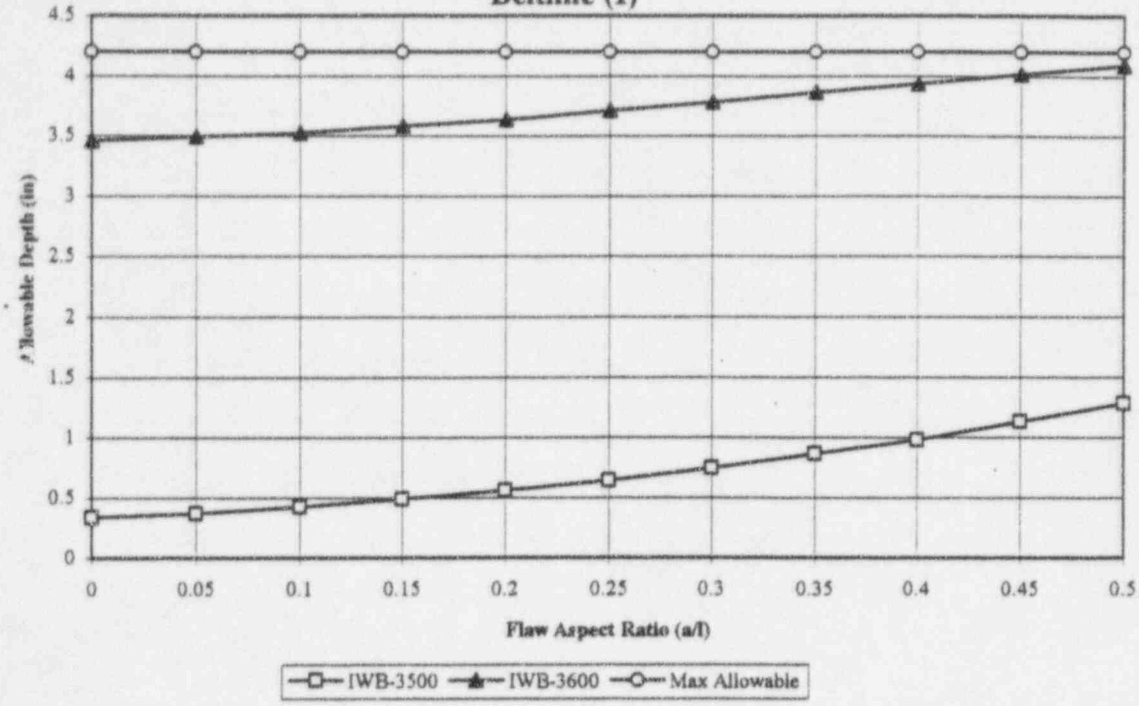

Circumferential Sub-Surface Flaw e/t = -0.35
Beltline (I)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.35
Beltline (I)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

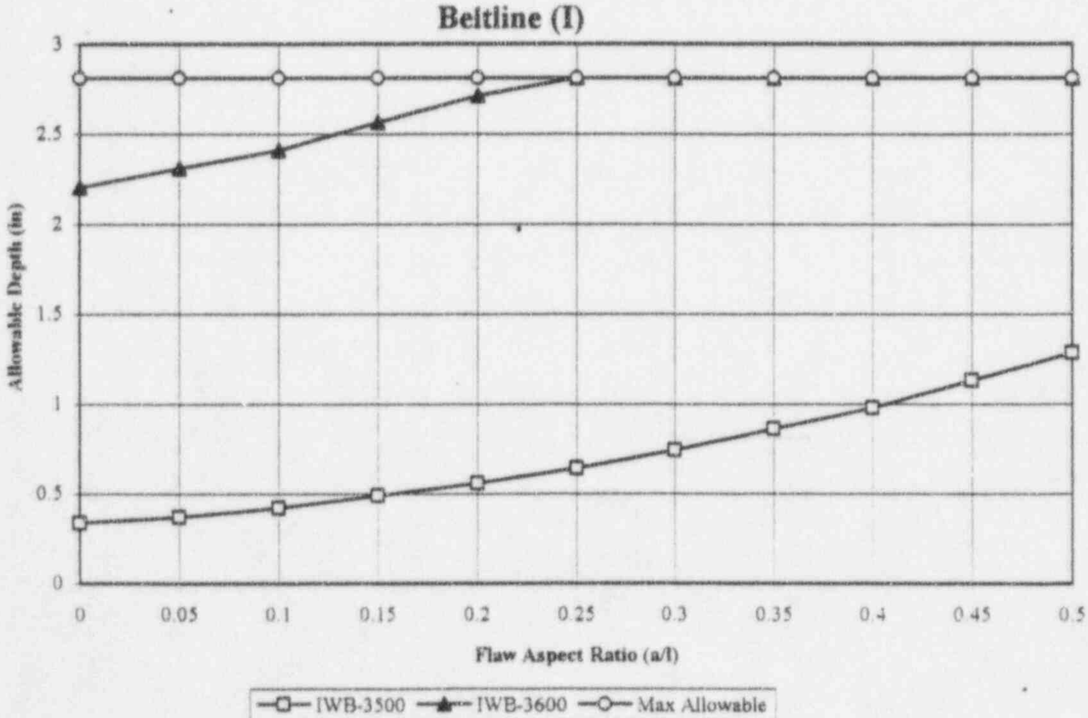

Circumferential Sub-Surface Flaw e/t = -0.25
Beltline (I)
Allowable Depth (in)
0
0.5
1
1.5
2
2.5
3
3.5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.25
Beltline (I)
Allowable Depth (in)
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

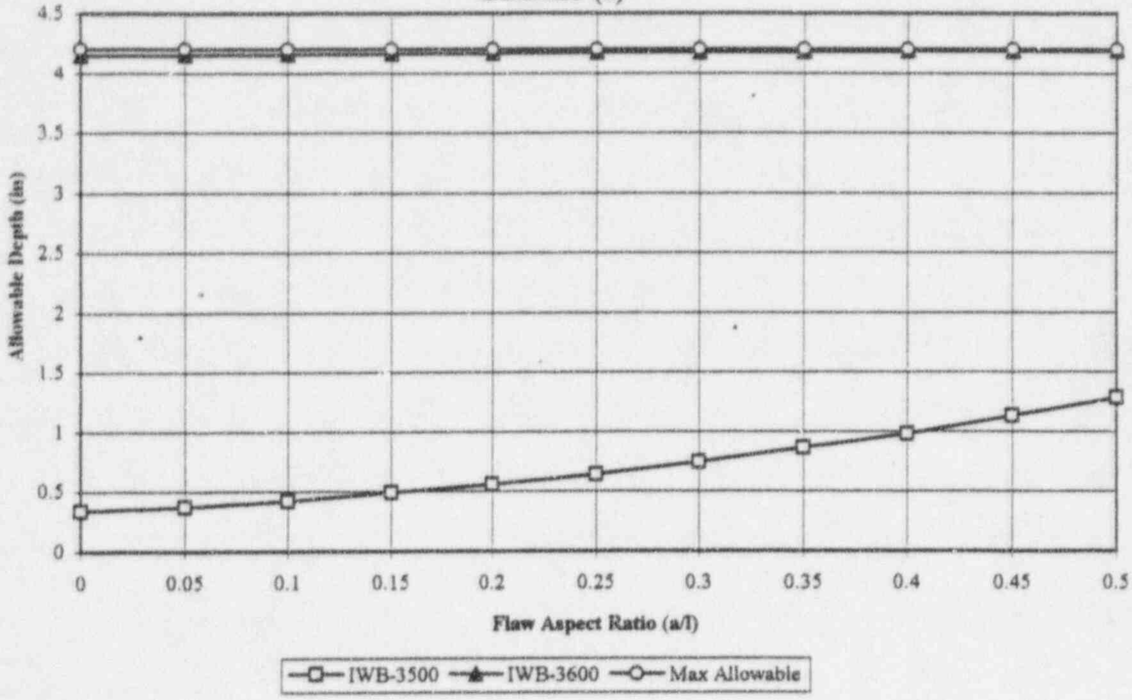
Circumferential Sub-Surface Flaw e/t = -0.1
Beltline (I)



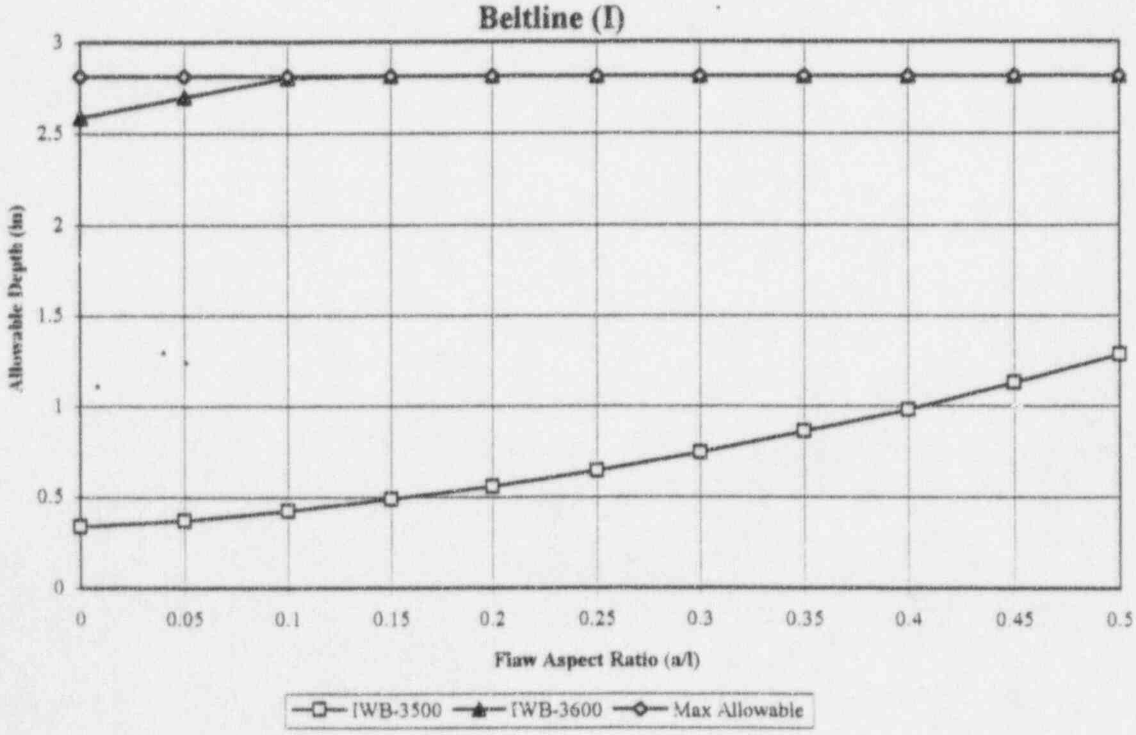
Axial Sub-Surface Flaw e/t = -0.1
Beltline (I)

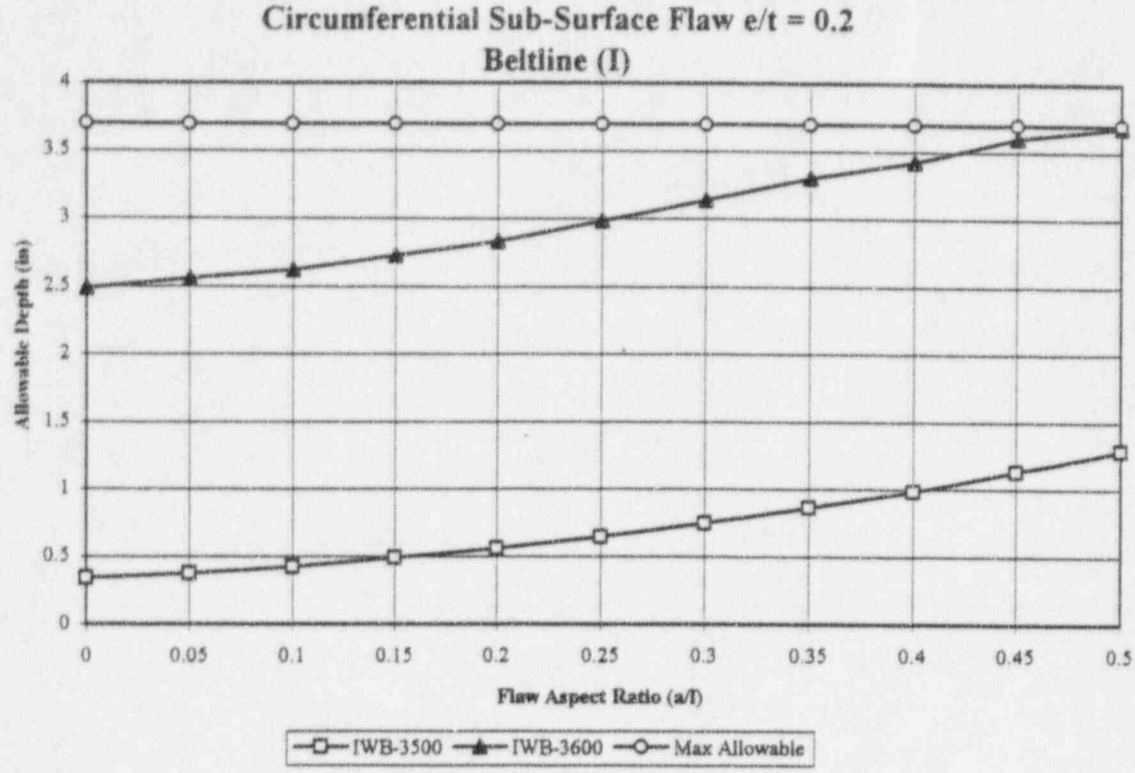


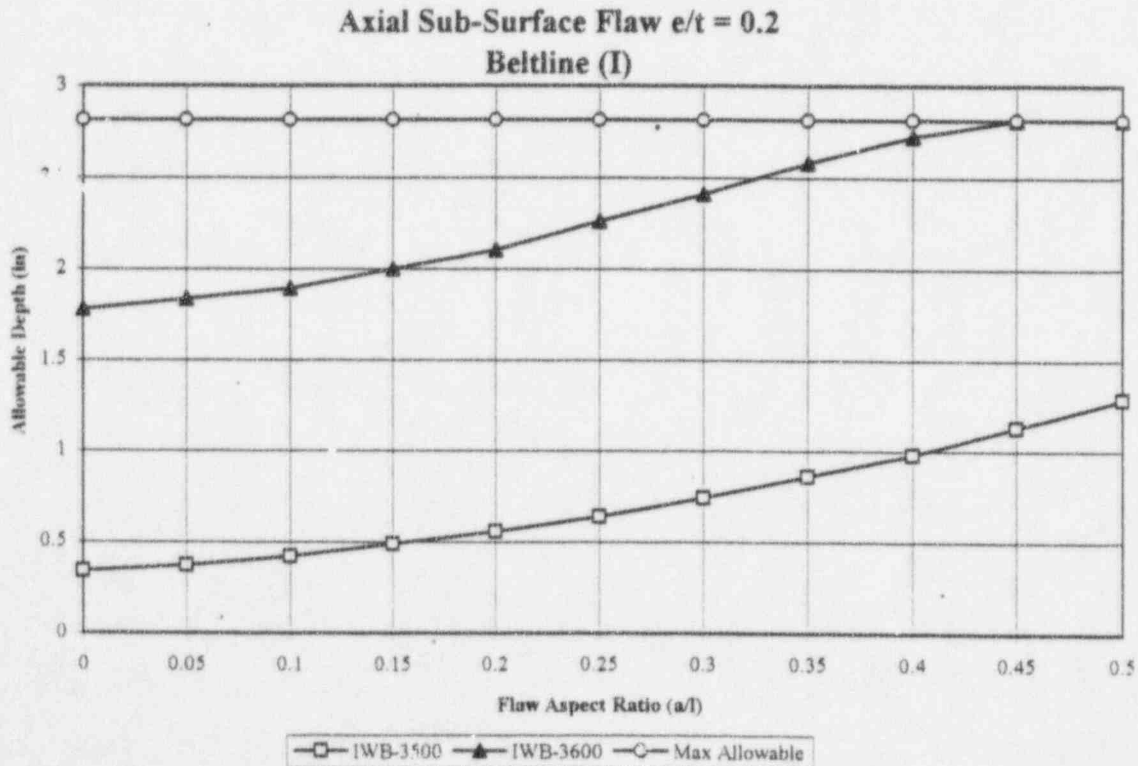
Circumferential Sub-Surface Flaw e/t = 0.0
Beltline (I)



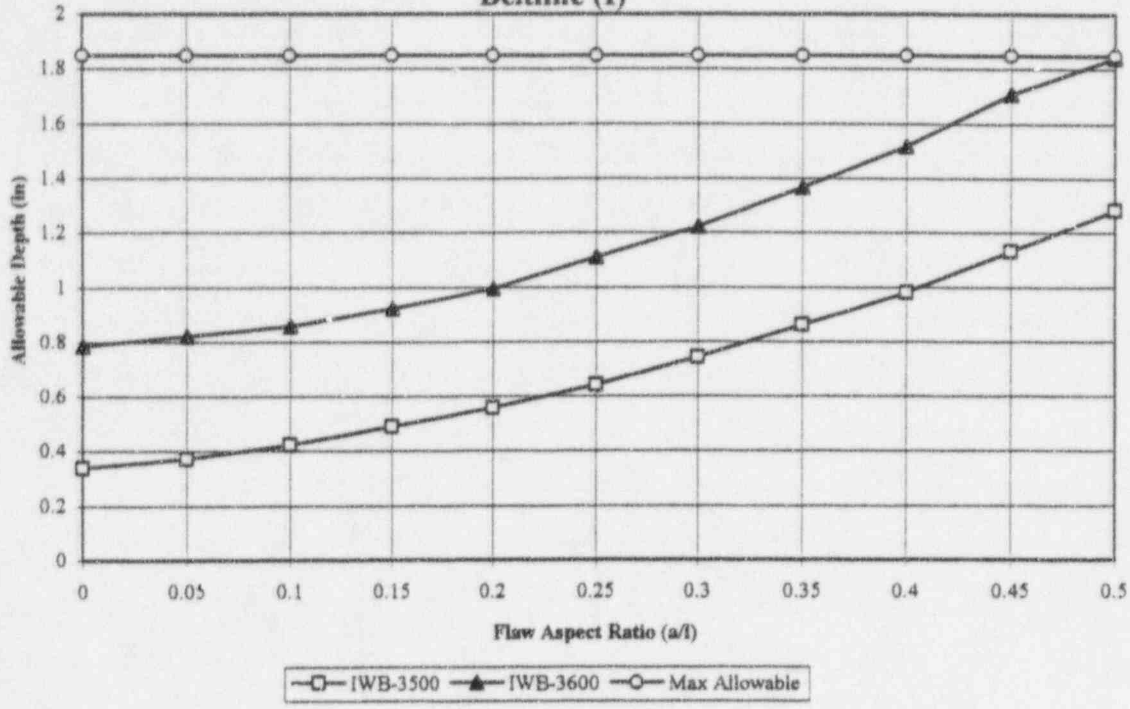
Axial Sub-Surface Flaw e/t = 0.0
Beltline (I)



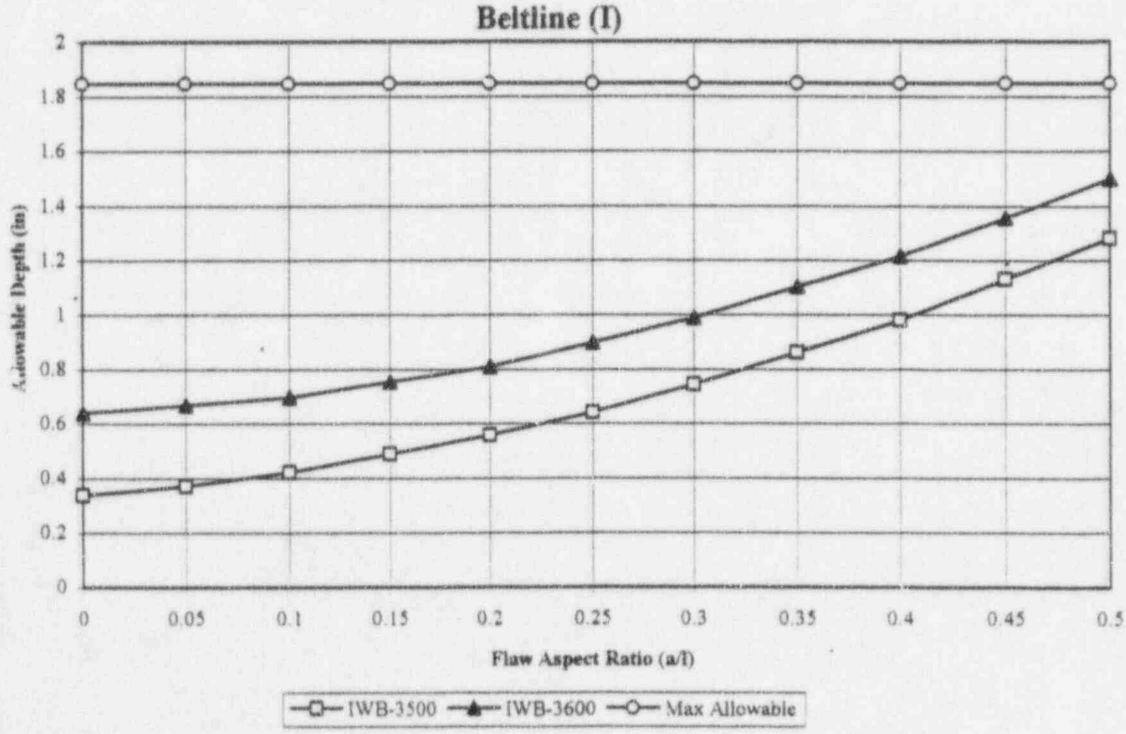

Circumferential Sub-Surface Flaw e/t = 0.2
Beltline (I)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.2
Beltline (I)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

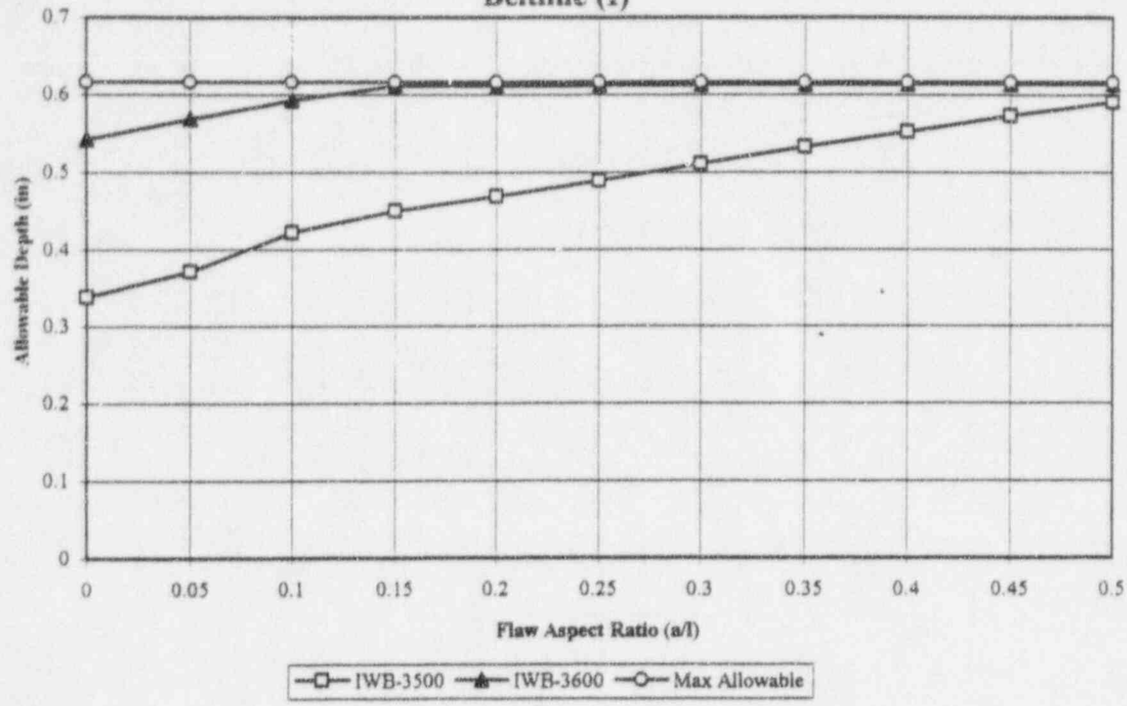
Circumferential Sub-Surface Flaw e/t = 0.35
Beltline (I)



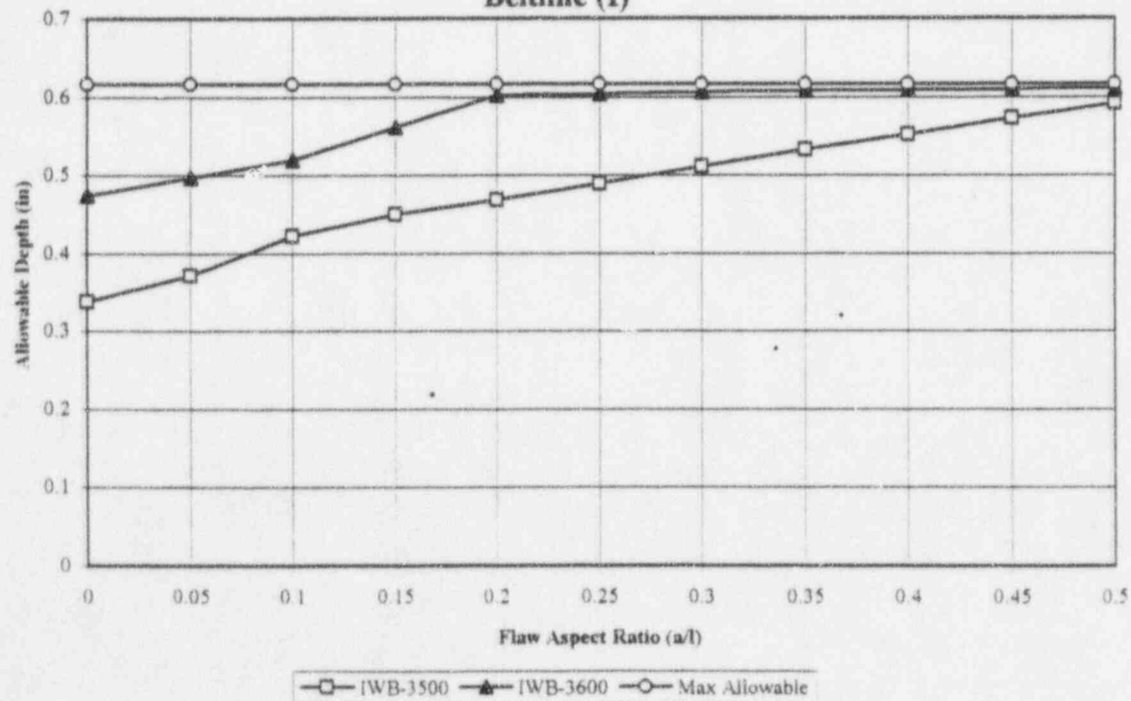
Axial Sub-Surface Flaw e/t = 0.35
Beltline (I)



Circumferential Sub-Surface Flaw e/t = 0.45
Beltline (I)



Axial Sub-Surface Flaw e/t = 0.45
Beltline (I)



APPENDIX G

Flaw Acceptance Diagrams for Region G Materials

Region G includes:

- Lower Shell (A2-207-1) *
- Upper Shell Longitudinal Welds (WF8,18)
- Upper Shell to Lower Shell Weld (WF 70)
- Lower Shell Longitudinal Weld (SA1580)**

Based on Minimum Thickness = 8.4375"

Default Maximum Allowable Flaw Sizes for All Charts:

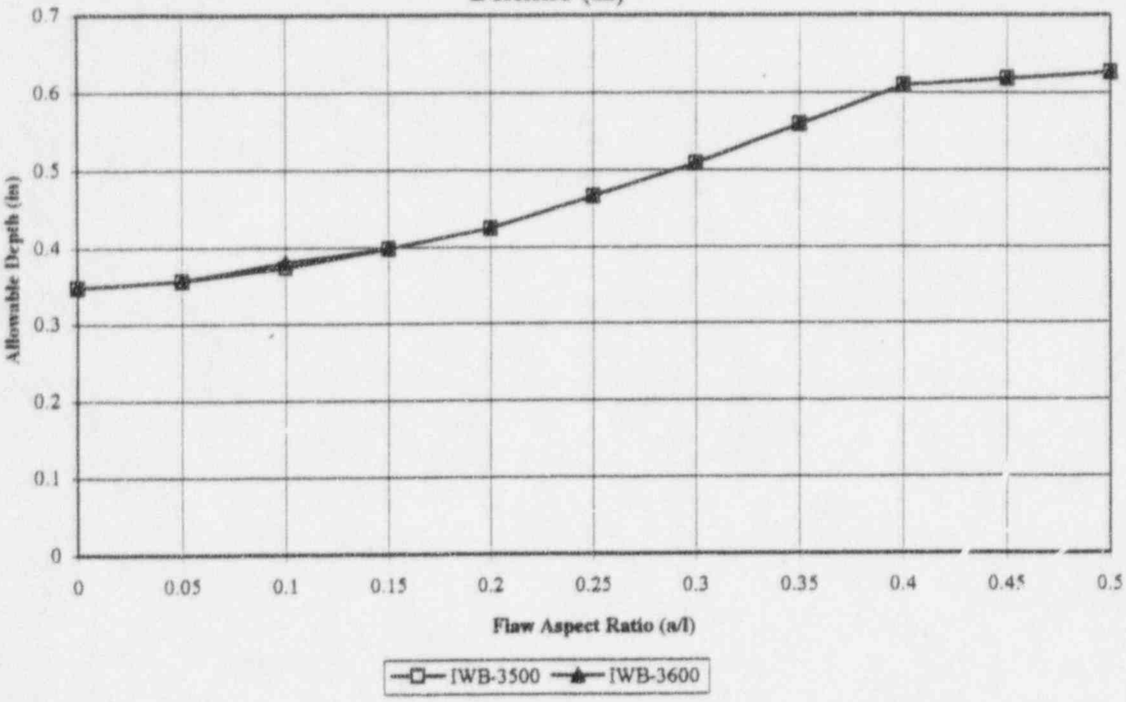
Axially-Oriented Flaws = 2.8"
Circumferentially-Oriented Flaws = 4.2"

Notes: * For flaw indications found in Lower Shell, need to also check Region F.
** Includes all portions of Lower Shell and Lower Shell Longitudinal Weld with thickness equal to 8.4375. For thickness <8.4375, need to check Region H (Lower Shell) and Region I (Lower Shell Longitudinal Weld).

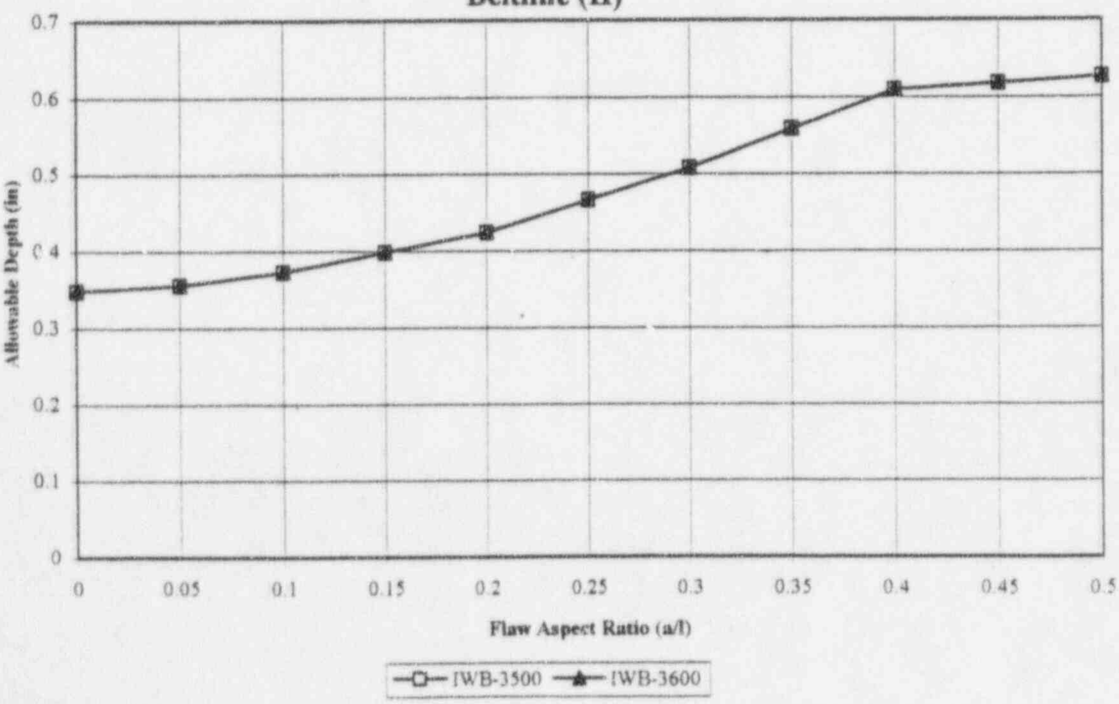
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. $2a$ = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

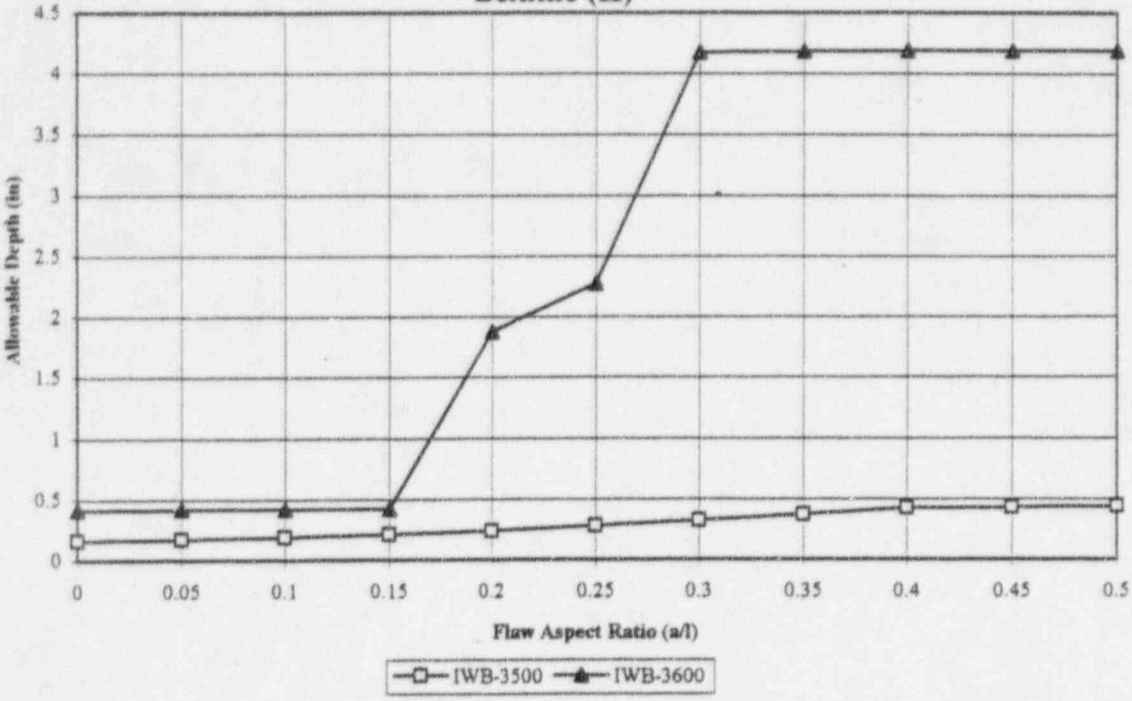
Inside Surface Circumferential Flaw
Beltline (II)



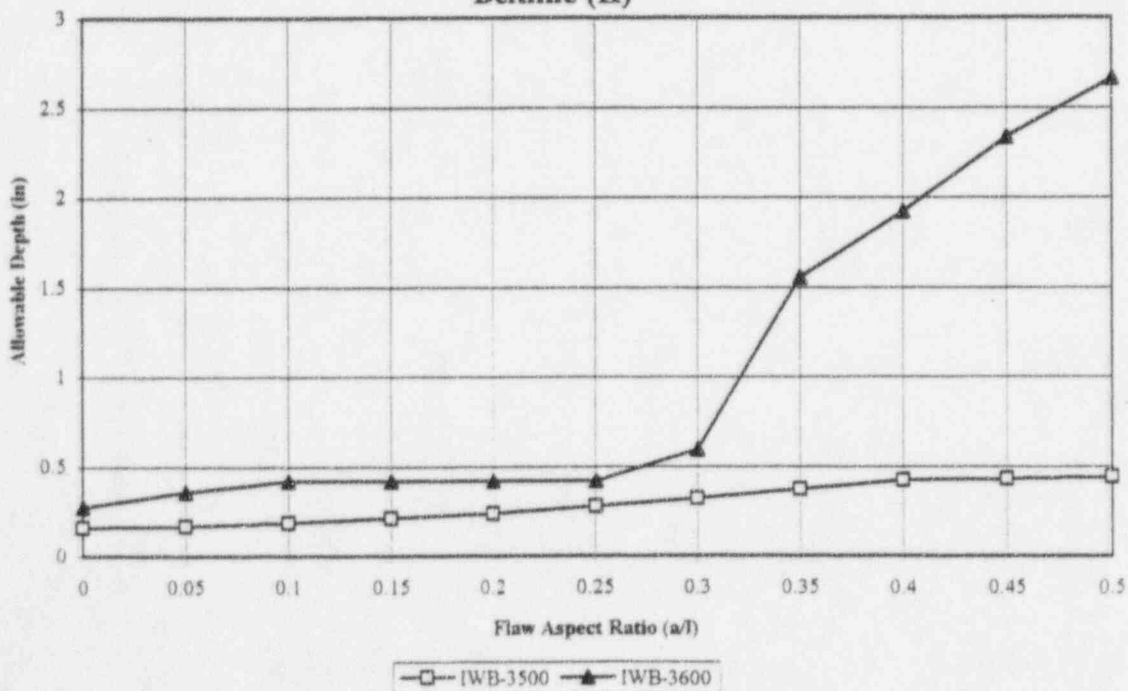
Inside Surface Axial Flaw
Beltline (II)



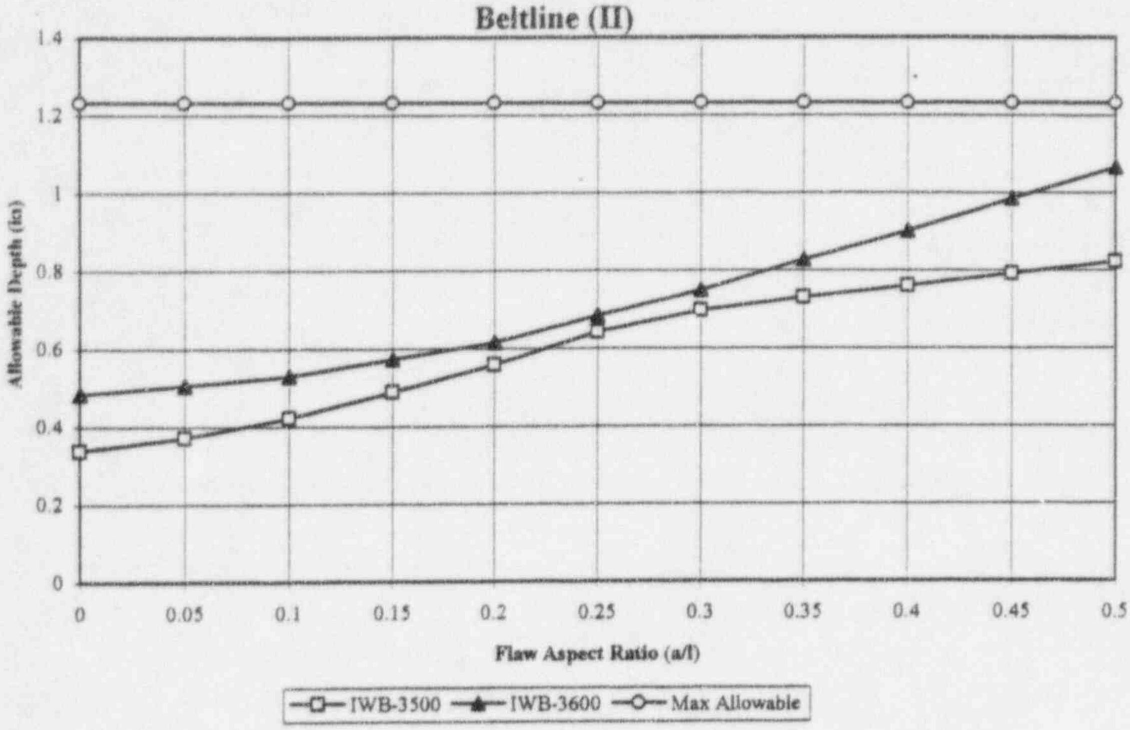
Outside Surface Circumferential Flaw
Beltline (II)



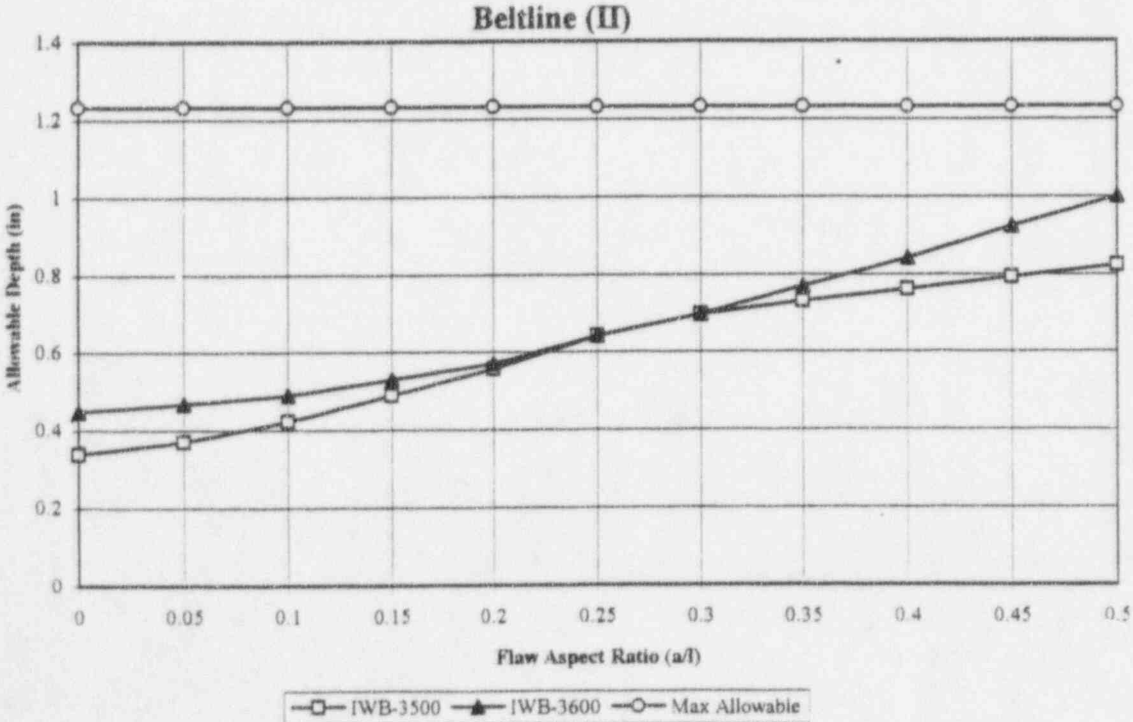
Outside Surface Axial Flaw
Beltline (II)



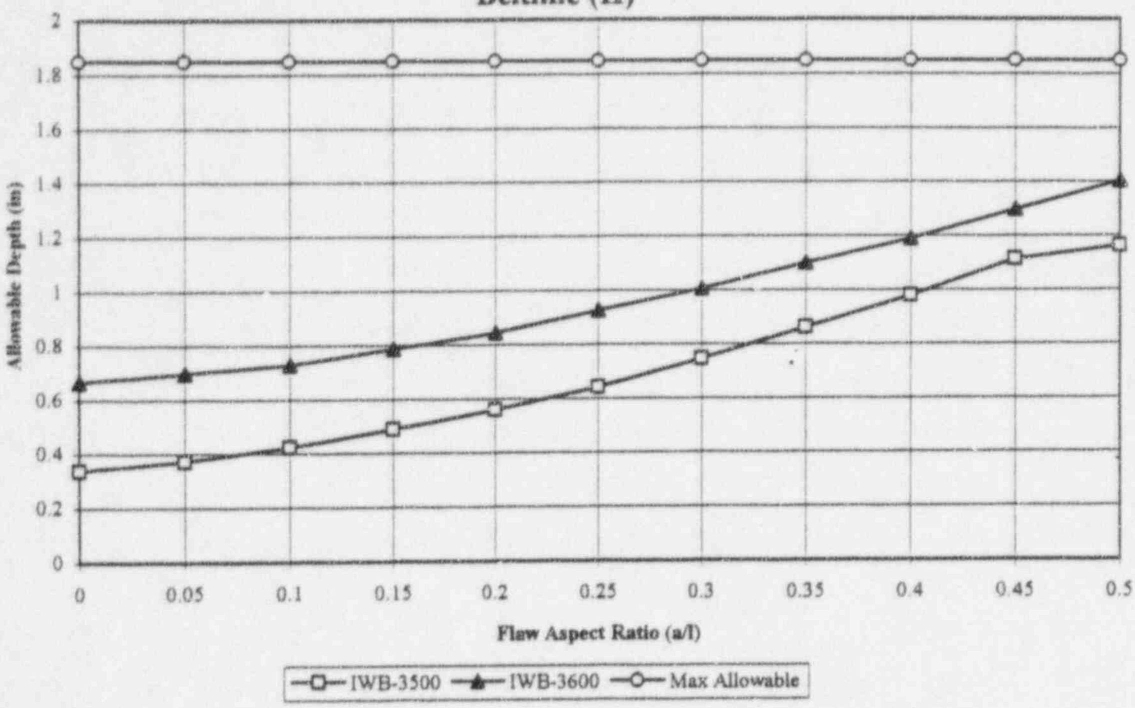
Circumferential Sub-Surface Flaw e/t = -0.4
Beltline (II)



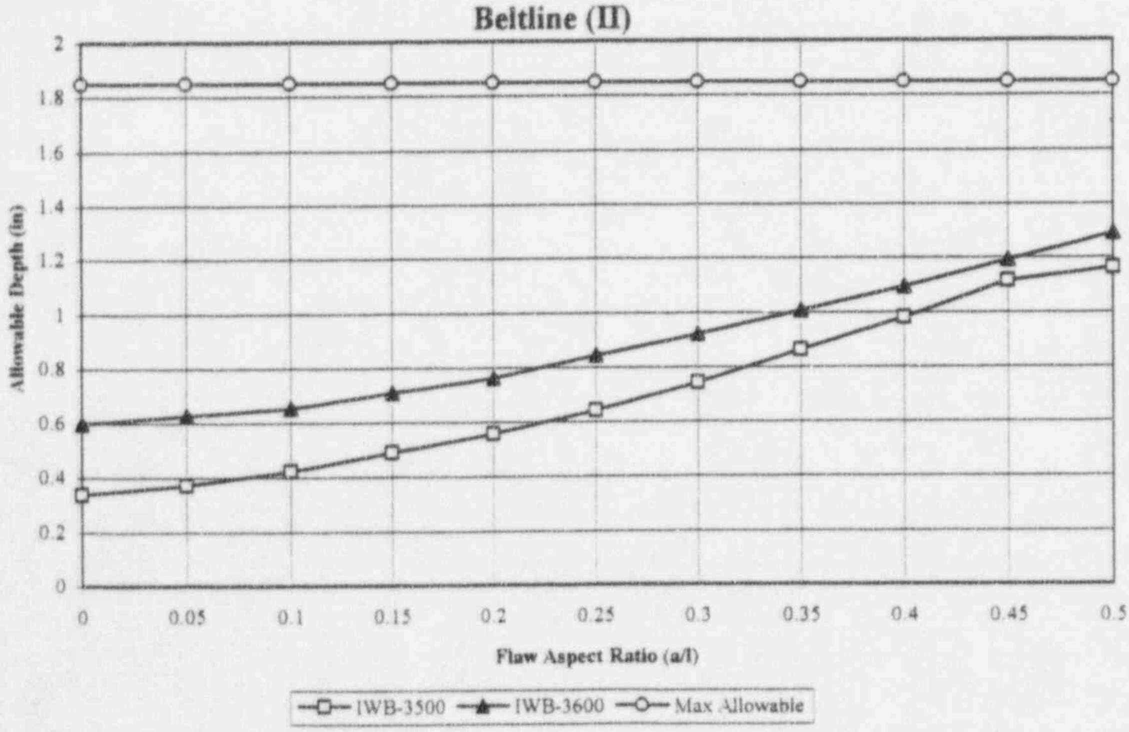
Axial Sub-Surface Flaw e/t = -0.4
Beltline (II)



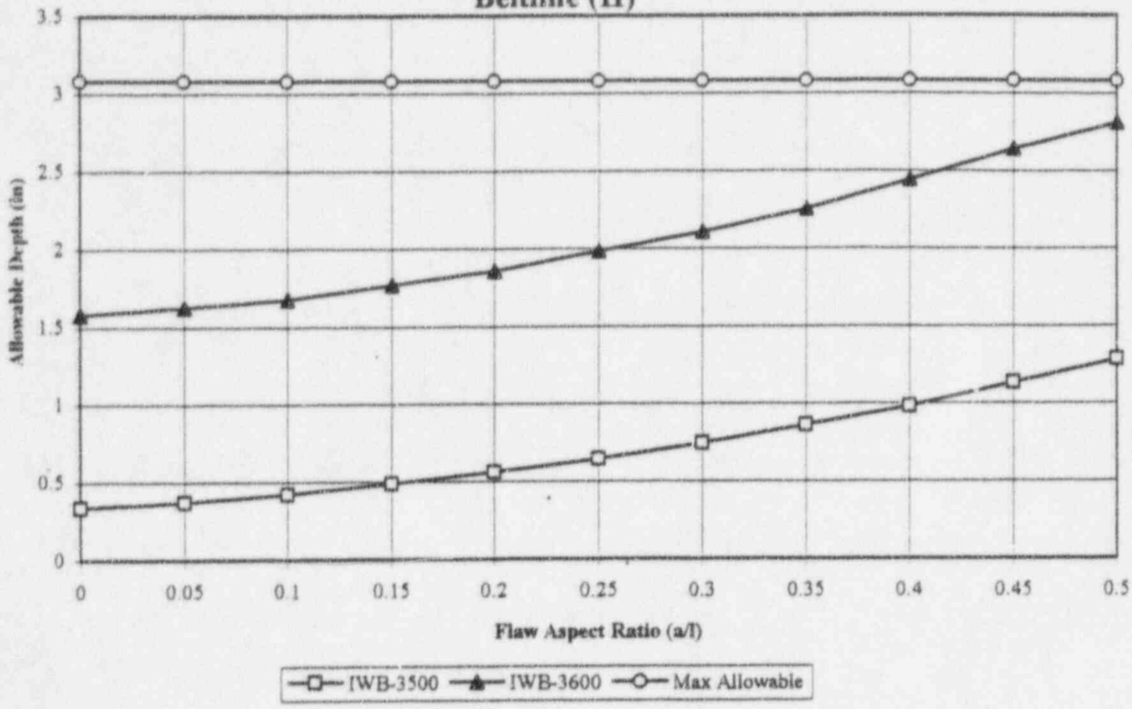
Circumferential Sub-Surface Flaw e/t = -0.35
Beltline (II)



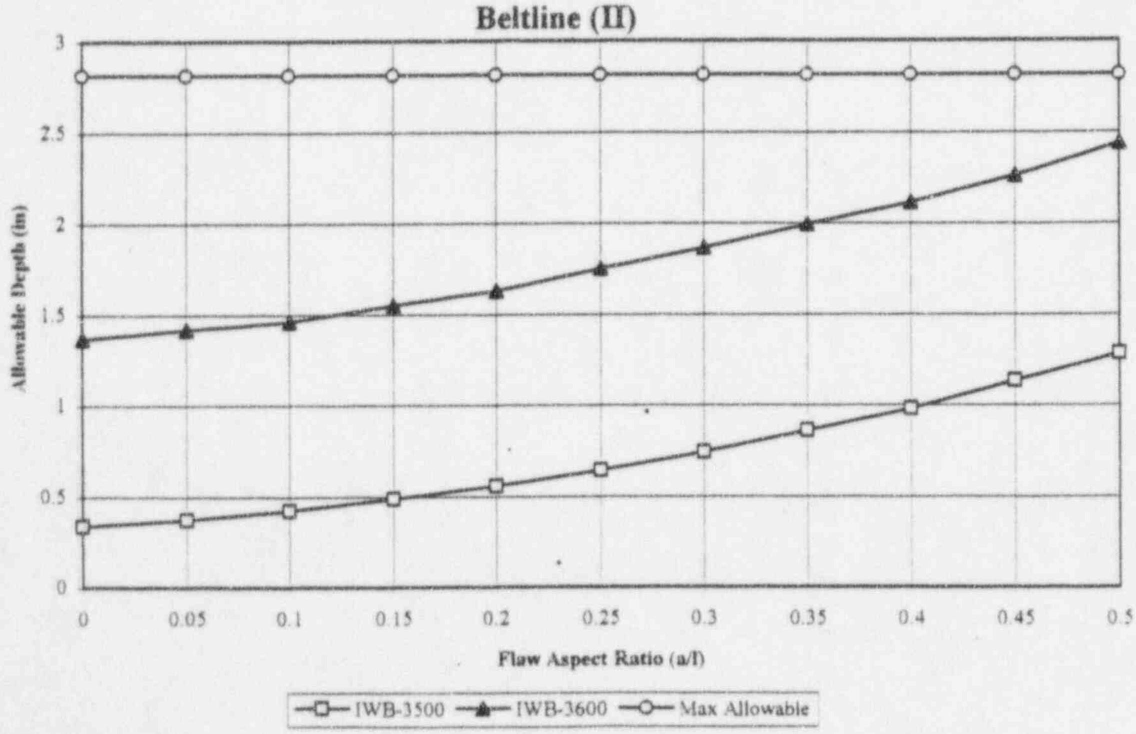
Axial Sub-Surface Flaw e/t = -0.35
Beltline (II)



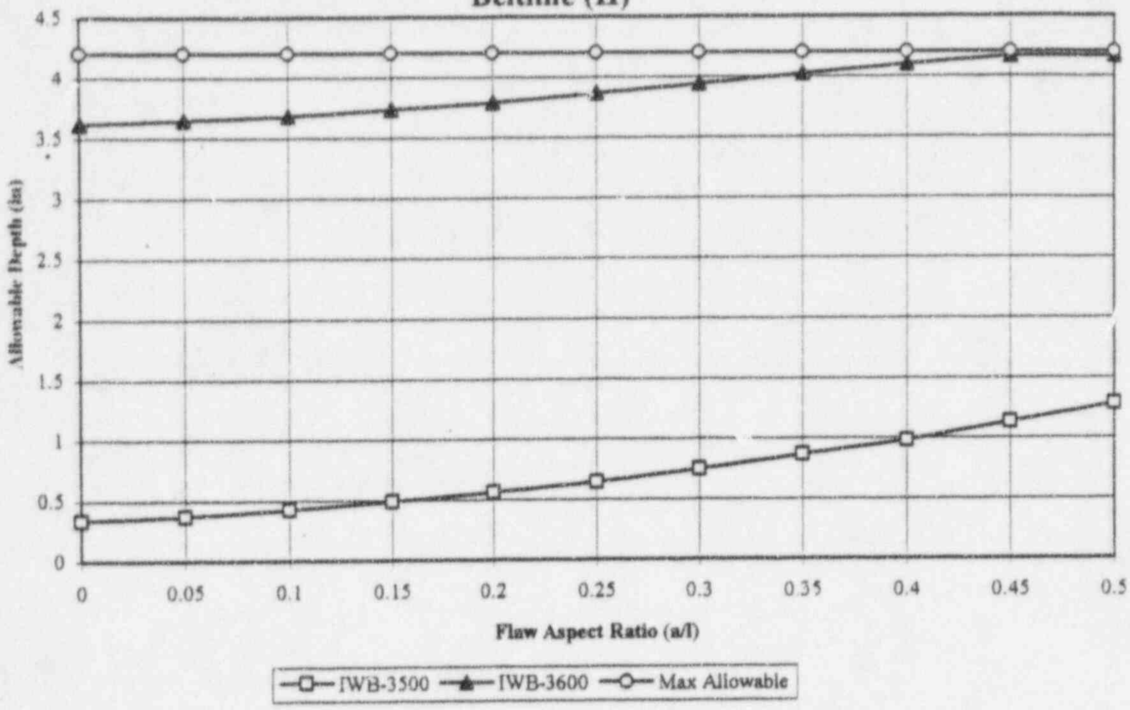
Circumferential Sub-Surface Flaw e/t = -0.25
Beltline (II)



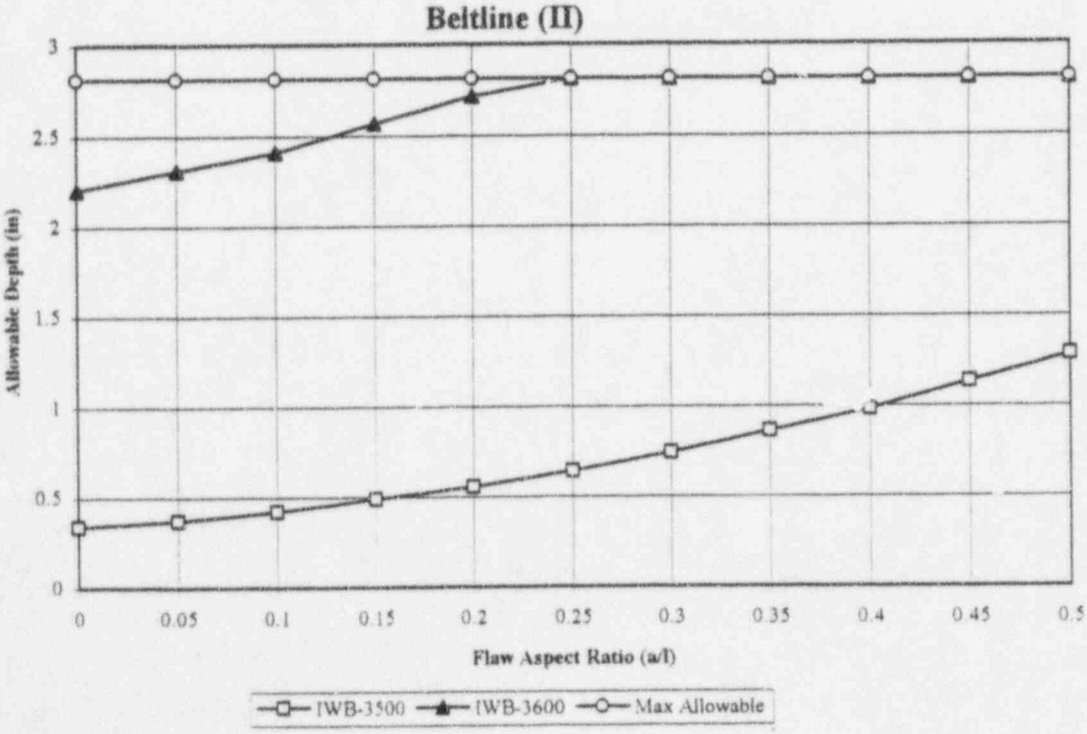
Axial Sub-Surface Flaw e/t = -0.25
Beltline (II)



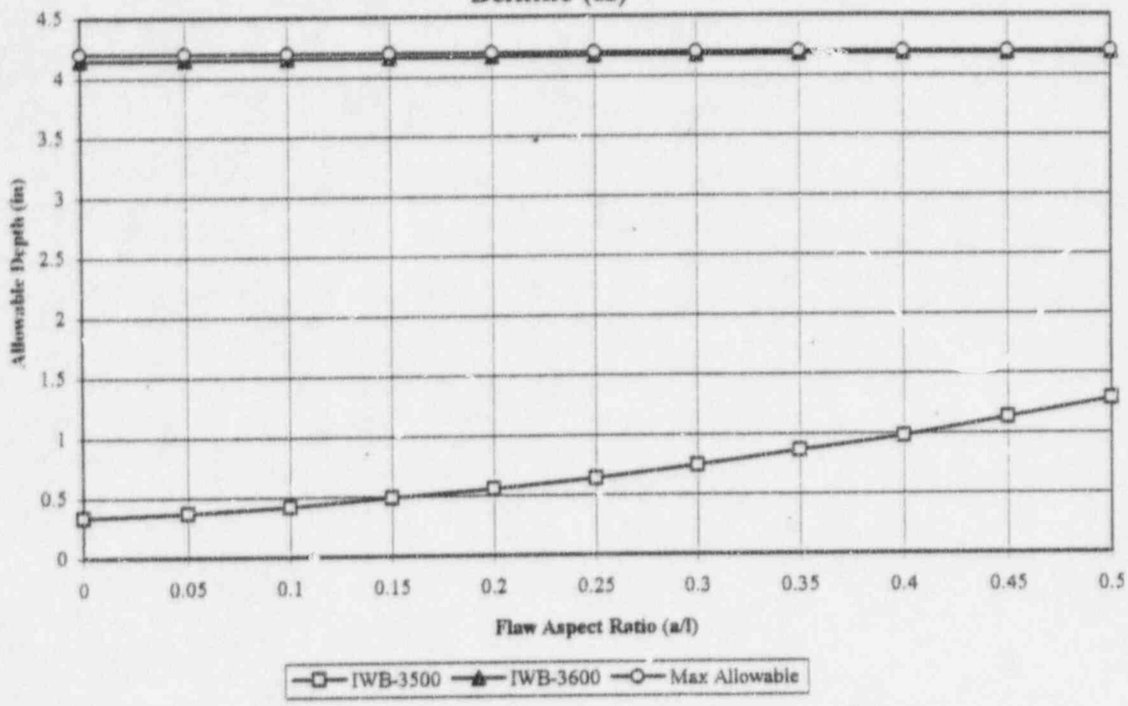
Circumferential Sub-Surface Flaw e/t = -0.1
Beltline (II)



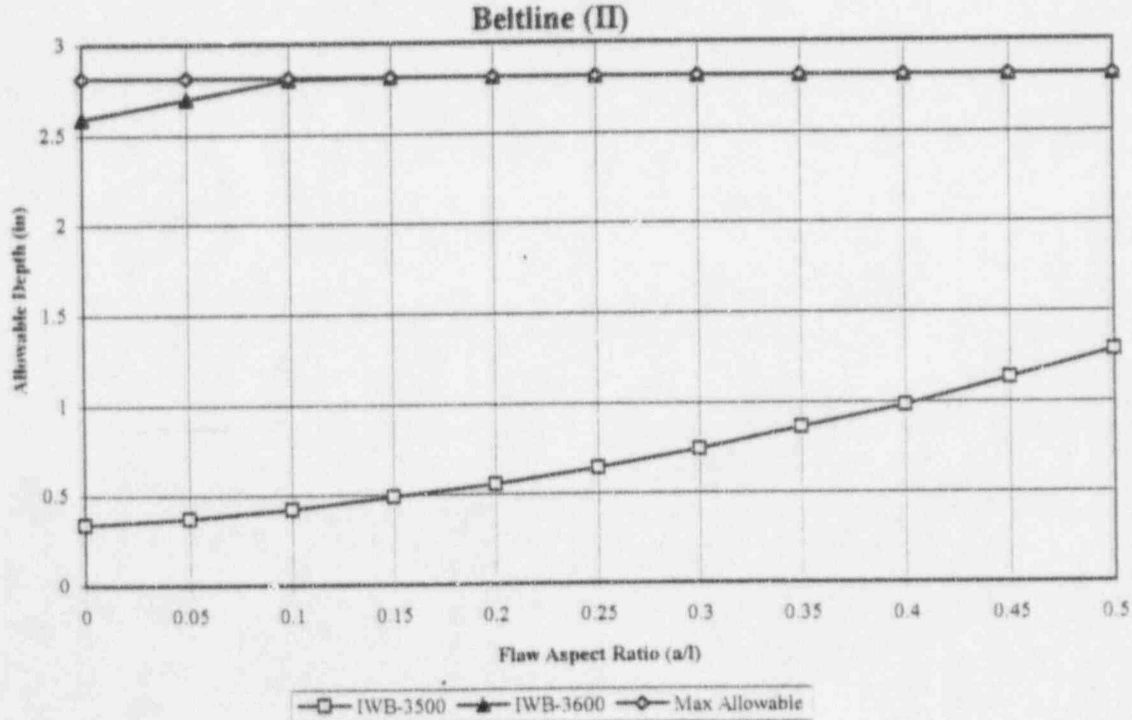
Axial Sub-Surface Flaw e/t = -0.1
Beltline (II)



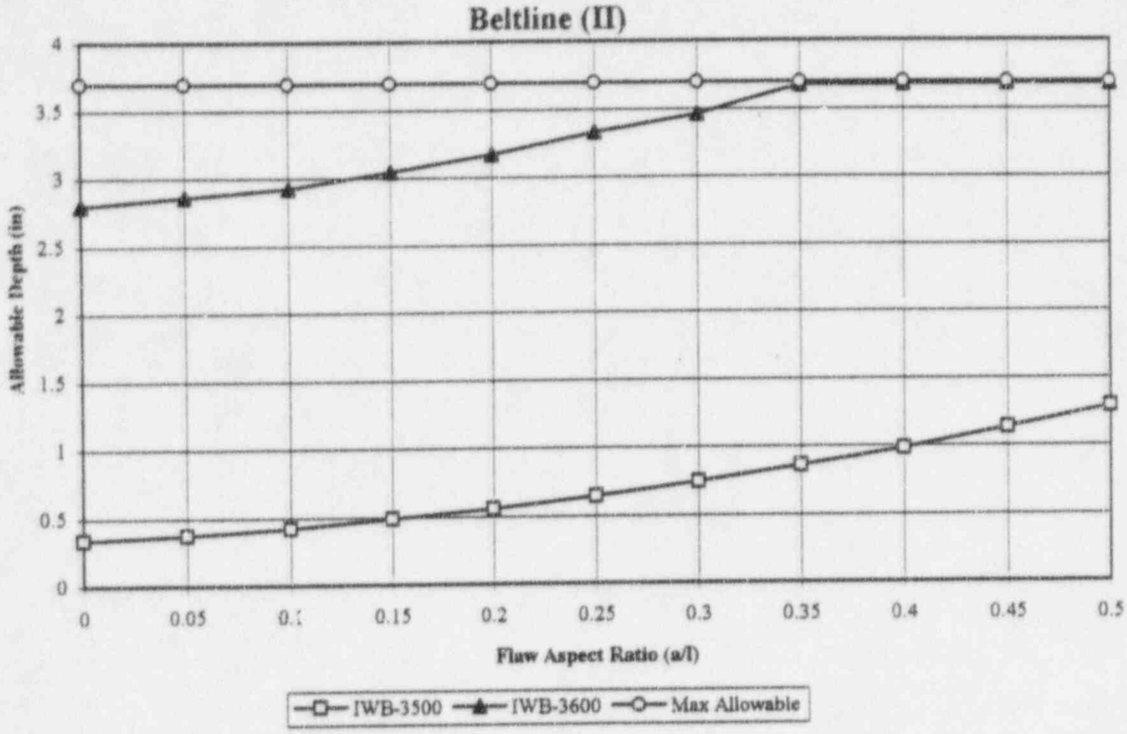
Circumferential Sub-Surface Flaw e/t = 0.0
Beltline (II)



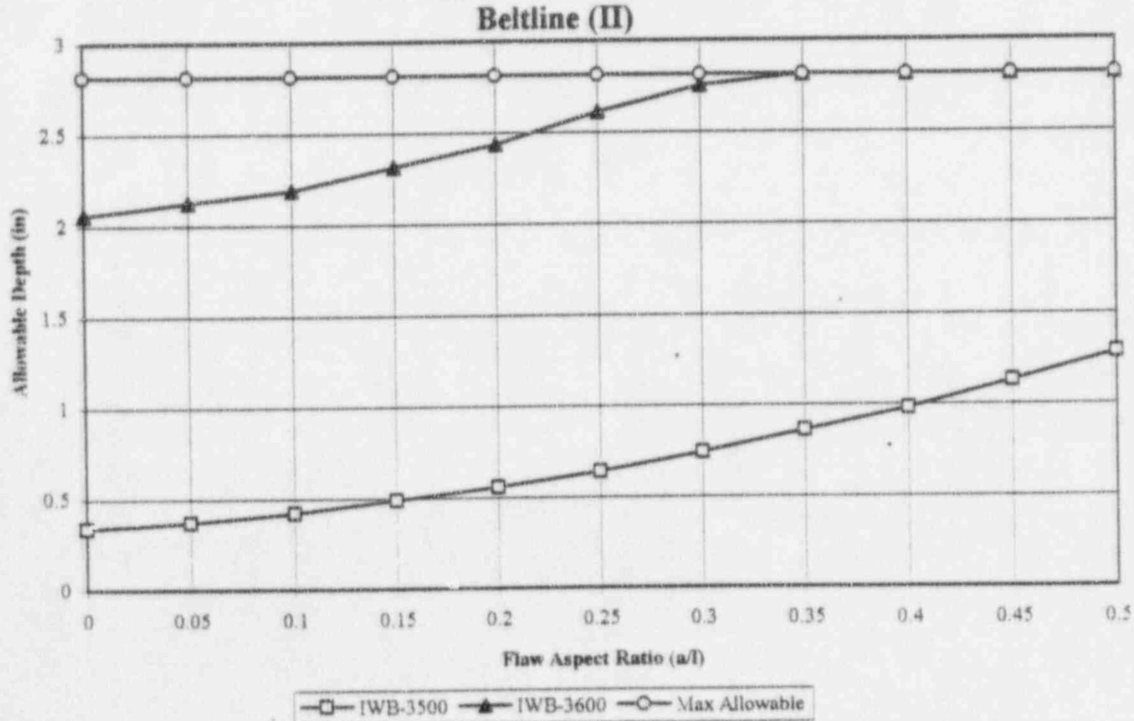
Axial Sub-Surface Flaw e/t = 0.0
Beltline (II)



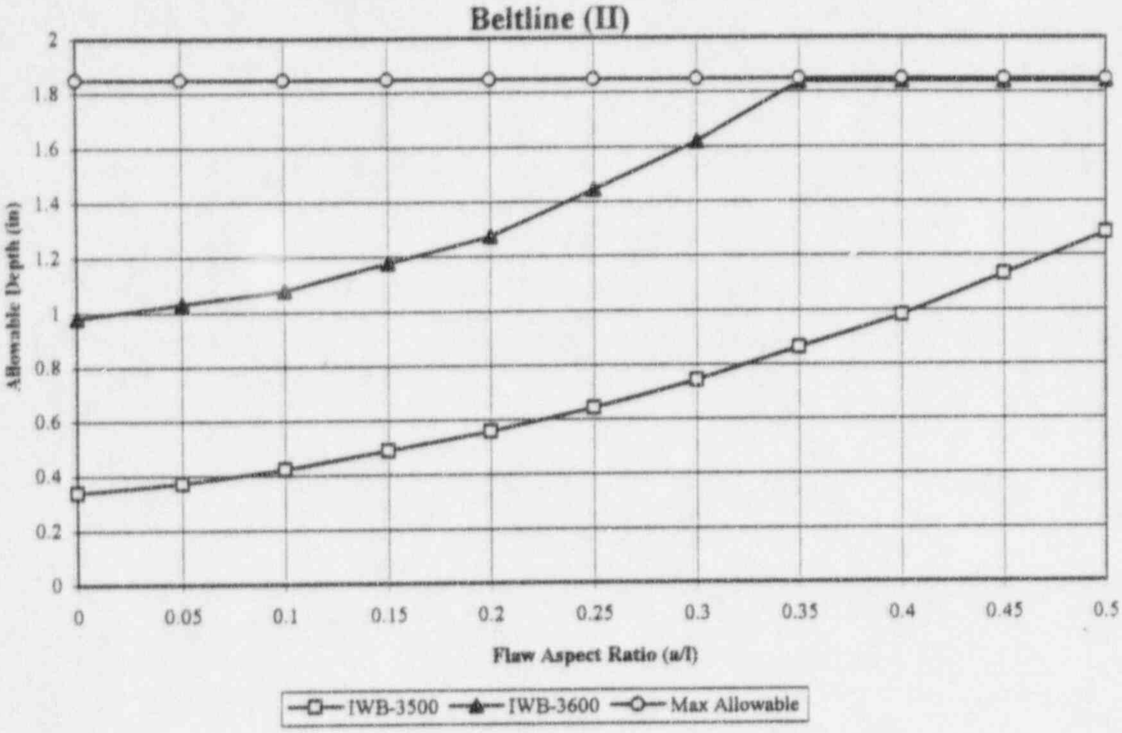
Circumferential Sub-Surface Flaw e/t = 0.2
Beltline (II)



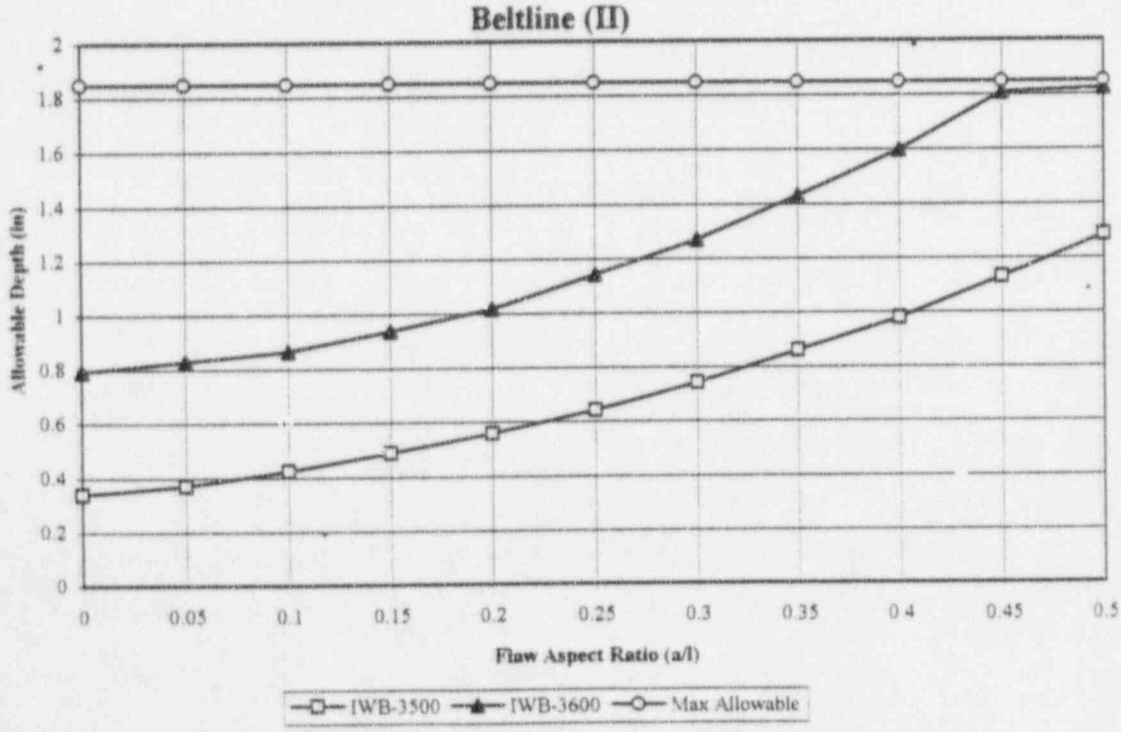
Axial Sub-Surface Flaw e/t = 0.2
Beltline (II)

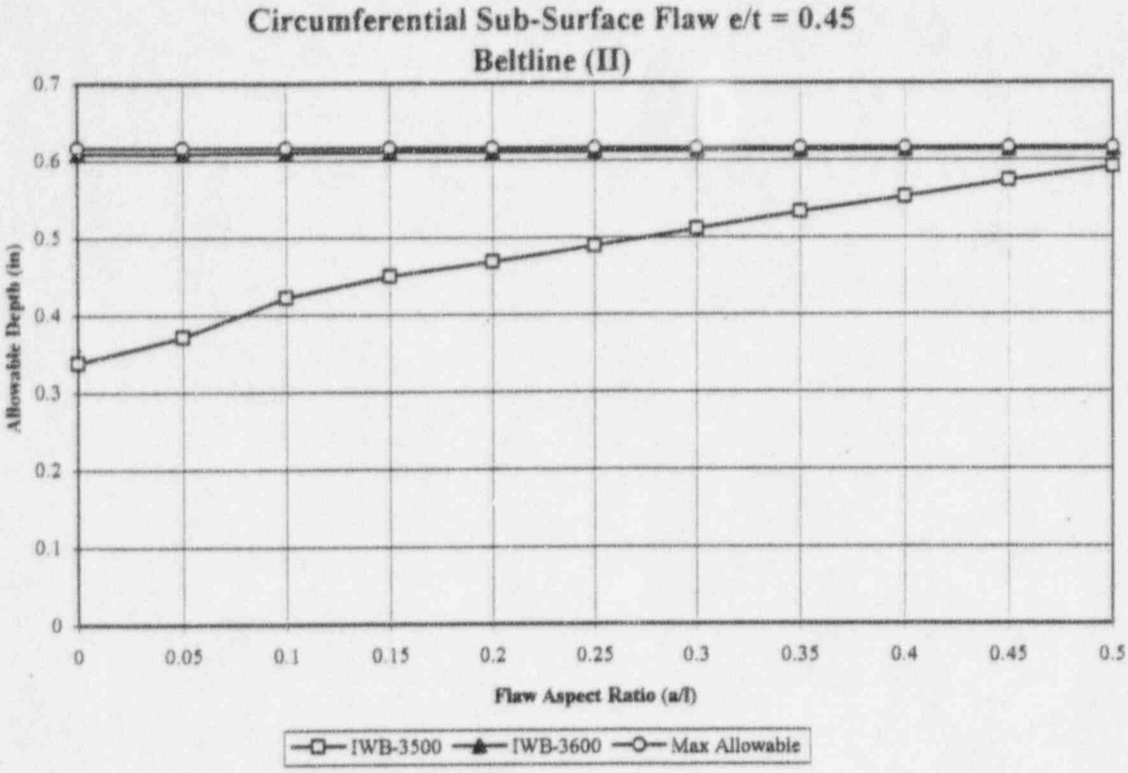


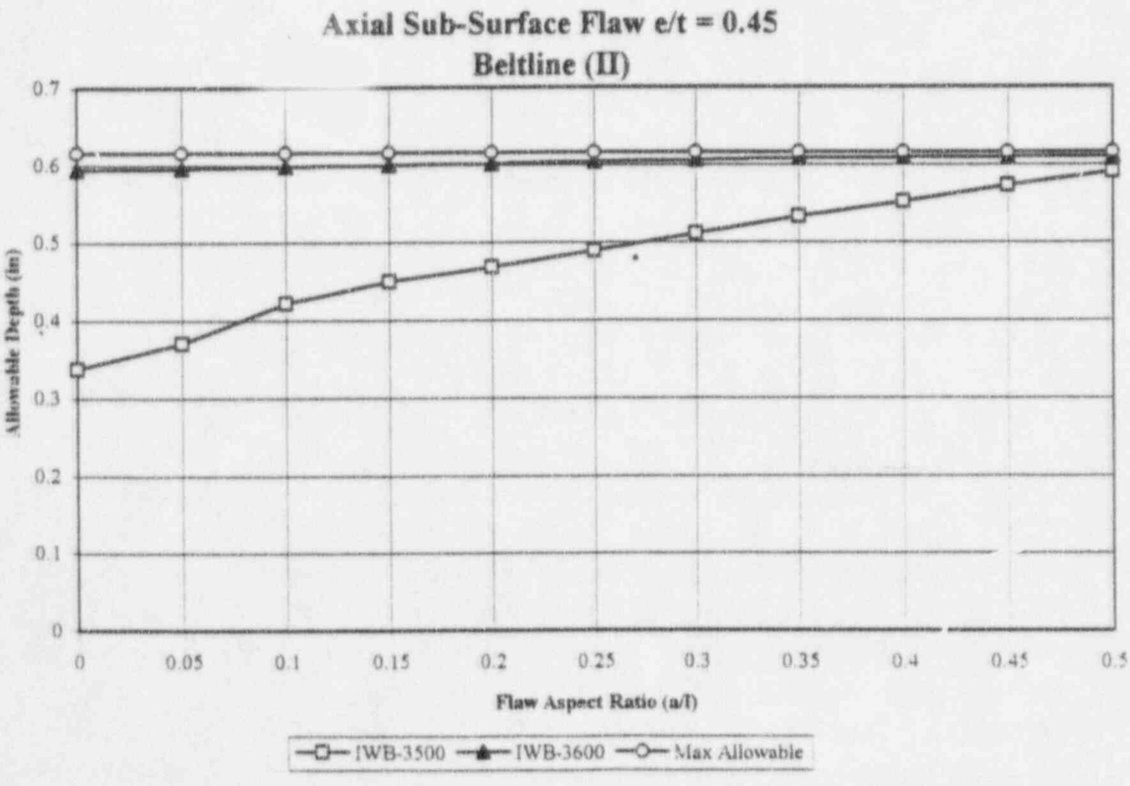
Circumferential Sub-Surface Flaw e/t = 0.35
Beltline (II)



Axial Sub-Surface Flaw e/t = 0.35
Beltline (II)




Circumferential Sub-Surface Flaw e/t = 0.45
Beltline (II)
Allowable Depth (in)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.45
Beltline (II)
Allowable Depth (in)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

APPENDIX H

Flaw Acceptance Diagrams for Region H Materials

Region H includes:

- Lower Shells (A2-207-1, -2) *

Based on Minimum Thickness = 5"

Default Maximum Allowable Flaw Sizes for All Charts:

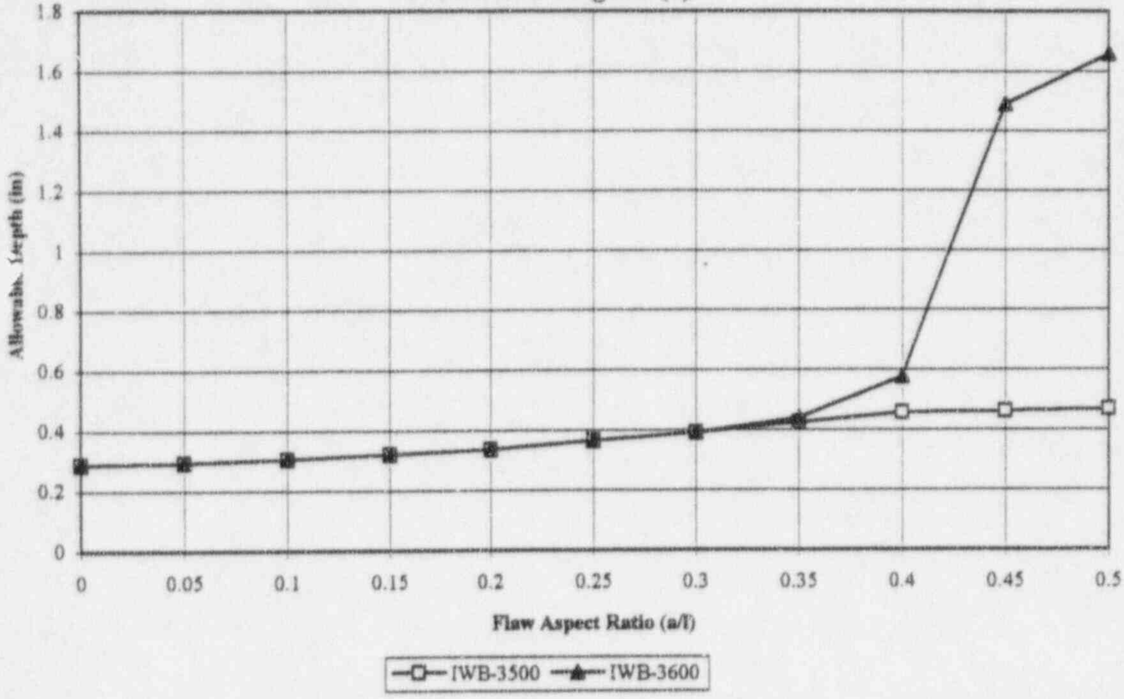
Axially-Oriented Flaws = 1.67"
Circumferentially-Oriented Flaws = 1.67"

Note: * Includes all portions of Lower Shell with thicknesses <8.4375. For portions of lower shell with thicknesses equal to 8.4375, see Regions F, G.

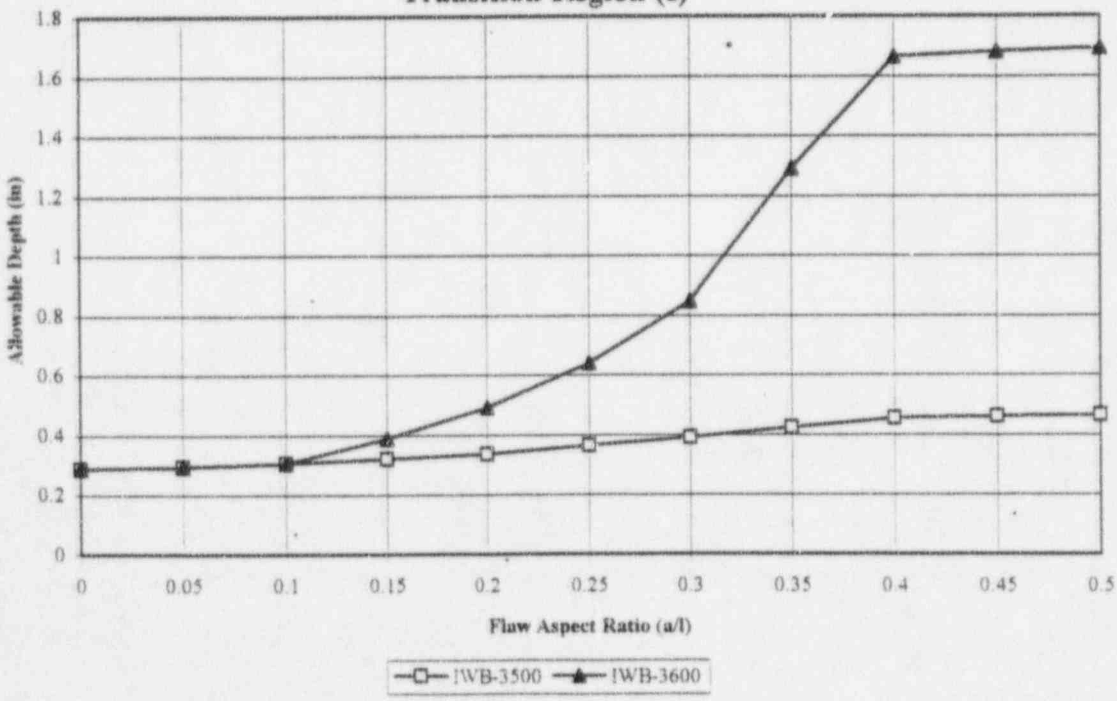
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

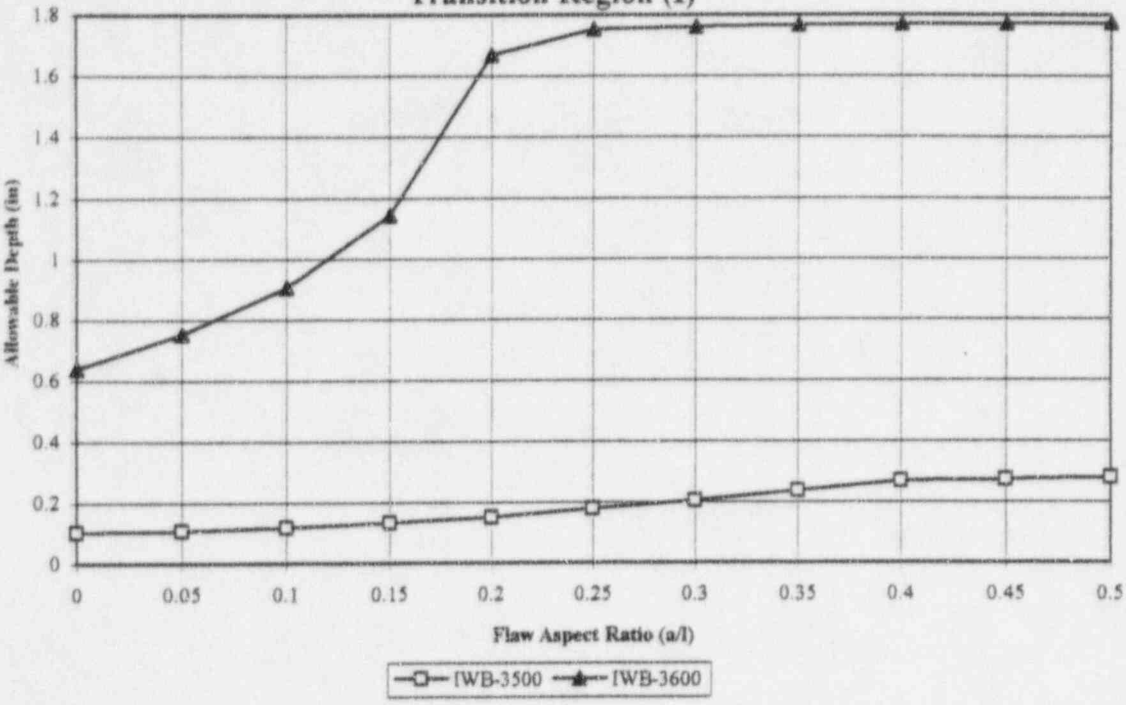
Inside Surface Circumferential Flaw
Transition Region (I)



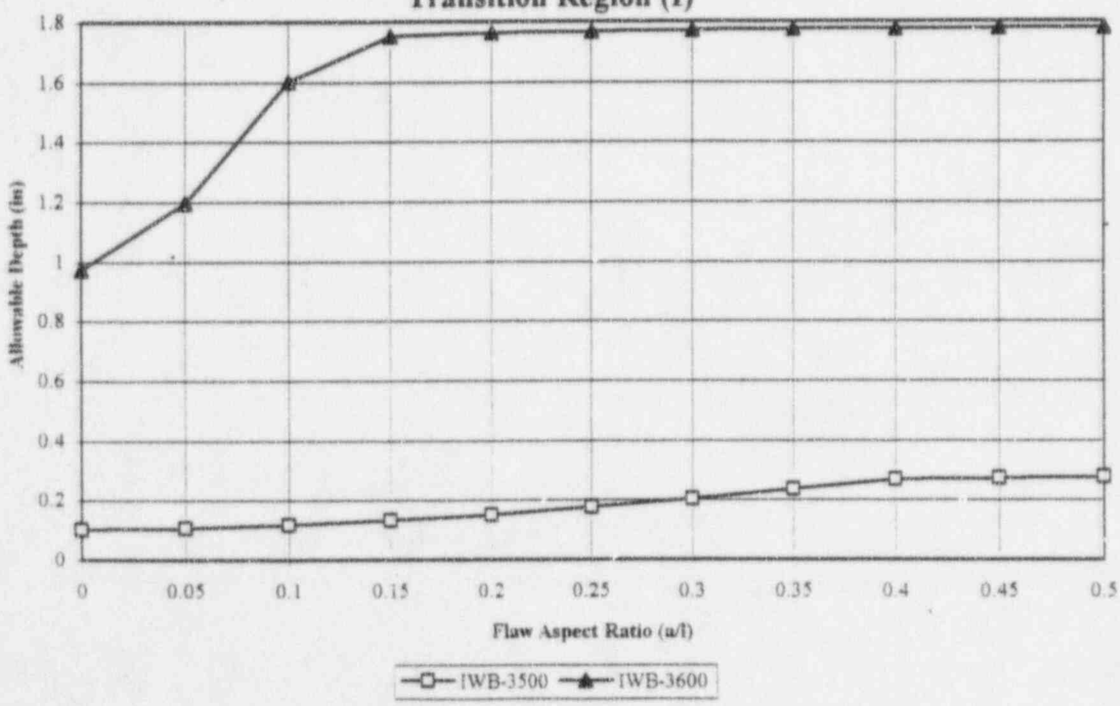
Inside Surface Axial Flaw
Transition Region (I)



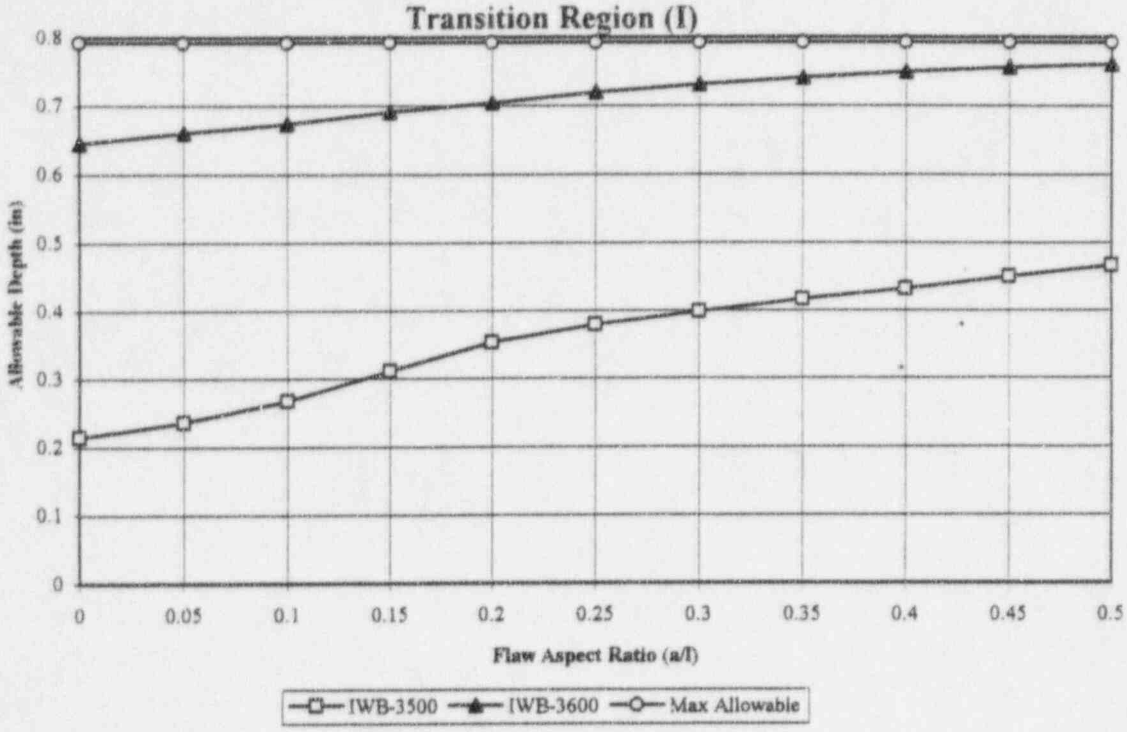
Outside Surface Circumferential Flaw Transition Region (I)



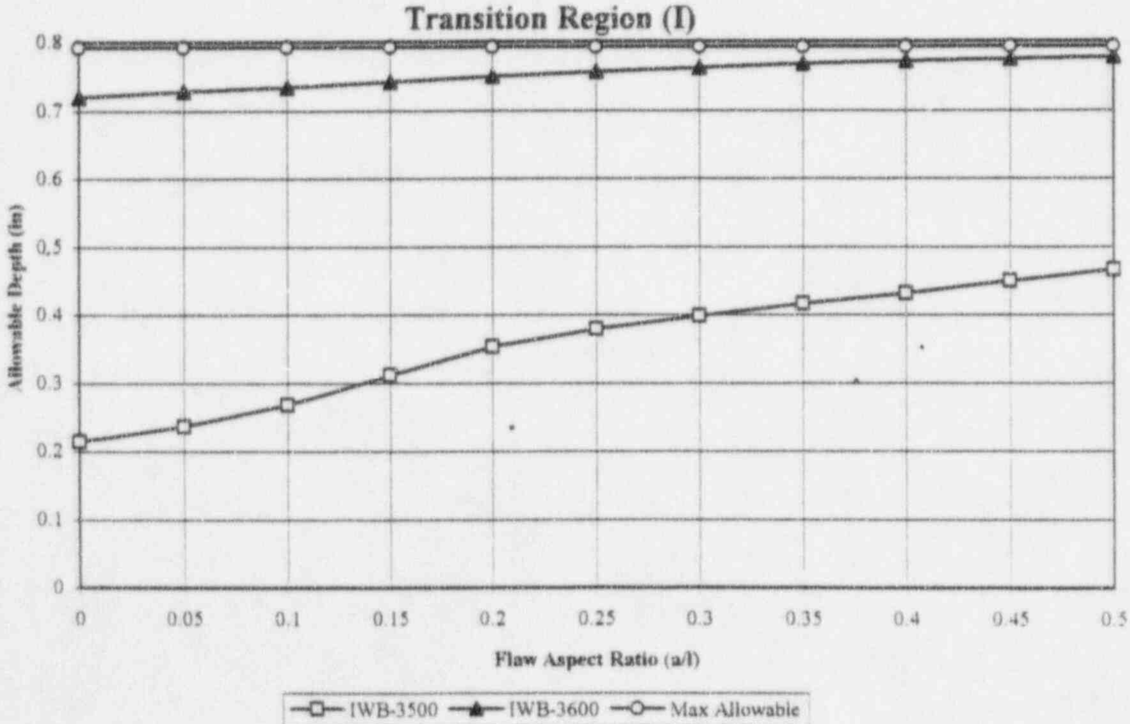
Outside Surface Axial Flaw Transition Region (I)



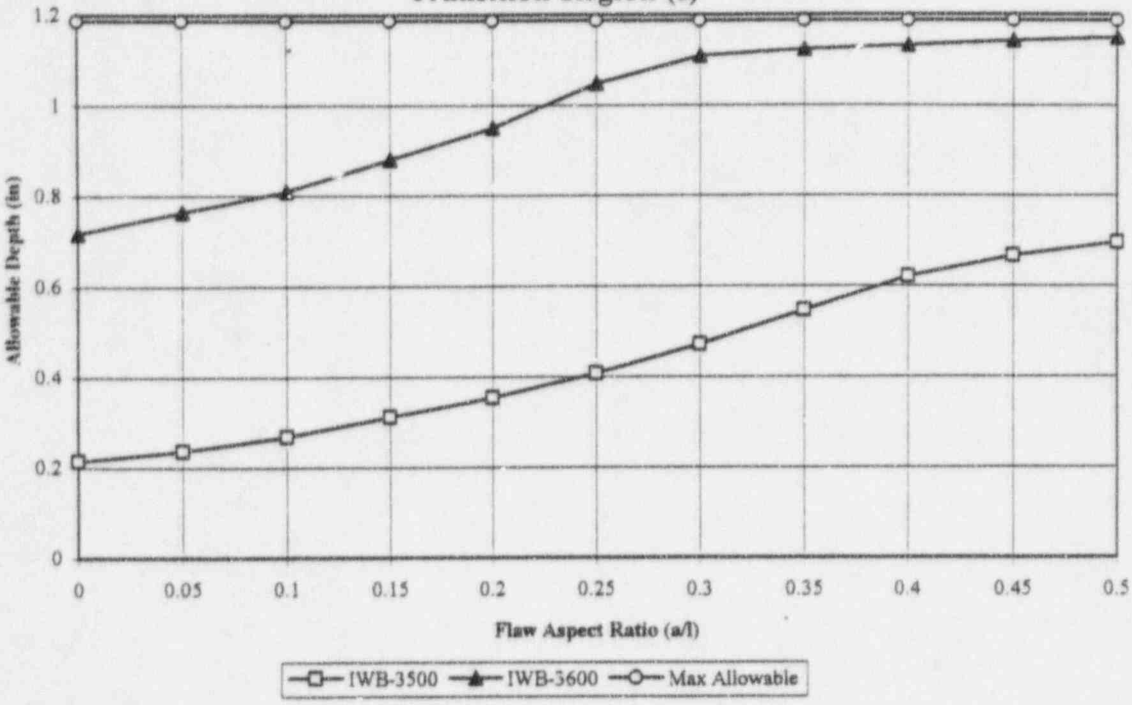
Circumferential Sub-Surface Flaw e/t = -0.4
Transition Region (I)



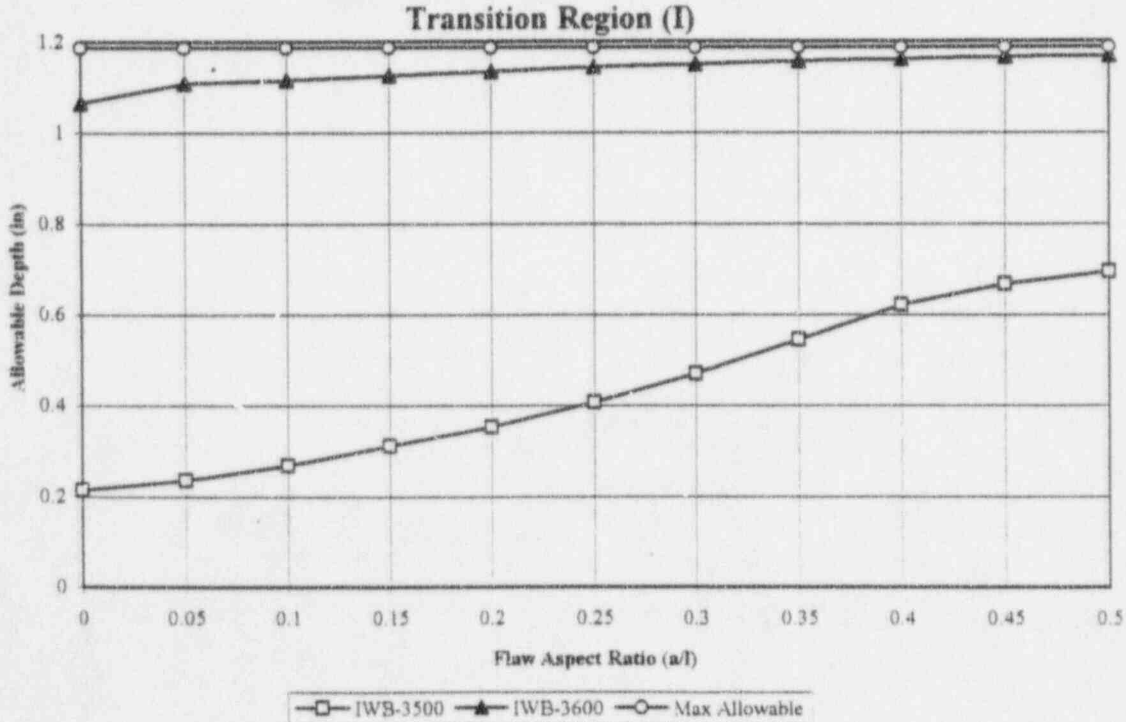
Axial Sub-Surface Flaw e/t = -0.4
Transition Region (I)



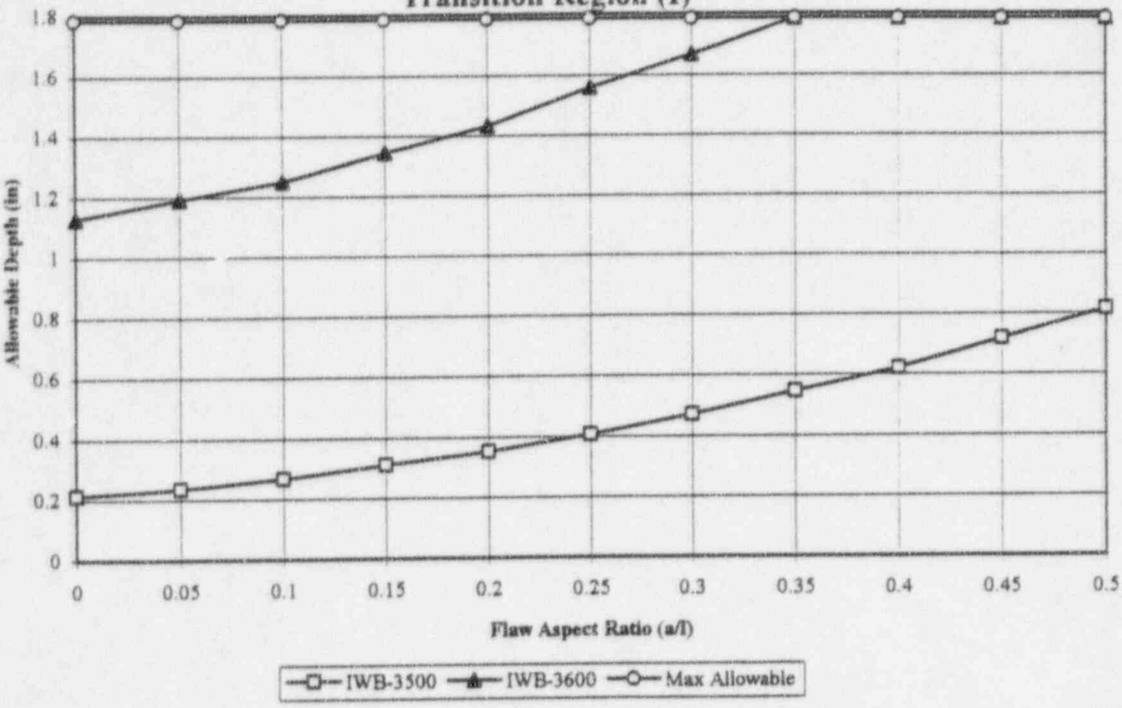
Circumferential Sub-Surface Flaw e/t = -0.35
Transition Region (I)



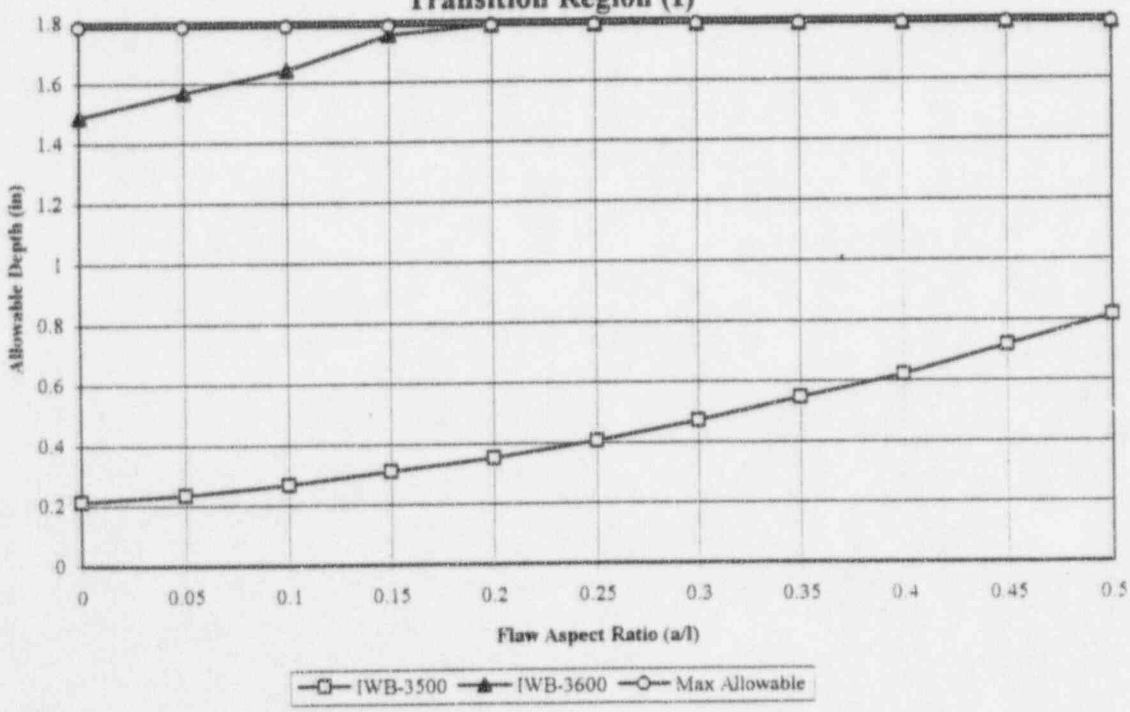
Axial Sub-Surface Flaw e/t = -0.35
Transition Region (I)

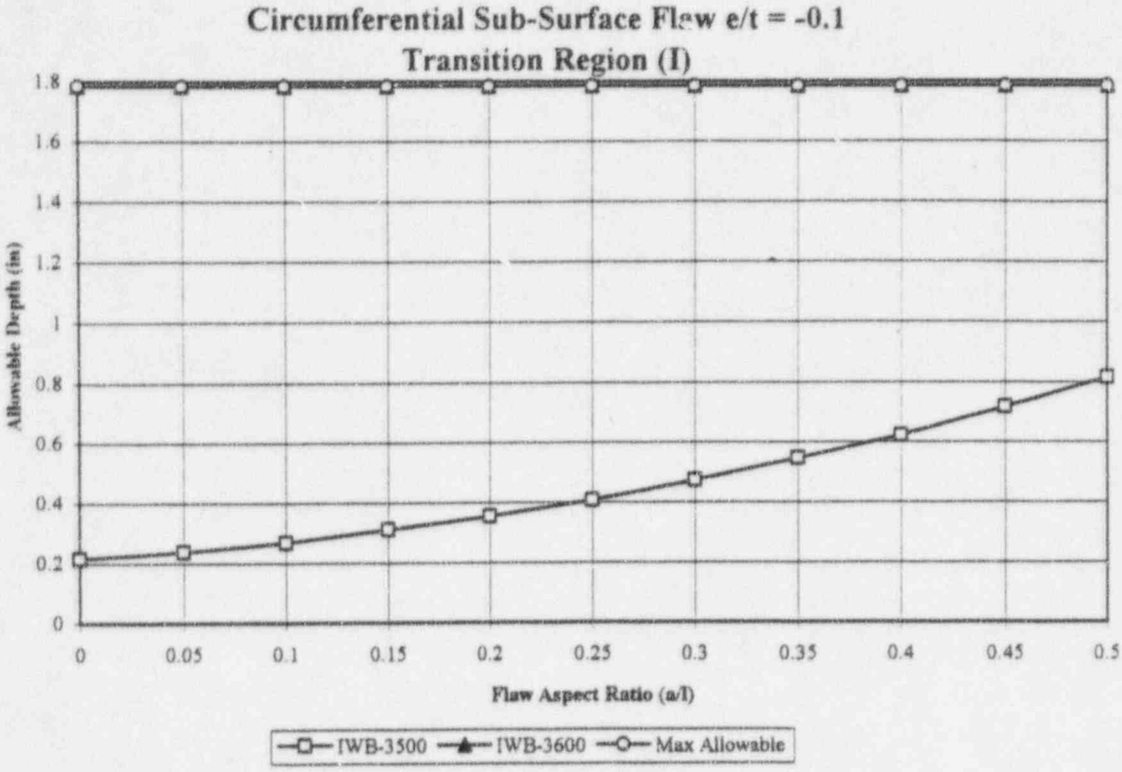


Circumferential Sub-Surface Flaw e/t = -0.25
Transition Region (I)

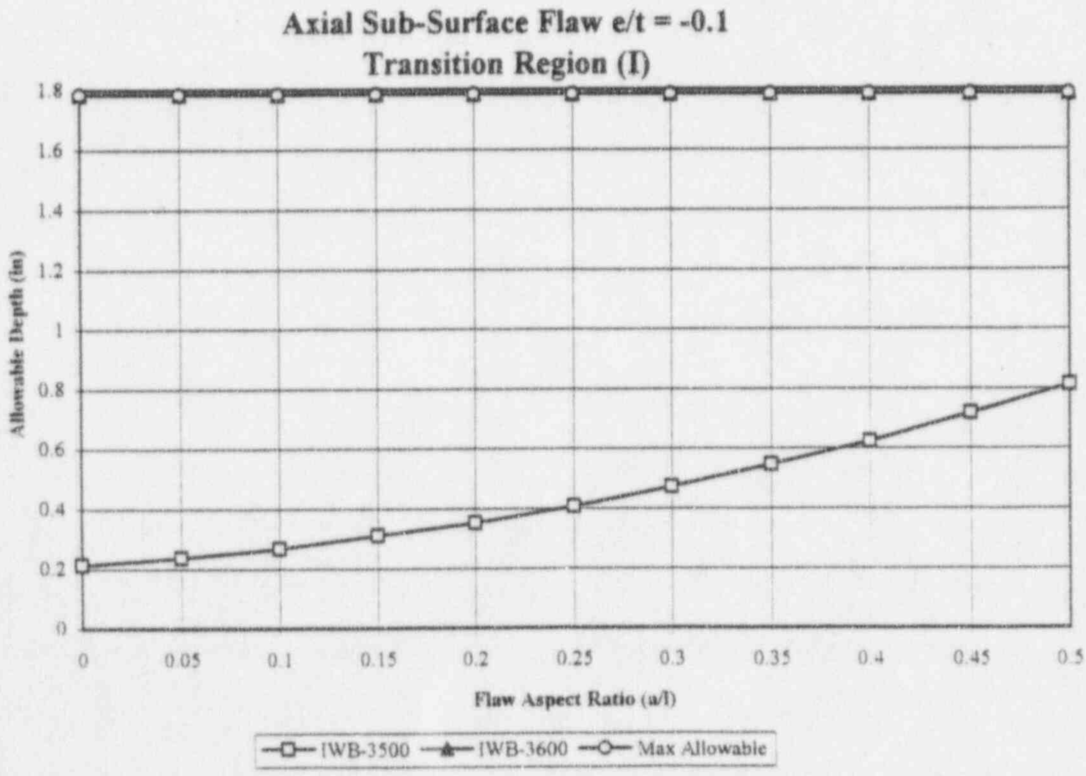


Axial Sub-Surface Flaw e/t = -0.25
Transition Region (I)

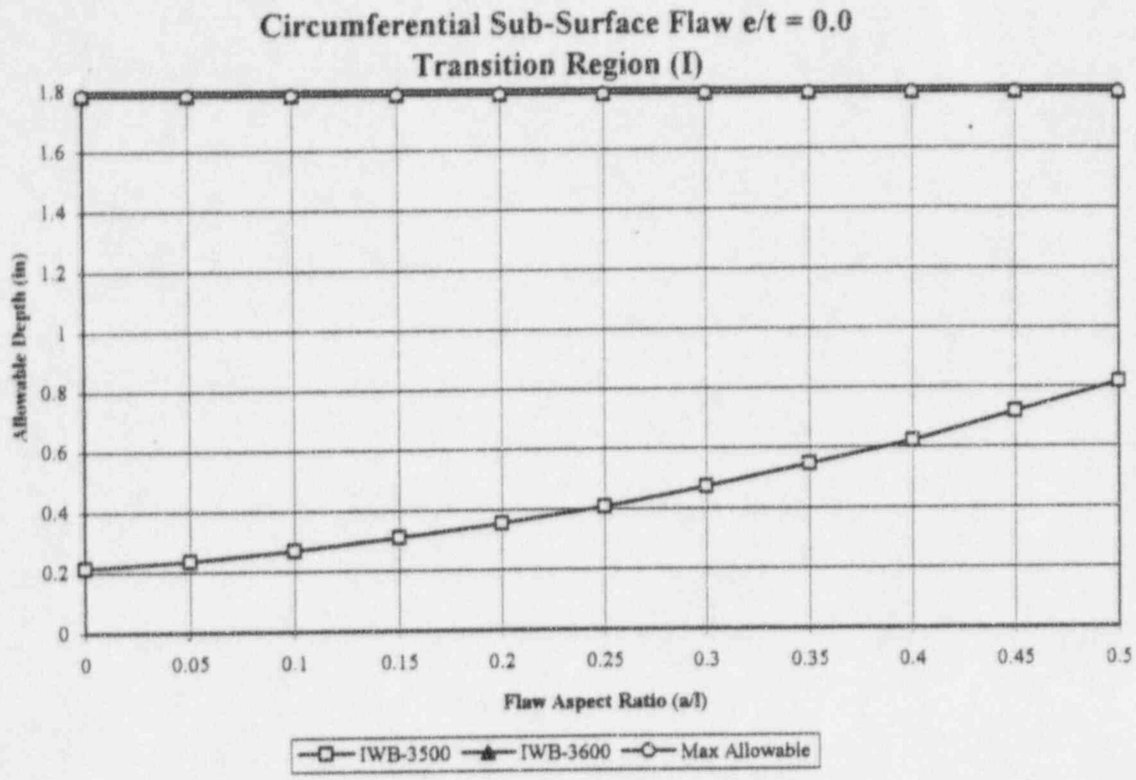


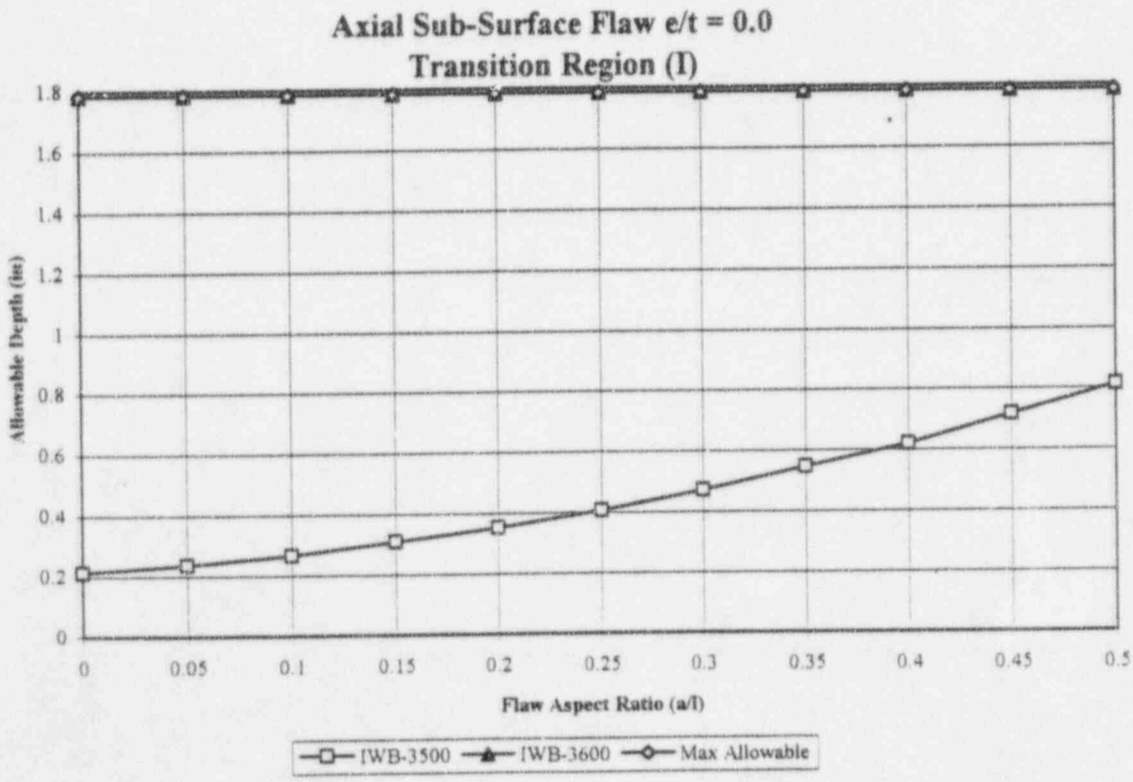


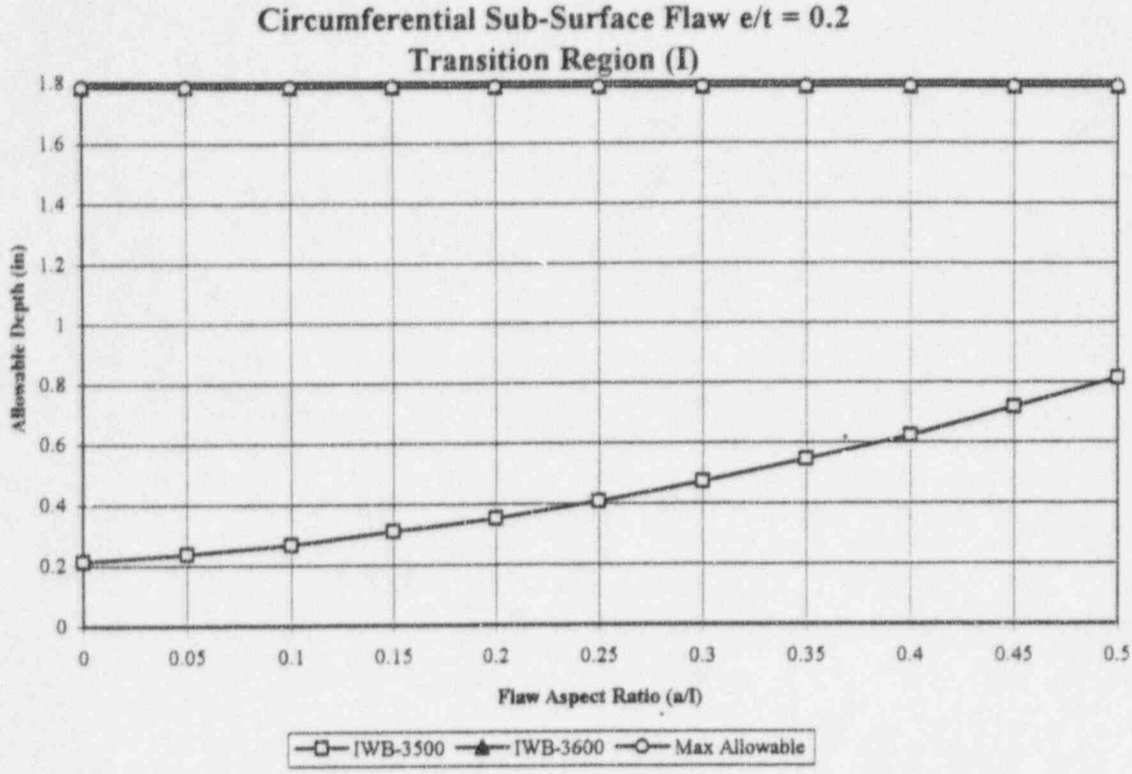
Circumferential Sub-Surface Flaw e/t = -0.1
Transition Region (I)
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable



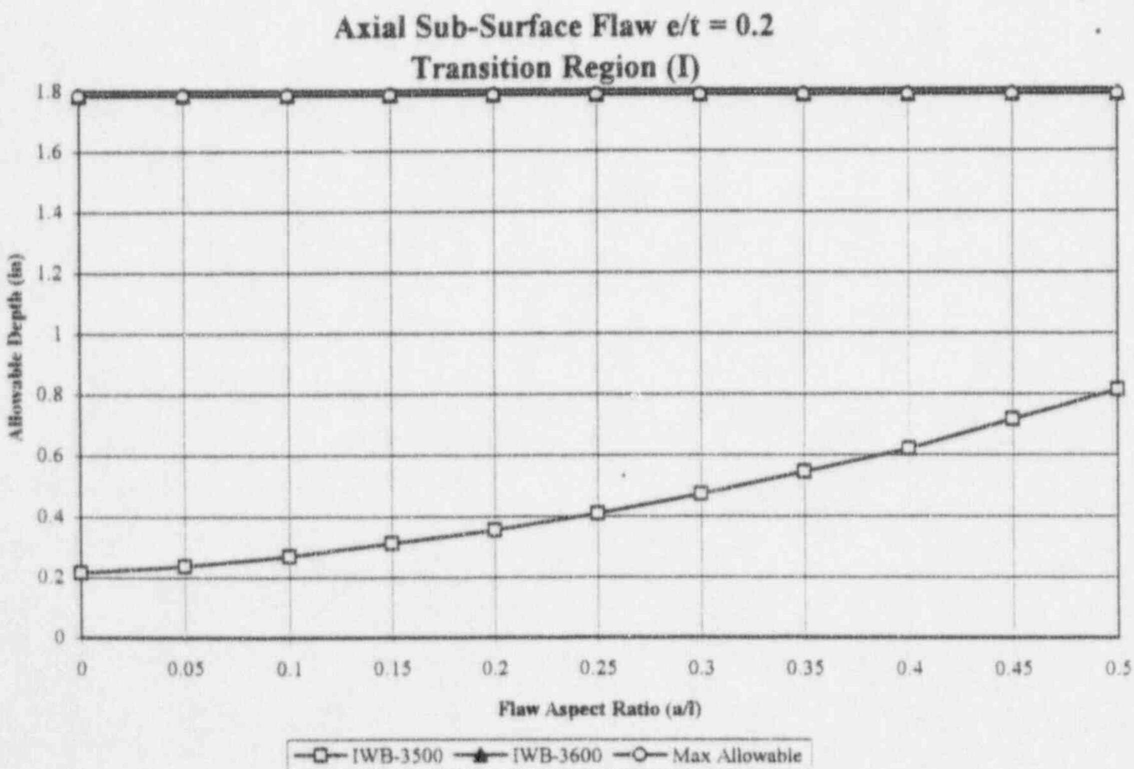
Axial Sub-Surface Flaw e/t = -0.1
Transition Region (I)
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Circumferential Sub-Surface Flaw e/t = 0.0
Transition Region (I)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.0
Transition Region (I)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

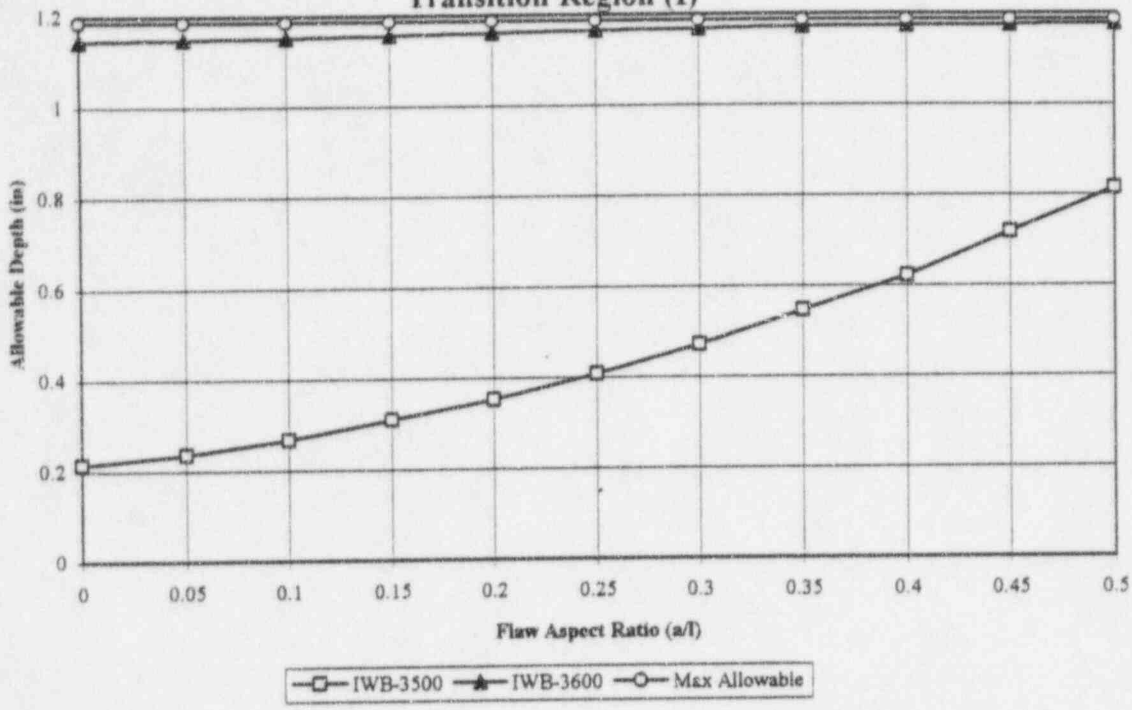


Circumferential Sub-Surface Flaw e/t = 0.2
Transition Region (I)
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

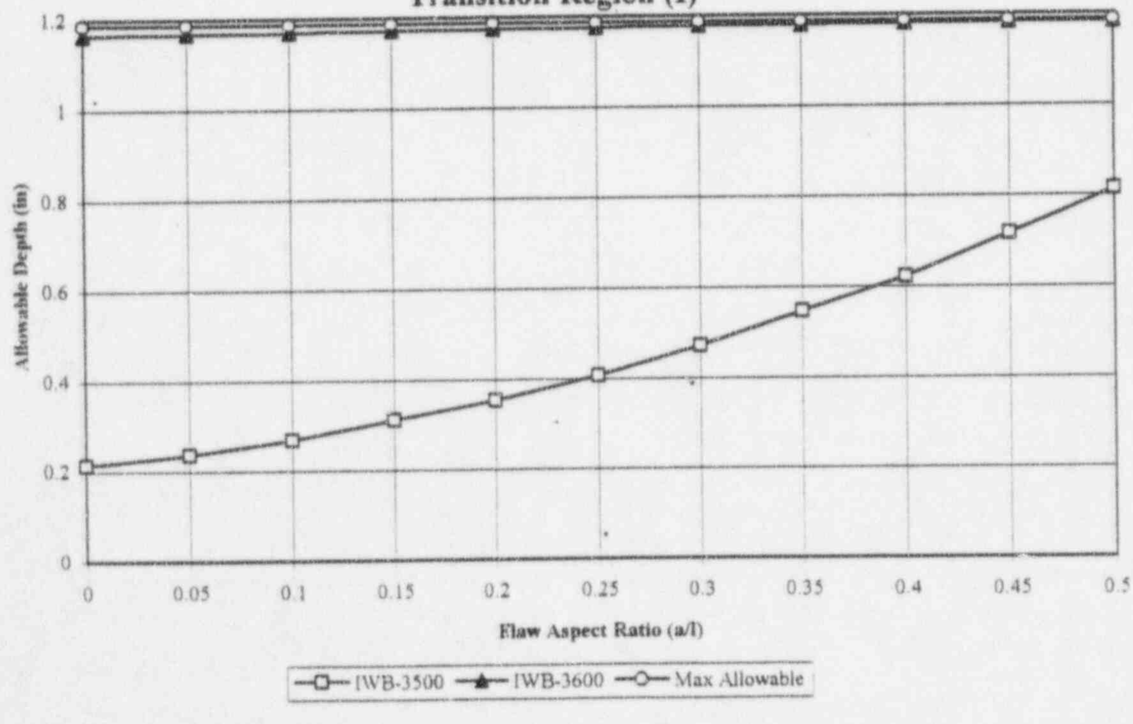


Axial Sub-Surface Flaw e/t = 0.2
Transition Region (I)
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

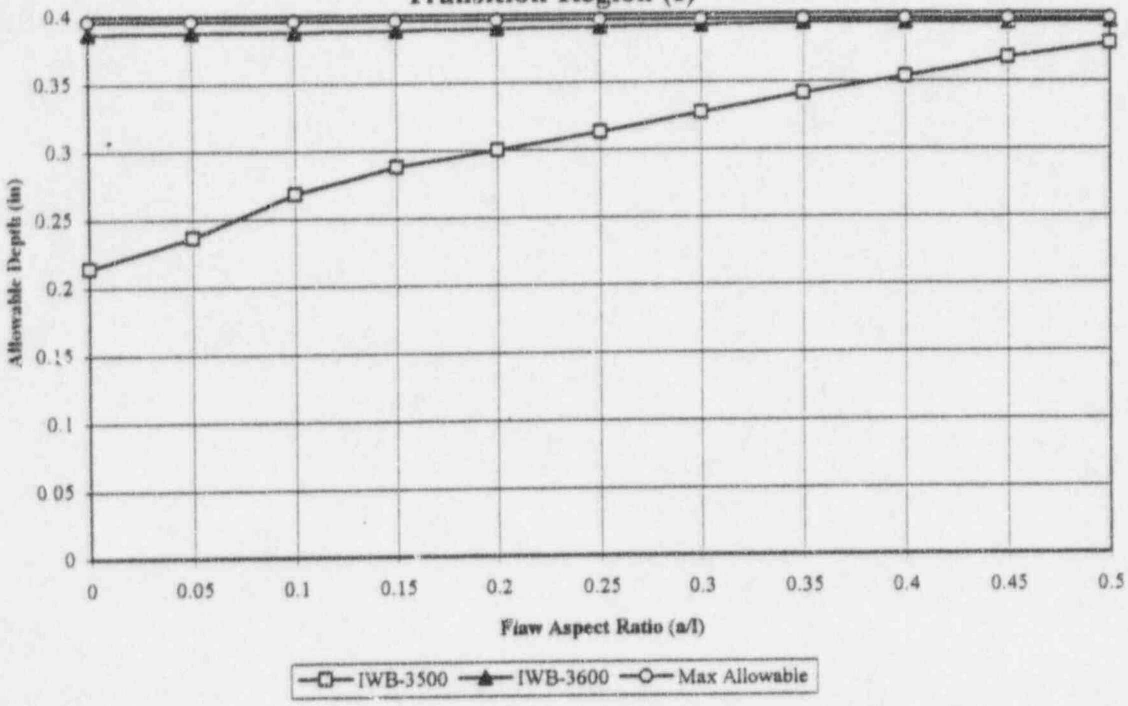
Circumferential Sub-Surface Flaw e/t = 0.35
Transition Region (I)



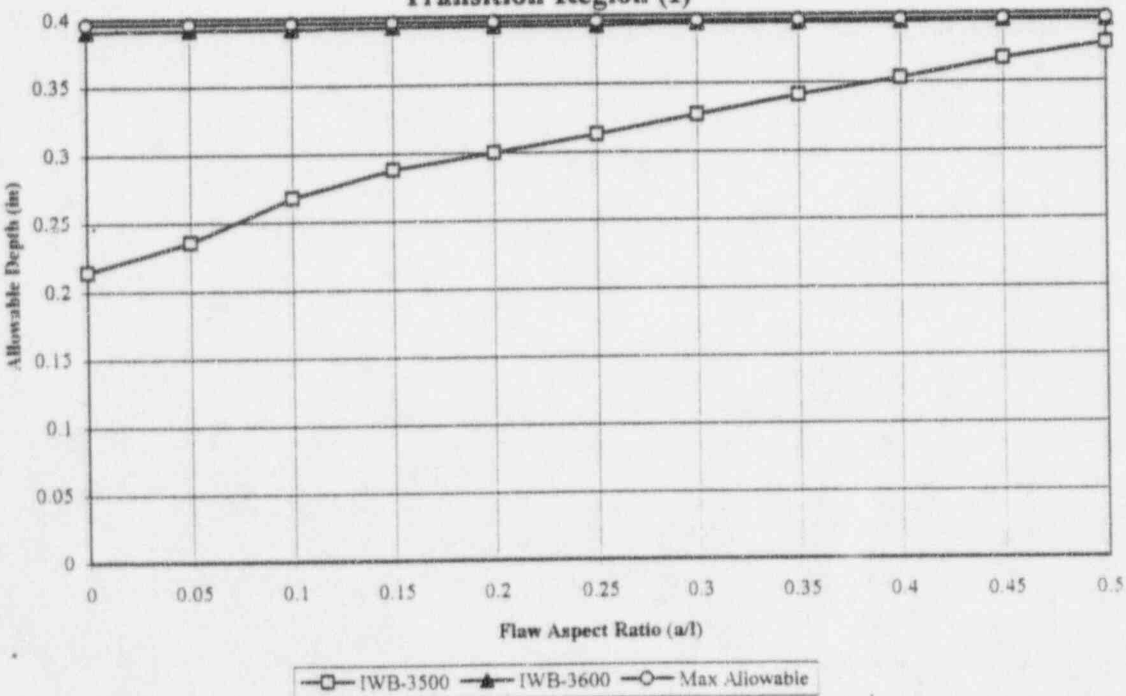
Axial Sub-Surface Flaw e/t = 0.35
Transition Region (I)



Circumferential Sub-Surface Flaw e/t = 0.45
Transition Region (I)



Axial Sub-Surface Flaw e/t = 0.45
Transition Region (I)



APPENDIX I

Flaw Acceptance Diagrams for Region I Materials

Region I includes:

- Lower Shell Longitudinal Weld (SA1580) *
- Lower Shell to Head Transition (WF154)
- Head Transition Piece **

Based on Minimum Thickness = 5"

Default Maximum Allowable Flaw Sizes for All Charts:

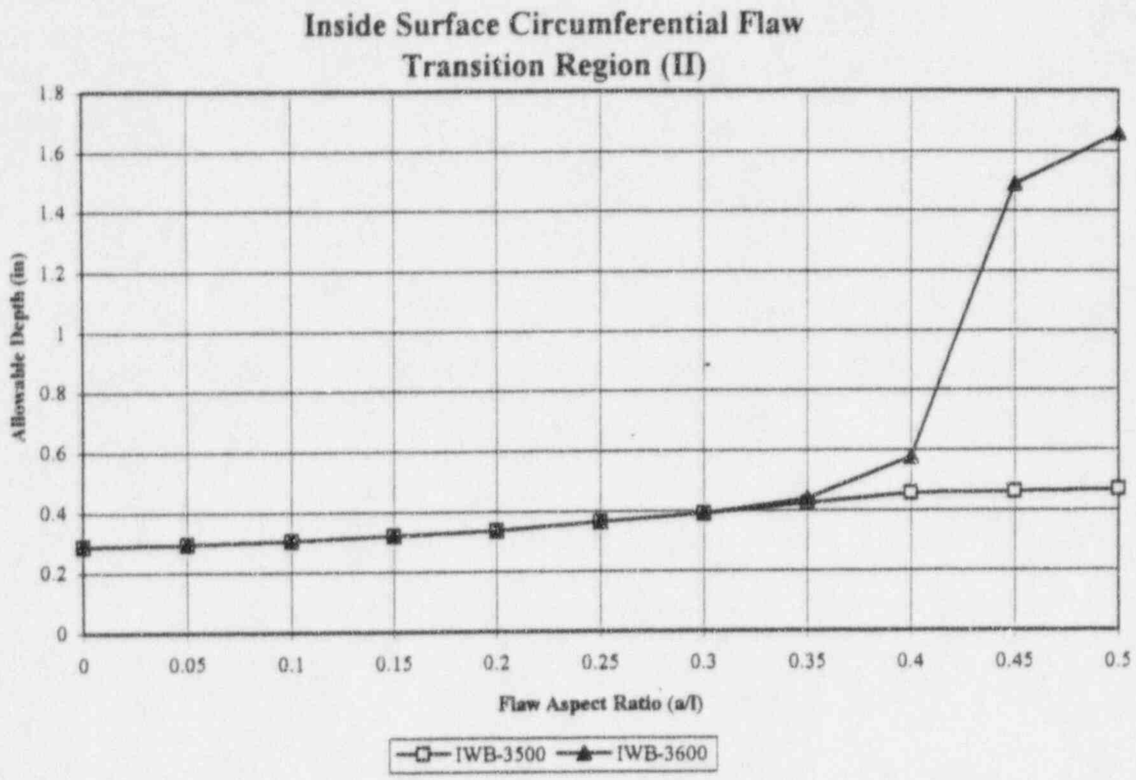
Axially-Oriented Flaws = 1.67"
Circumferentially-Oriented Flaws = 1.67"

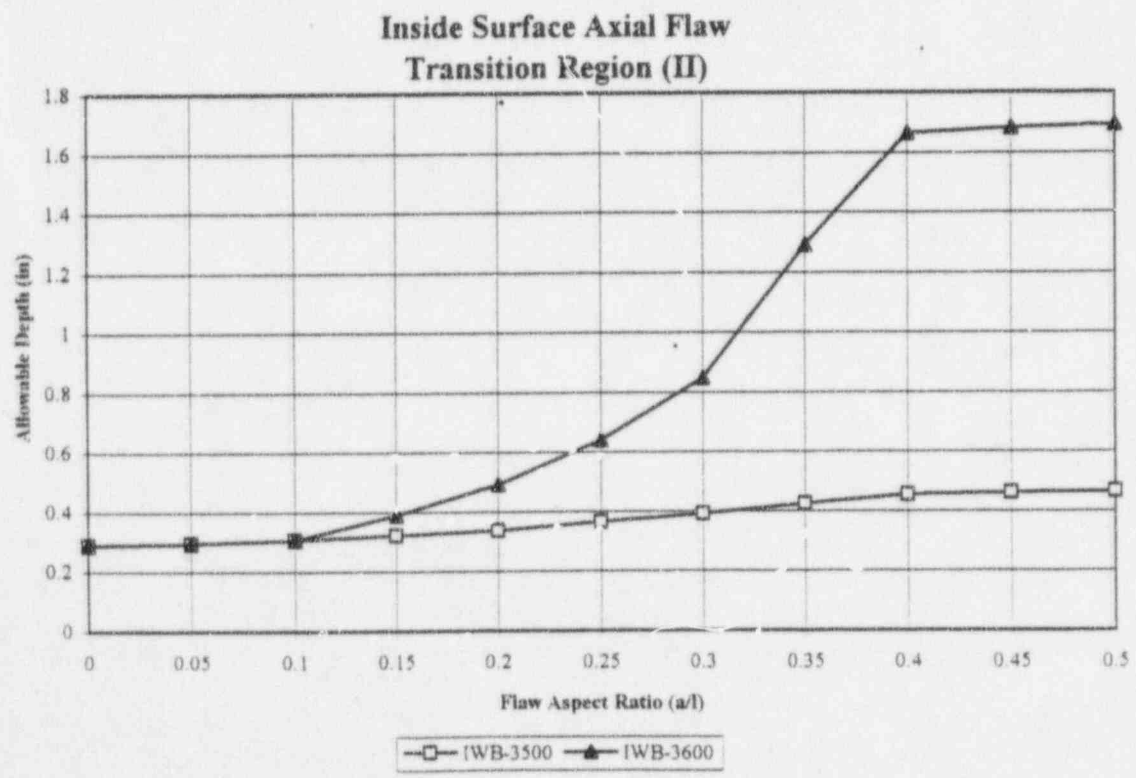
Notes: * Includes all portions of Lower Shell Longitudinal Weld with thicknesses <8.4375. For portions equal to 8.4375, see Region G.

** Includes all irradiated portions of Head Transition Piece. For unirradiated portions, see Region J.

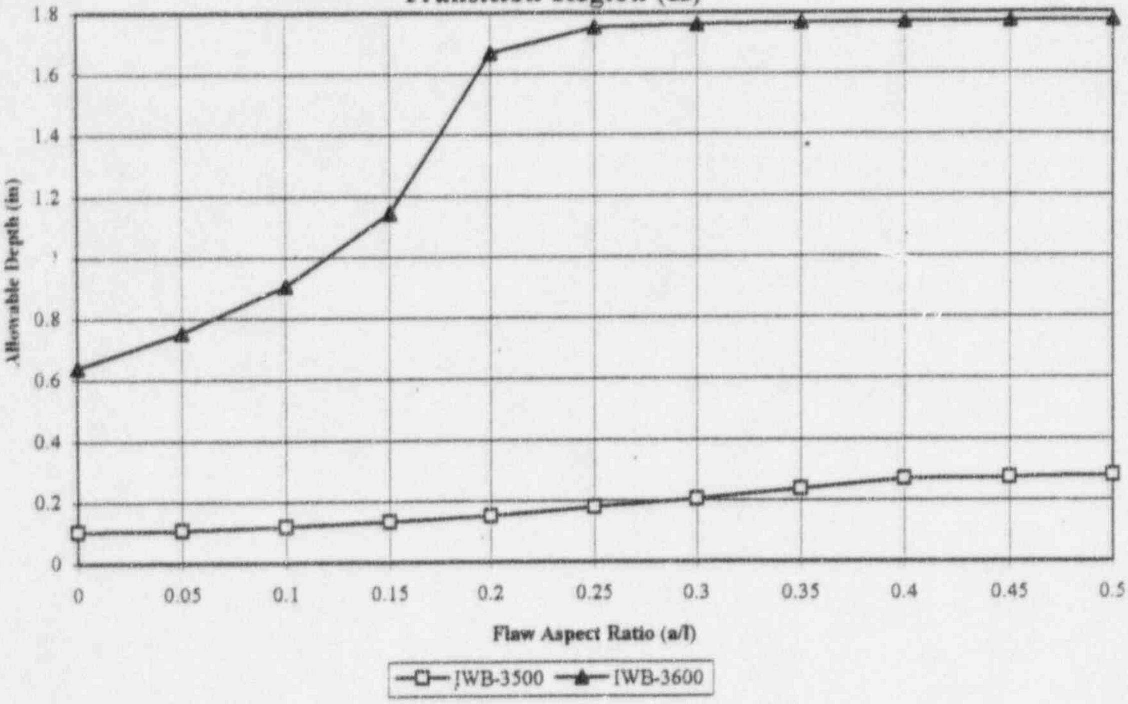
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

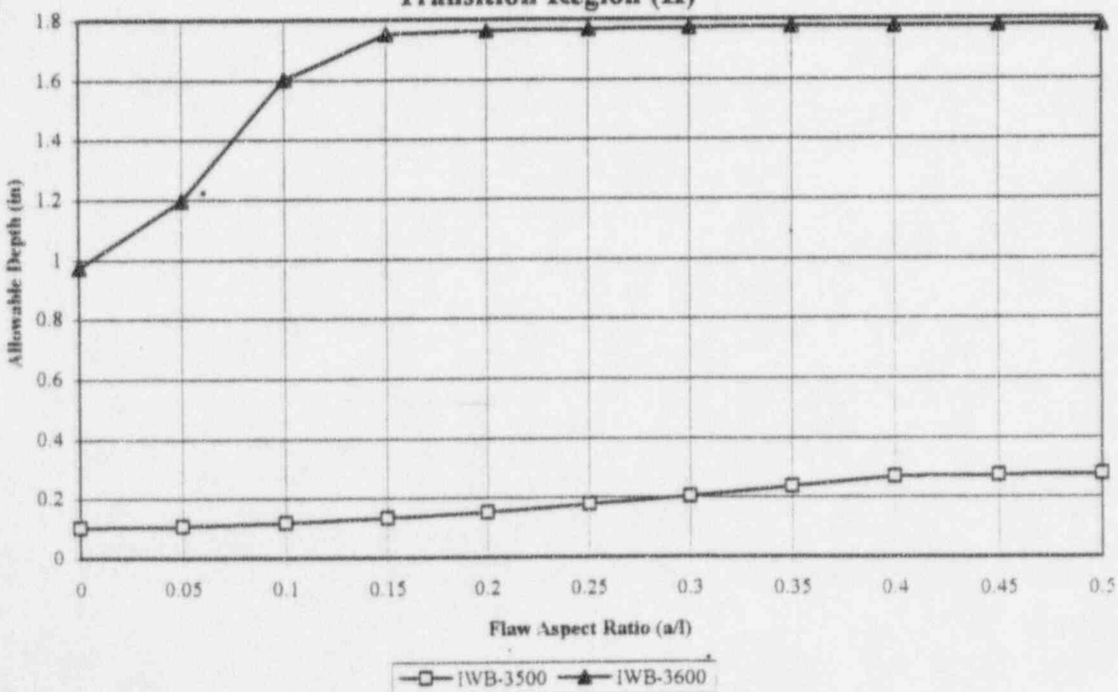

Inside Surface Circumferential Flaw
Transition Region (II)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600


Inside Surface Axial Flaw
Transition Region (II)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

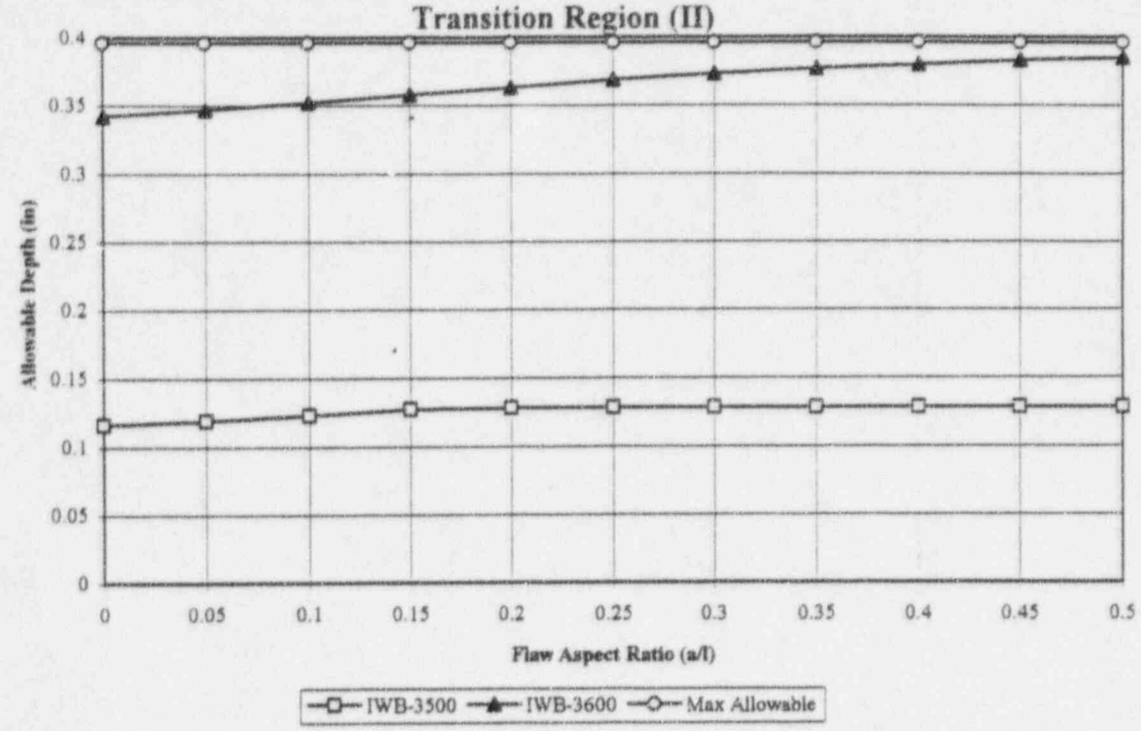
Outside Surface Circumferential Flaw
Transition Region (II)



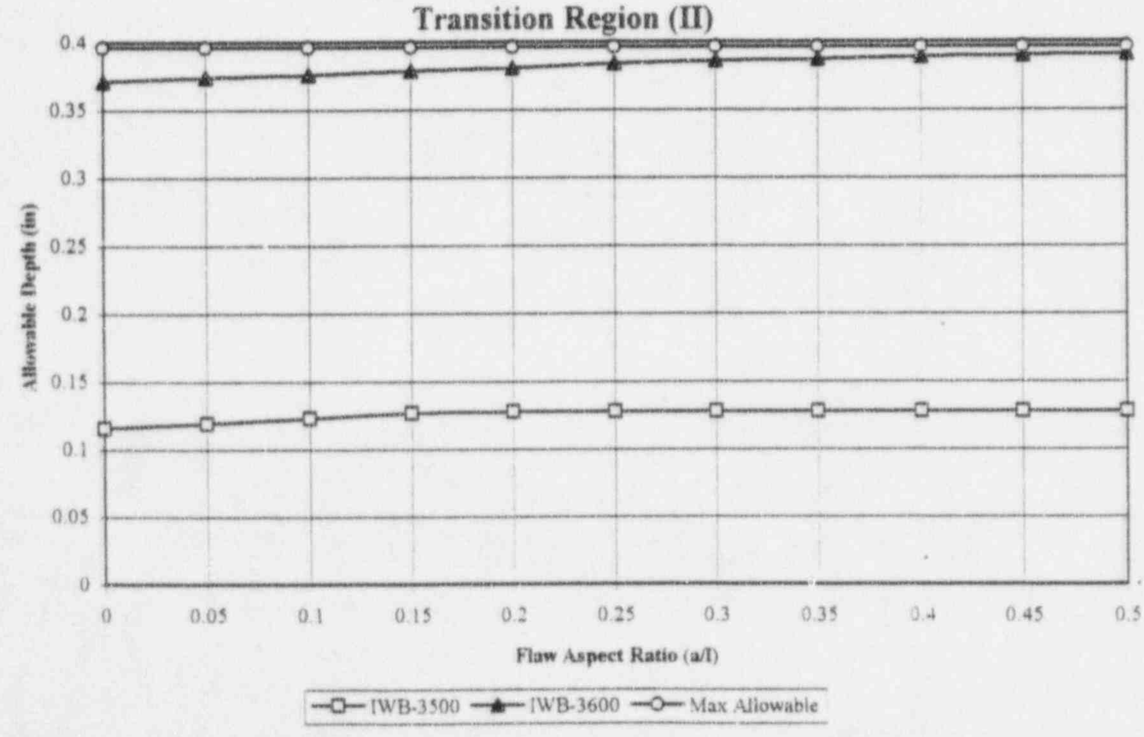
Outside Surface Axial Flaw
Transition Region (II)

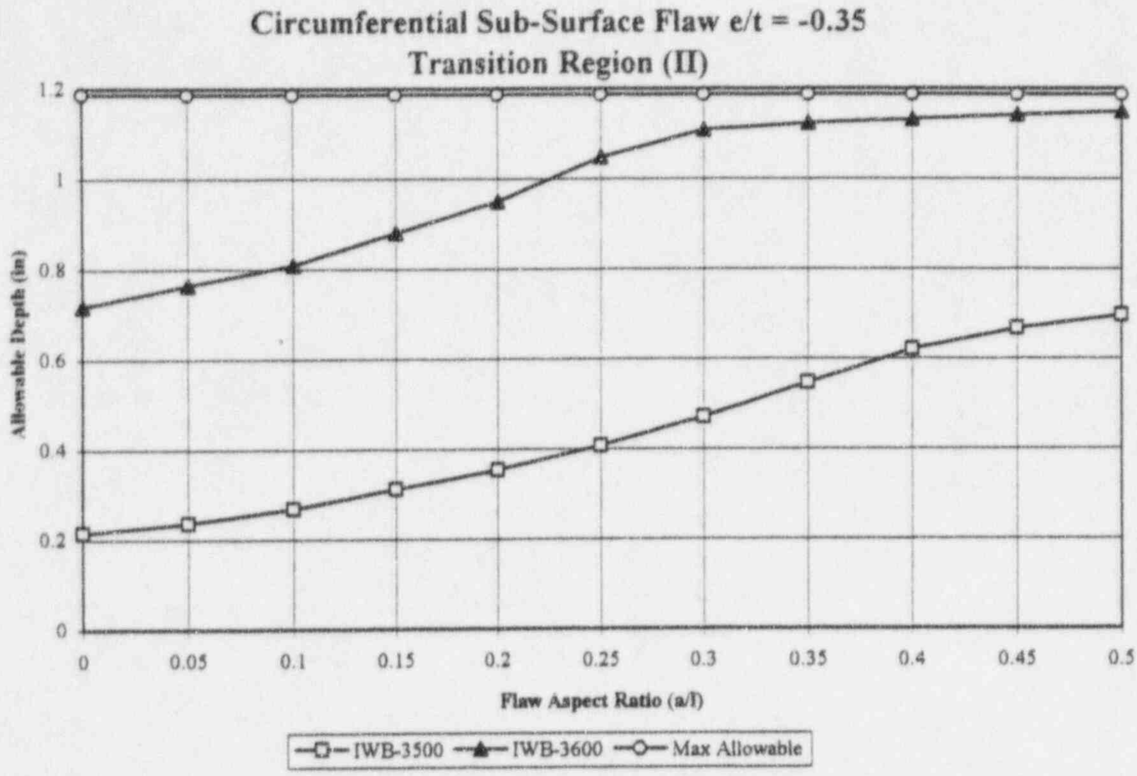


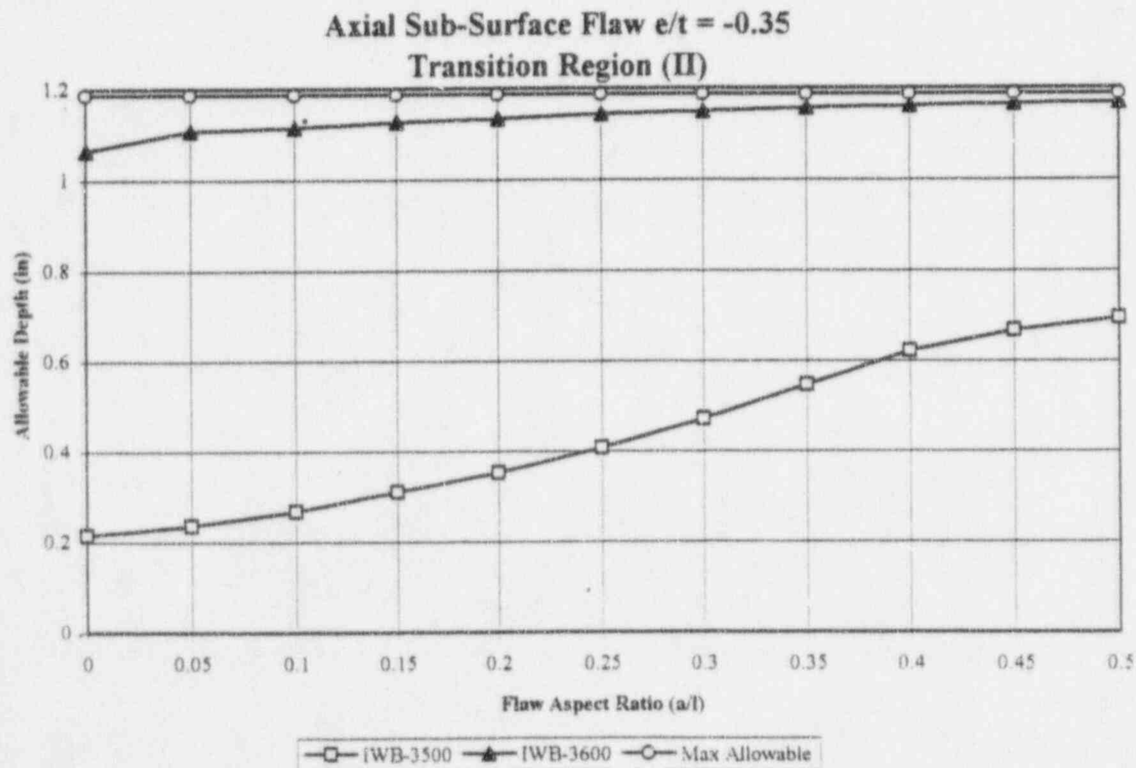
Circumferential Sub-Surface Flaw e/t = -0.4
Transition Region (II)

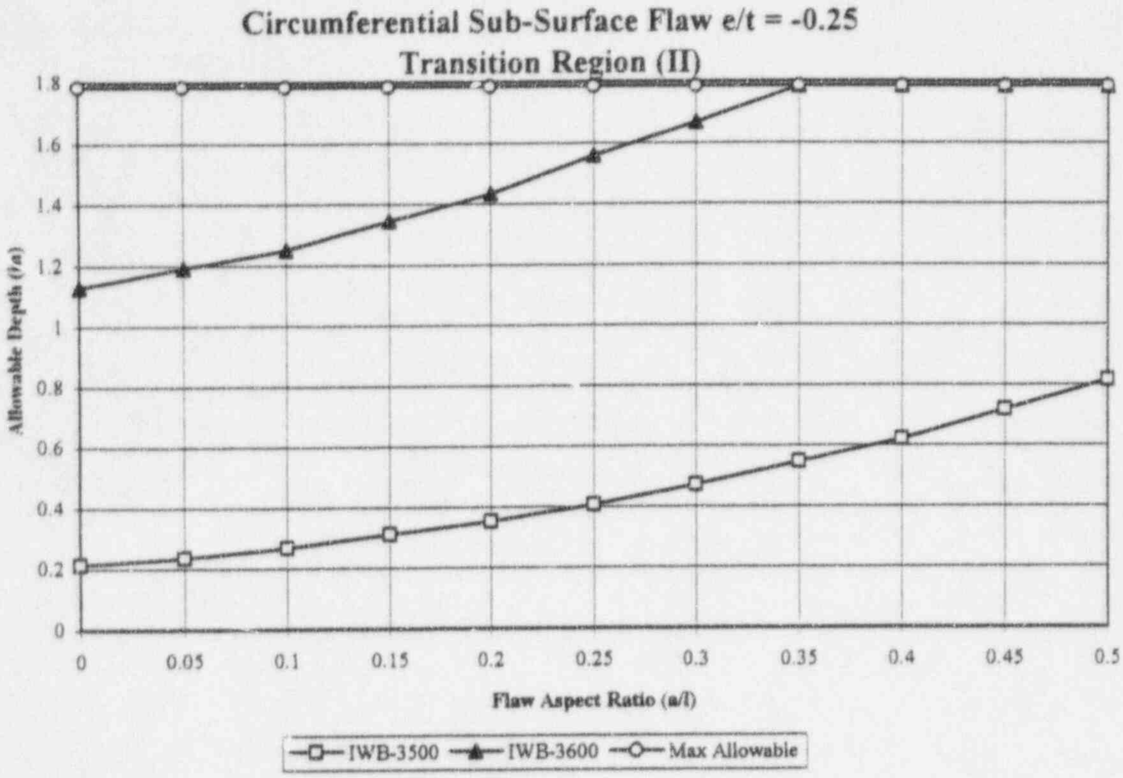


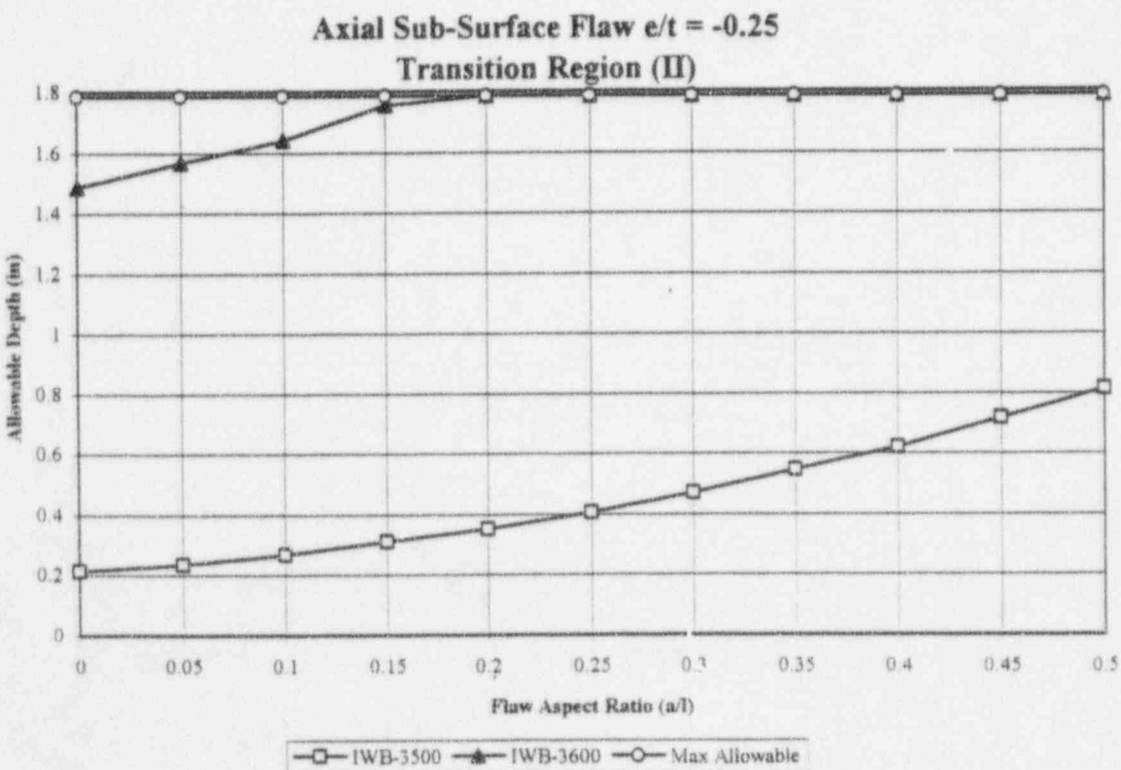
Axial Sub-Surface Flaw e/t = -0.4
Transition Region (II)



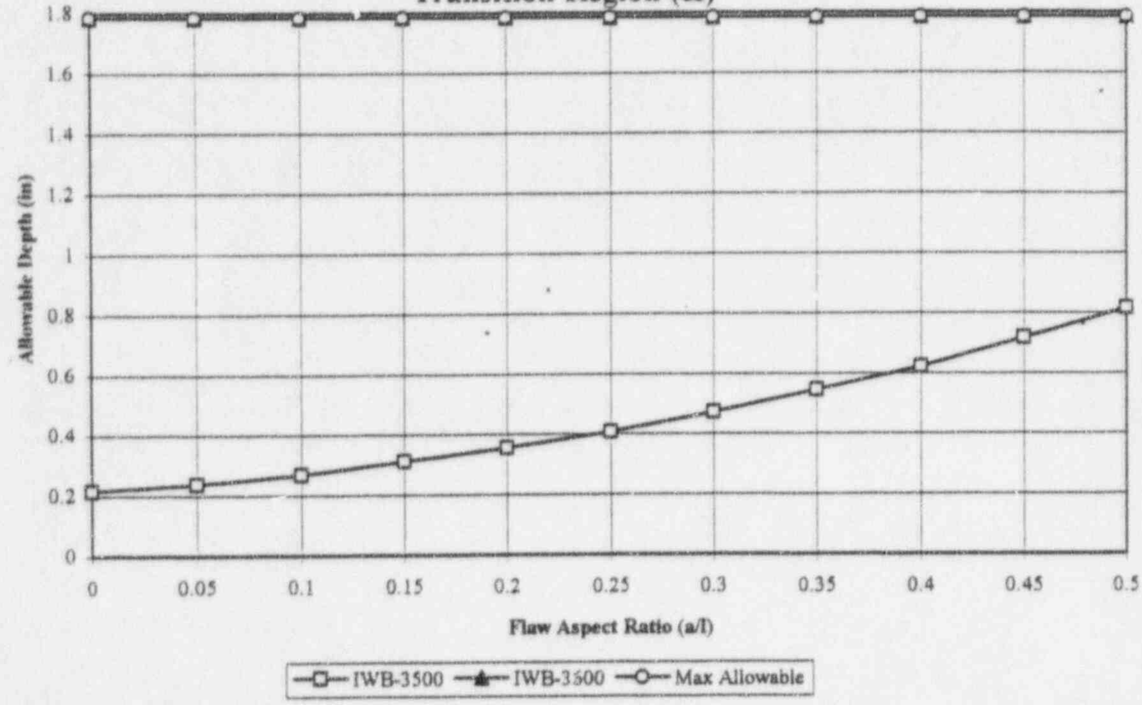

Circumferential Sub-Surface Flaw e/t = -0.35
Transition Region (II)
Allowable Depth (in)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.35
Transition Region (II)
Allowable Depth (in)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

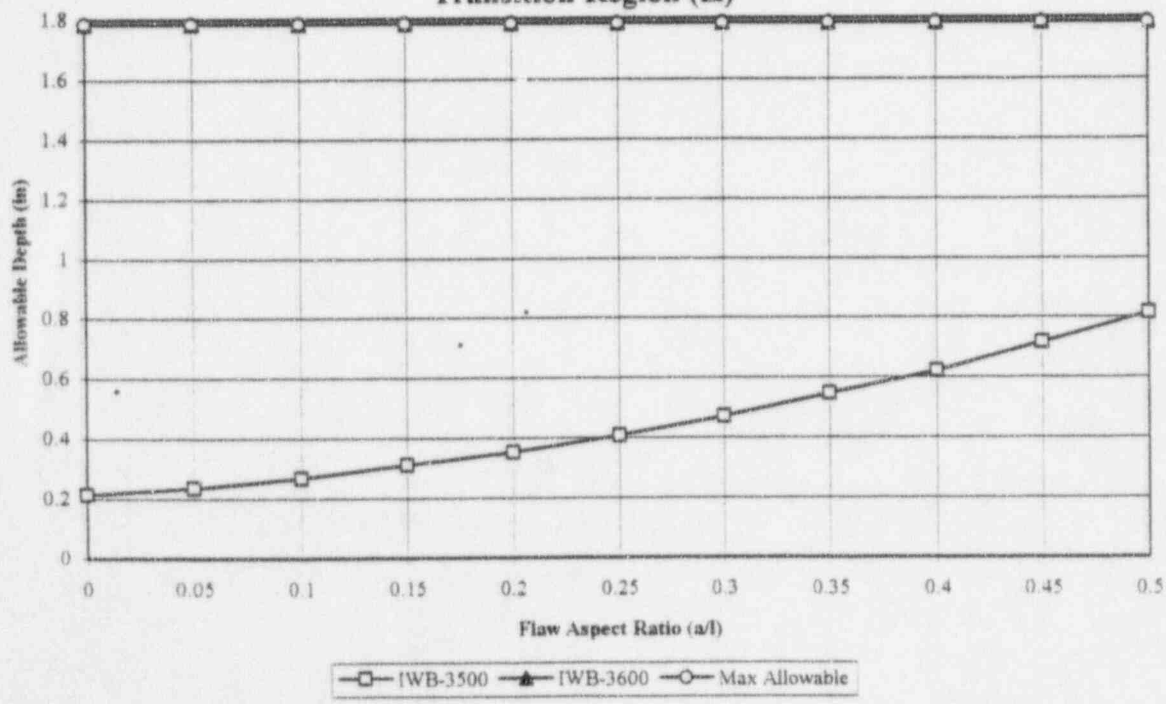

Circumferential Sub-Surface Flaw e/t = -0.25
Transition Region (II)
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.25
Transition Region (II)
Allowable Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

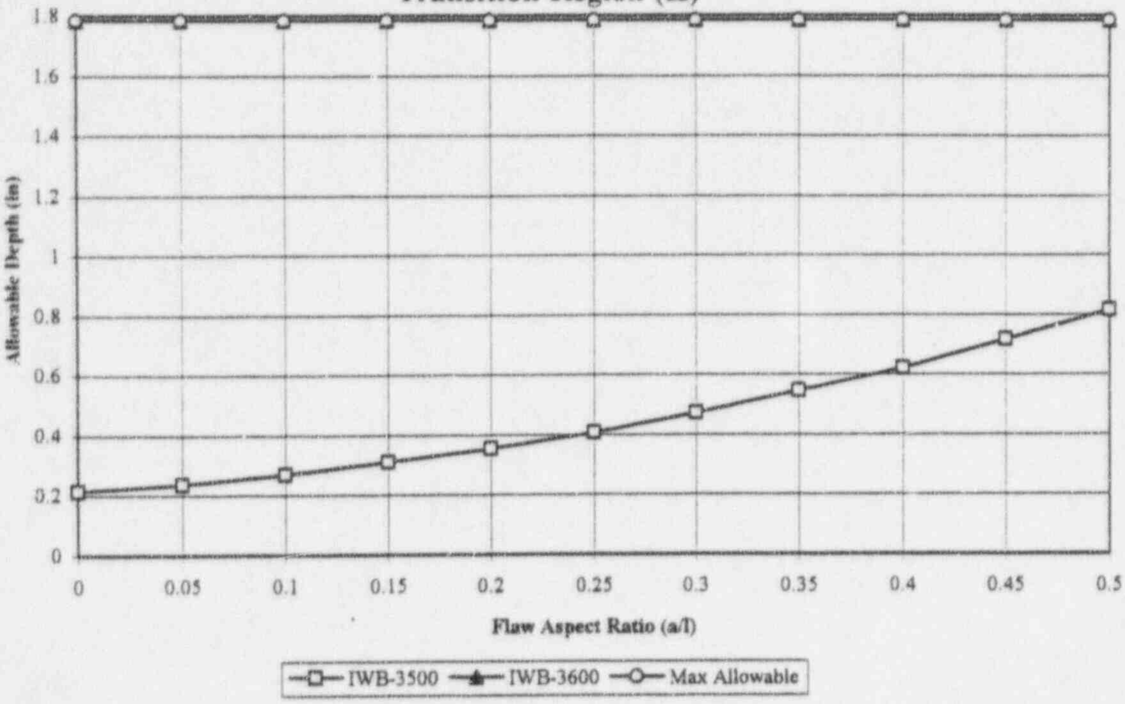
Circumferential Sub-Surface Flaw e/t = -0.1
Transition Region (II)



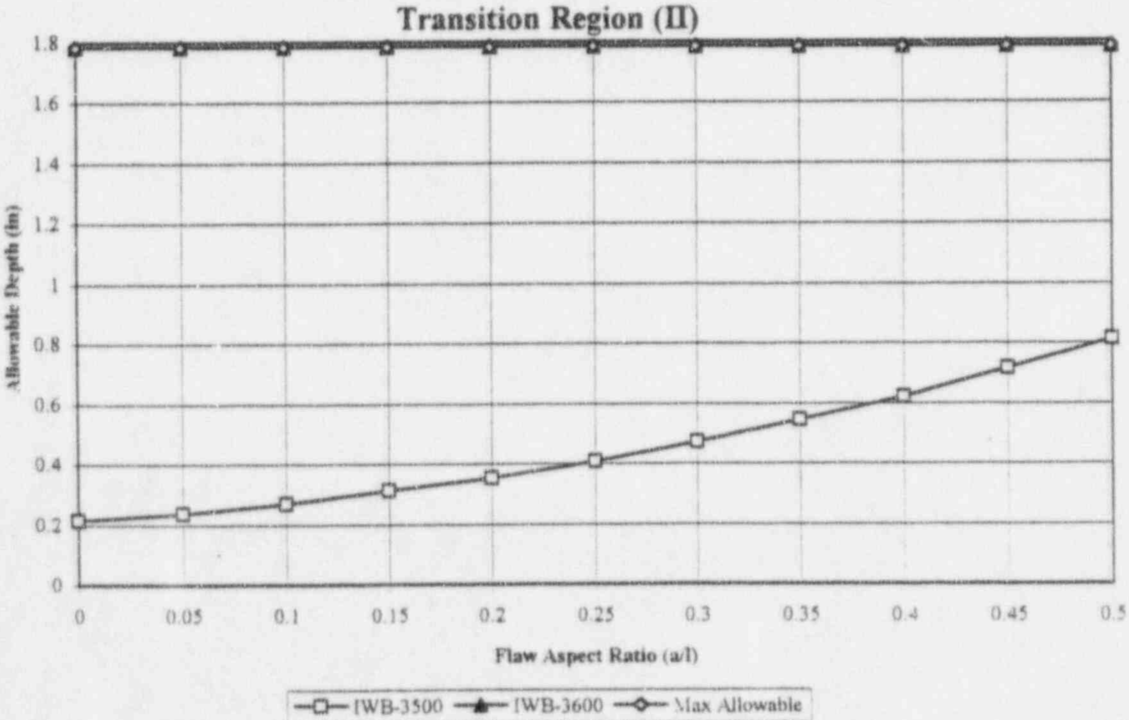
Axial Sub-Surface Flaw e/t = -0.1
Transition Region (II)



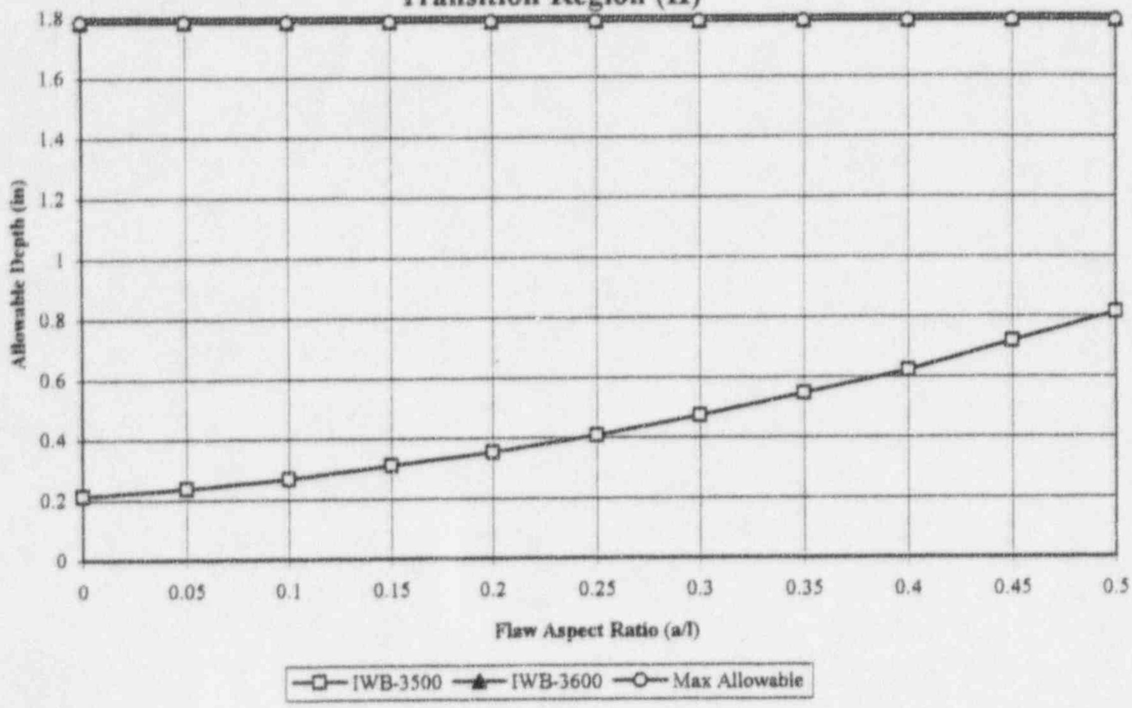
Circumferential Sub-Surface Flaw e/t = 0.0
Transition Region (II)



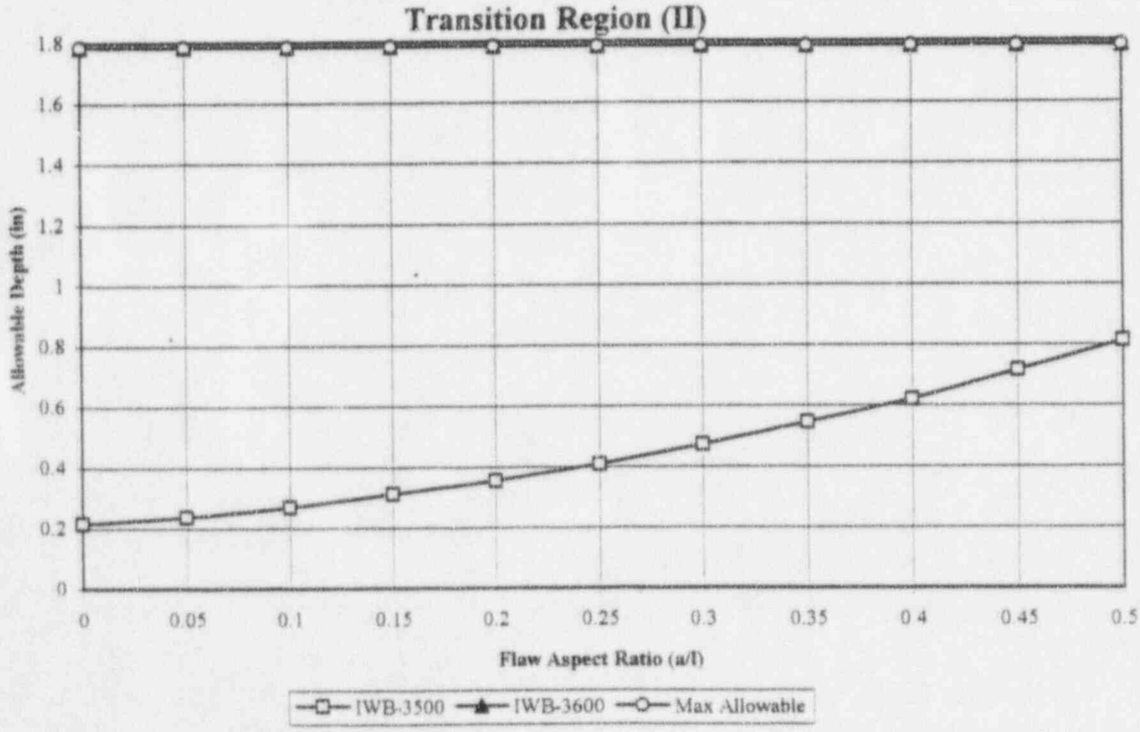
Axial Sub-Surface Flaw e/t = 0.0
Transition Region (II)



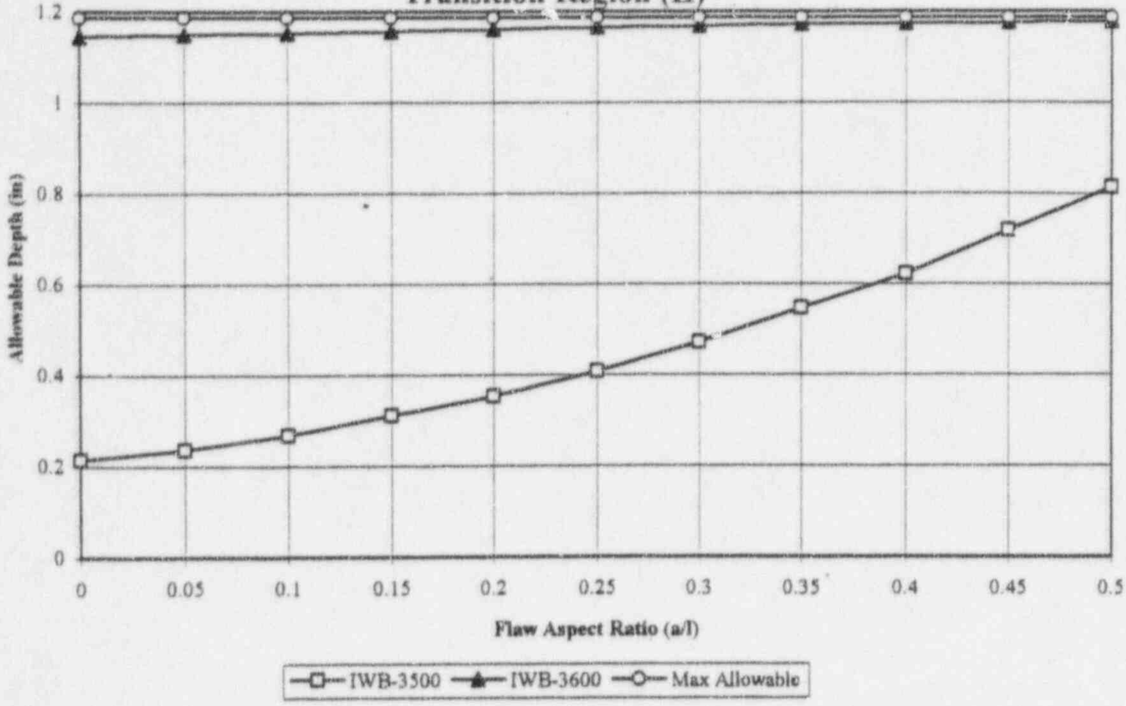
Circumferential Sub-Surface Flaw e/t = 0.2
Transition Region (II)



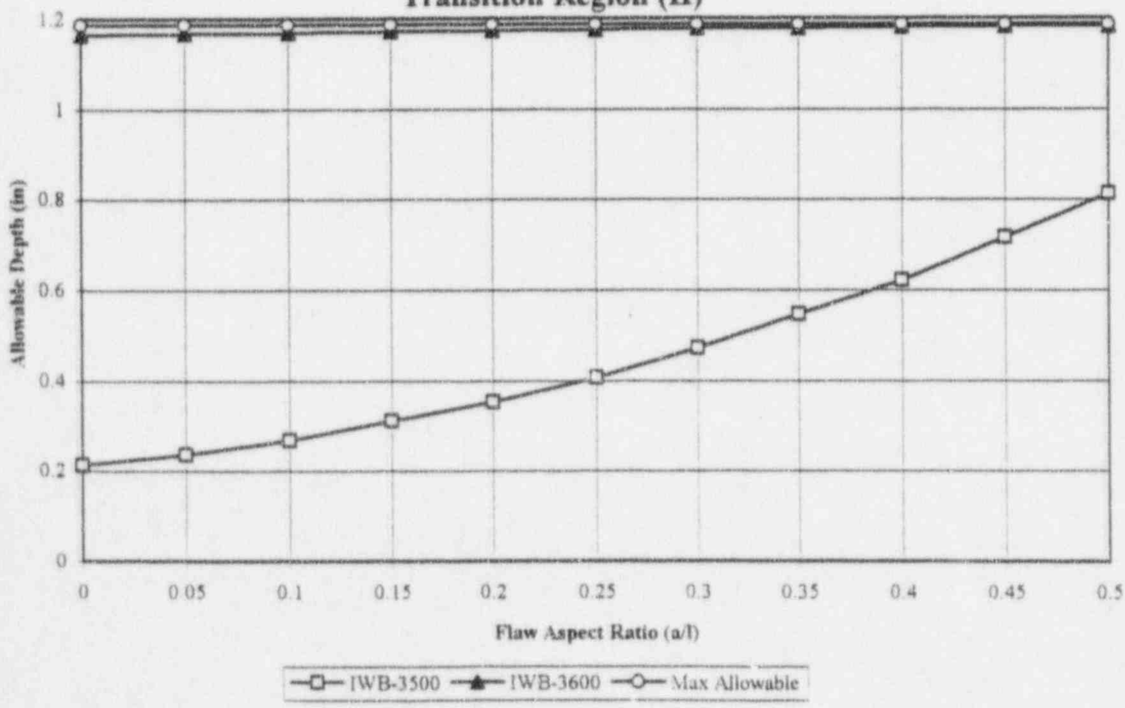
Axial Sub-Surface Flaw e/t = 0.2
Transition Region (II)



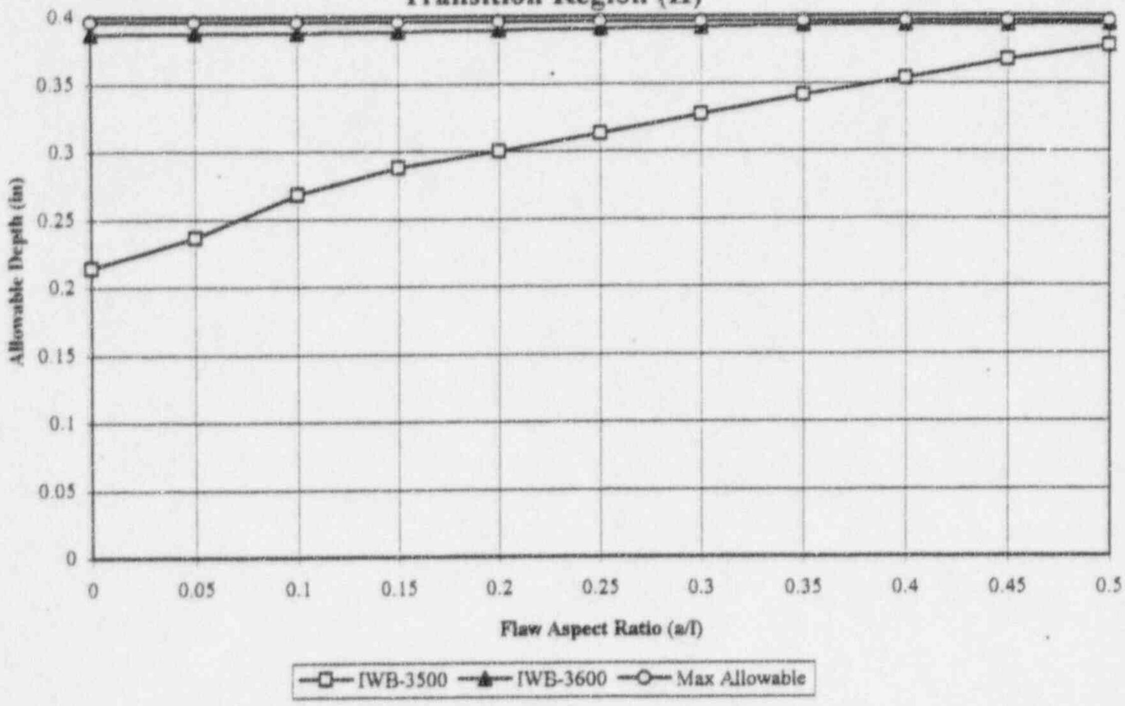
Circumferential Sub-Surface Flaw e/t = 0.35
Transition Region (II)



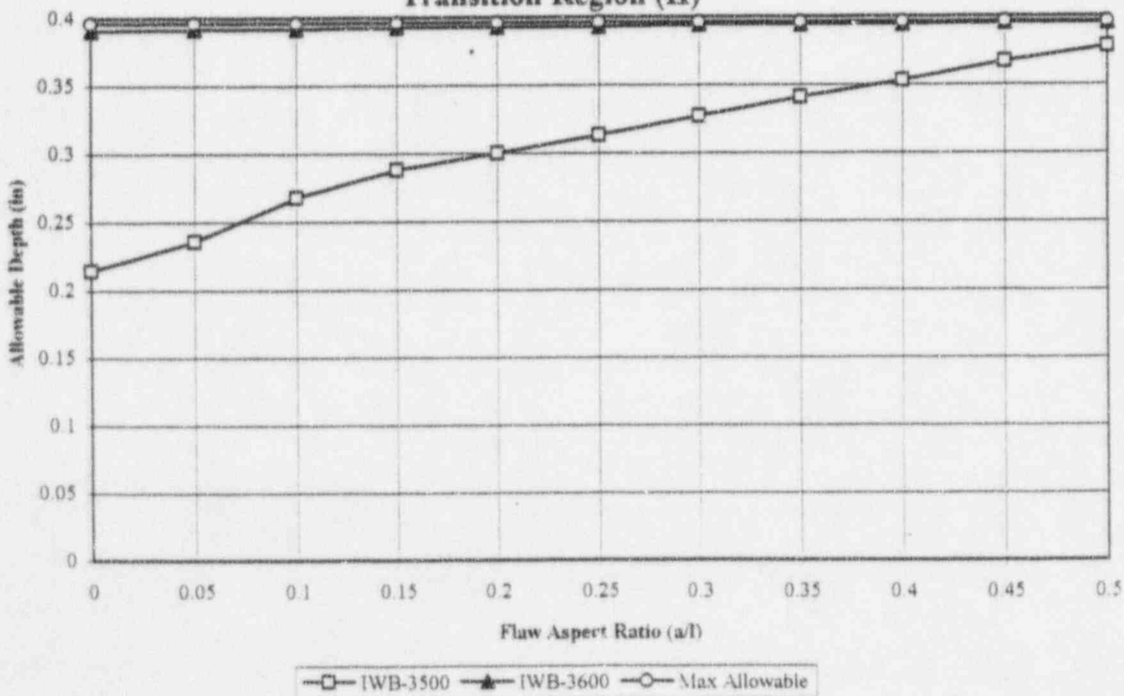
Axial Sub-Surface Flaw e/t = 0.35
Transition Region (II)



Circumferential Sub-Surface Flaw e/t = 0.45
Transition Region (II)



Axial Sub-Surface Flaw e/t = 0.45
Transition Region (II)



APPENDIX J

Flaw Acceptance Diagrams for Region J Materials

Region J includes:

- Head Transition Piece *
- Head Transition to Bottom Head Weld
- Bottom Head

Based on Minimum Thickness = 5"

Default Maximum Allowable Flaw Sizes for All Charts:

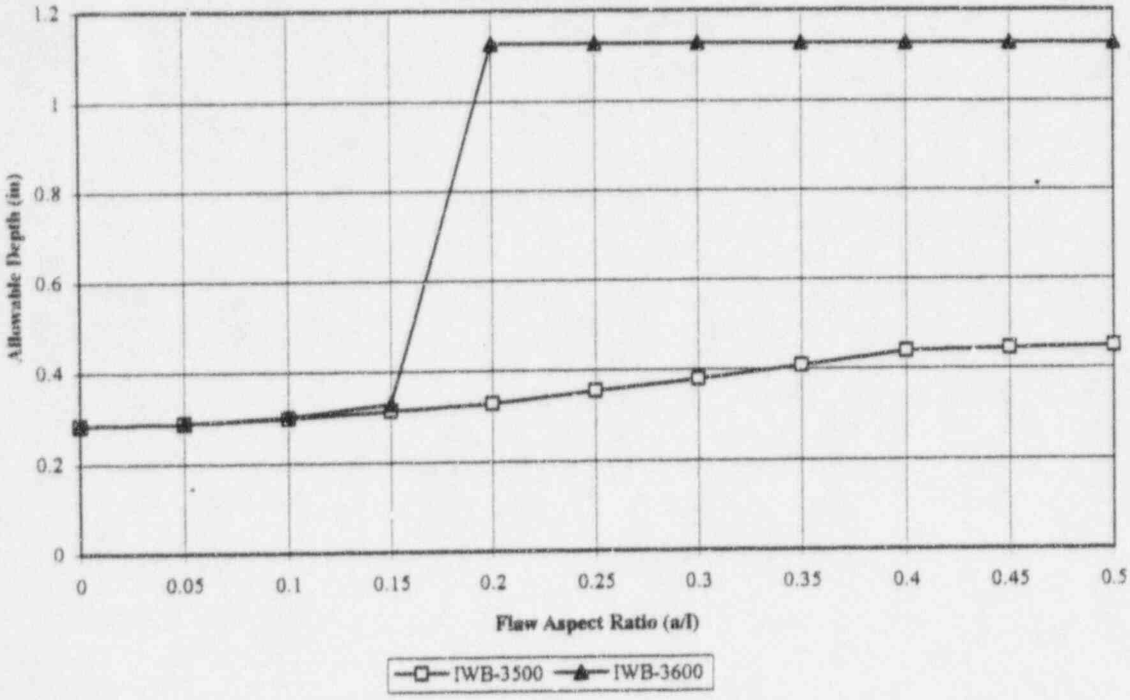
Axially-Oriented Flaws = 1.67"
Circumferentially-Oriented Flaws = 1.67"

Note: * Includes all unirradiated portions of Head Transition Piece. For irradiated portions, see Region I.

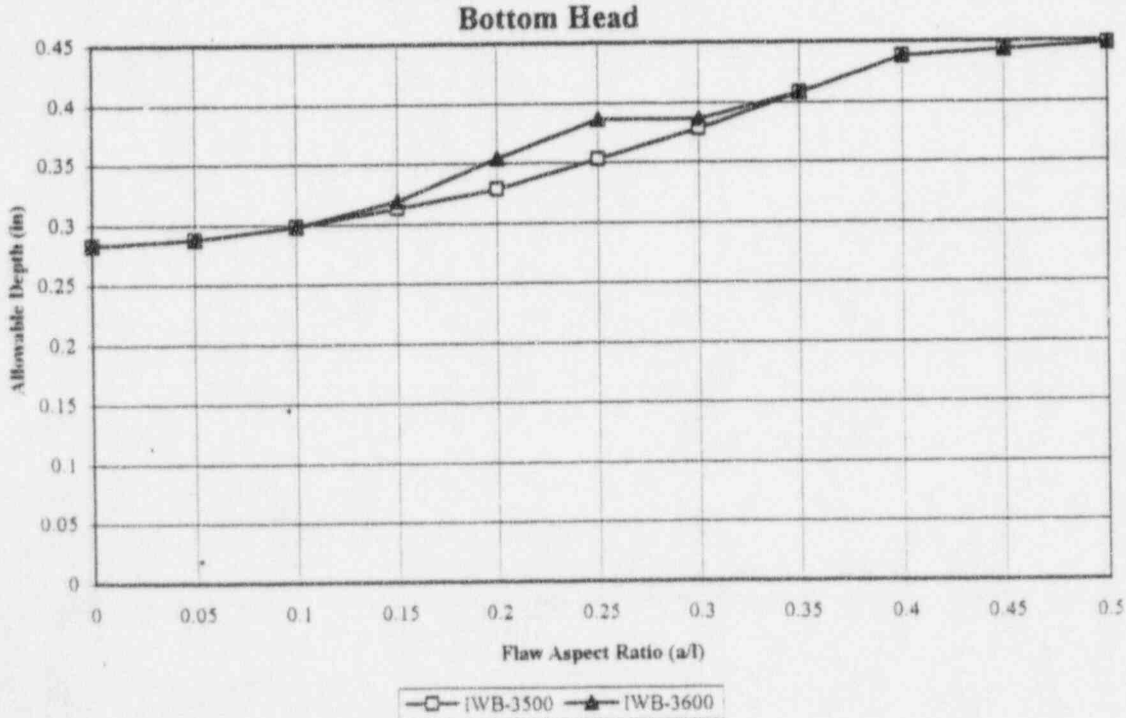
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

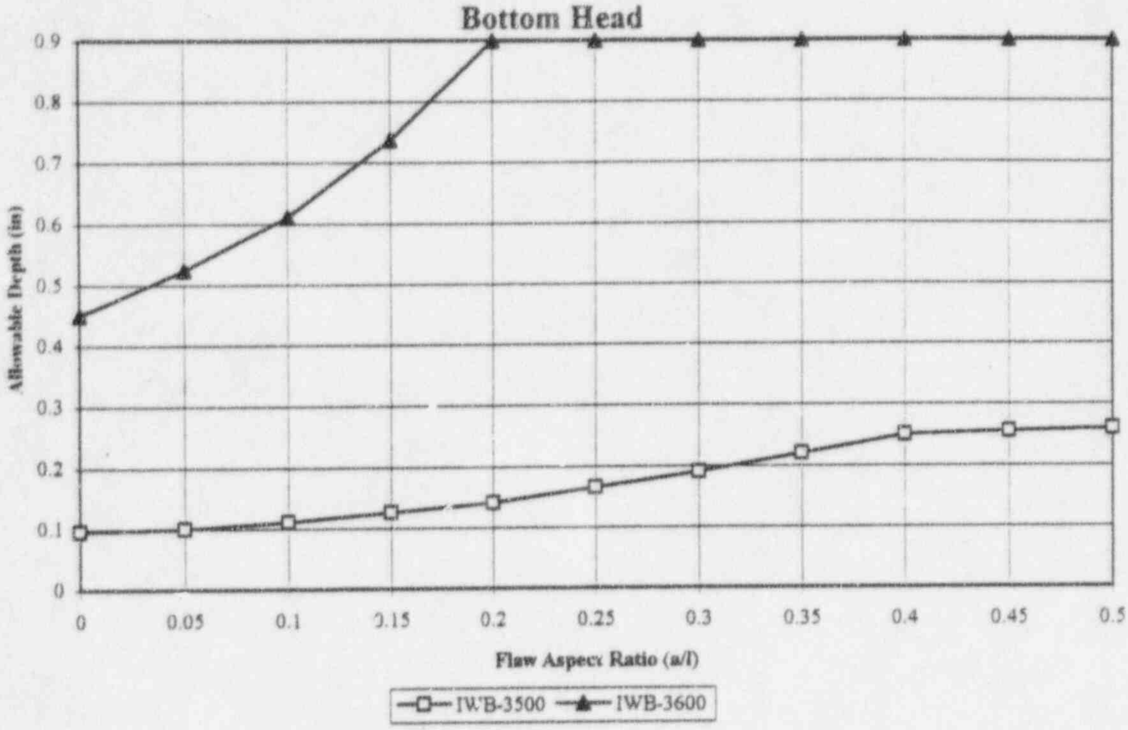
Inside Surface Circumferential Flaw
Bottom Head



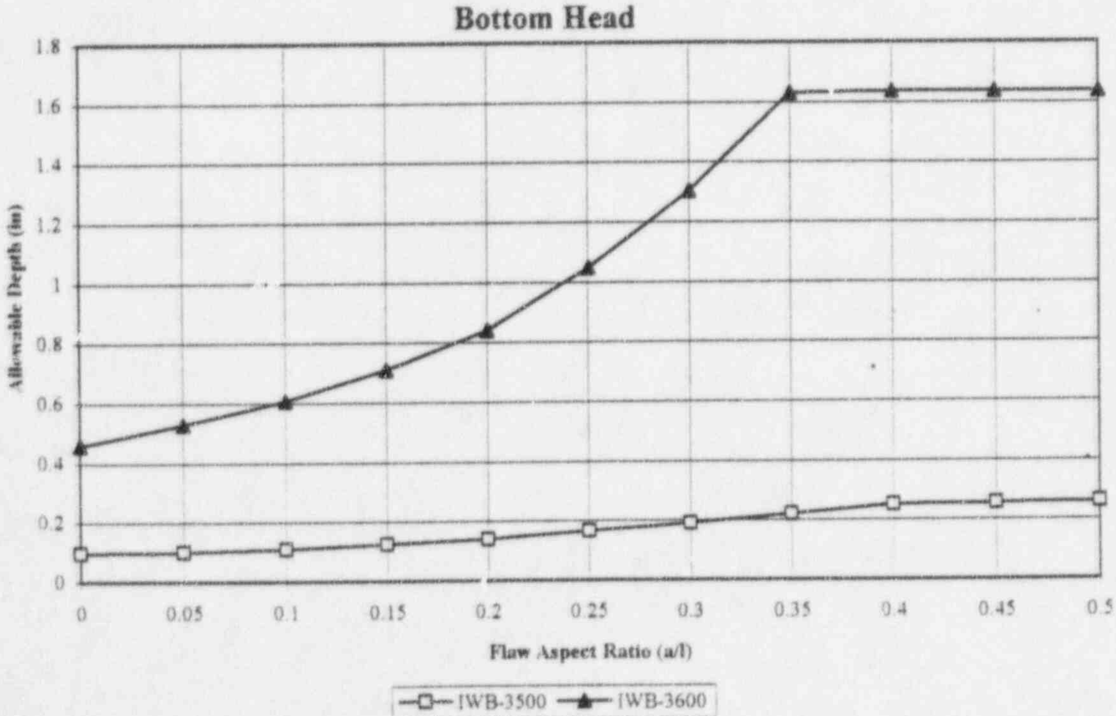
Inside Surface Axial Flaw
Bottom Head

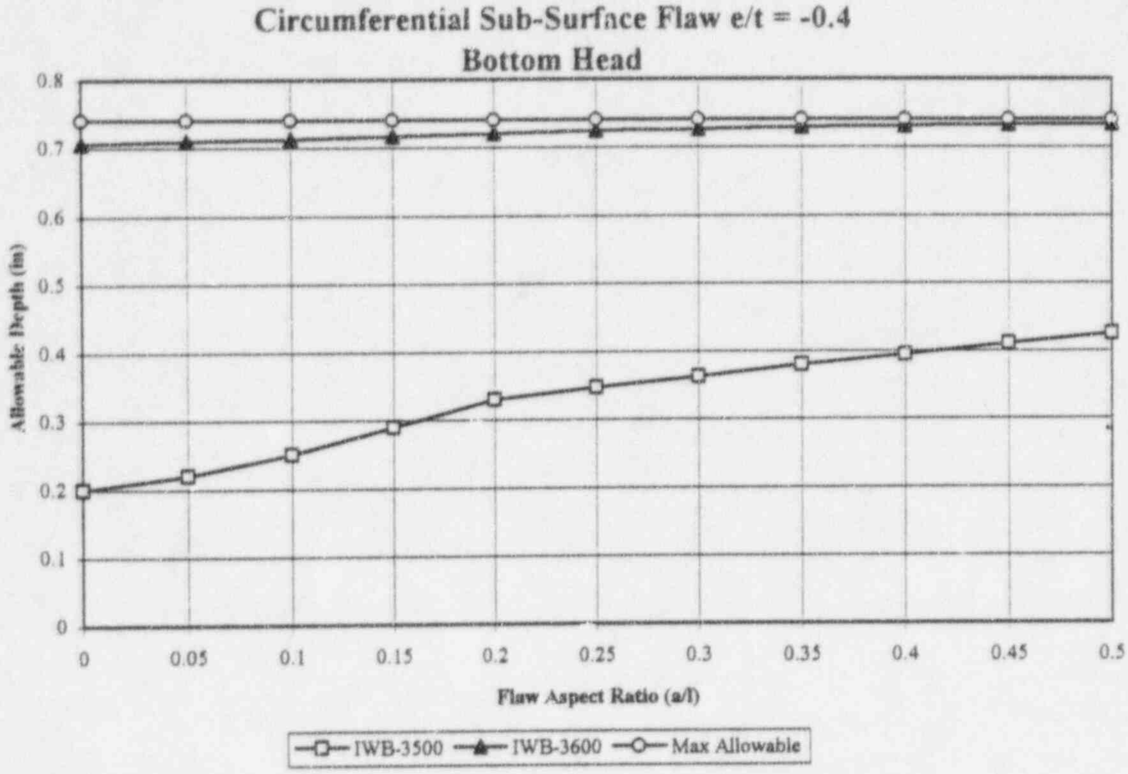


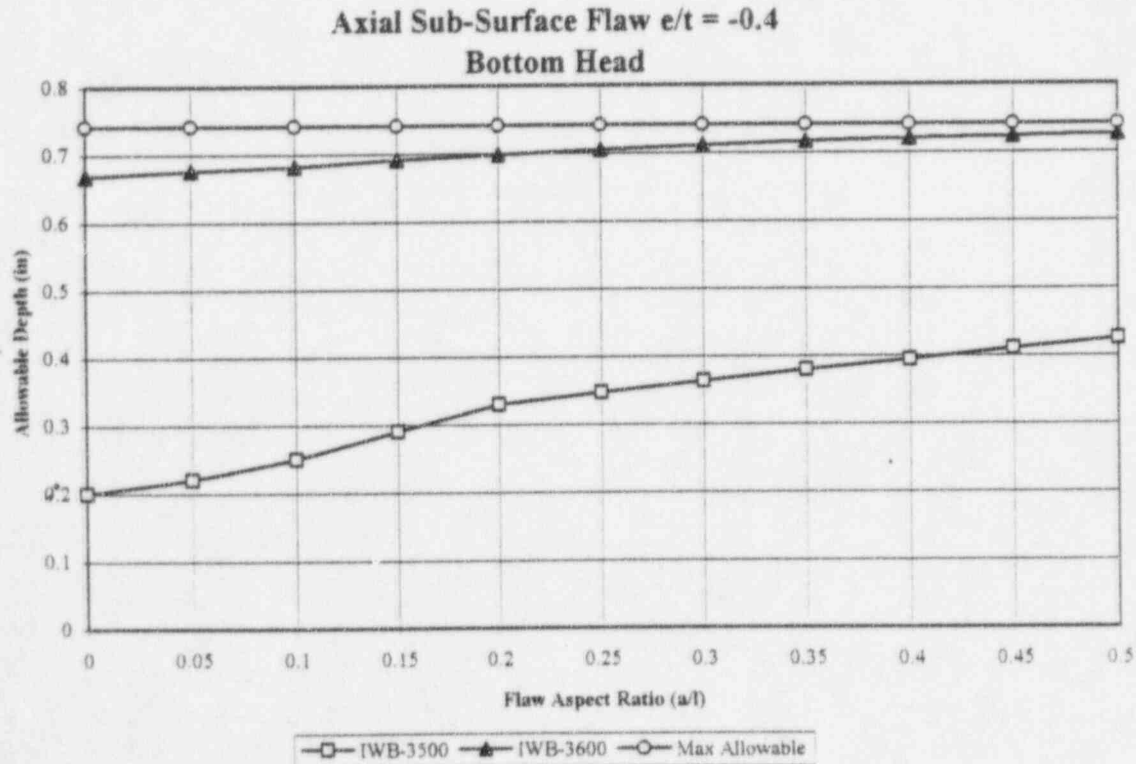
Outside Surface Circumferential Flaw
Bottom Head



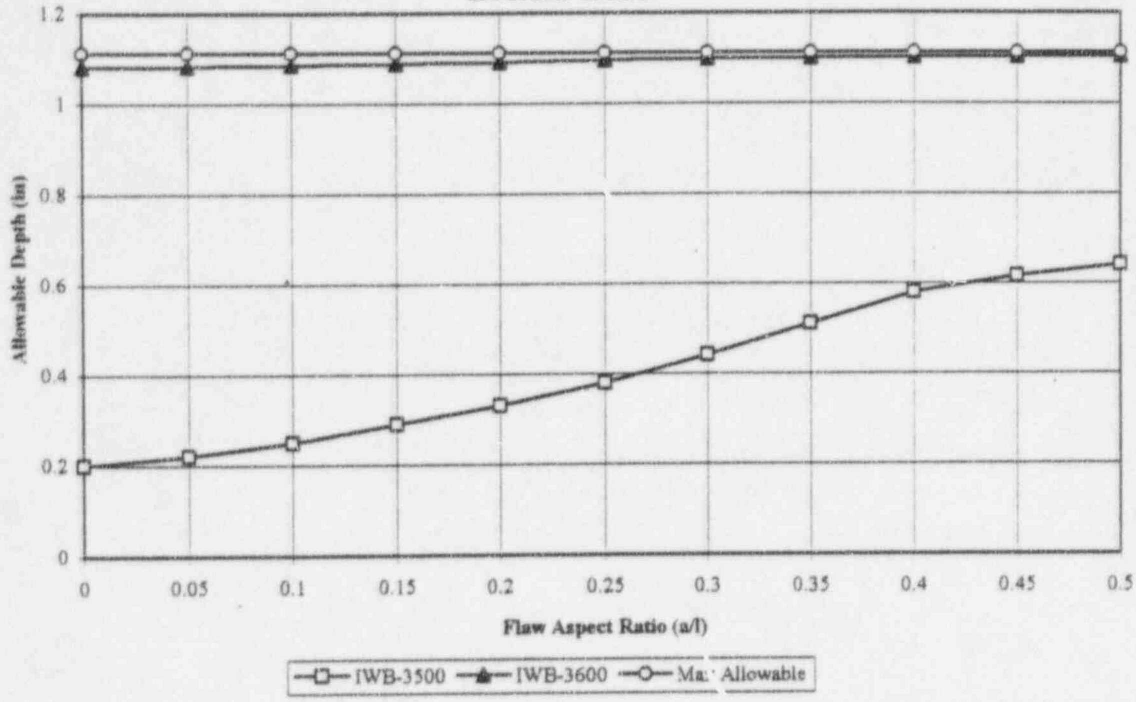
Outside Surface Axial Flaw
Bottom Head



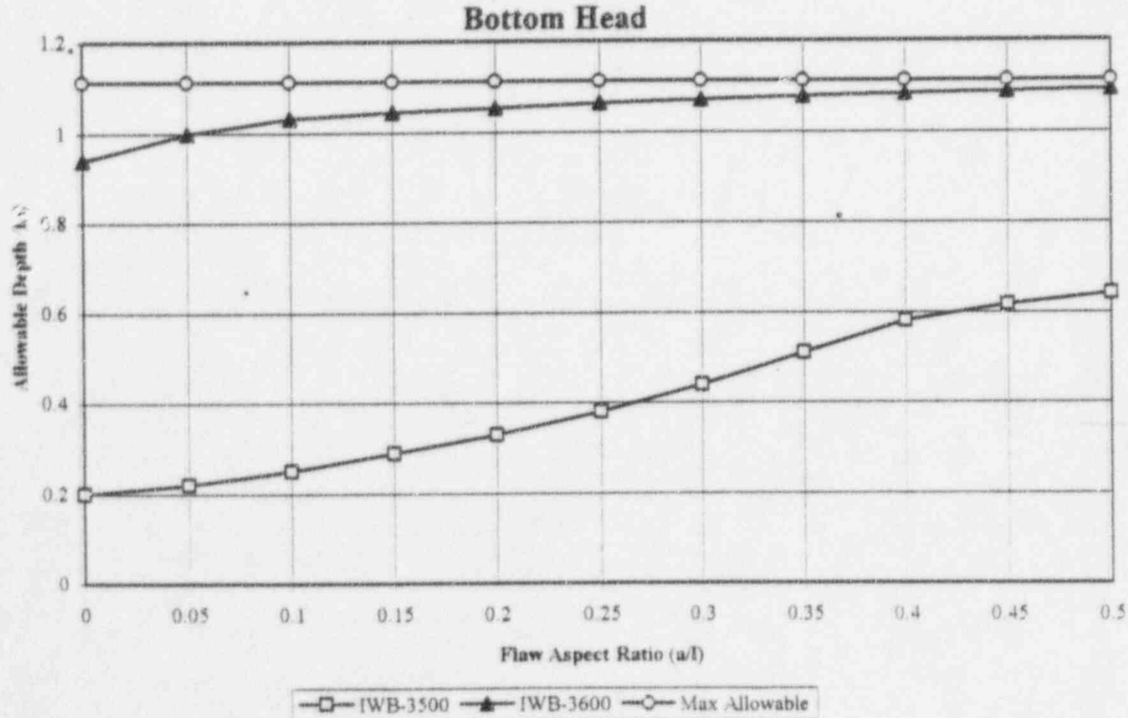

Circumferential Sub-Surface Flaw e/t = -0.4
Bottom Head
Allowable Depth (in)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.4
Bottom Head
Allowable Depth (in)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

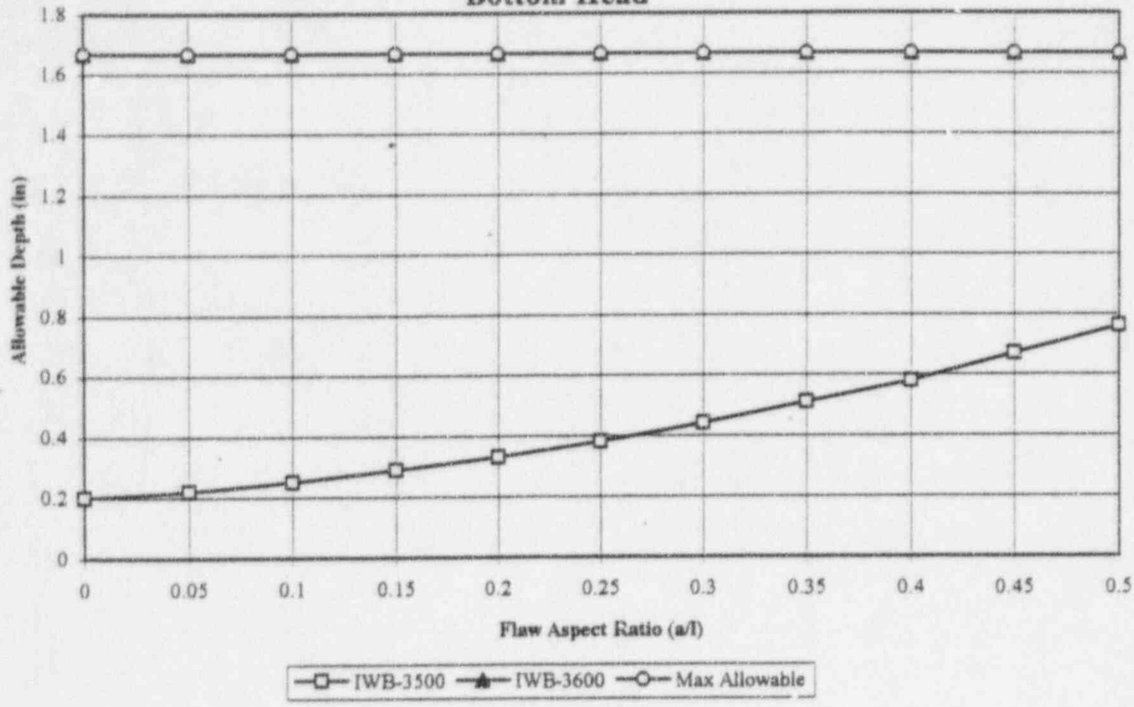
Circumferential Sub-Surface Flaw e/t = -0.35
Bottom Head



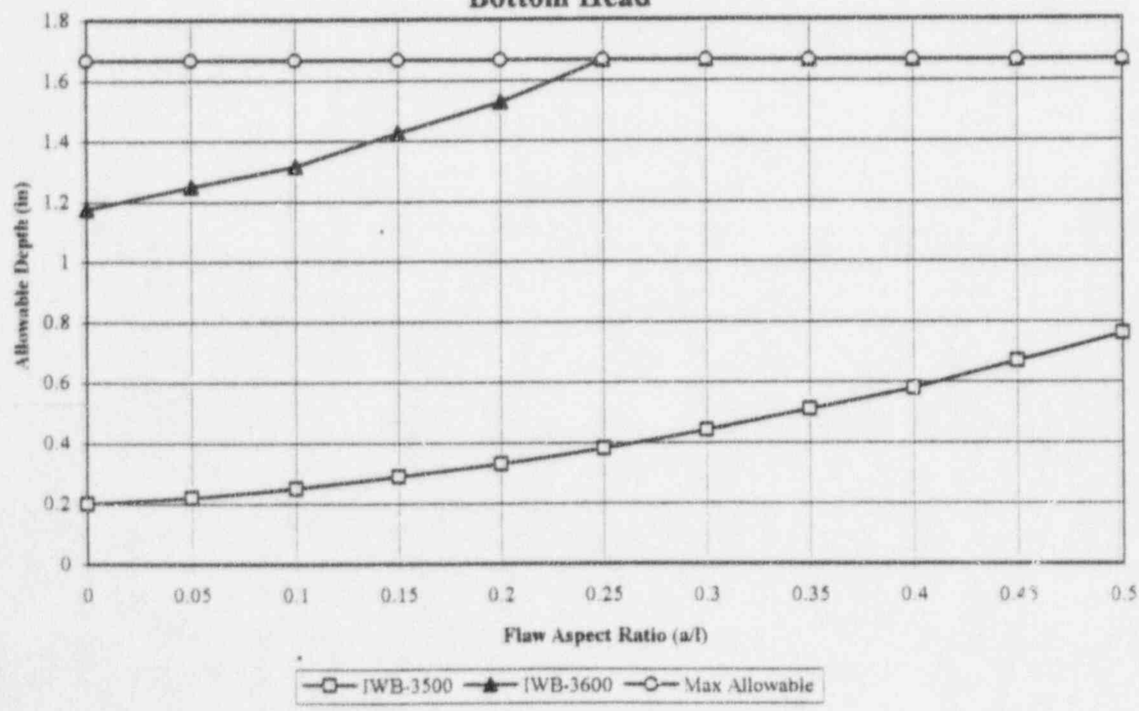
Axial Sub-Surface Flaw e/t = -0.35
Bottom Head



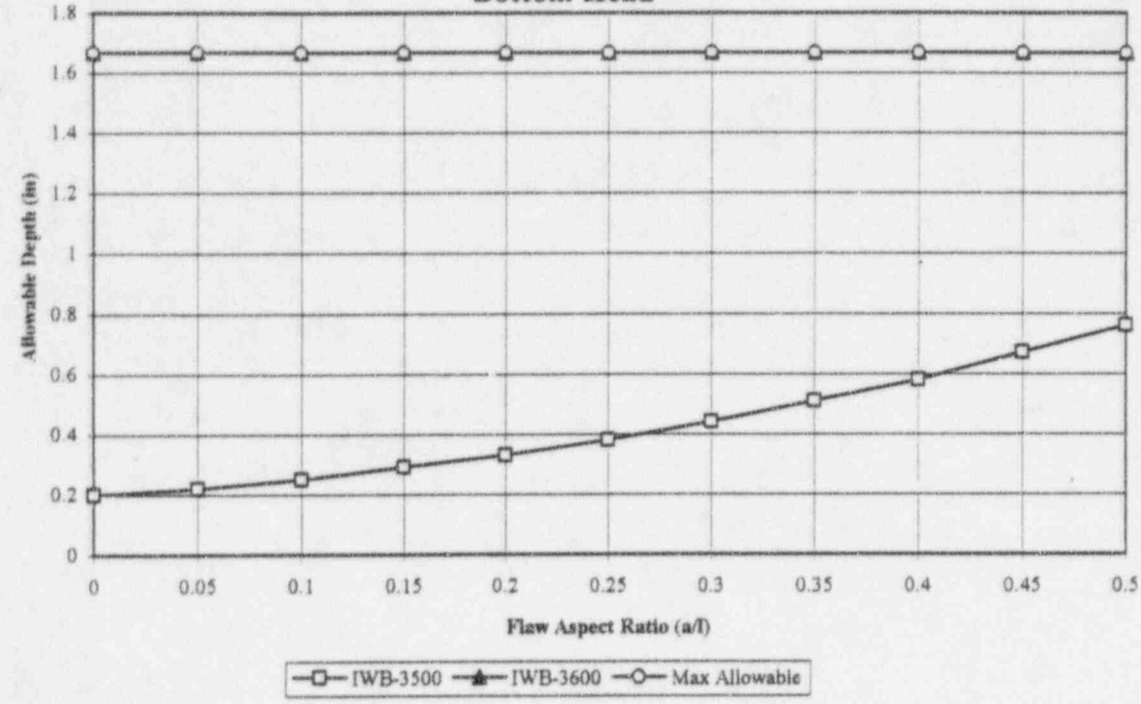
Circumferential Sub-Surface Flaw e/t = -0.25
Bottom Head



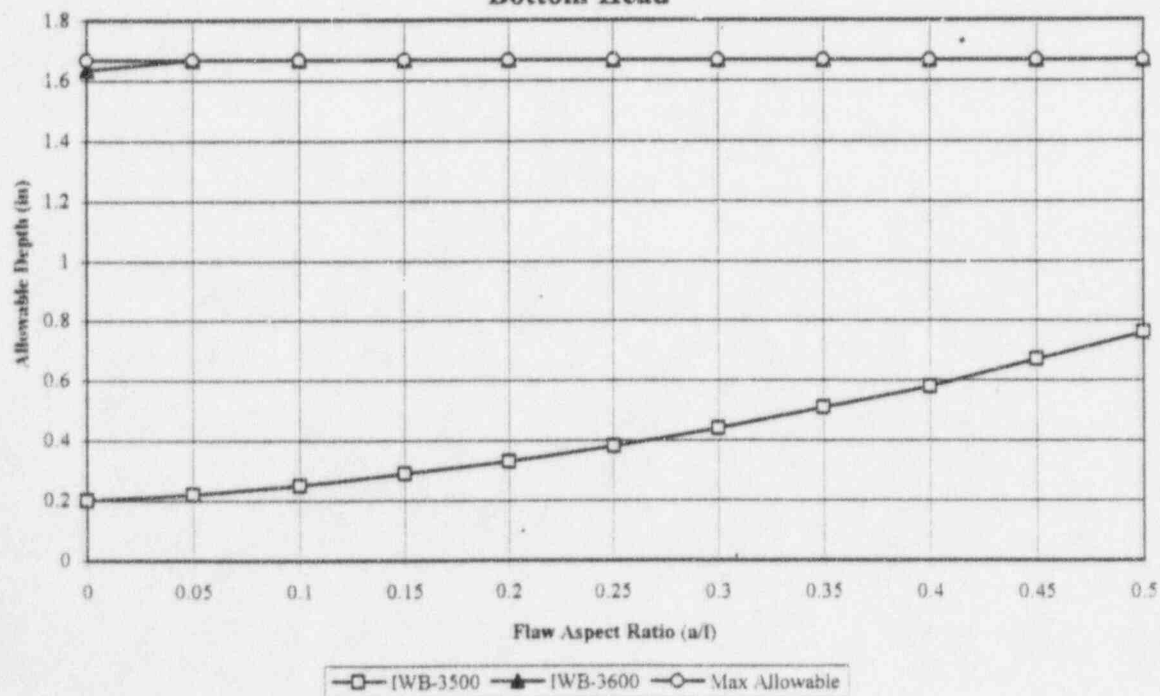
Axial Sub-Surface Flaw e/t = -0.25
Bottom Head



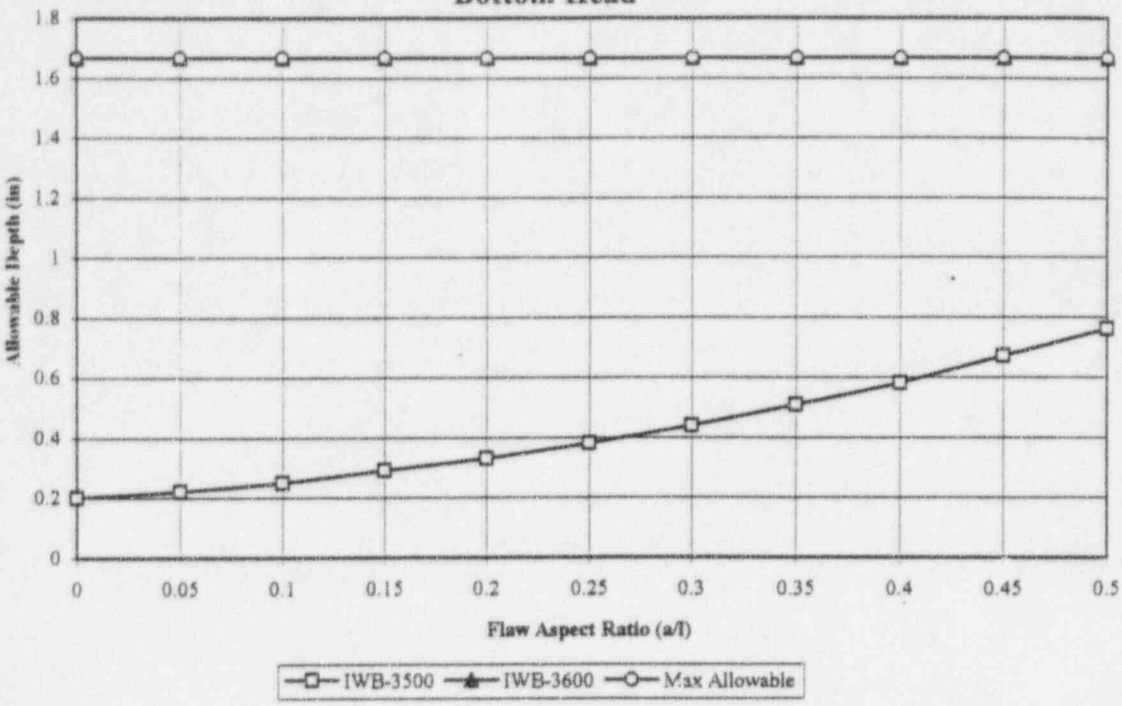
Circumferential Sub-Surface Flaw e/t = -0.1
Bottom Head



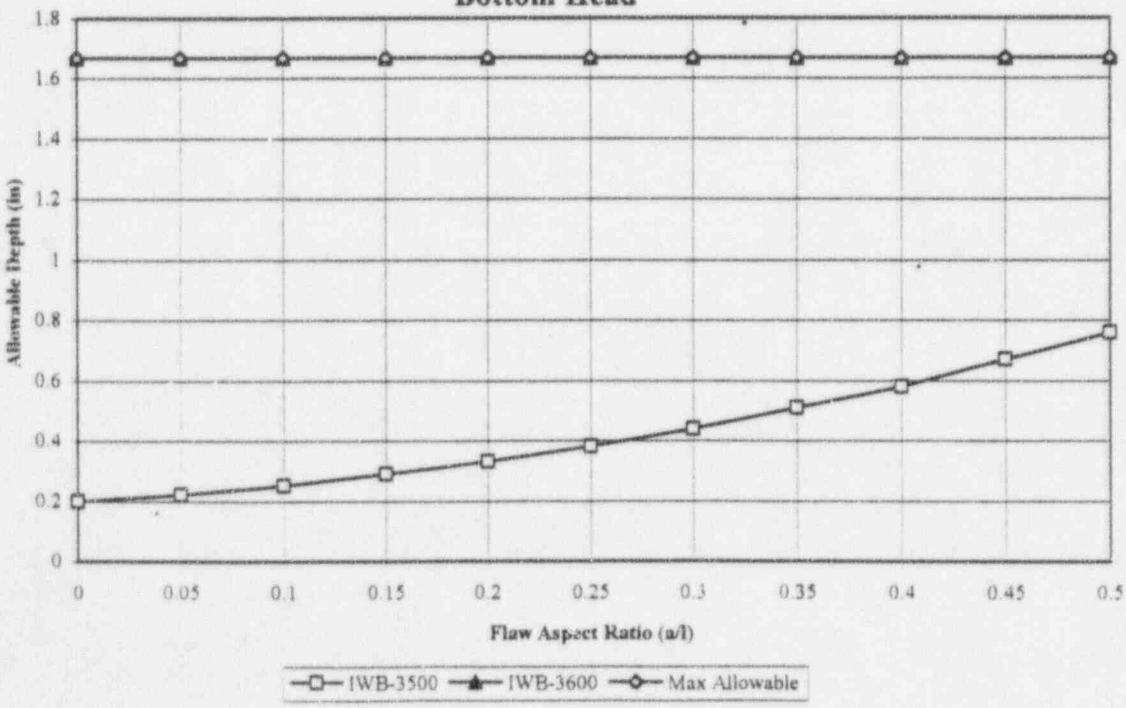
Axial Sub-Surface Flaw e/t = -0.1
Bottom Head



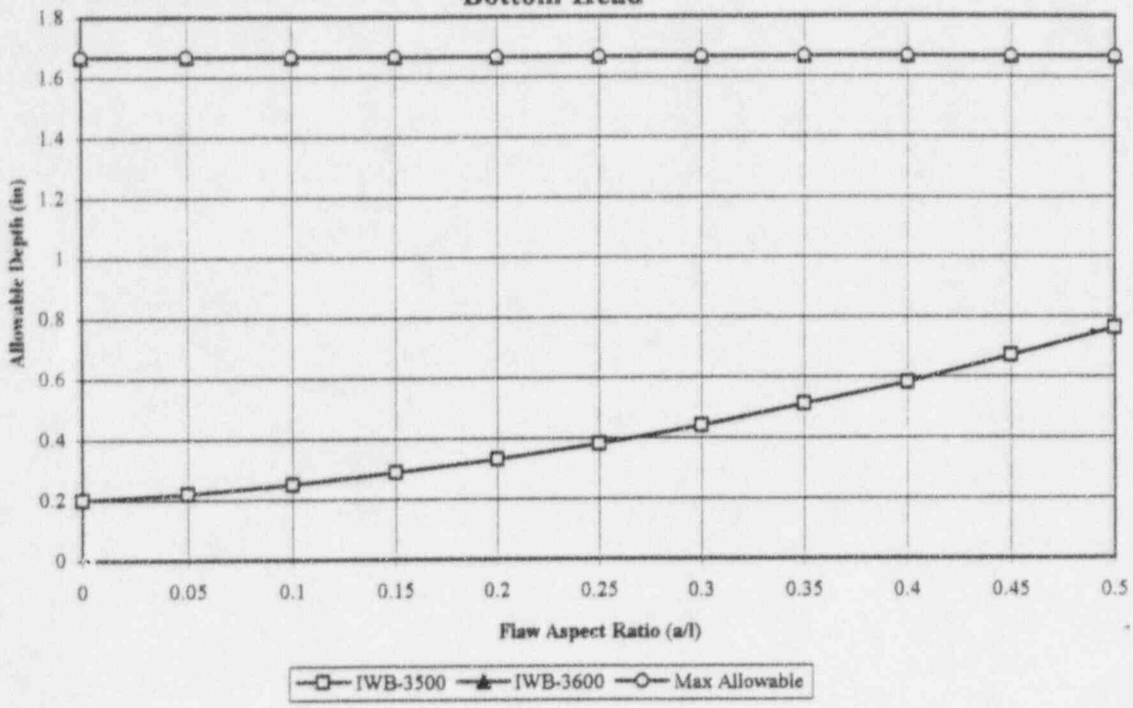
Circumferential Sub-Surface Flaw e/t = 0.0
Bottom Head



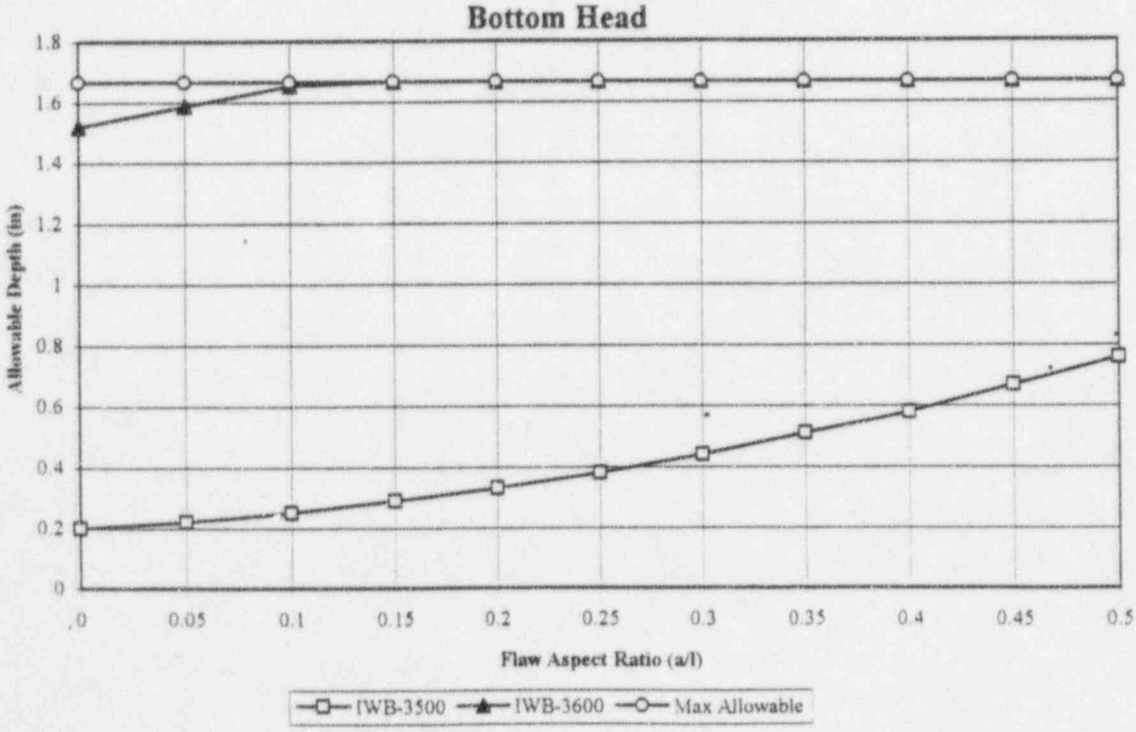
Axial Sub-Surface Flaw e/t = 0.0
Bottom Head

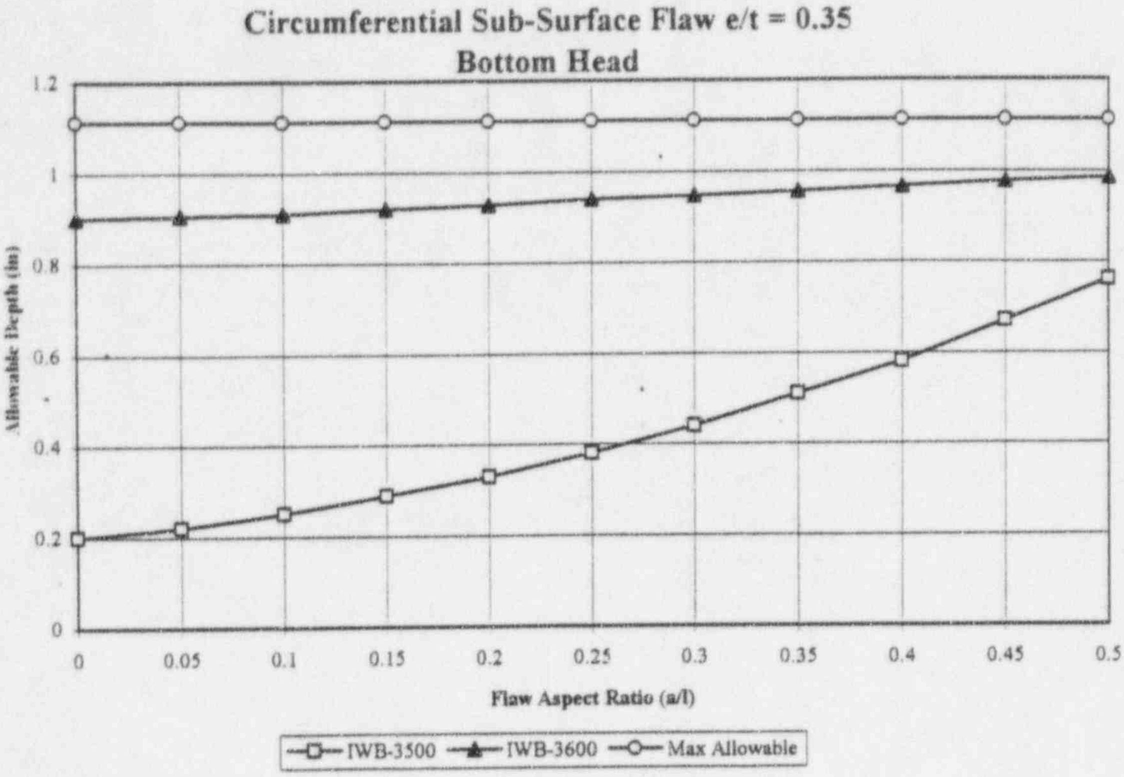


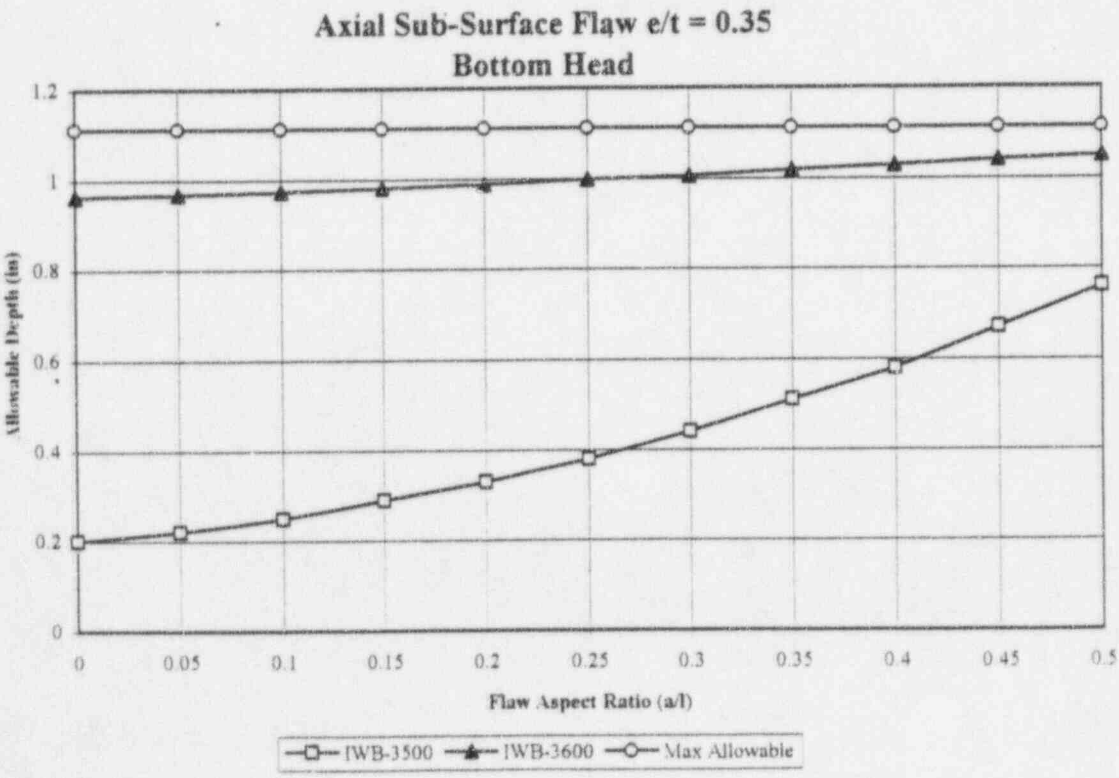
Circumferential Sub-Surface Flaw e/t = 0.2
Bottom Head



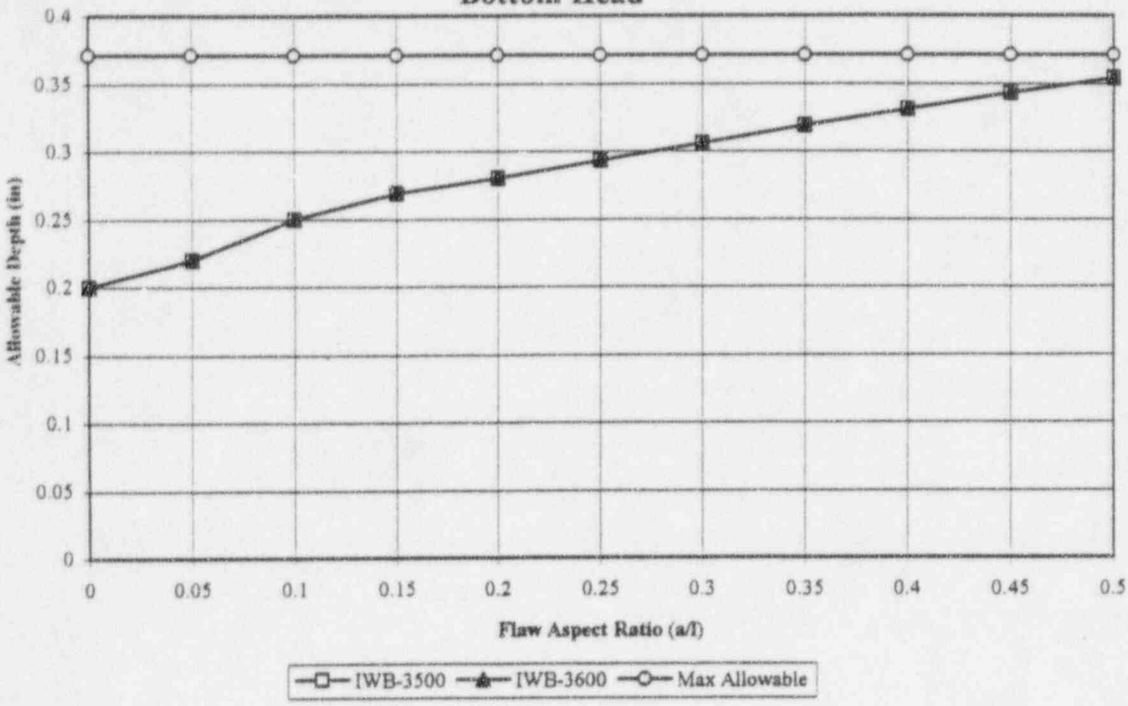
Axial Sub-Surface Flaw e/t = 0.2
Bottom Head



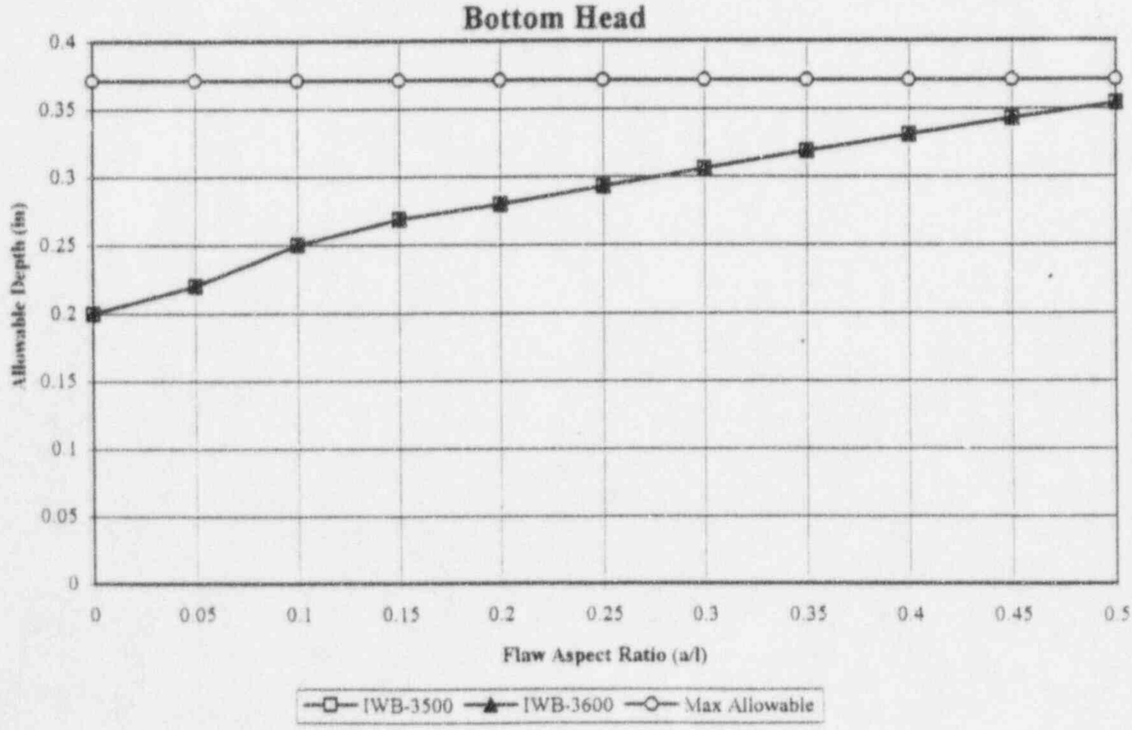

Circumferential Sub-Surface Flaw e/t = 0.35
Bottom Head
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.35
Bottom Head
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

Circumferential Sub-Surface Flaw e/t = 0.45
Bottom Head



Axial Sub-Surface Flaw e/t = 0.45
Bottom Head



APPENDIX K

Flaw Acceptance Diagrams for Region K Materials

> Diagrams on pages K-1 through K-10 are for 0°-45° and 135°-180° locations.
> Diagrams on pages K1-1 through K1-10 are for 45°-135° locations.

Region K includes:

- Upper Nozzle Shell
- Inlet Nozzles (MK#18)
- Inlet Nozzle to Shell Weld

Based on Minimum Thickness = 12.125"

Default Maximum Allowable Flaw Sizes for All Charts:

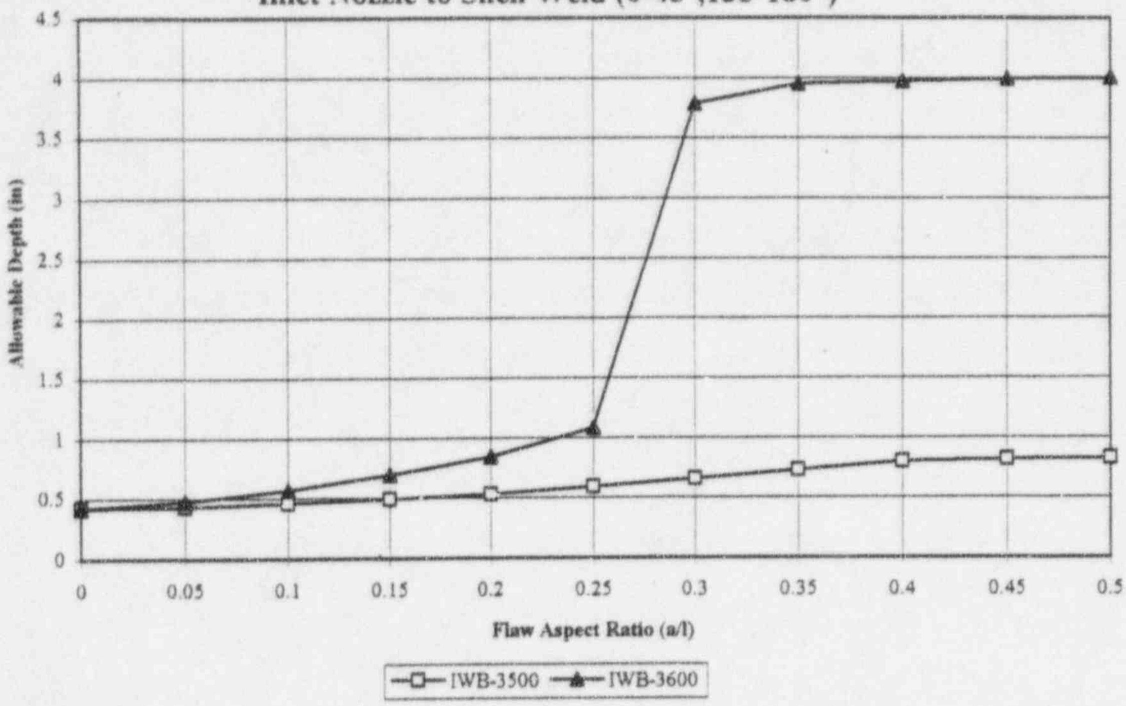
Axially (parallel to weld)-Oriented Flaws = 4.08"
Transverse Oriented Flaws = 4.08"

Note: For all flaw acceptance diagrams in Appendix K, "axial" refers to flaws oriented axial to weld (as affected by hoop stresses) and "circumferential" refers to flaws oriented transverse to weld (as affected by radial stresses).

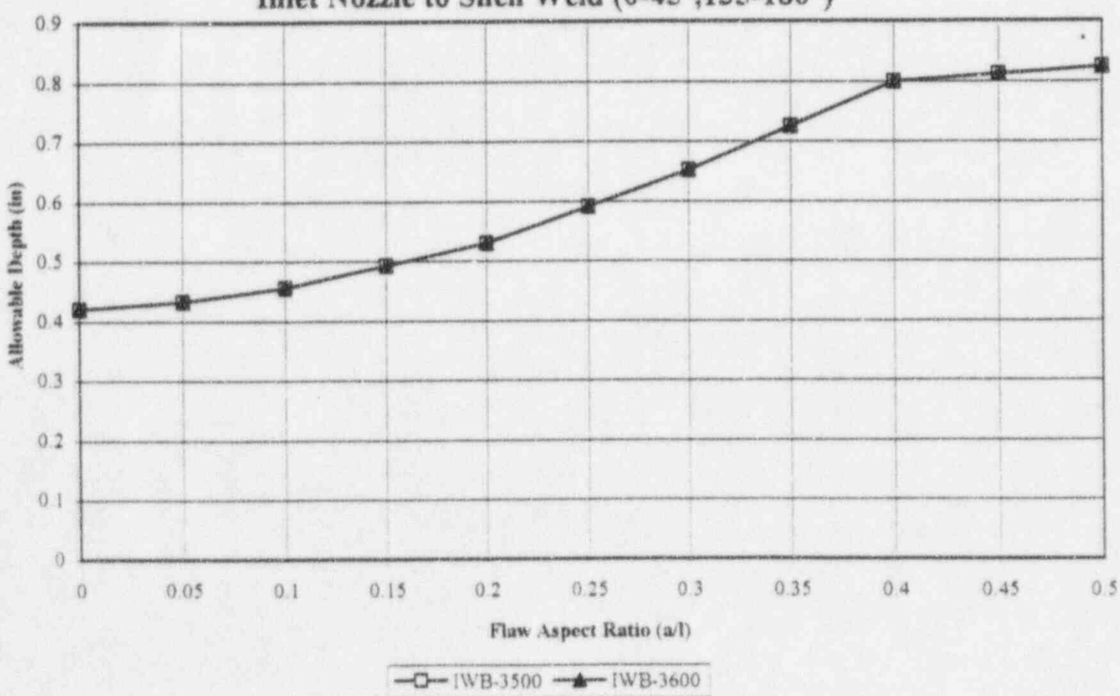
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

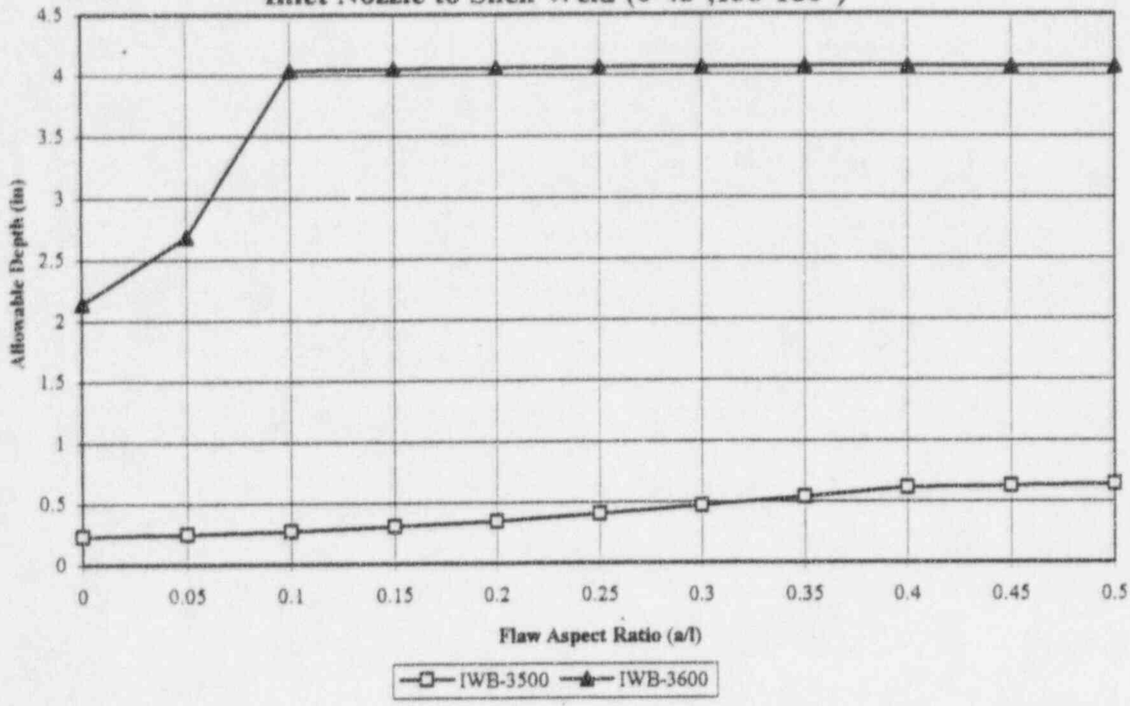
Inside Surface Circumferential Flaw
Inlet Nozzle to Shell Weld (0-45°,135-180°)



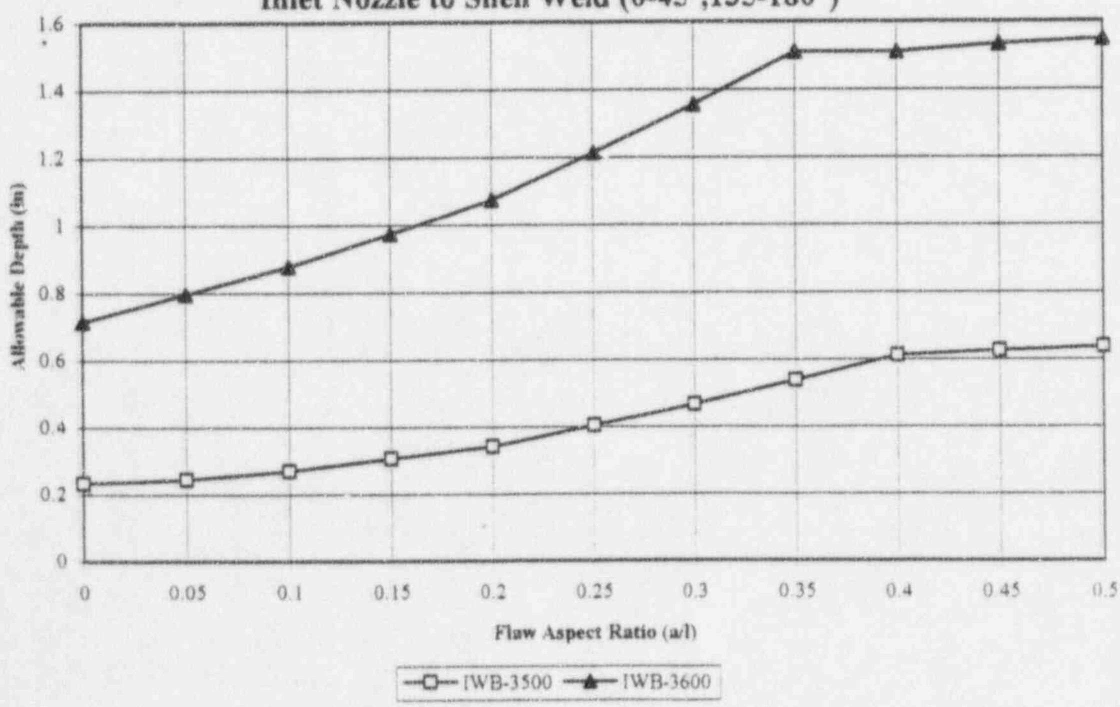
Inside Surface Axial Flaw
Inlet Nozzle to Shell Weld (0-45°,135-180°)



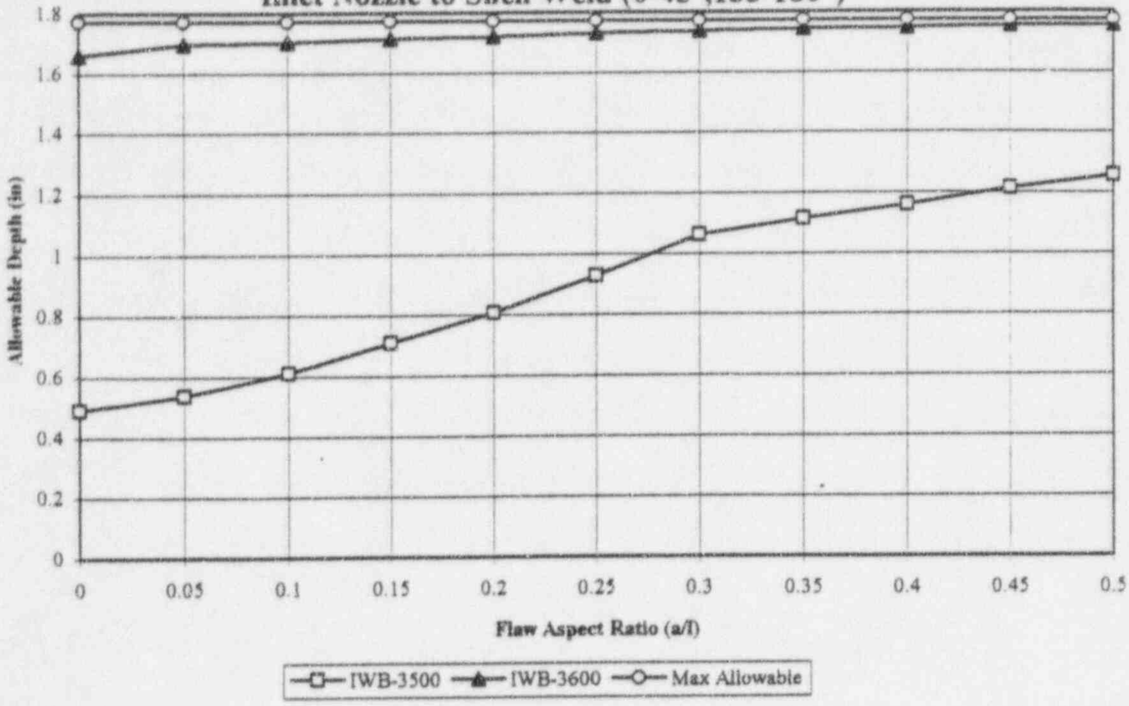
Outside Surface Circumferential Flaw
Inlet Nozzle to Shell Weld (0-45°,135-180°)



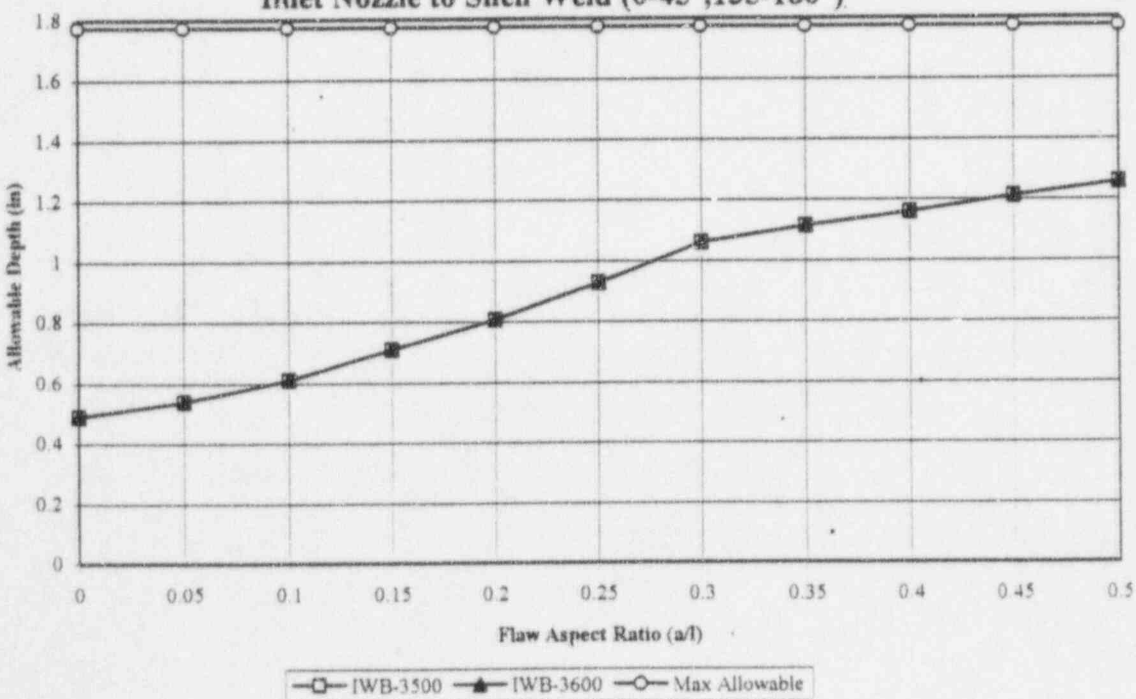
Outside Surface Axial Flaw
Inlet Nozzle to Shell Weld (0-45°,135-180°)



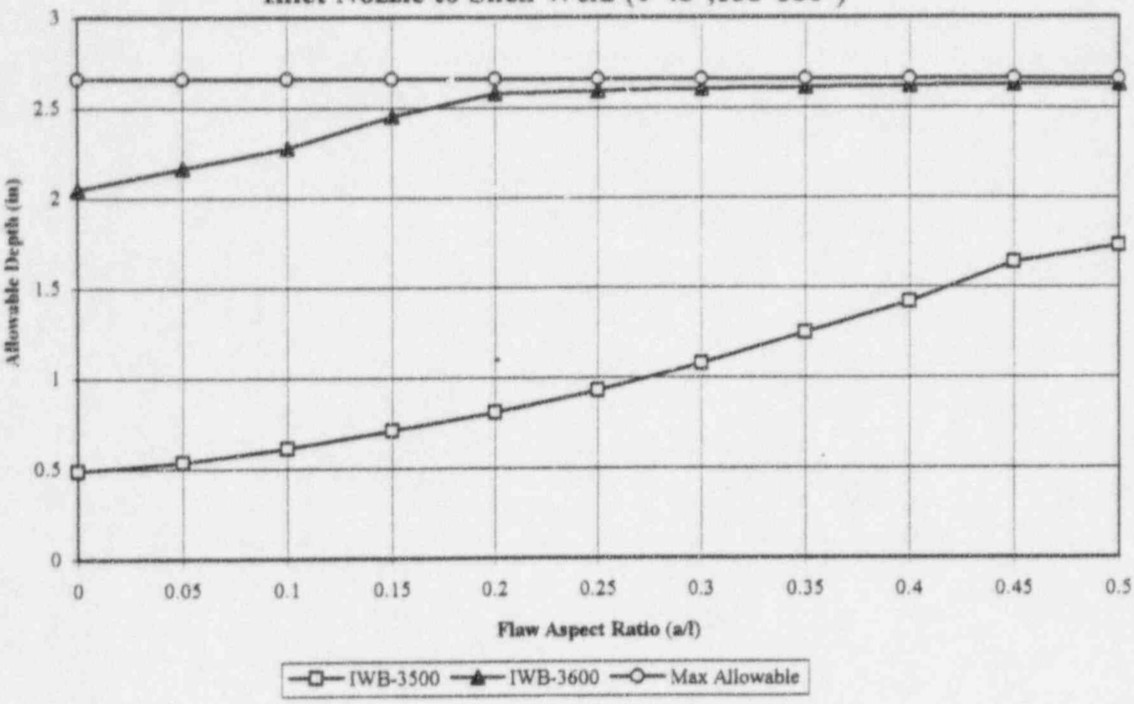
Circumferential Sub-Surface Flaw e/t = -0.4
Inlet Nozzle to Shell Weld (0-45°,135-180°)



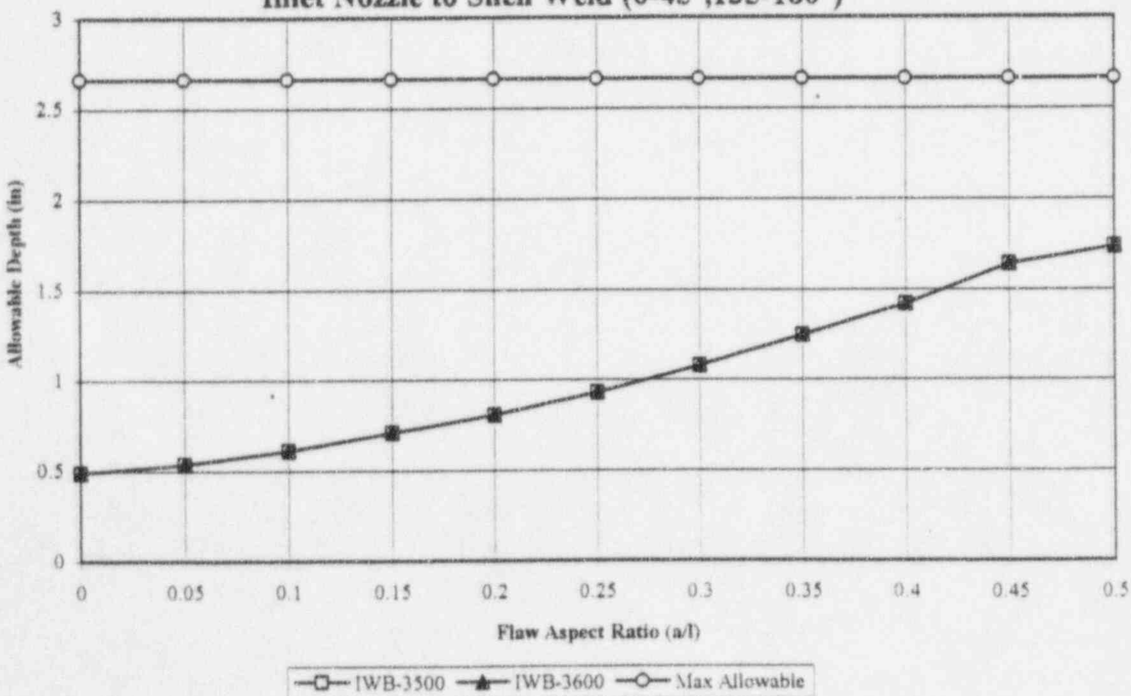
Axial Sub-Surface Flaw e/t = -0.4
Inlet Nozzle to Shell Weld (0-45°,135-180°)

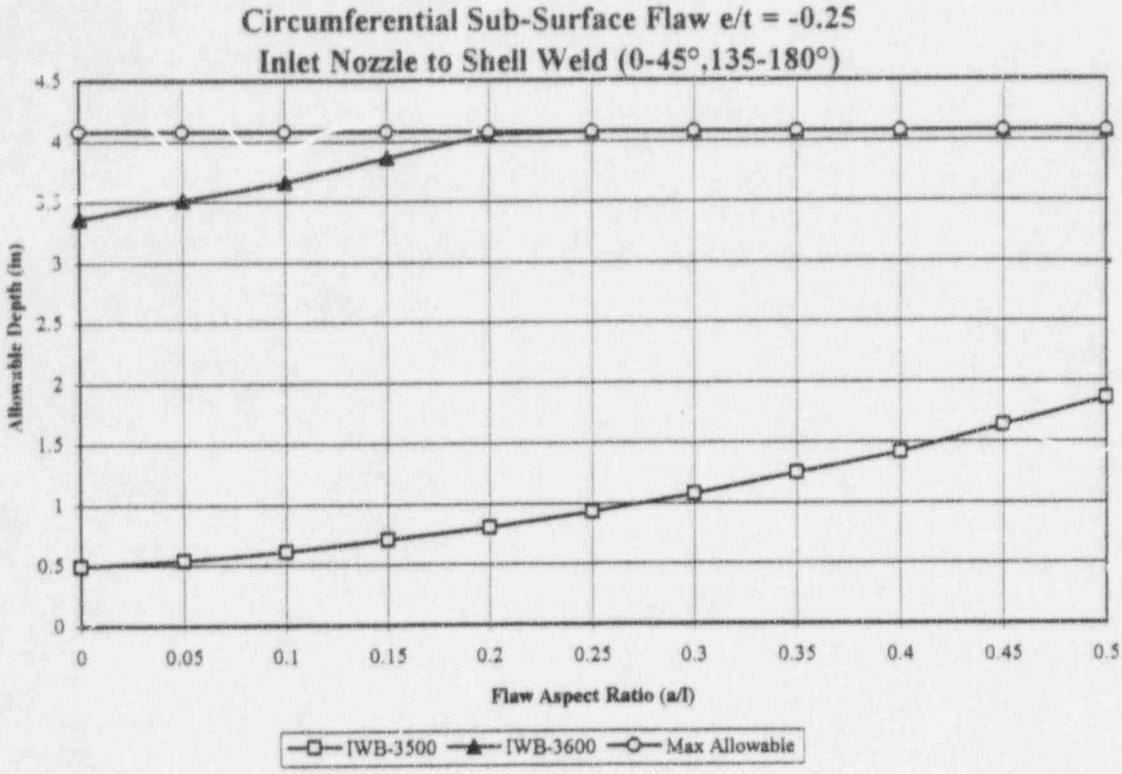


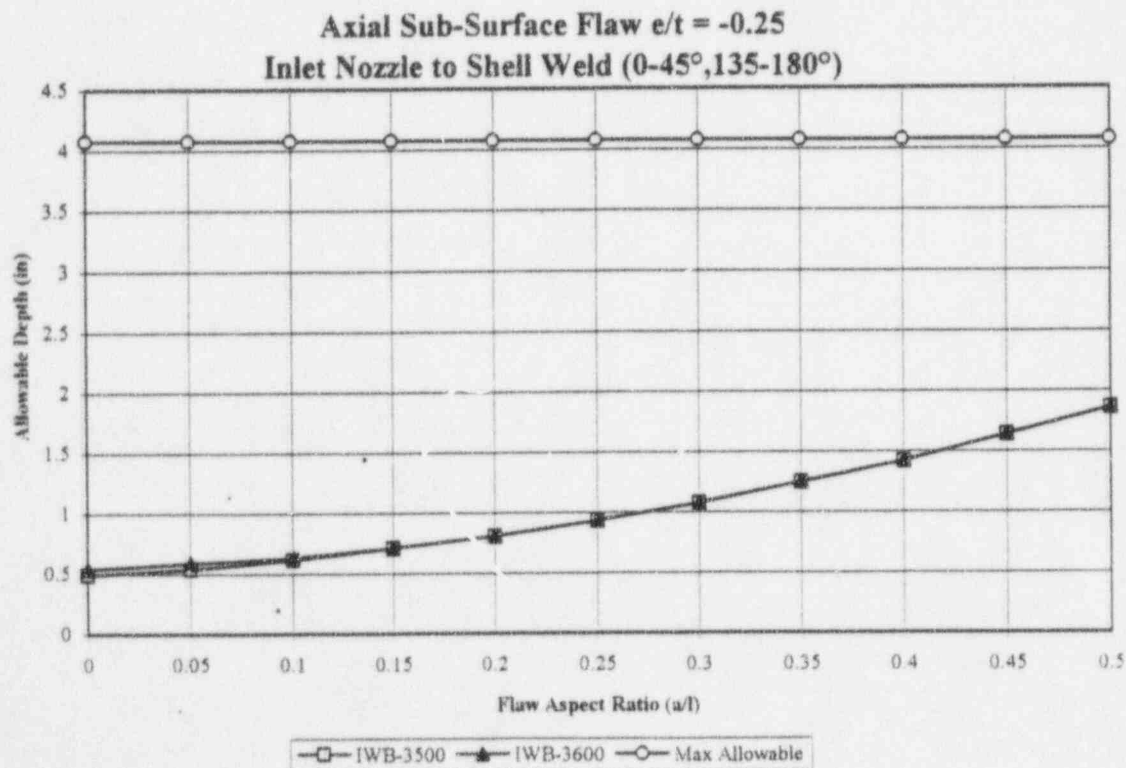
Circumferential Sub-Surface Flaw e/t = -0.35
Inlet Nozzle to Shell Weld (0-45°,135-180°)



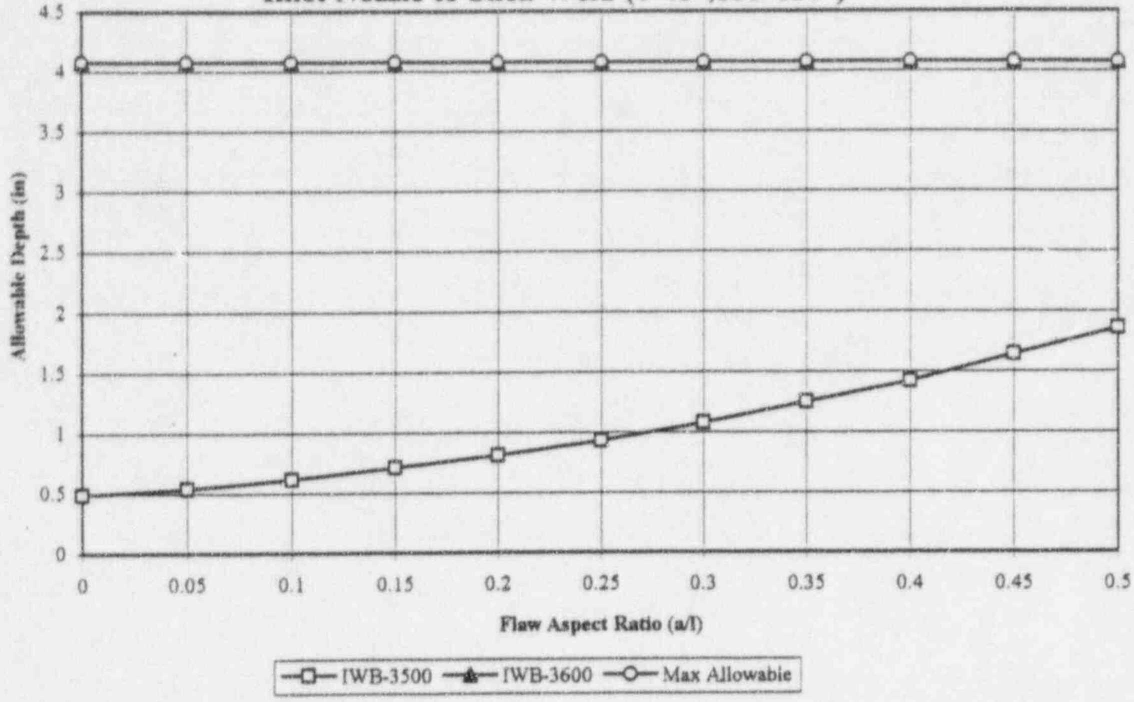
Axial Sub-Surface Flaw e/t = -0.35
Inlet Nozzle to Shell Weld (0-45°,135-180°)



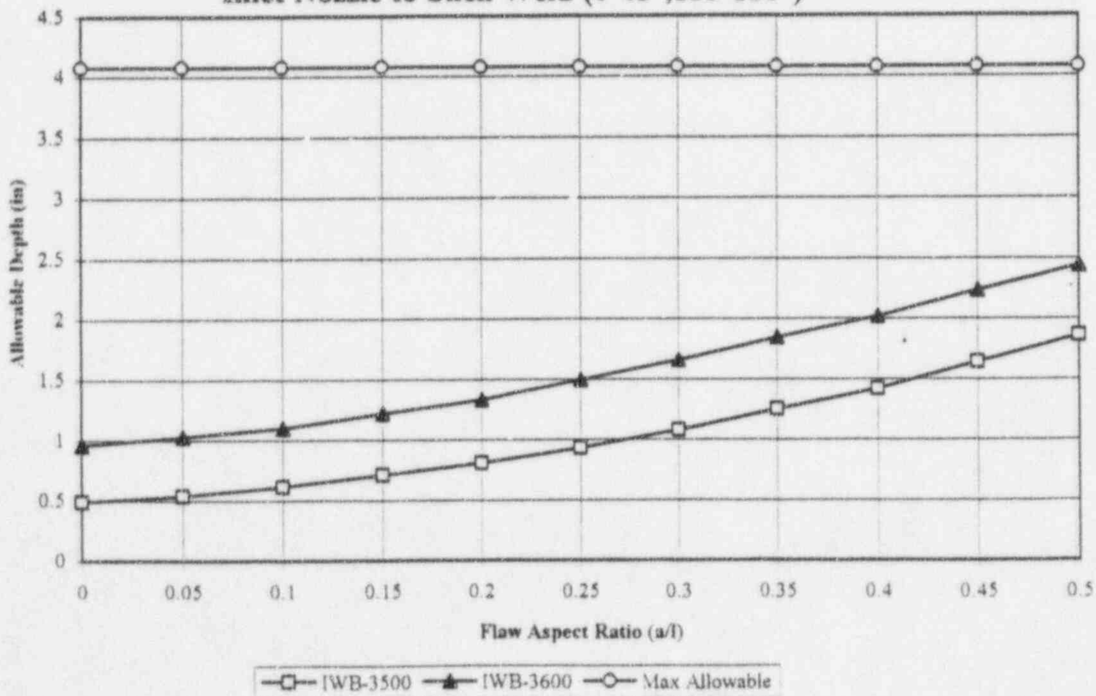

Circumferential Sub-Surface Flaw e/t = -0.25
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

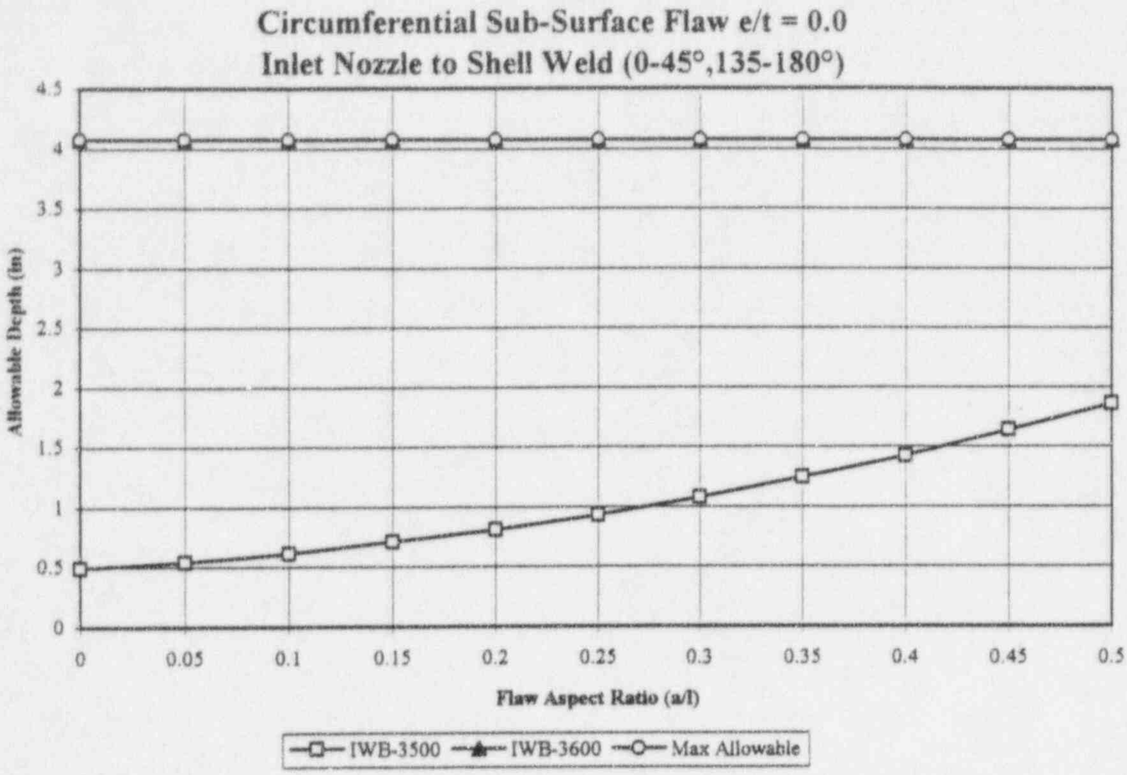

Axial Sub-Surface Flaw e/t = -0.25
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

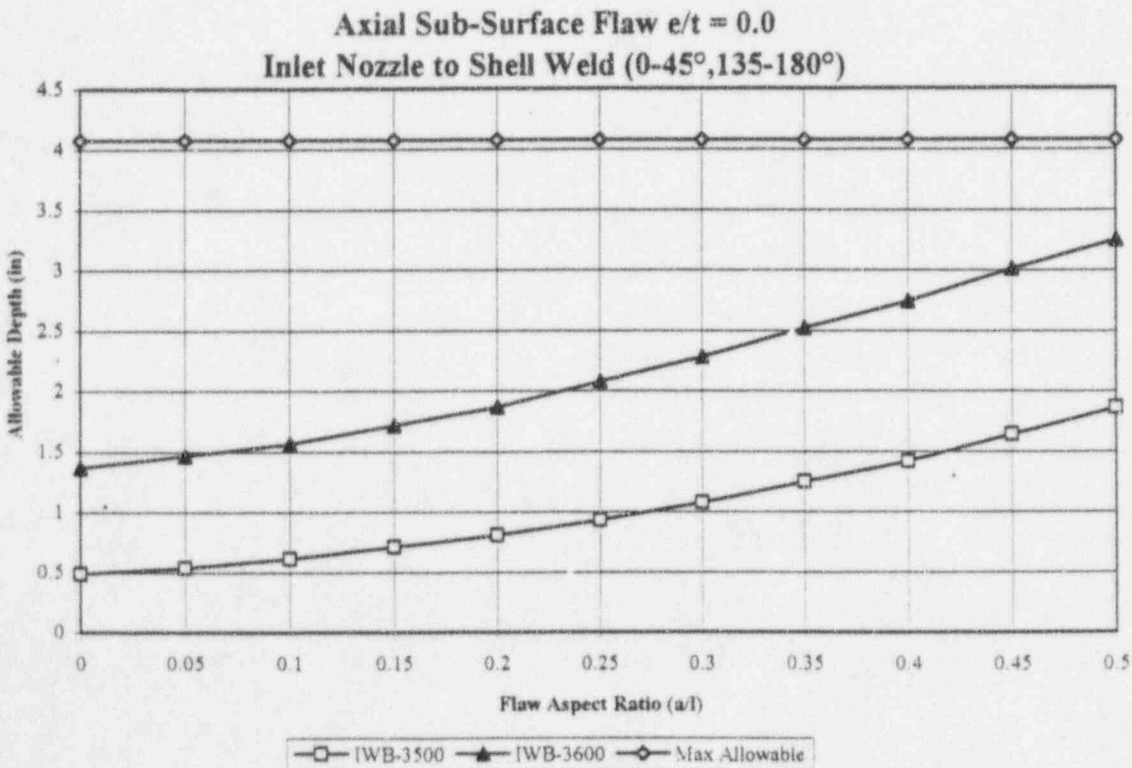
Circumferential Sub-Surface Flaw e/t = -0.1
Inlet Nozzle to Shell Weld (0-45°,135-180°)



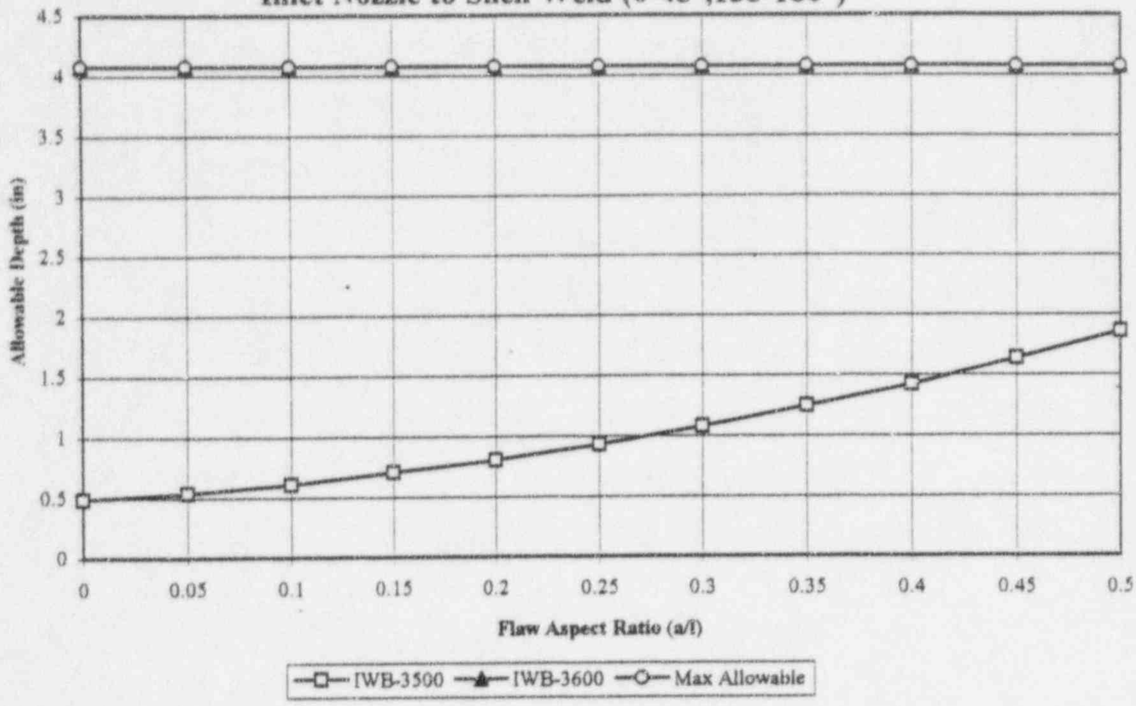
Axial Sub-Surface Flaw e/t = -0.1
Inlet Nozzle to Shell Weld (0-45°,135-180°)



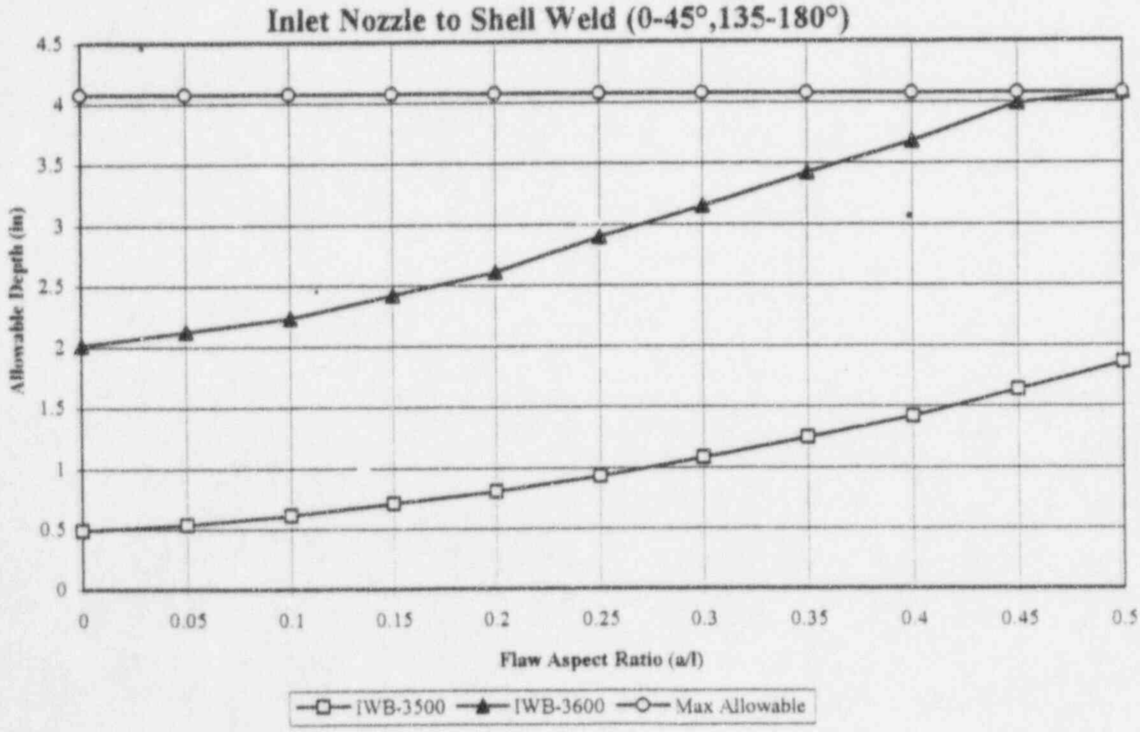

Circumferential Sub-Surface Flaw e/t = 0.0
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
IWB-3500
IWB-3600
Max Allowable

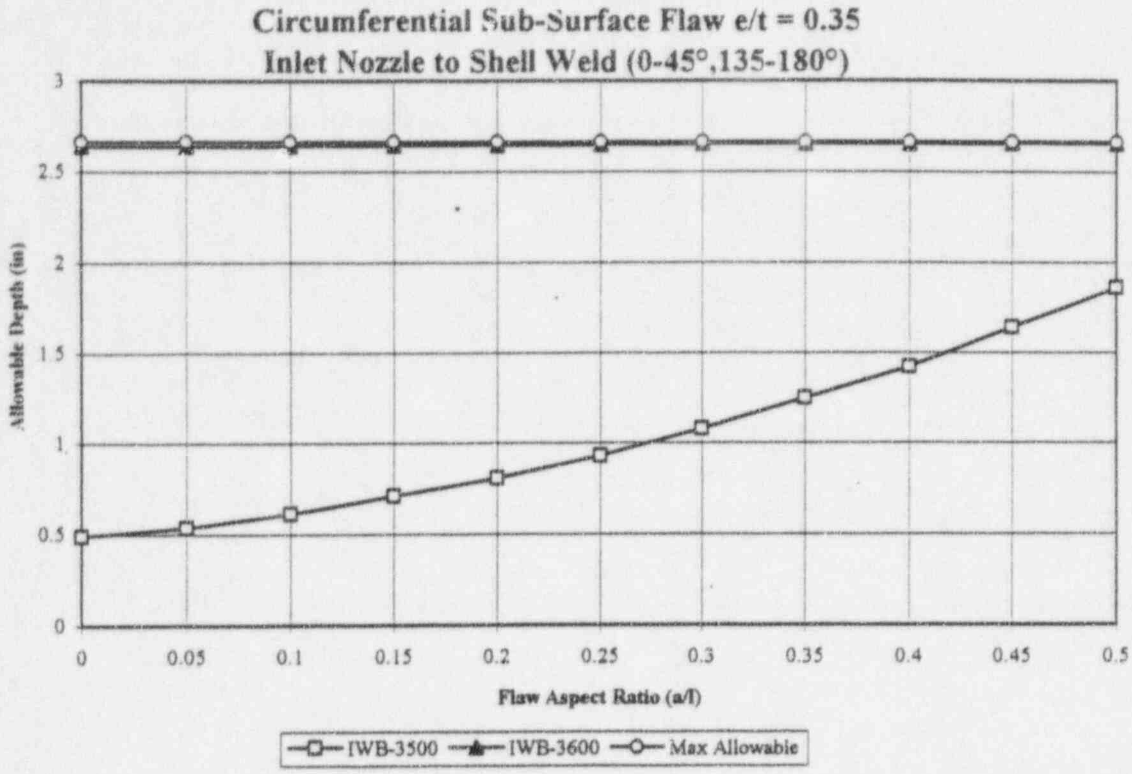

Axial Sub-Surface Flaw e/t = 0.0
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
IWB-3500
IWB-3600
Max Allowable

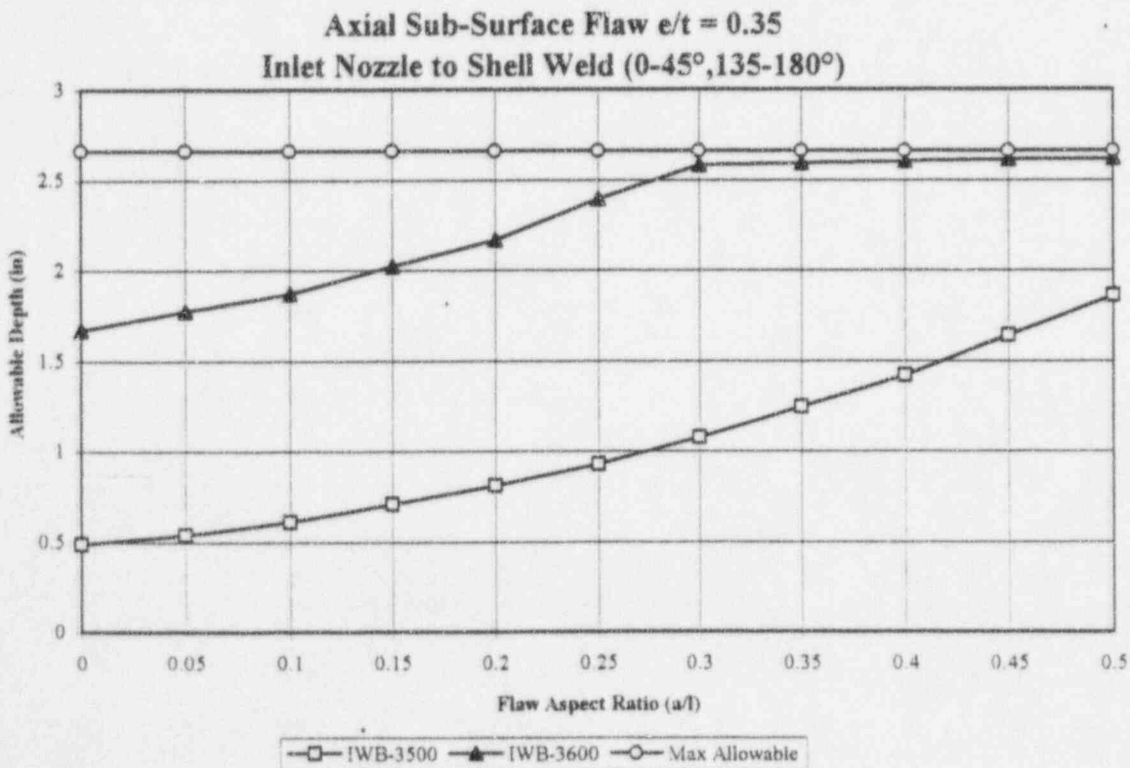
Circumferential Sub-Surface Flaw e/t = 0.2
Inlet Nozzle to Shell Weld (0-45°,135-180°)

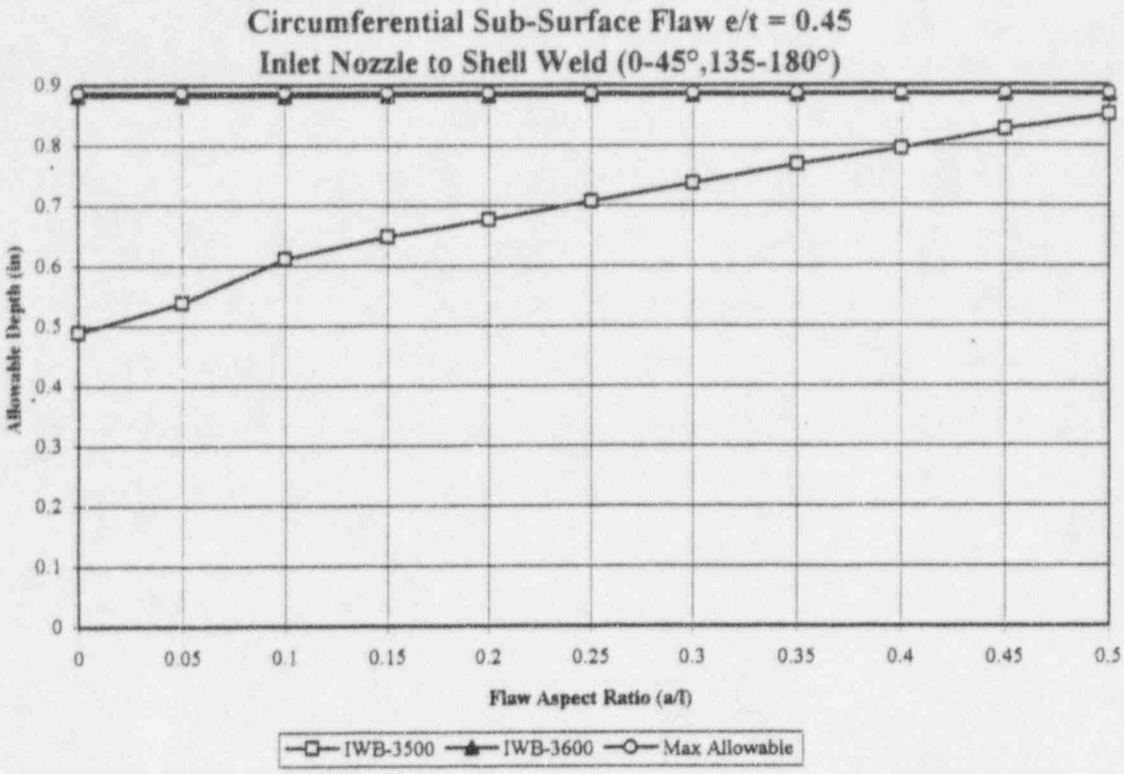


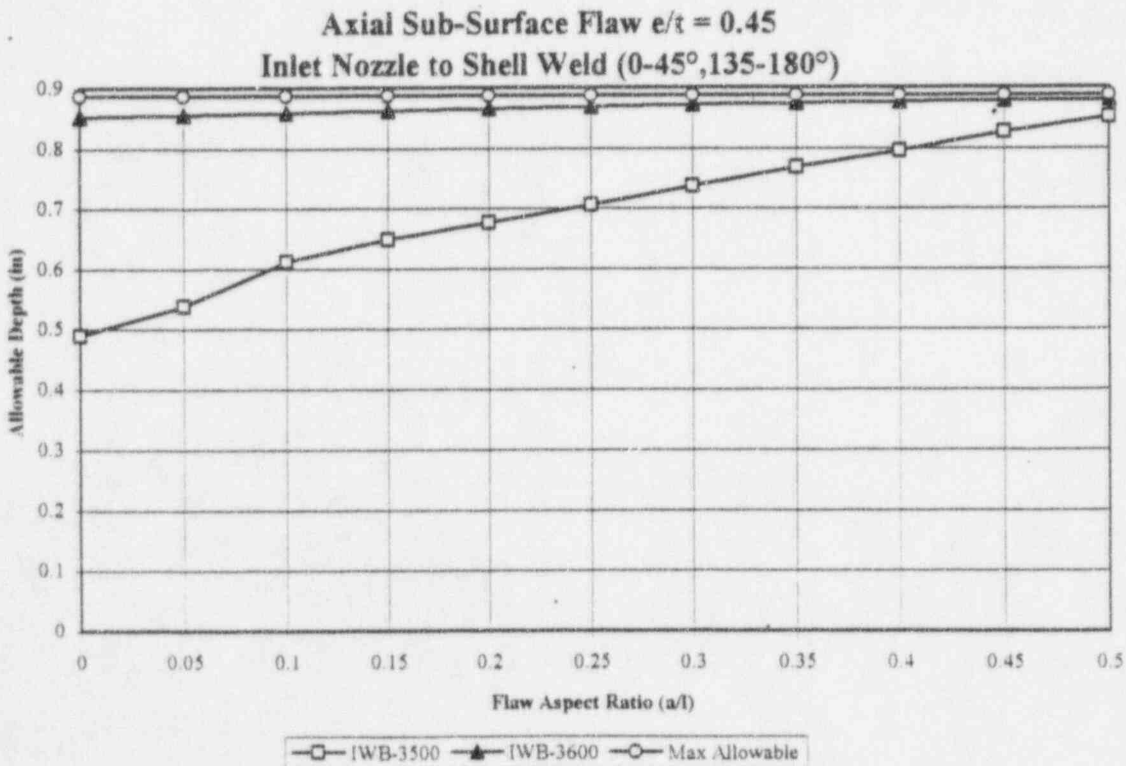
Axial Sub-Surface Flaw e/t = 0.2
Inlet Nozzle to Shell Weld (0-45°,135-180°)

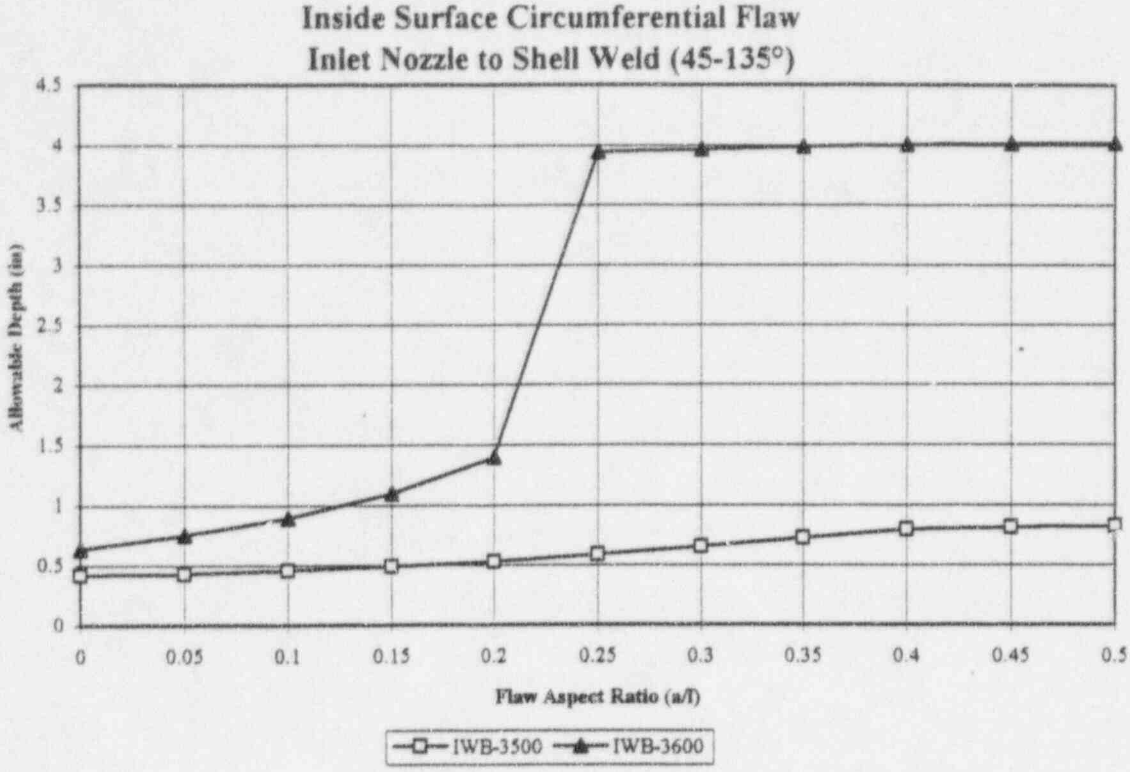


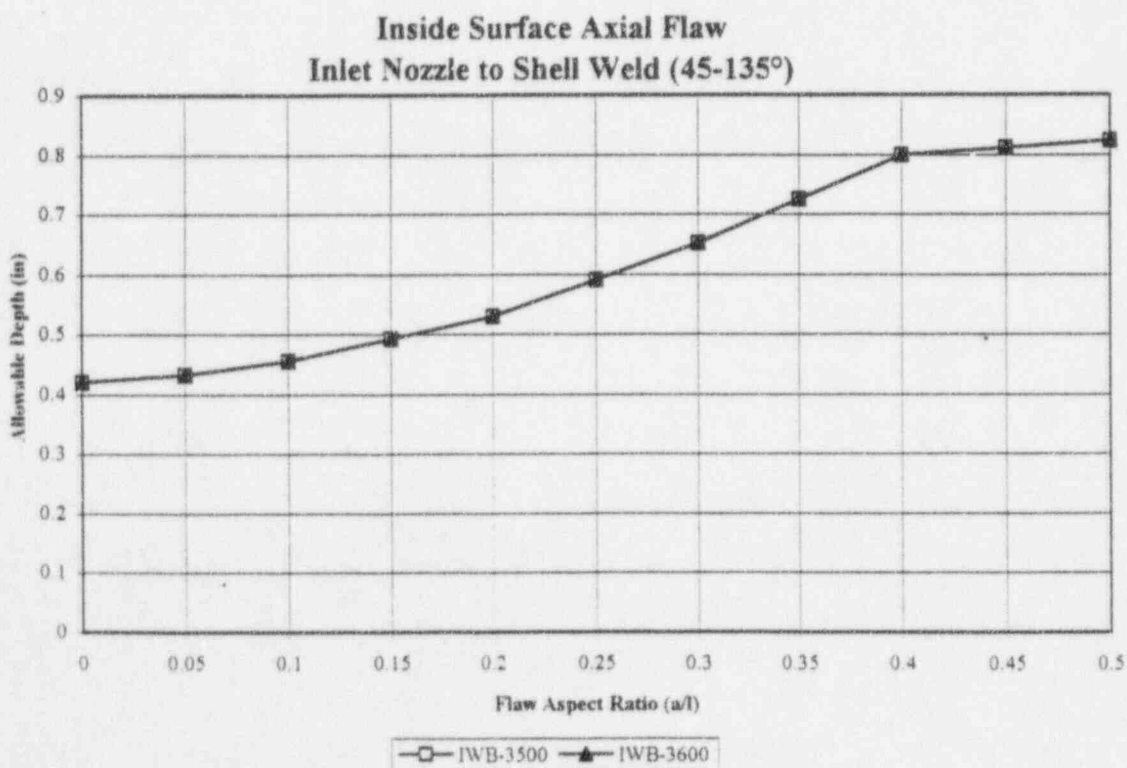

Circumferential Sub-Surface Flaw e/t = 0.35
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

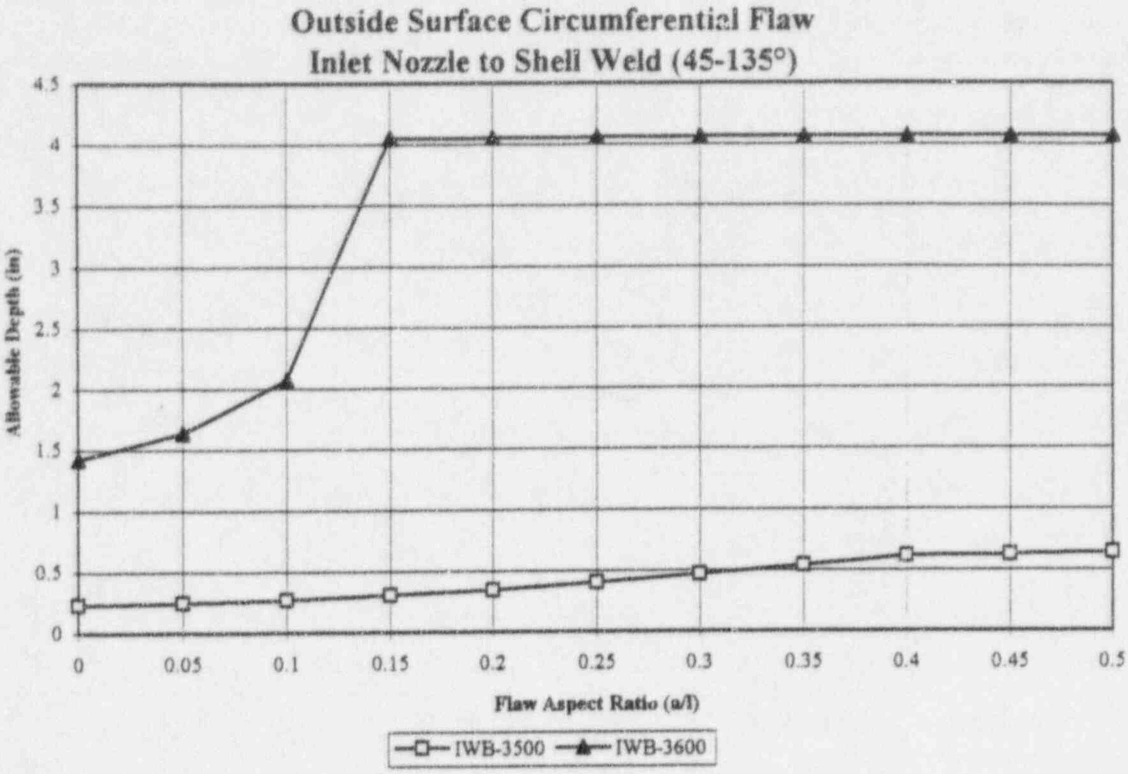

Axial Sub-Surface Flaw e/t = 0.35
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Circumferential Sub-Surface Flaw e/t = 0.45
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

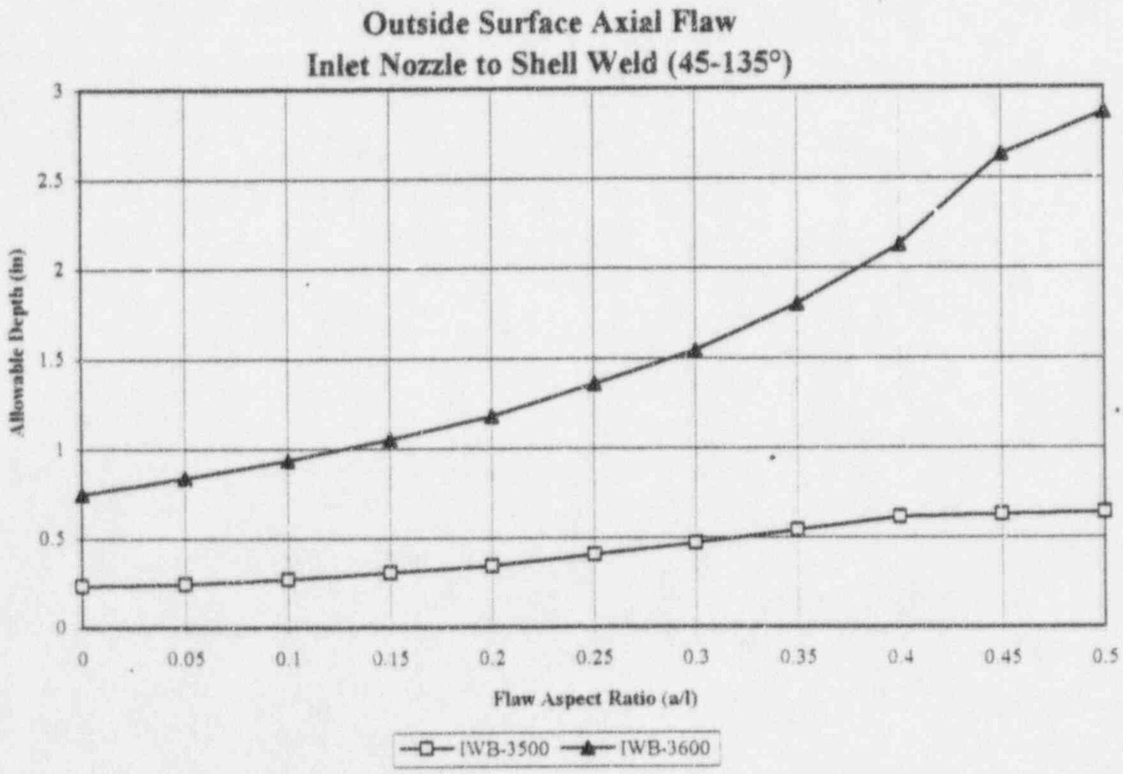

Axial Sub-Surface Flaw e/t = 0.45
Inlet Nozzle to Shell Weld (0-45°,135-180°)
Allowable Depth (in)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Inside Surface Circumferential Flaw
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600


Inside Surface Axial Flaw
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

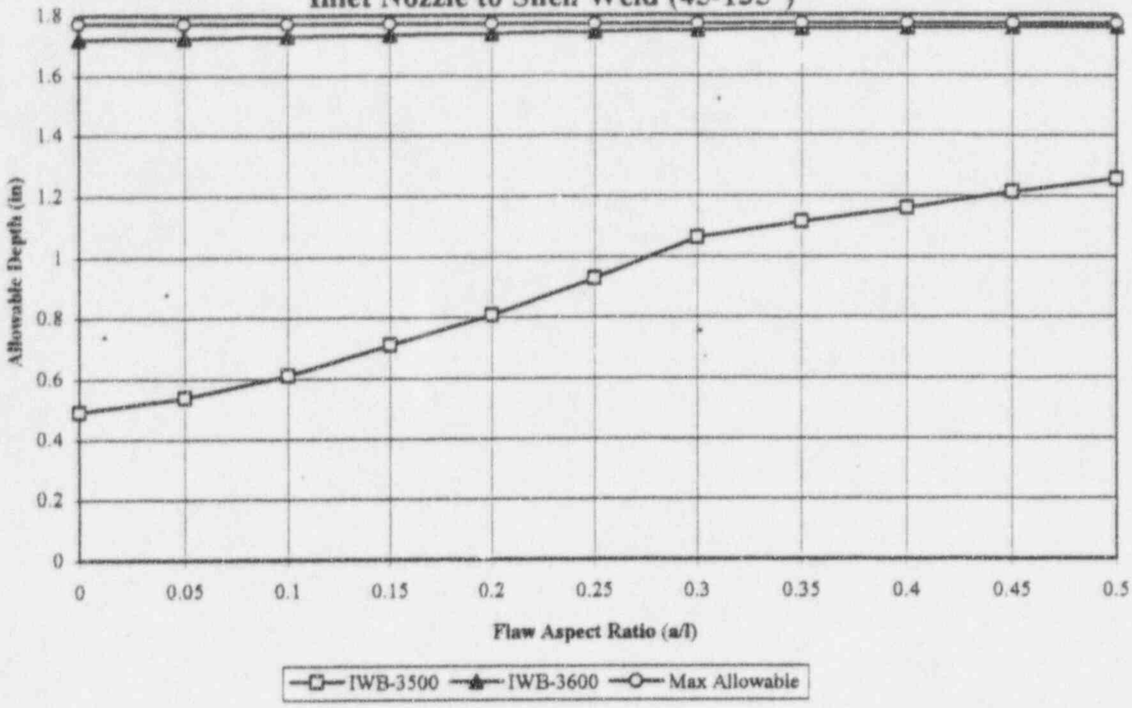


Outside Surface Circumferential Flaw
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

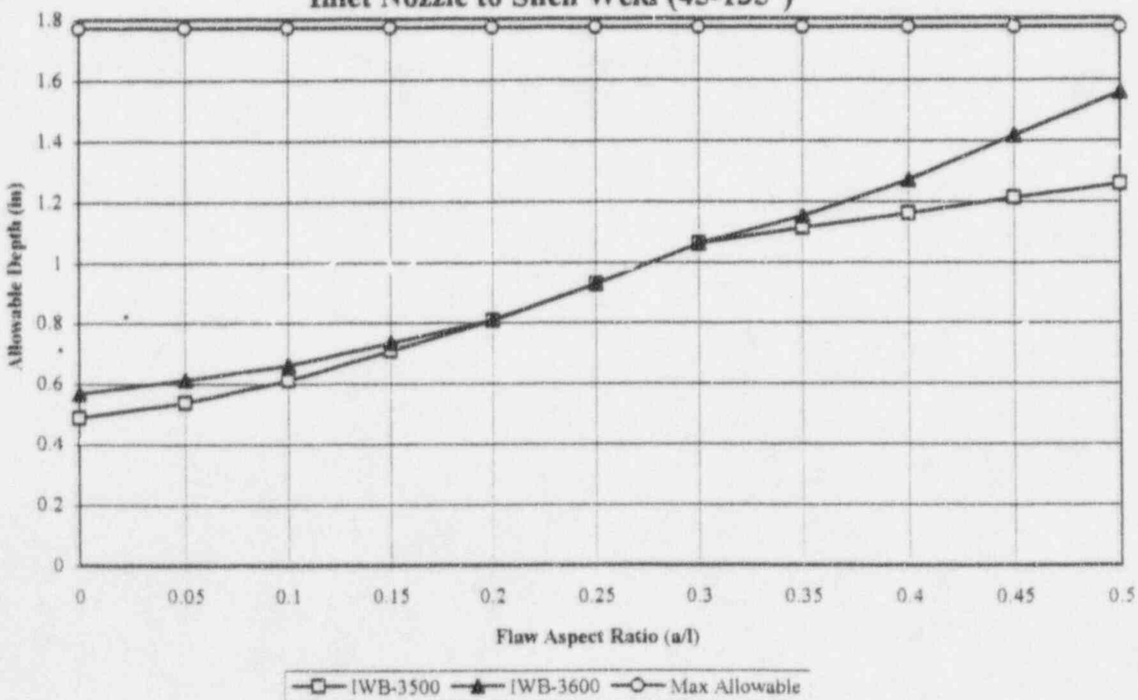


Outside Surface Axial Flaw
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

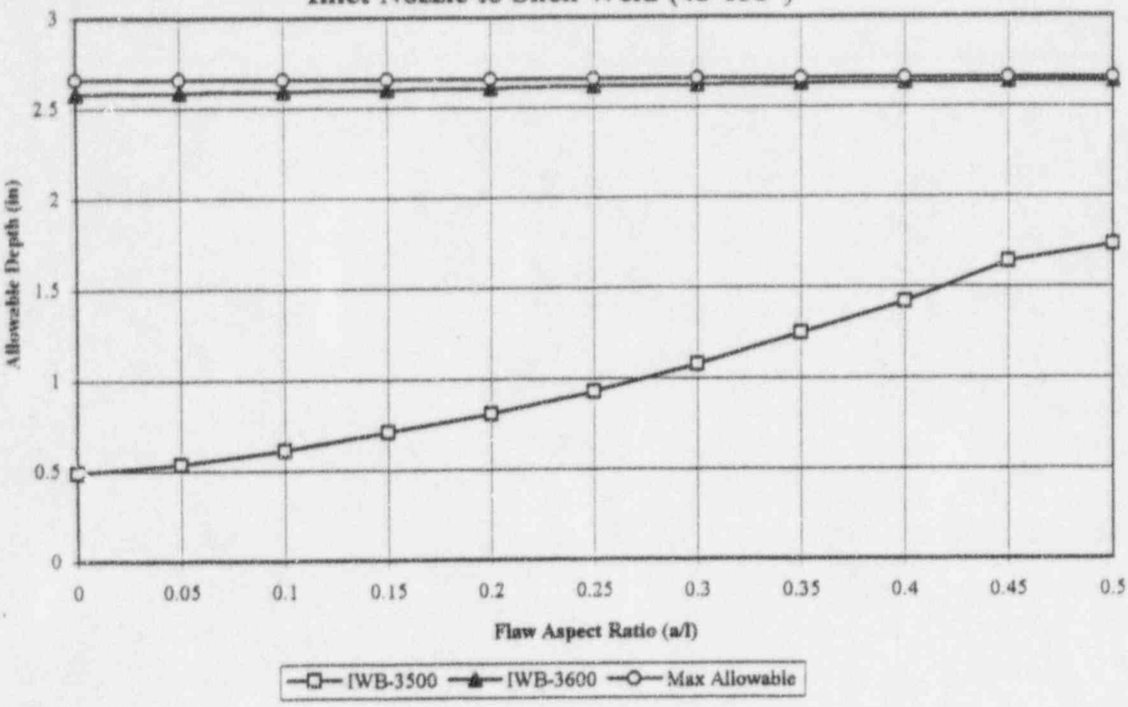
Circumferential Sub-Surface Flaw e/t = -0.4
Inlet Nozzle to Shell Weld (45-135°)



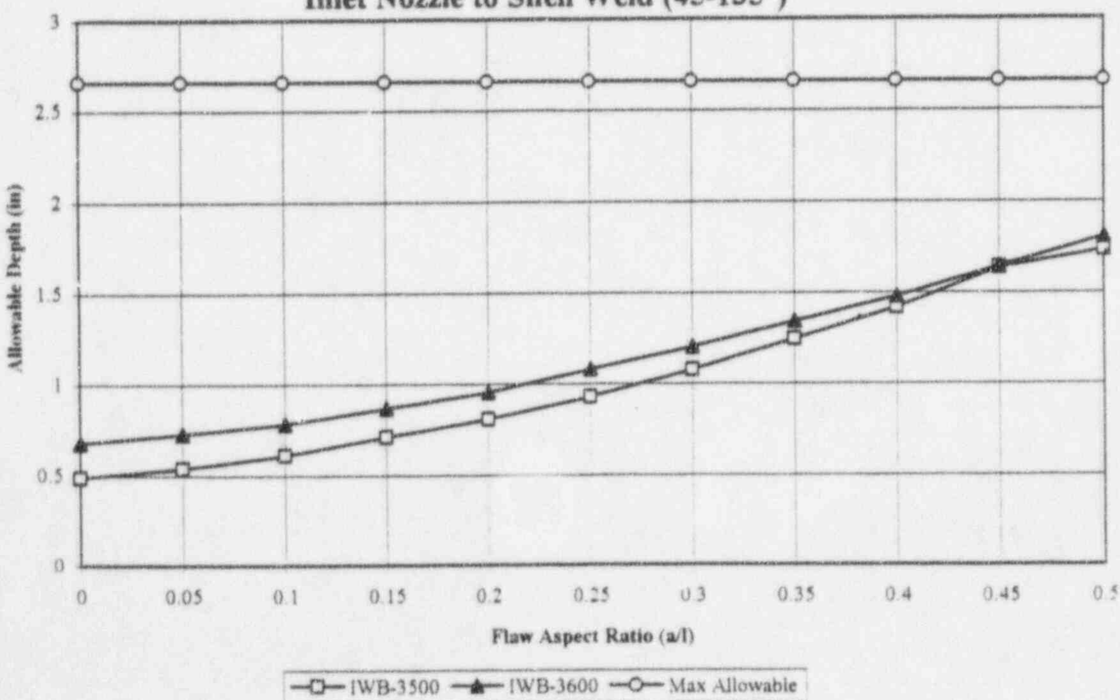
Axial Sub-Surface Flaw e/t = -0.4
Inlet Nozzle to Shell Weld (45-135°)

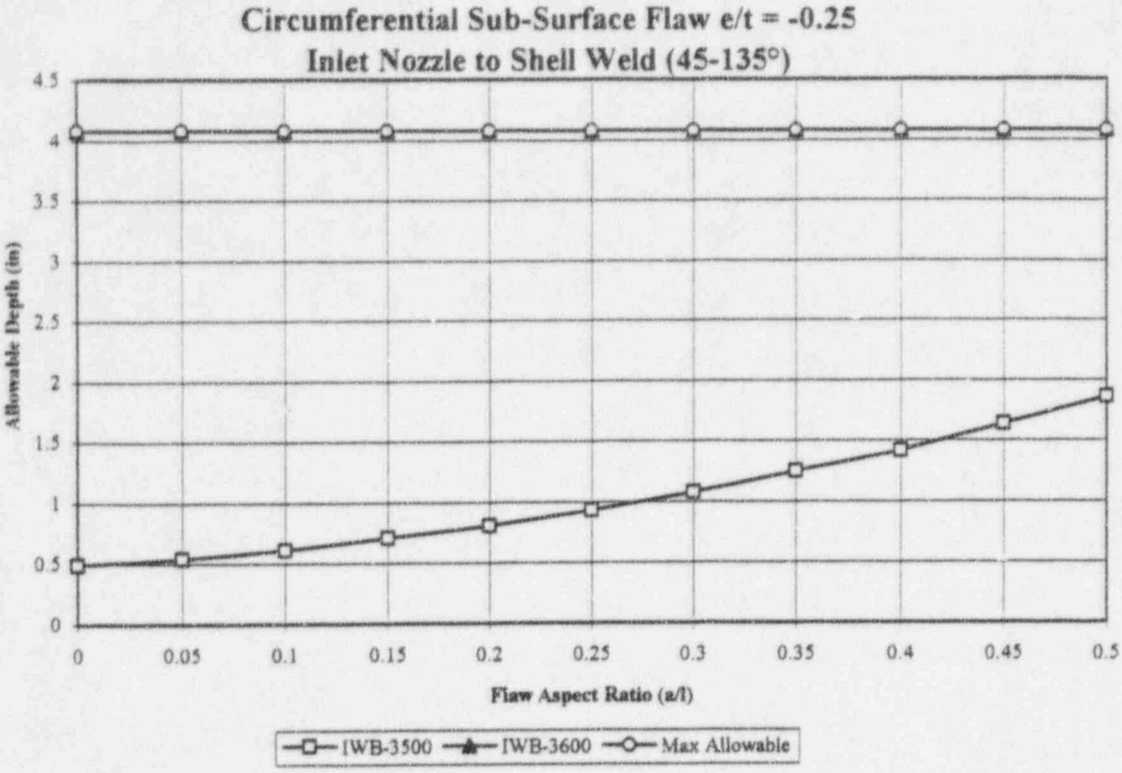


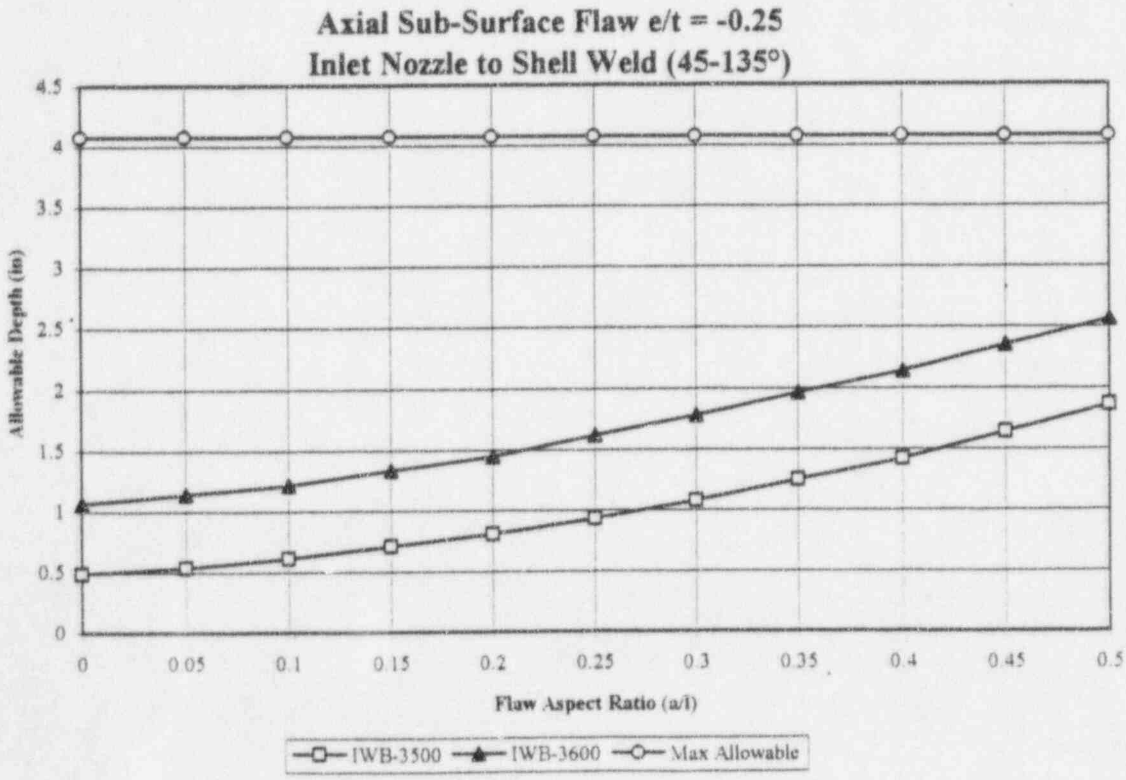
Circumferential Sub-Surface Flaw e/t = -0.35
Inlet Nozzle to Shell Weld (45-135°)

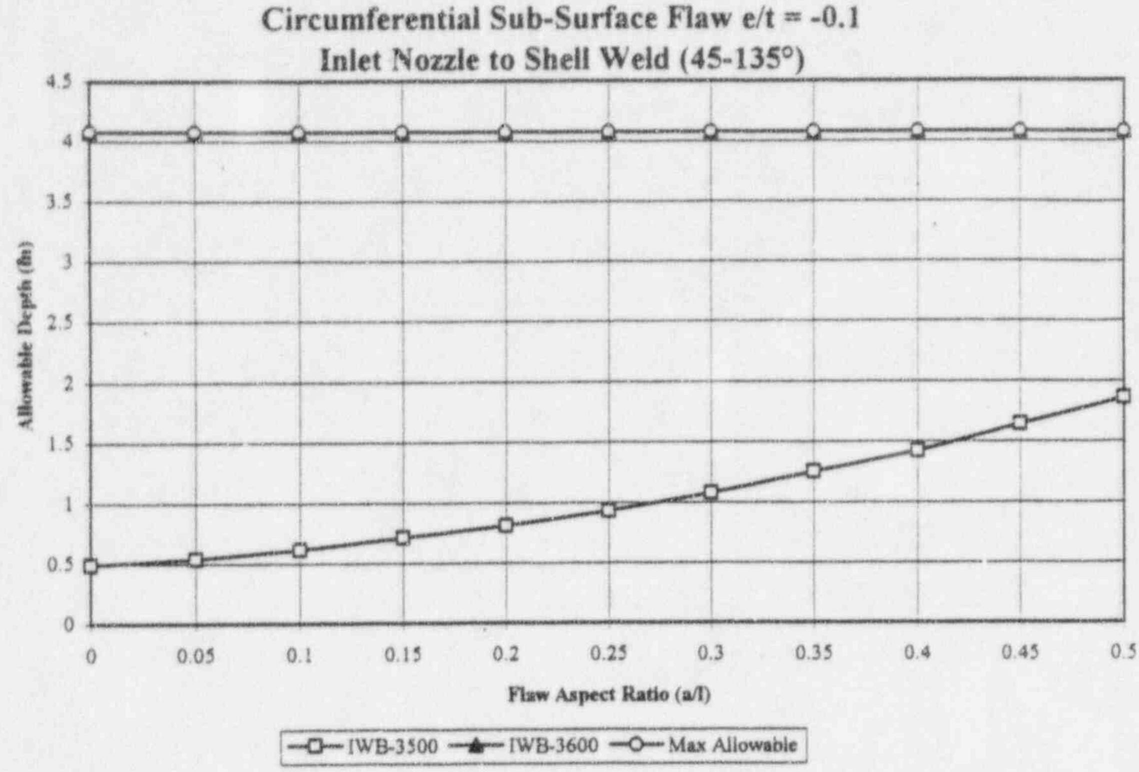


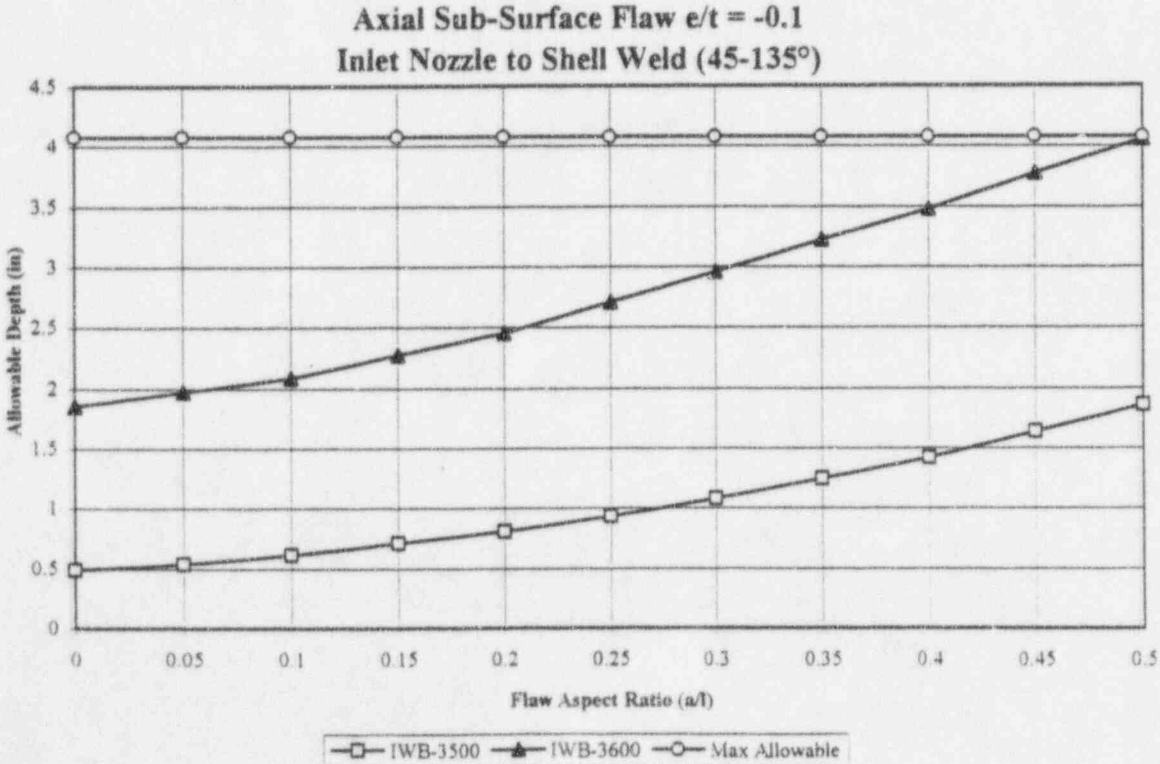
Axial Sub-Surface Flaw e/t = -0.35
Inlet Nozzle to Shell Weld (45-135°)



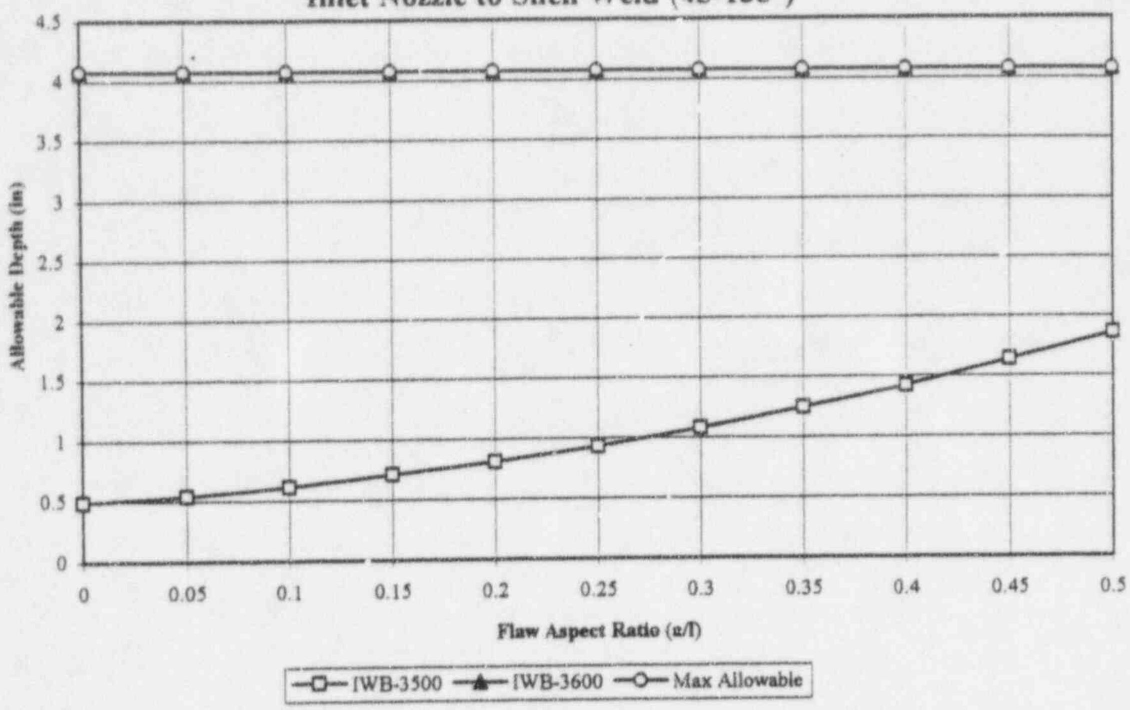

Circumferential Sub-Surface Flaw e/t = -0.25
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.25
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

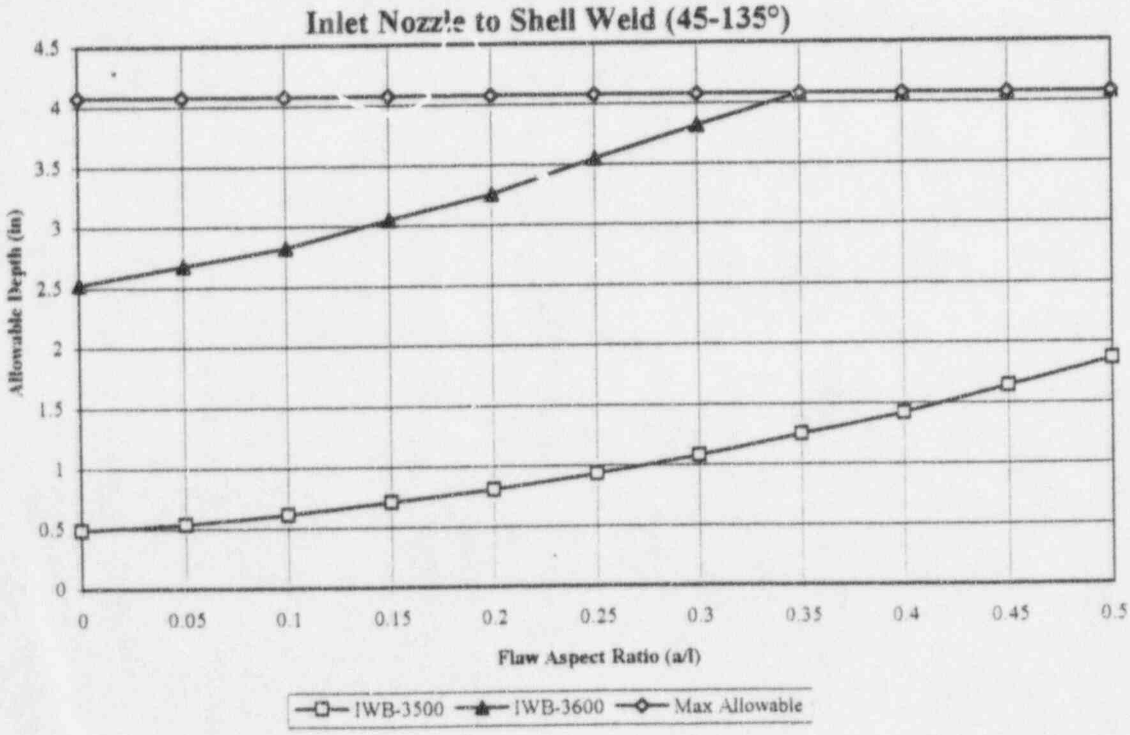

Circumferential Sub-Surface Flaw e/t = -0.1
Inlet Nozzle to Shell Weld (45-135°)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.1
Inlet Nozzle to Shell Weld (45-135°)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Allowable Depth (in)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

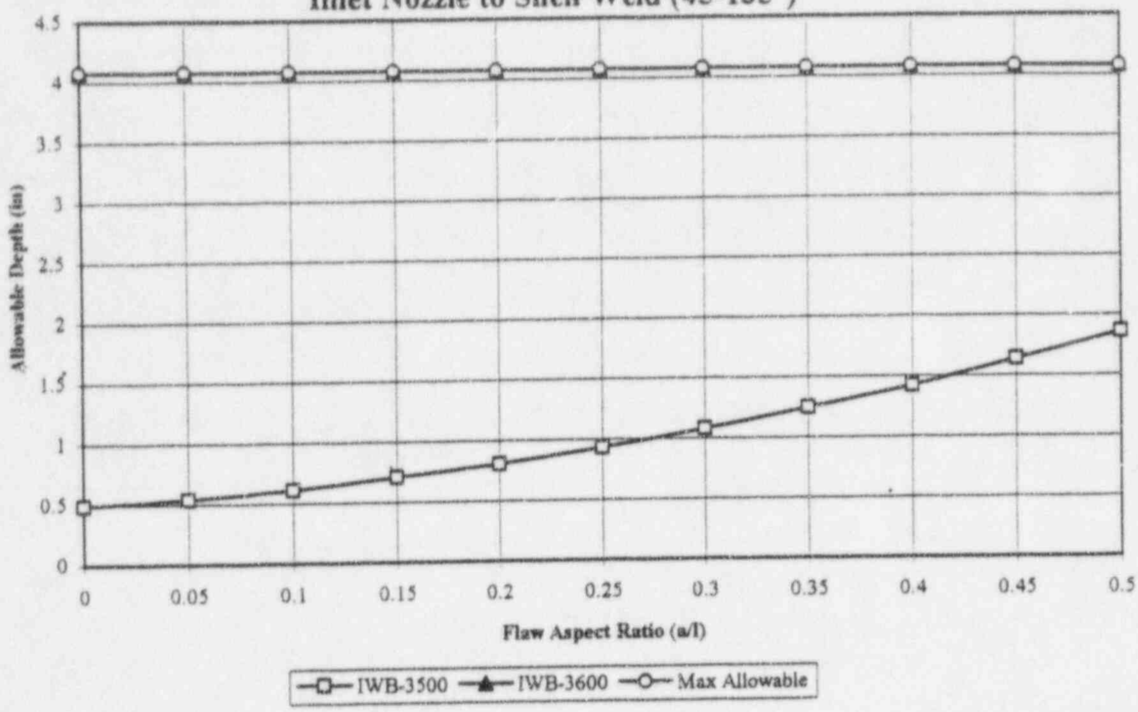
Circumferential Sub-Surface Flaw e/t = 0.0
Inlet Nozzle to Shell Weld (45-135°)



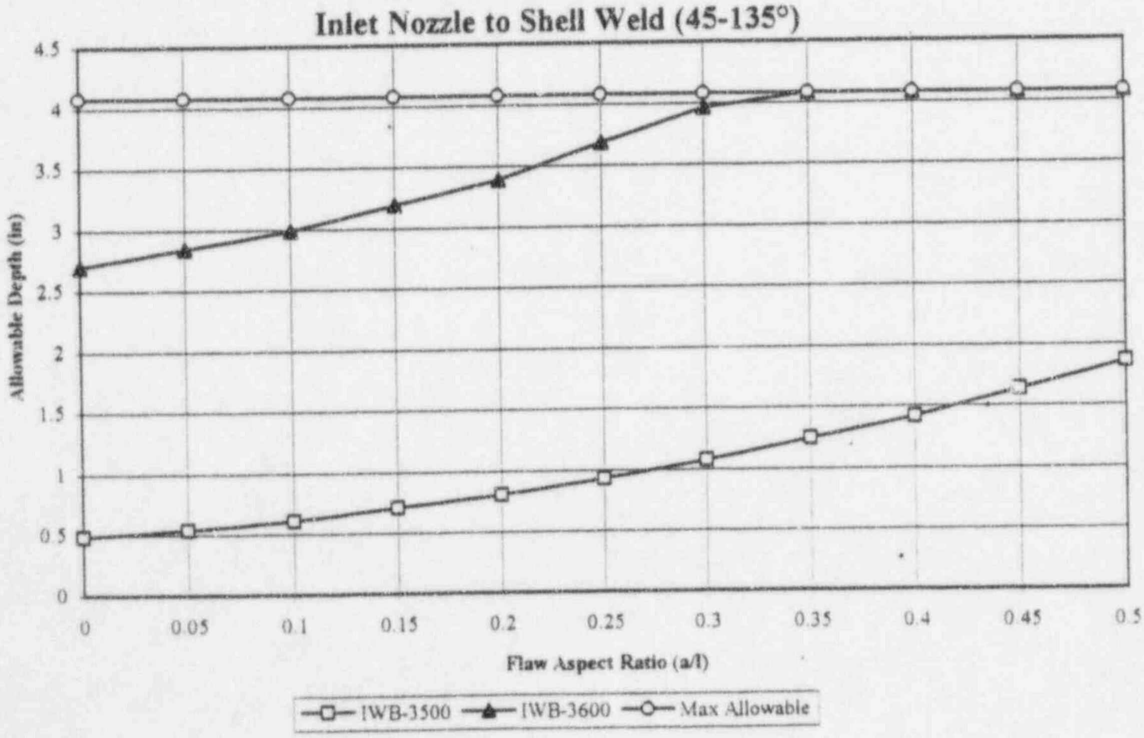
Axial Sub-Surface Flaw e/t = 0.0
Inlet Nozzle to Shell Weld (45-135°)

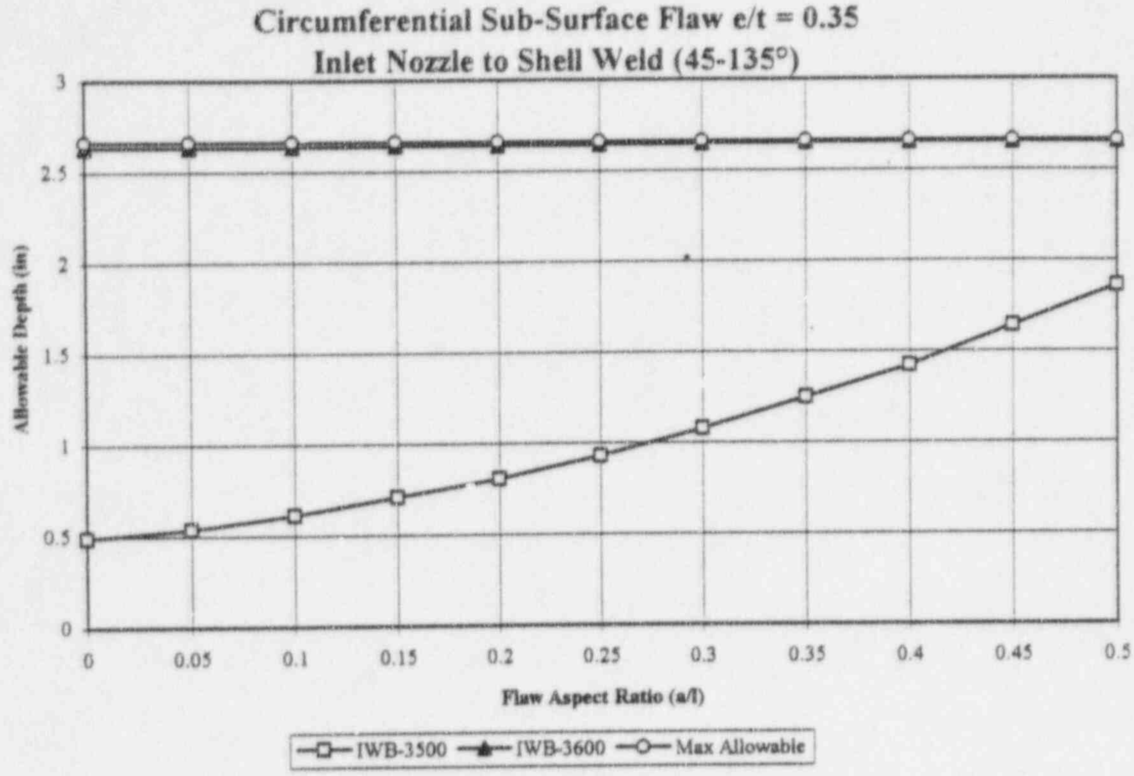


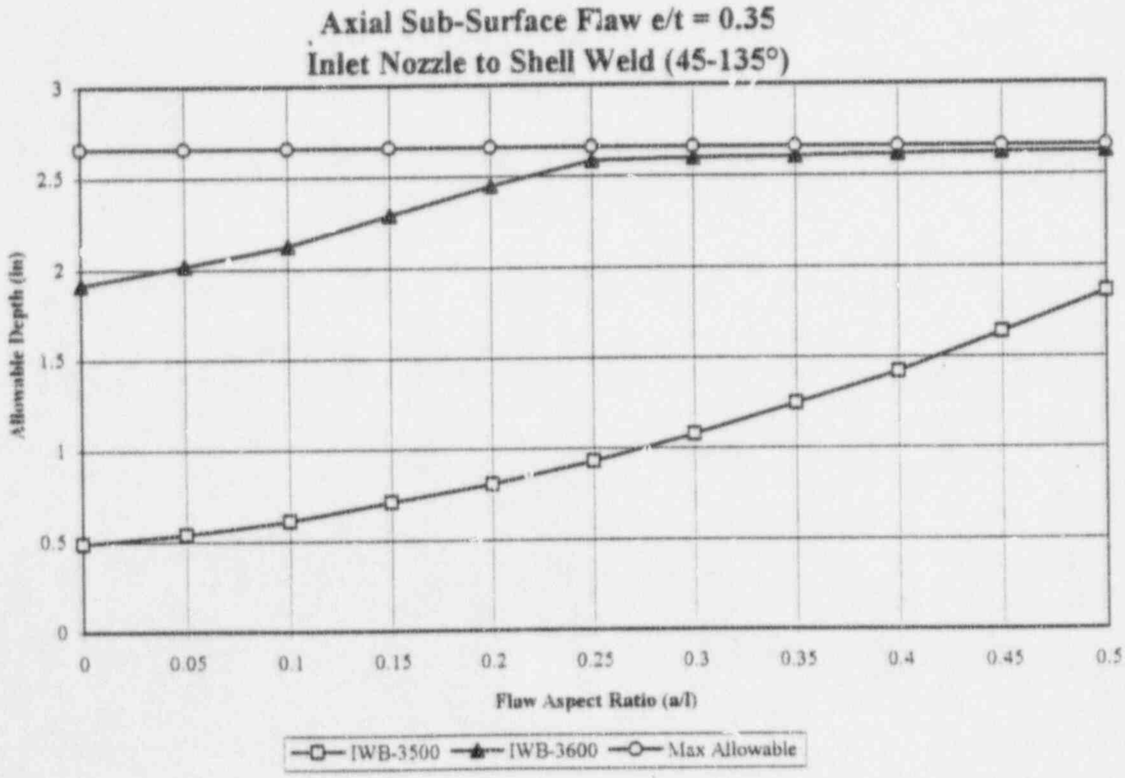
Circumferential Sub-Surface Flaw e/t = 0.2
Inlet Nozzle to Shell Weld (45-135°)



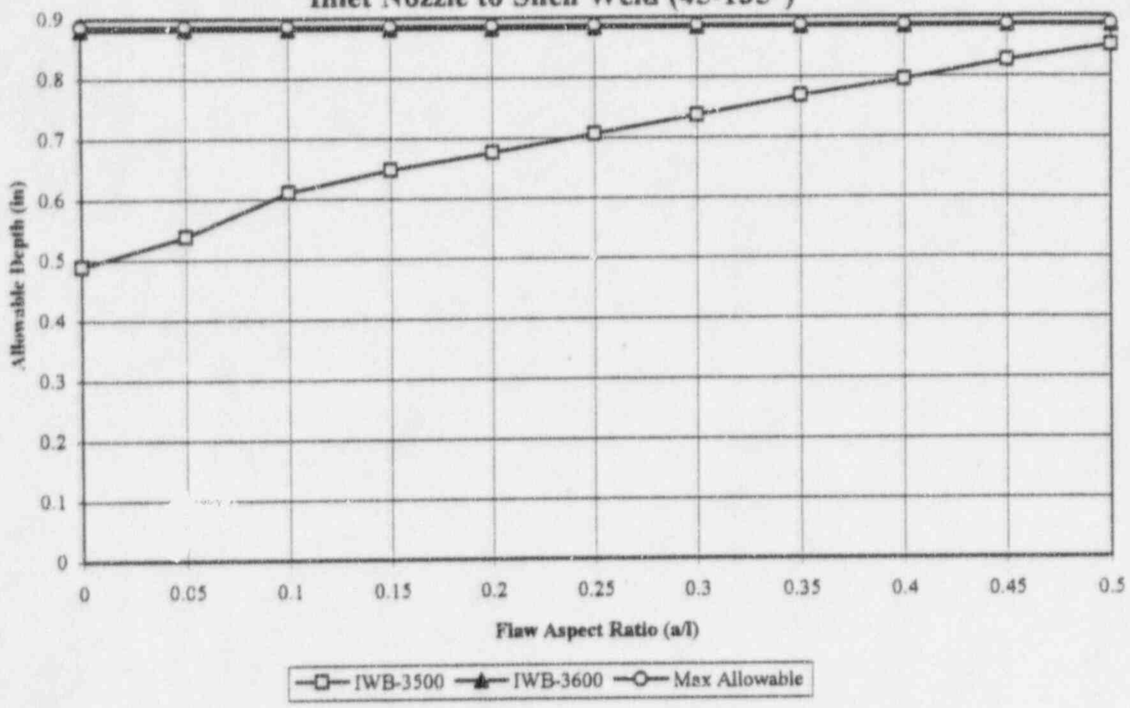
Axial Sub-Surface Flaw e/t = 0.2
Inlet Nozzle to Shell Weld (45-135°)



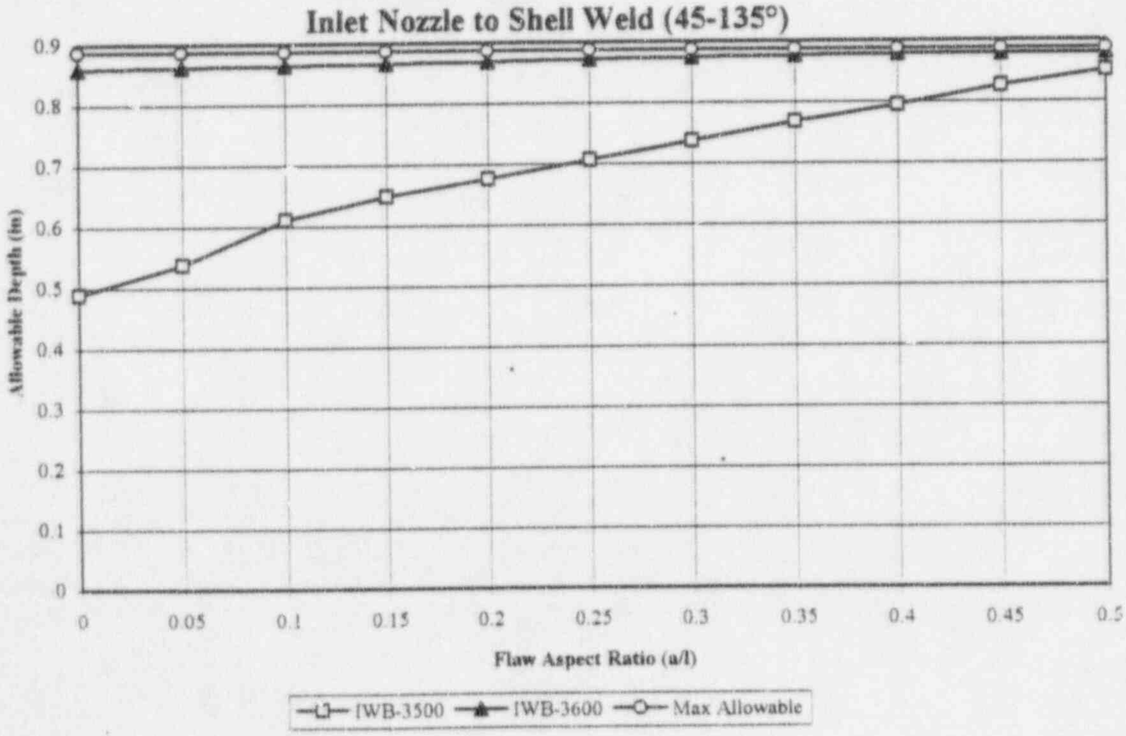

Circumferential Sub-Surface Flaw e/t = 0.35
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.35
Inlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

Circumferential Sub-Surface Flaw e/t = 0.45
Inlet Nozzle to Shell Weld (45-135°)



Axial Sub-Surface Flaw e/t = 0.45
Inlet Nozzle to Shell Weld (45-135°)



APPENDIX L

Flaw Acceptance Diagrams for Region L Materials

Diagrams on pages L-1 through L-10 are for 0°-45° and 135°-180° locations. Diagrams on pages L1-1 through L1-10 are for 45°-135° locations.

Region L includes:

- Upper Nozzle Shell
- Outlet Nozzle (MK #19)
- Outlet Nozzle to Shell Weld

Based on Minimum Thickness = 12.125"

Default Maximum Allowable Flaw Sizes for All Charts:

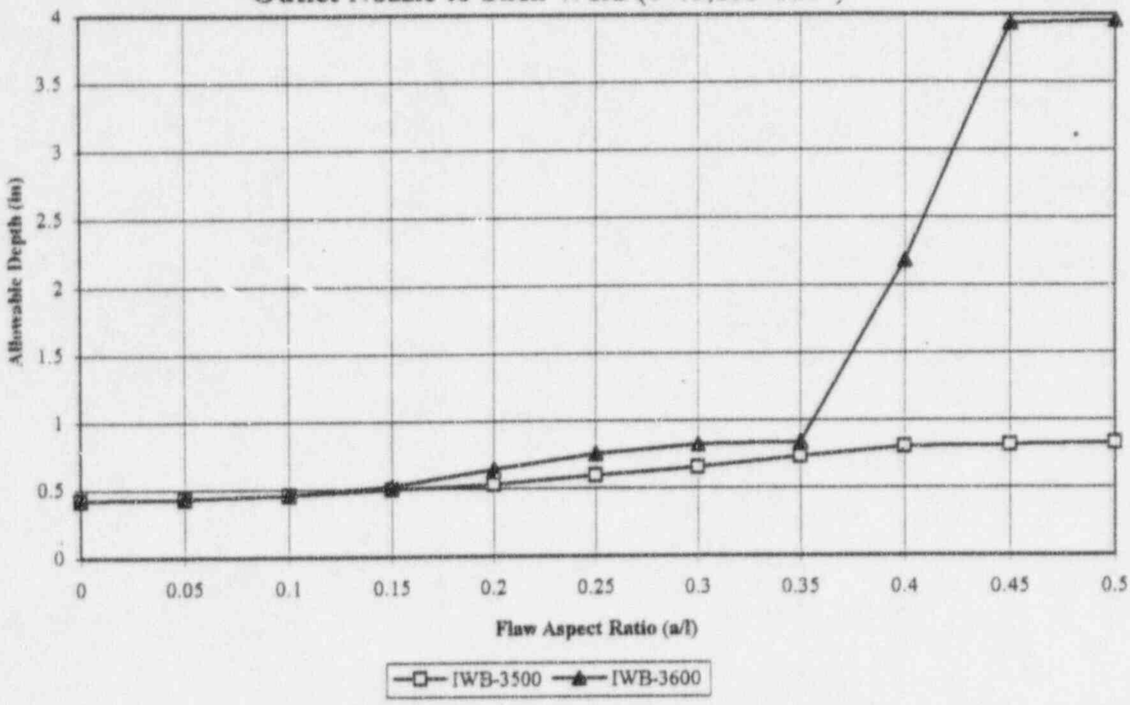
Axially (parallel to weld)-Oriented Flaws = 4.08"
Transverse-Oriented Flaws = 4.08"

Note: For all flaw acceptance diagrams in Appendix L, "axial" refers to flaws oriented axial to weld (as affected by hoop stresses) and "circumferential" refers to flaws oriented transverse to weld (as affected by radial stresses).

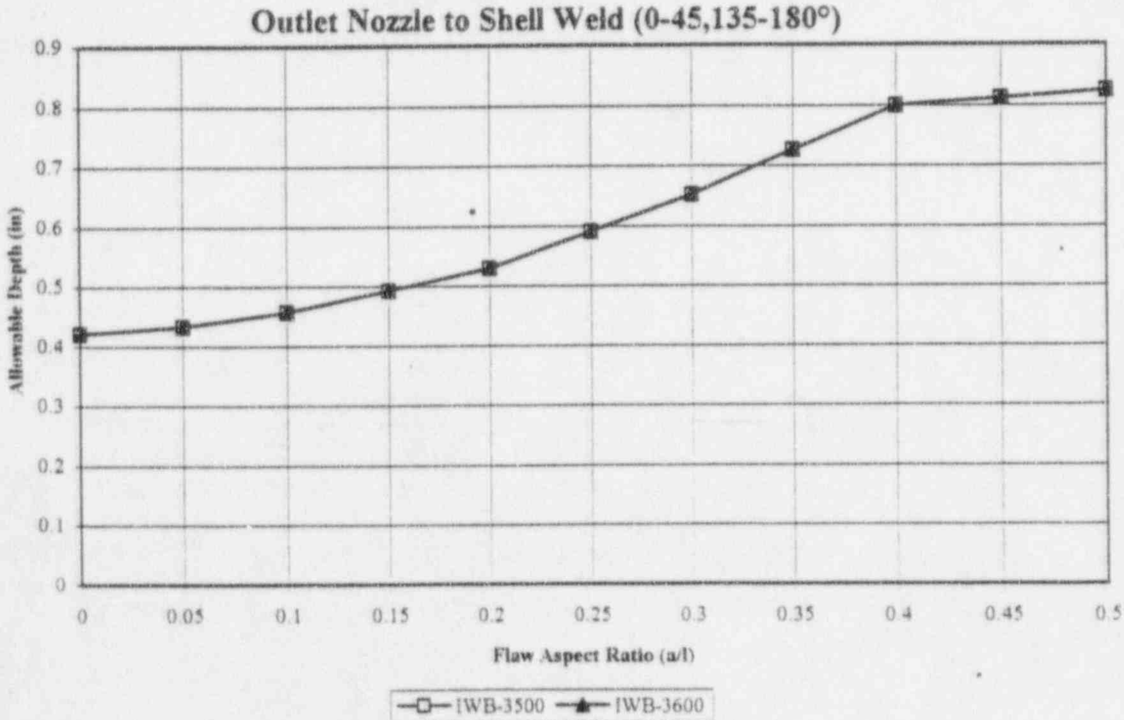
General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

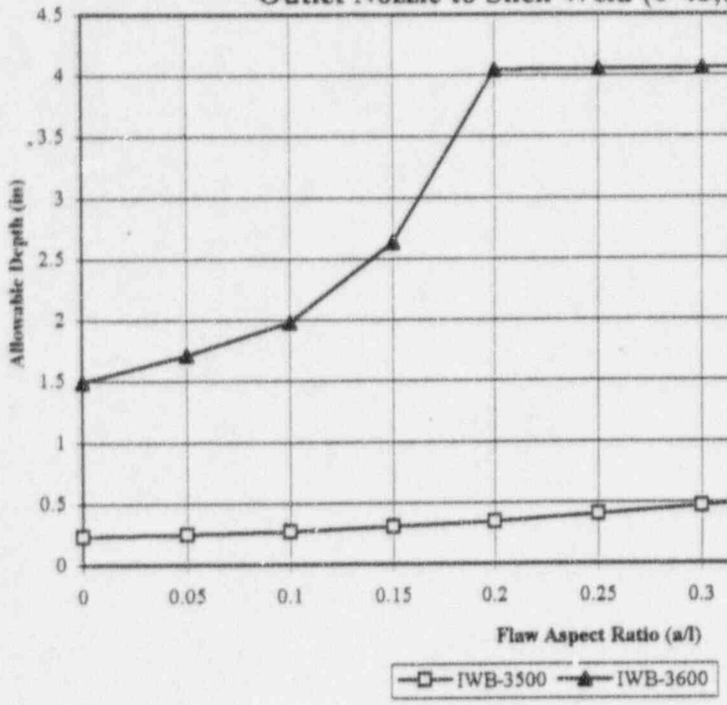
Inside Surface Circumferential Flaw
Outlet Nozzle to Shell Weld (0-45,135-180°)



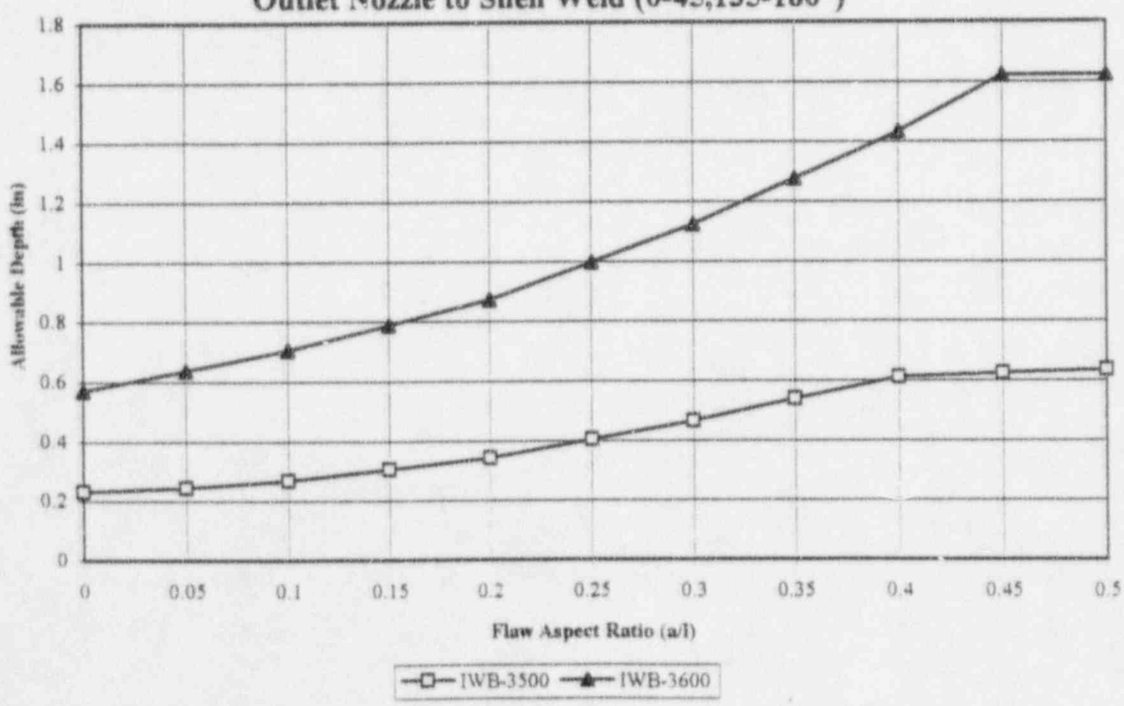
Inside Surface Axial Flaw
Outlet Nozzle to Shell Weld (0-45,135-180°)



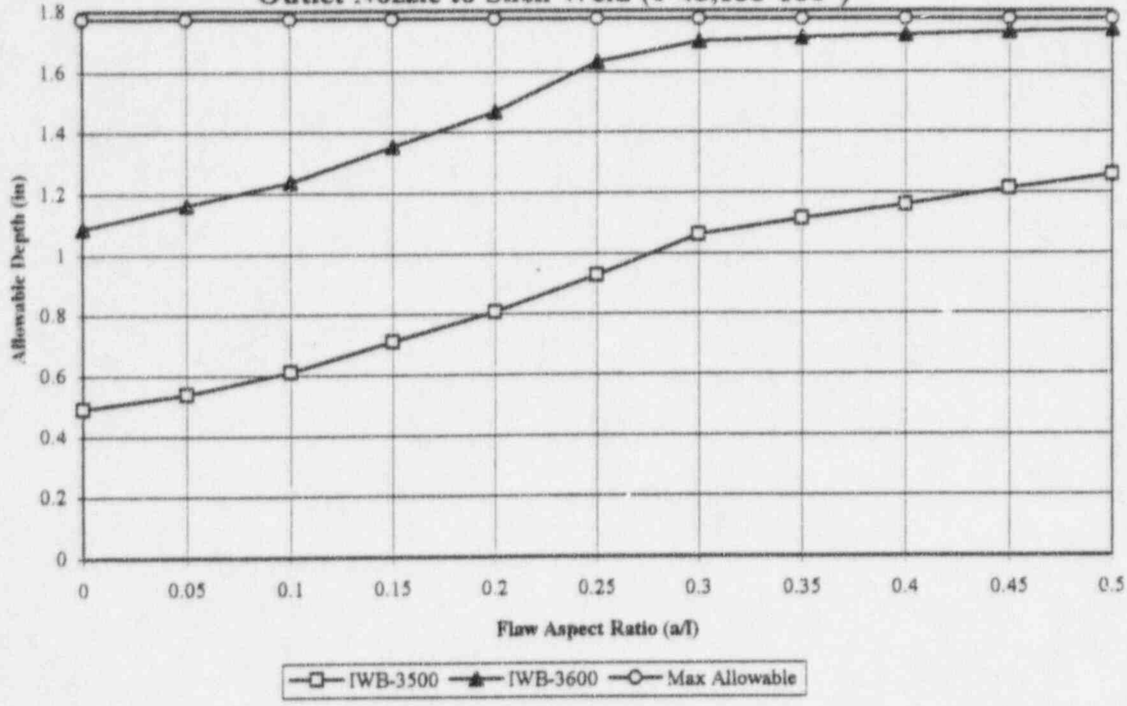
Outside Surface Circumferential Flaw
Outlet Nozzle to Shell Weld (0-45,135-180°)



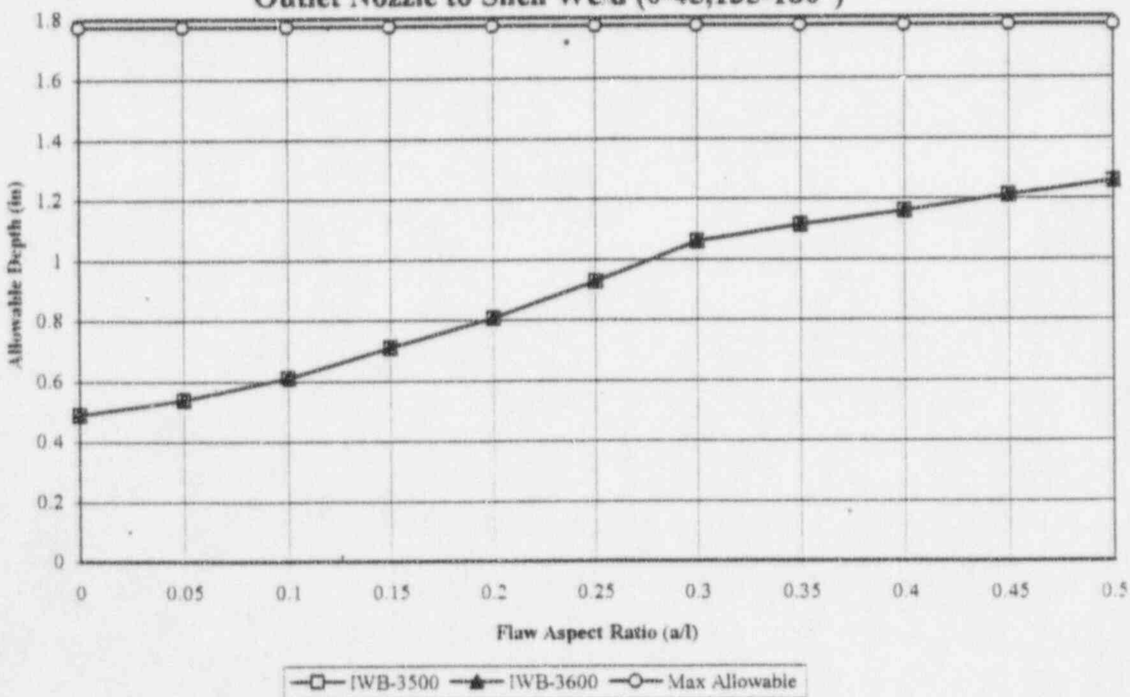
Outside Surface Axial Flaw
Outlet Nozzle to Shell Weld (0-45,135-180°)

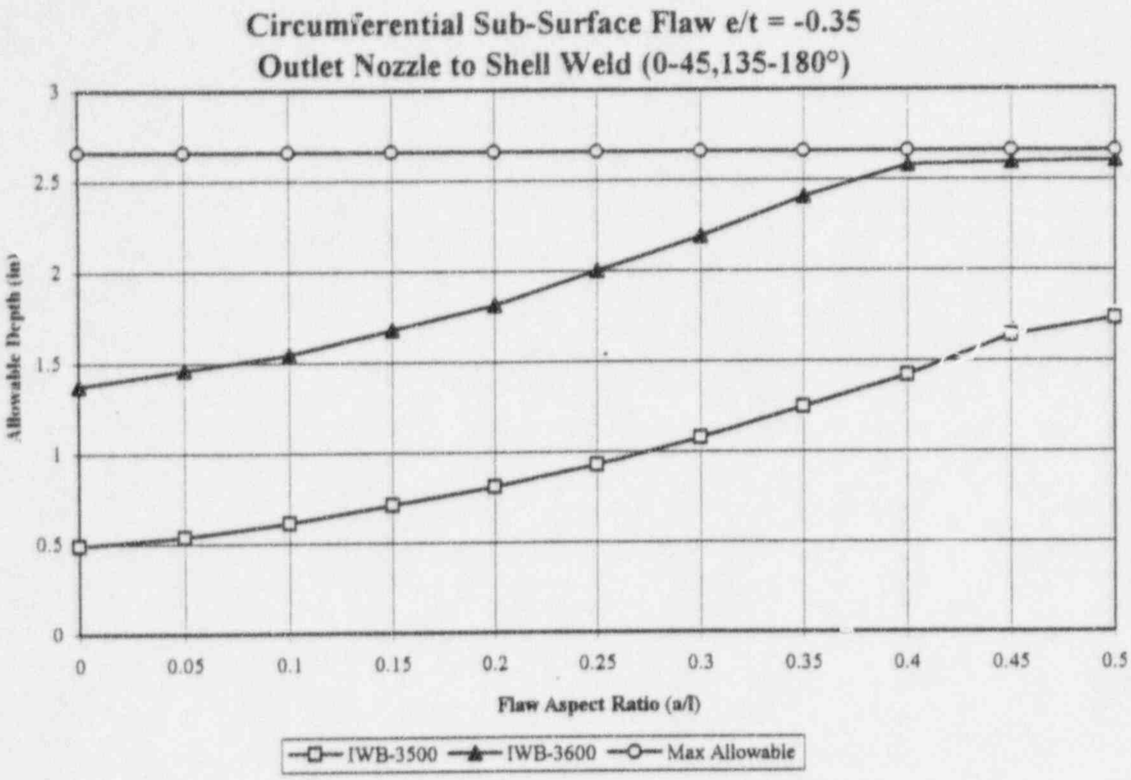


Circumferential Sub-Surface Flaw e/t = -0.4
Outlet Nozzle to Shell Weld (0-45,135-180°)

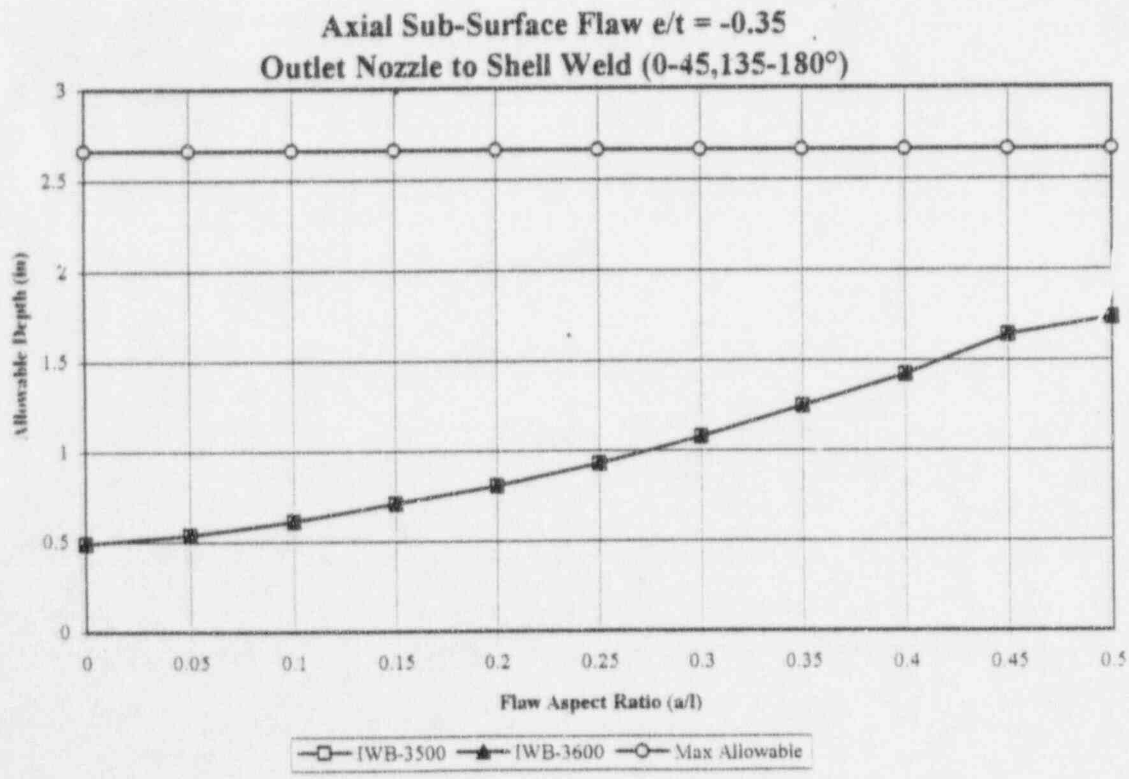


Axial Sub-Surface Flaw e/t = -0.4
Outlet Nozzle to Shell Weld (0-45,135-180°)



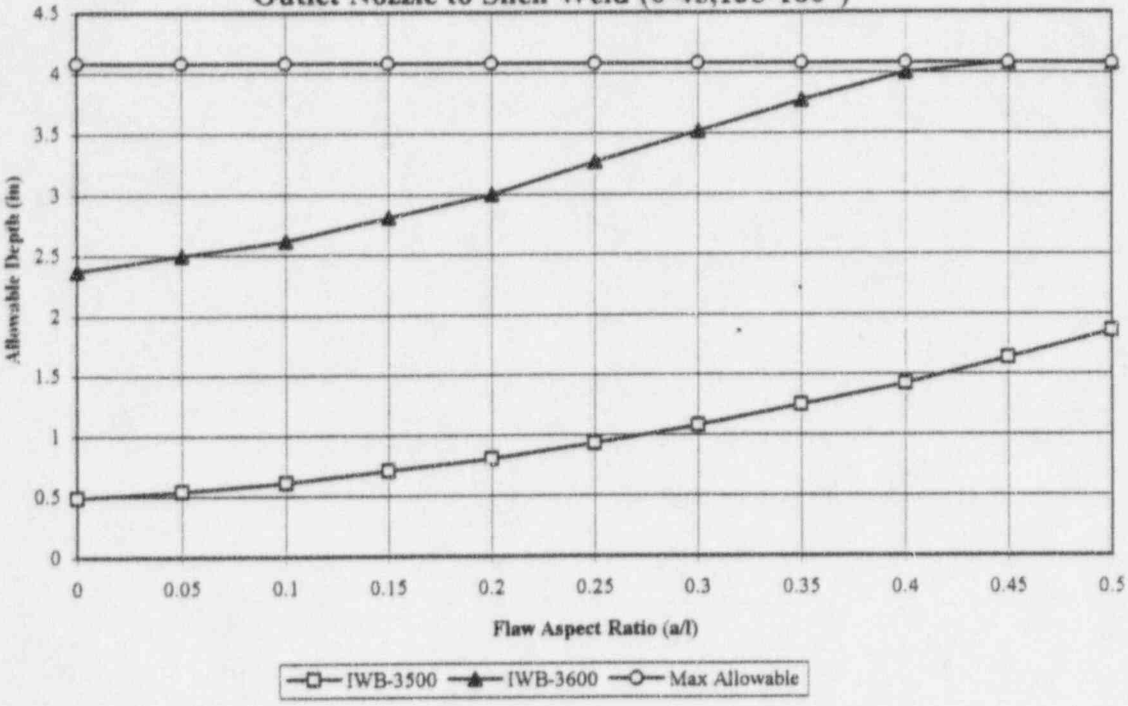


Circumferential Sub-Surface Flaw e/t = -0.35
Outlet Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

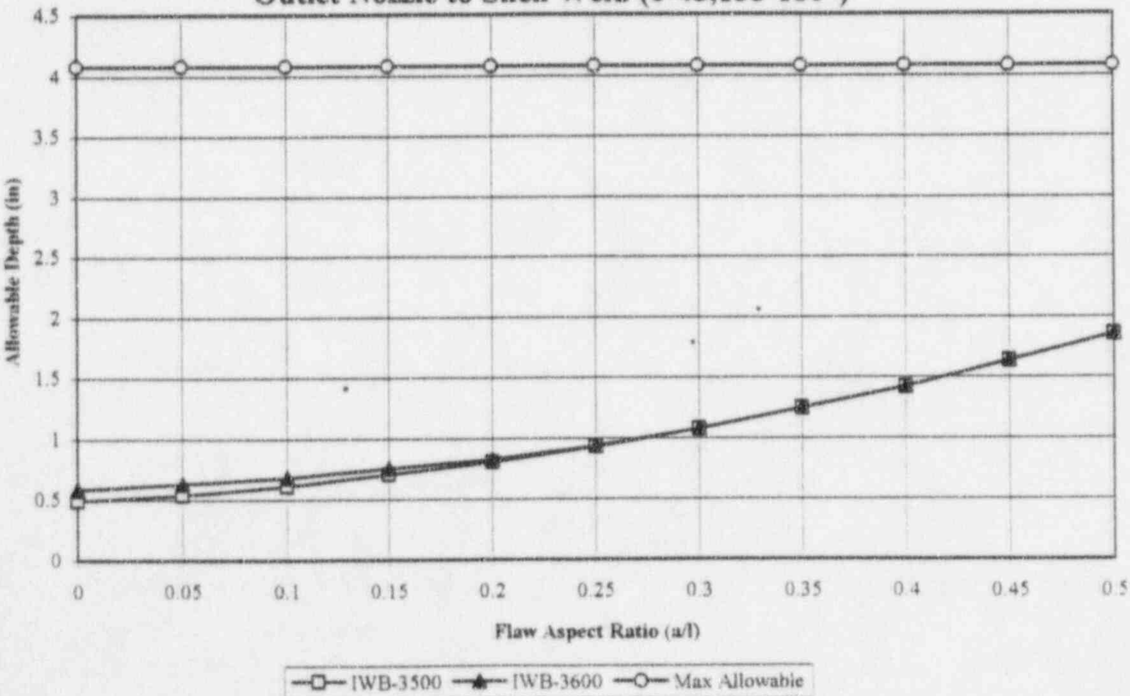


Axial Sub-Surface Flaw e/t = -0.35
Outlet Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

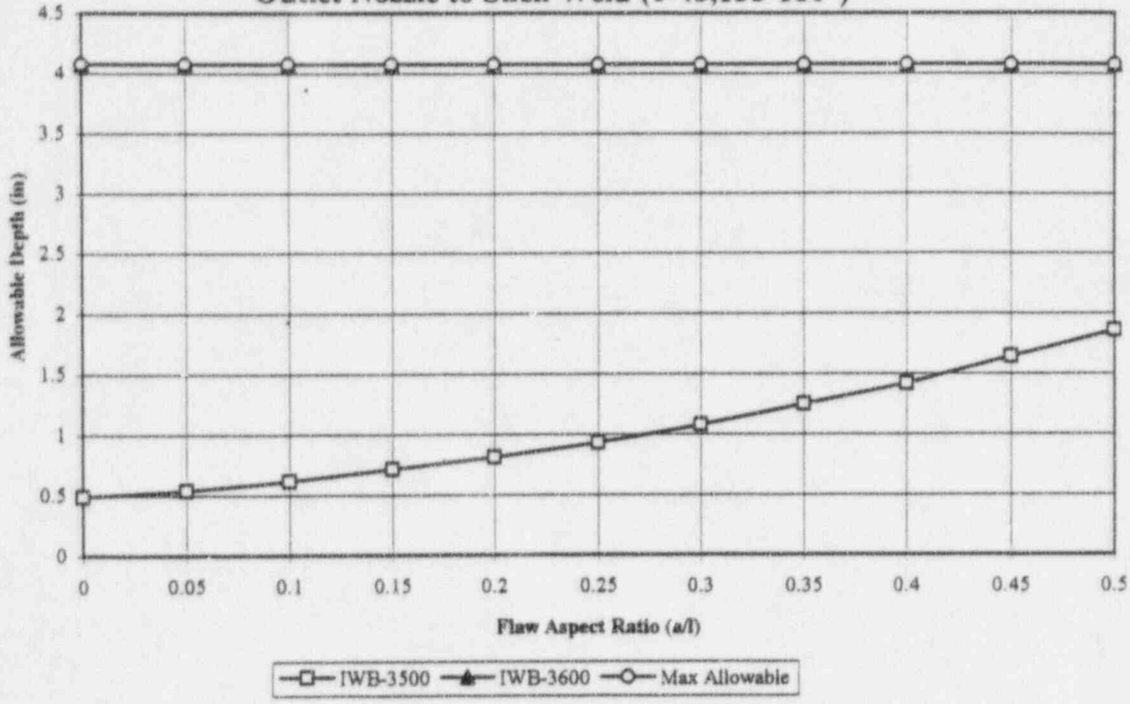
Circumferential Sub-Surface Flaw e/t = -0.25
Outlet Nozzle to Shell Weld (0-45,135-180°)



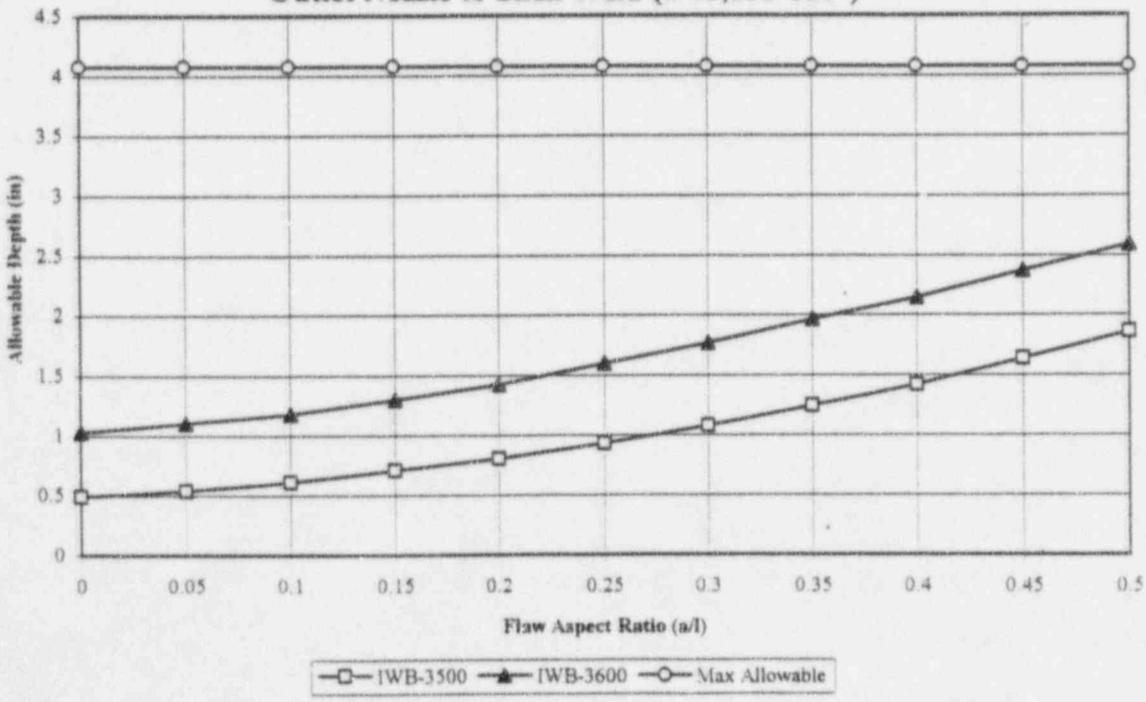
Axial Sub-Surface Flaw e/t = -0.25
Outlet Nozzle to Shell Weld (0-45,135-180°)



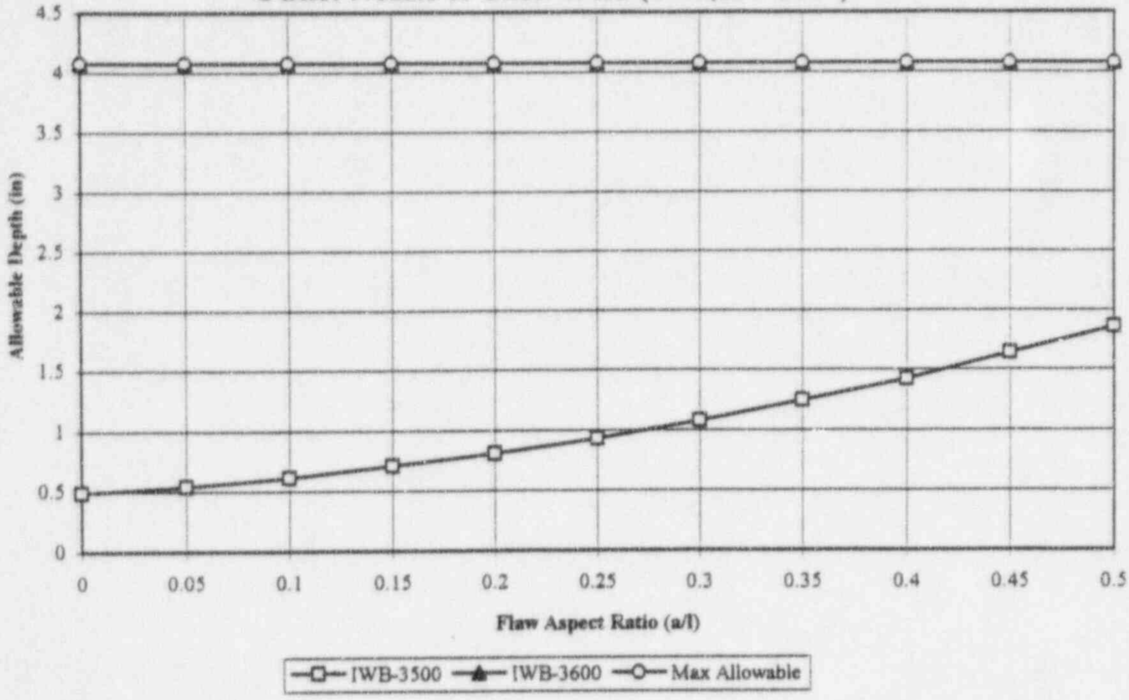
Circumferential Sub-Surface Flaw e/t = -0.1
Outlet Nozzle to Shell Weld (0-45,135-180°)



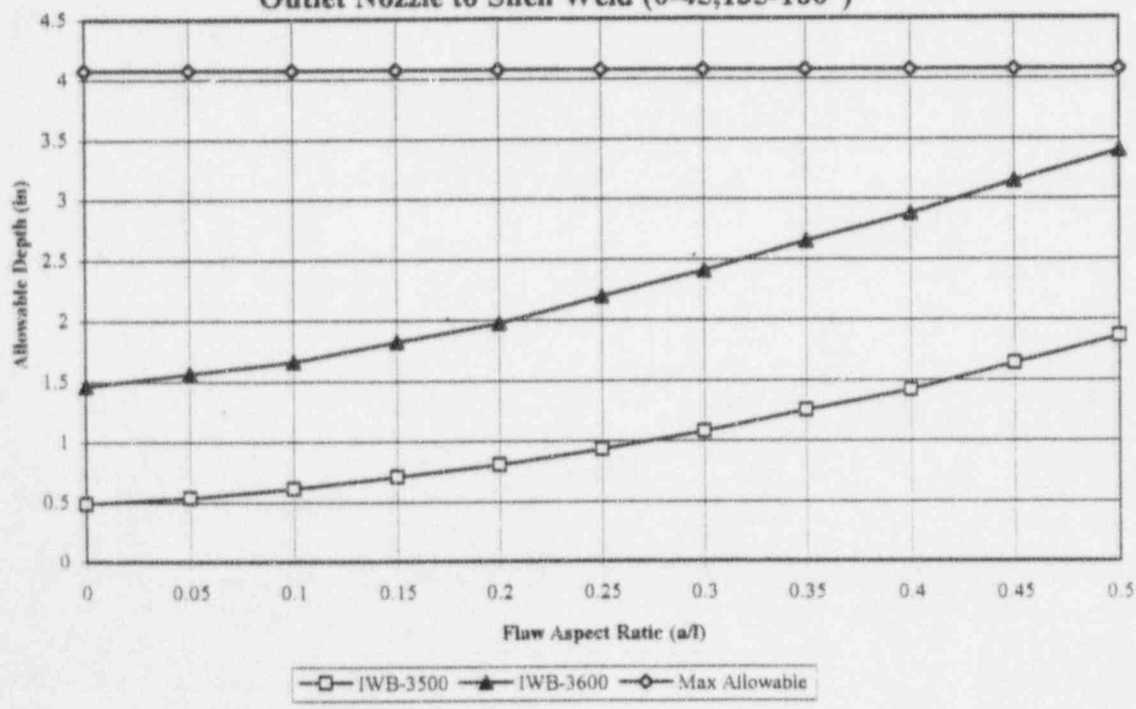
Axial Sub-Surface Flaw e/t = -0.1
Outlet Nozzle to Shell Weld (0-45,135-180°)



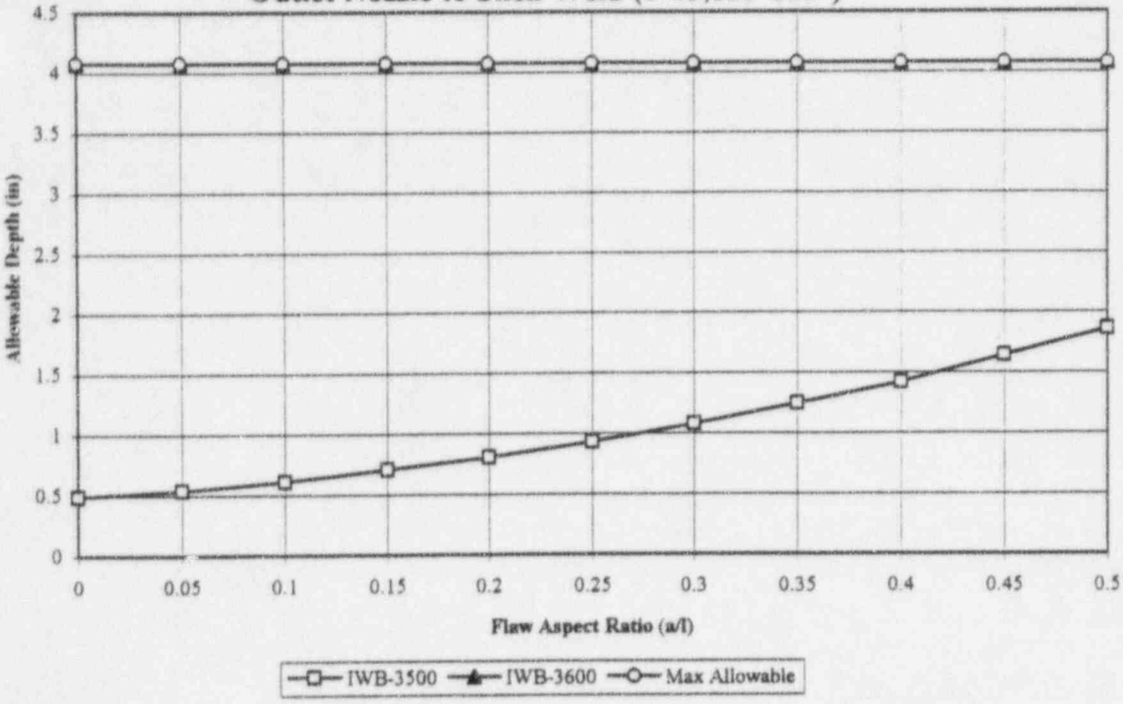
Circumferential Sub-Surface Flaw e/t = 0.0
Outlet Nozzle to Shell Weld (0-45,135-180°)



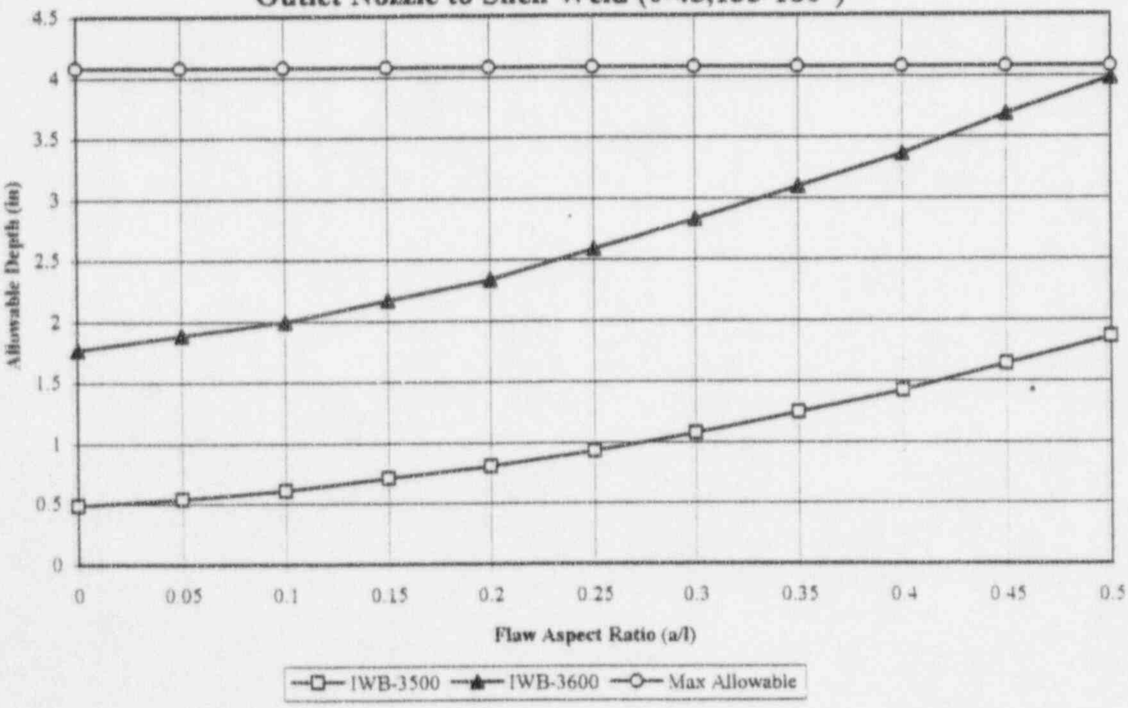
Axial Sub-Surface Flaw e/t = 0.0
Outlet Nozzle to Shell Weld (0-45,135-180°)

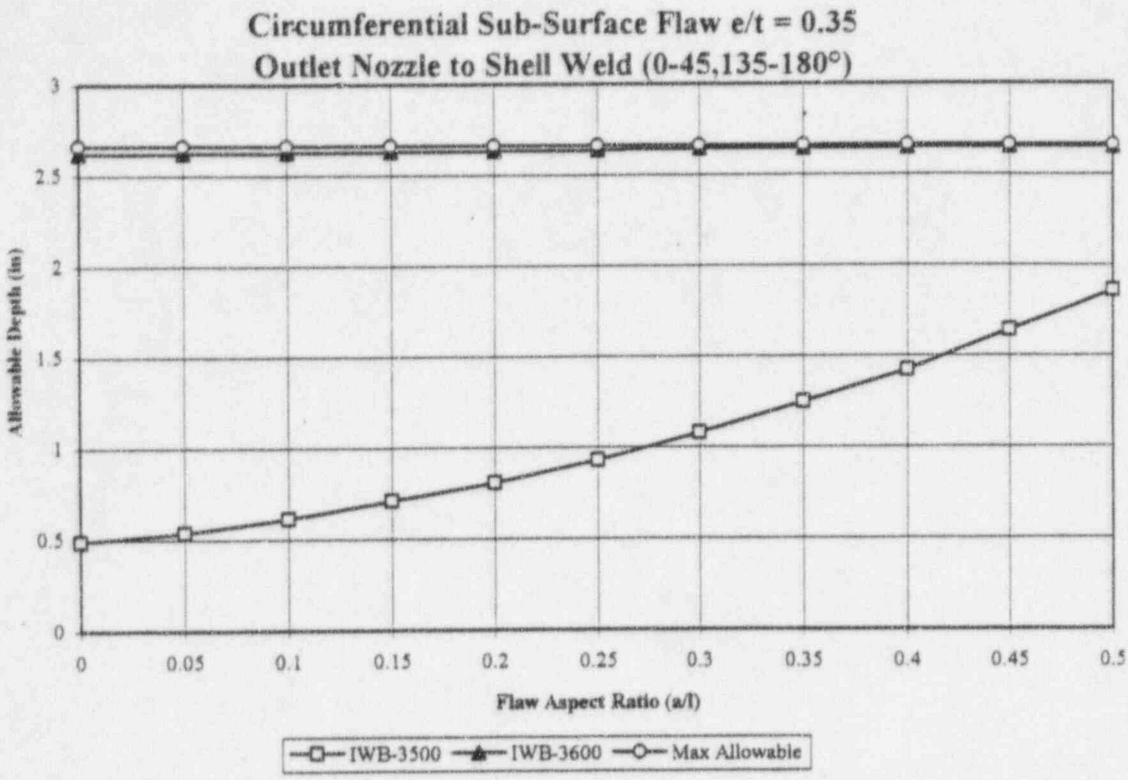


Circumferential Sub-Surface Flaw e/t = 0.2
Outlet Nozzle to Shell Weld (0-45,135-180°)

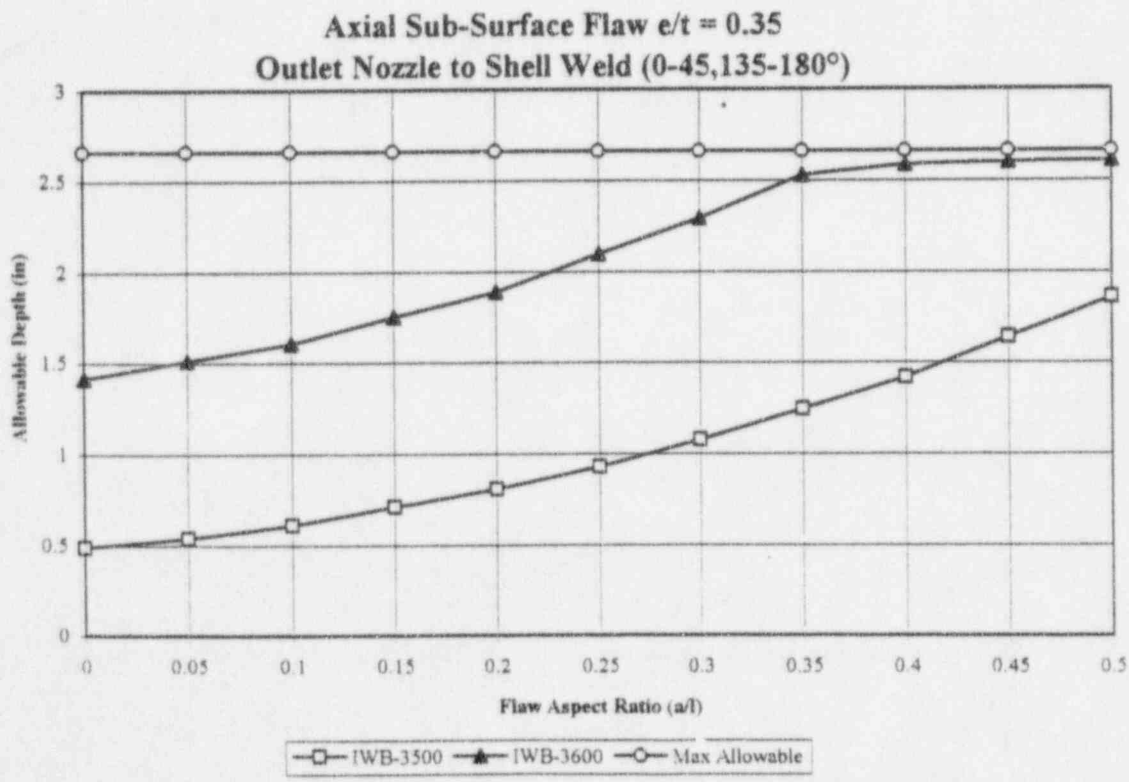


Axial Sub-Surface Flaw e/t = 0.2
Outlet Nozzle to Shell Weld (0-45,135-180°)



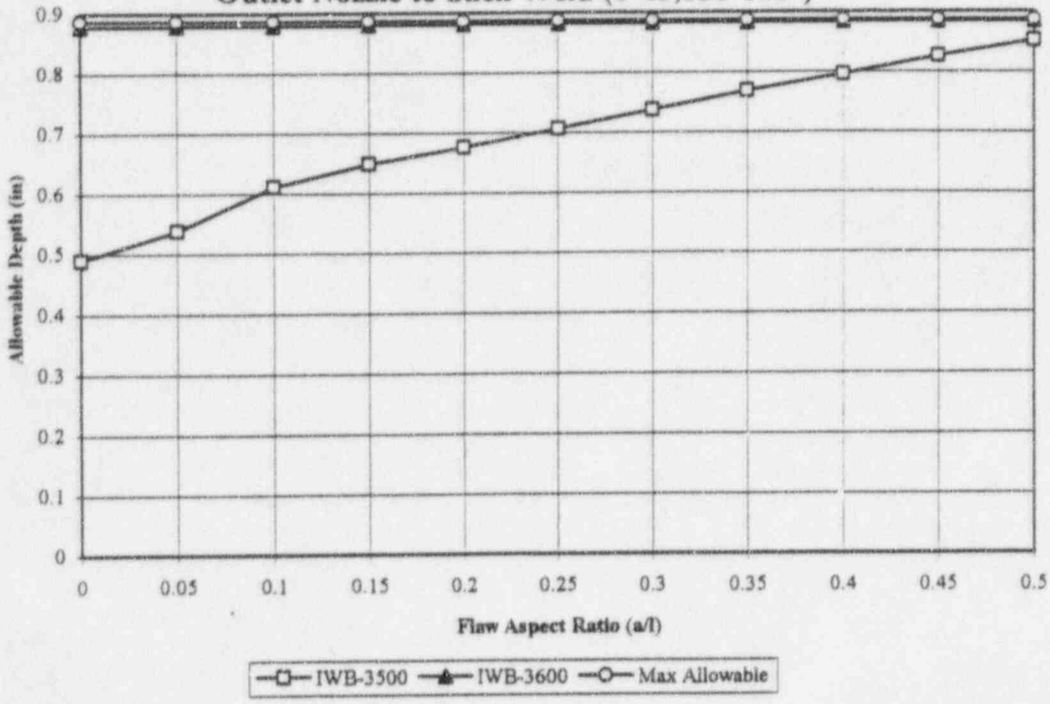


Circumferential Sub-Surface Flaw e/t = 0.35
Outlet Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

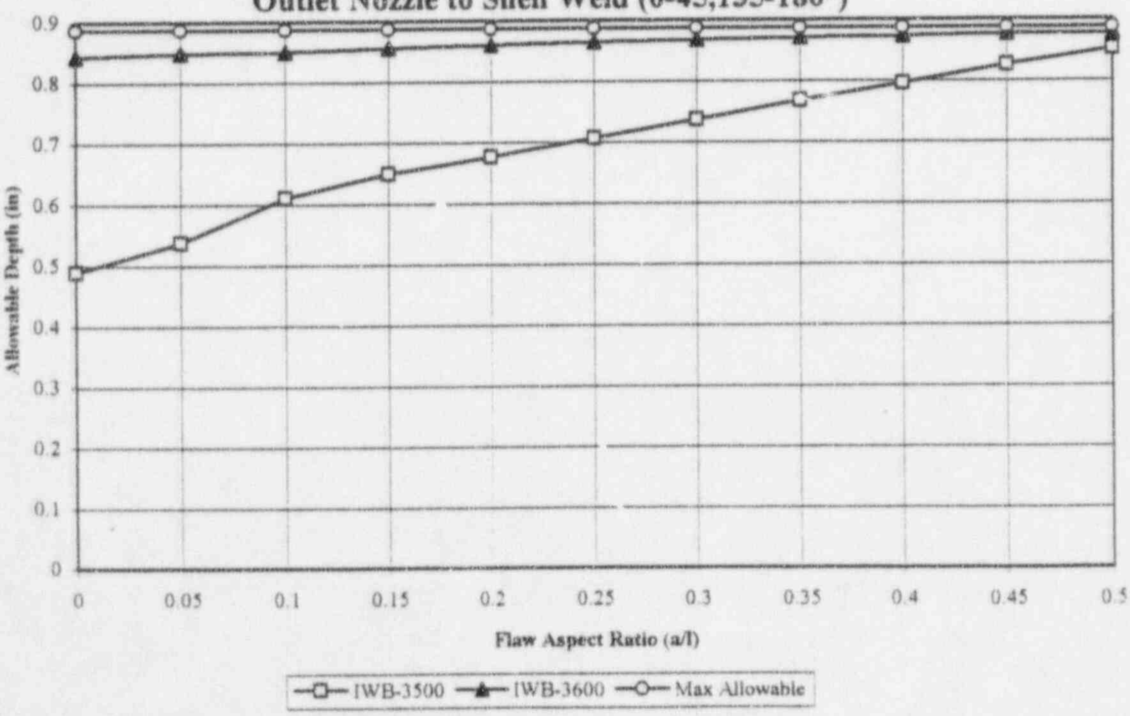


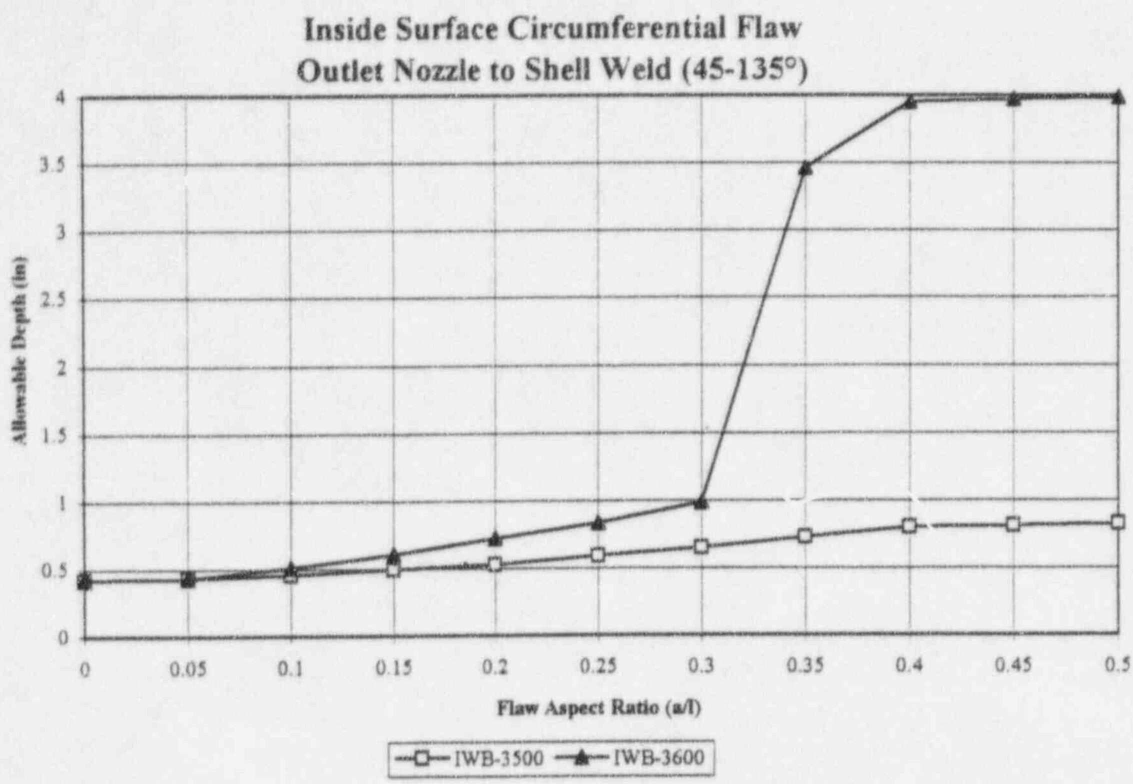
Axial Sub-Surface Flaw e/t = 0.35
Outlet Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

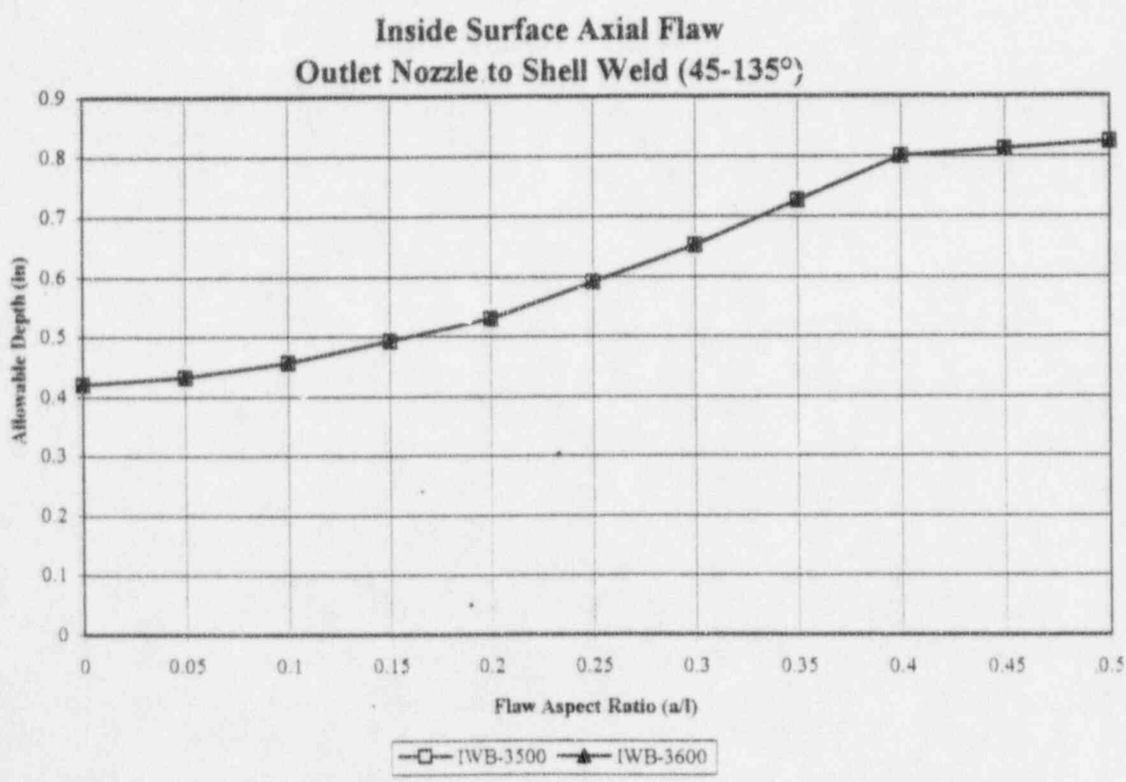
Circumferential Sub-Surface Flaw e/t = 0.45
Outlet Nozzle to Shell Weld (0-45,135-180°)



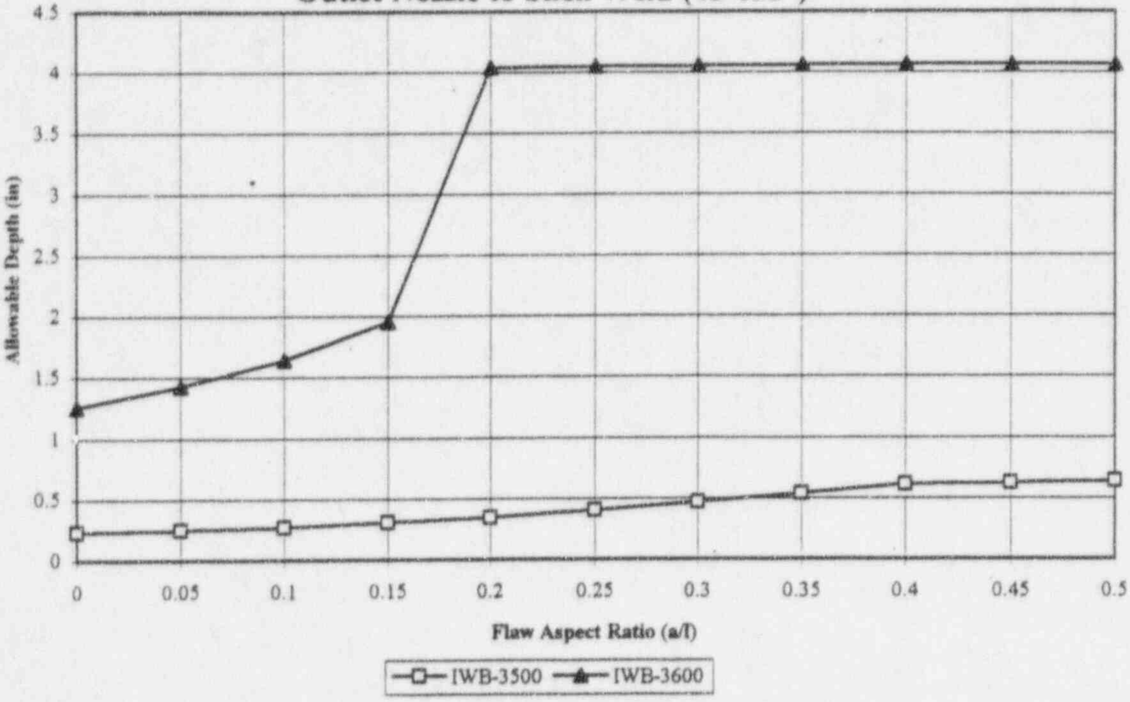
Axial Sub-Surface Flaw e/t = 0.45
Outlet Nozzle to Shell Weld (0-45,135-180°)



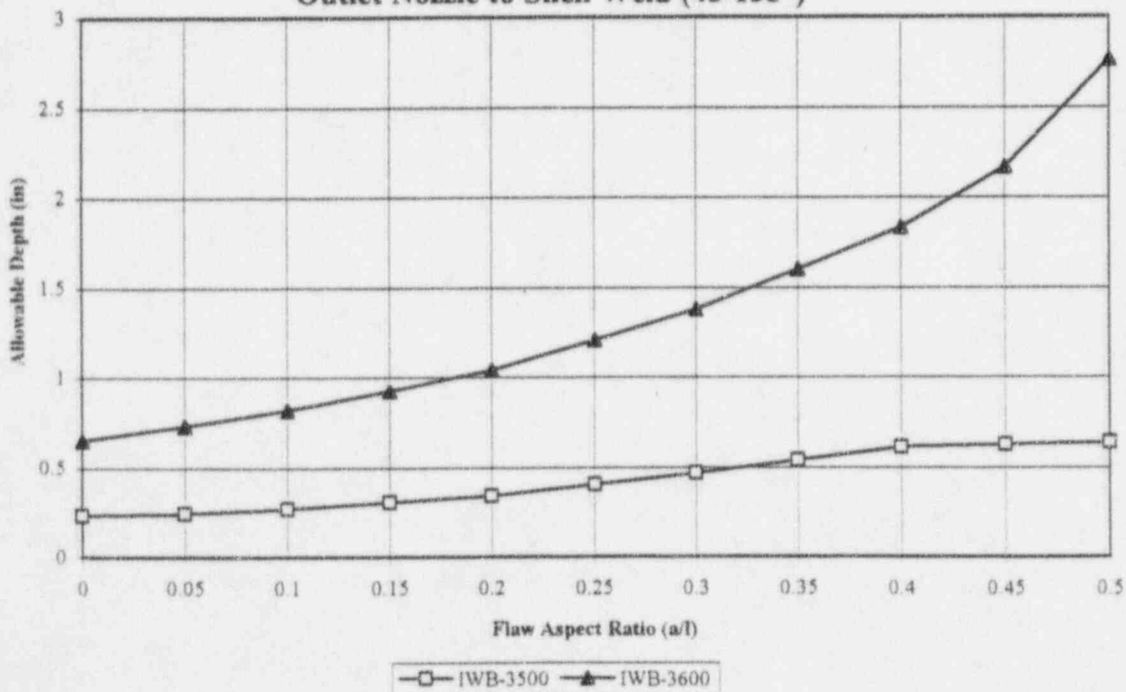

Inside Surface Circumferential Flaw
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

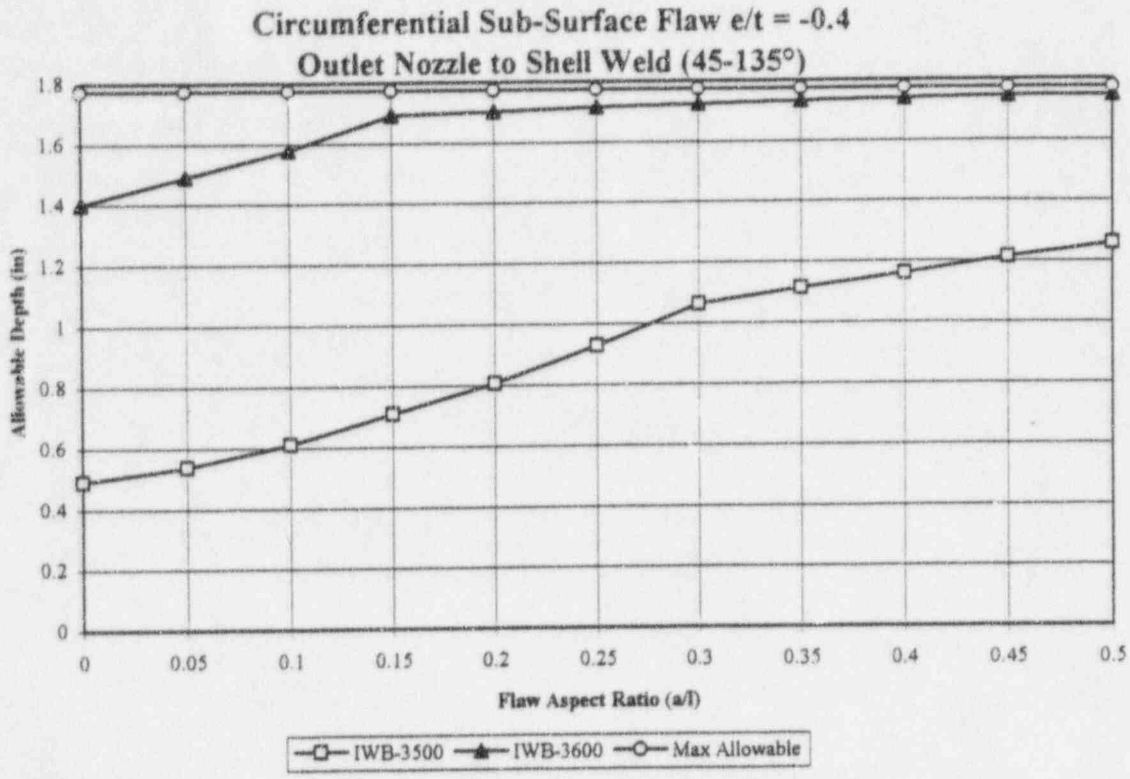

Inside Surface Axial Flaw
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

Outside Surface Circumferential Flaw
Outlet Nozzle to Shell Weld (45-135°)

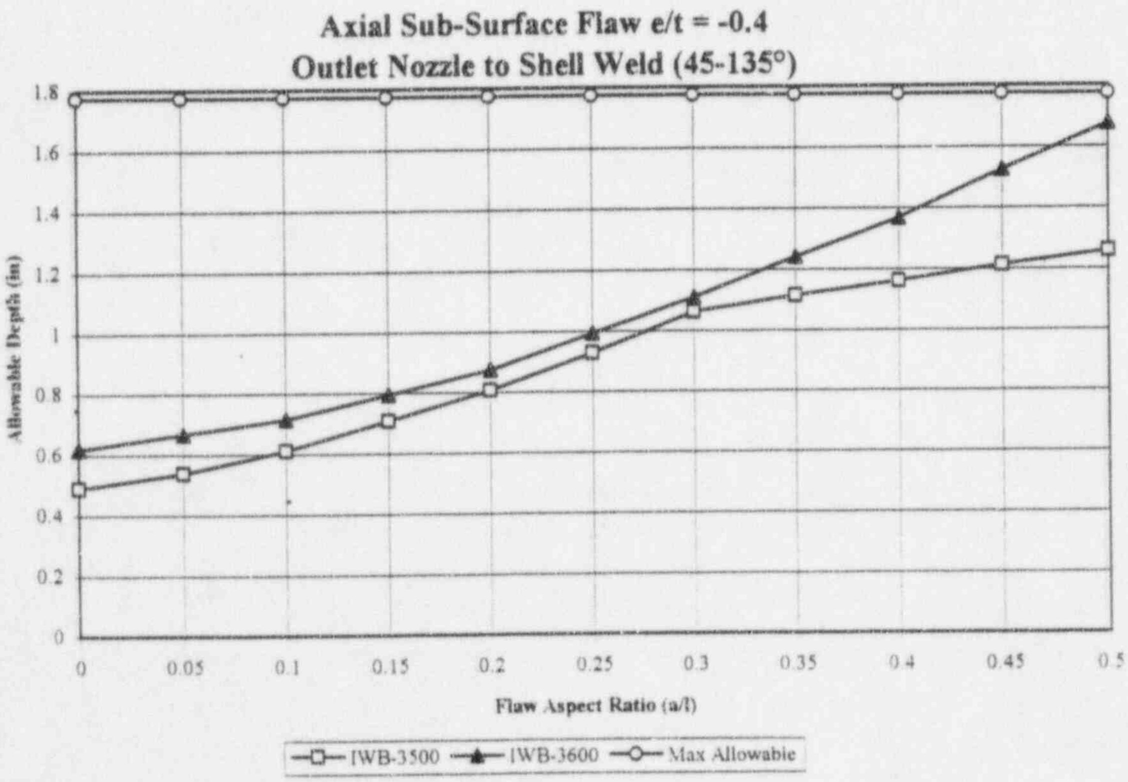


Outside Surface Axial Flaw
Outlet Nozzle to Shell Weld (45-135°)



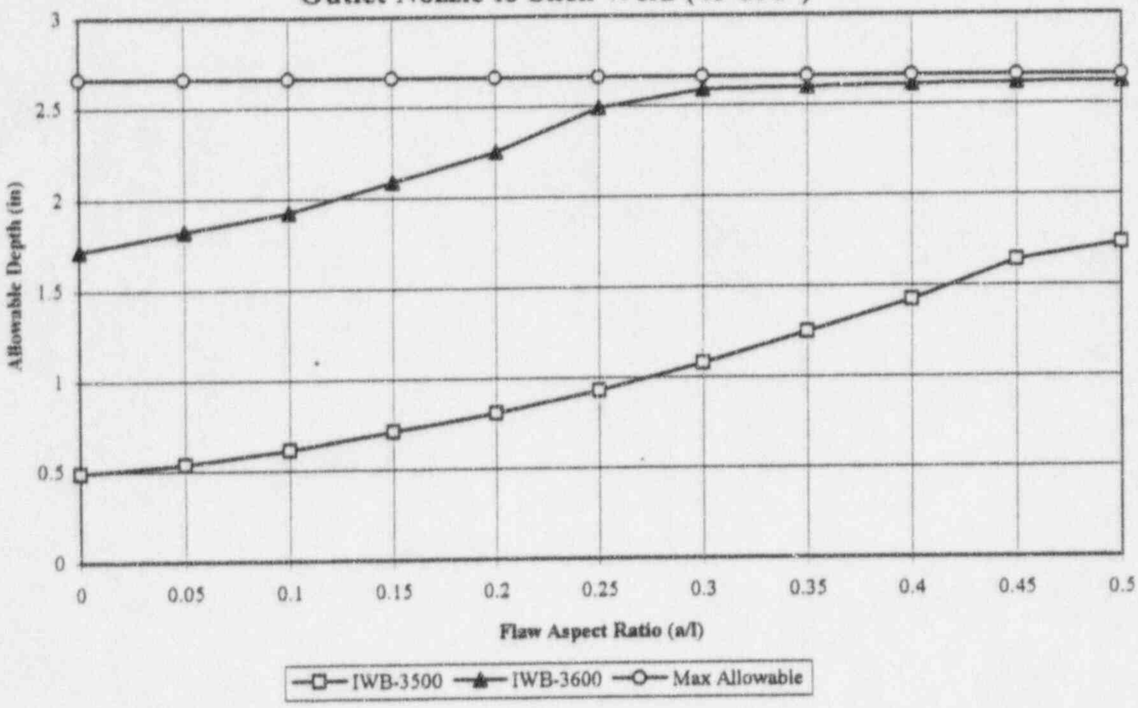


Circumferential Sub-Surface Flaw e/t = -0.4
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

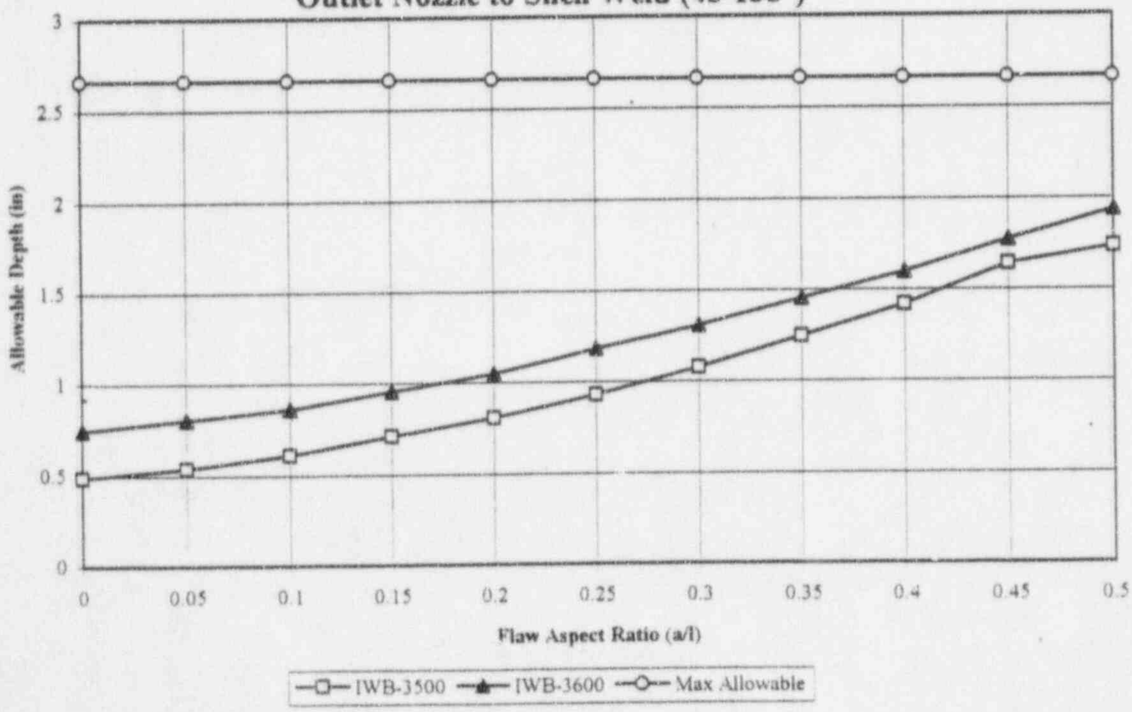


Axial Sub-Surface Flaw e/t = -0.4
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

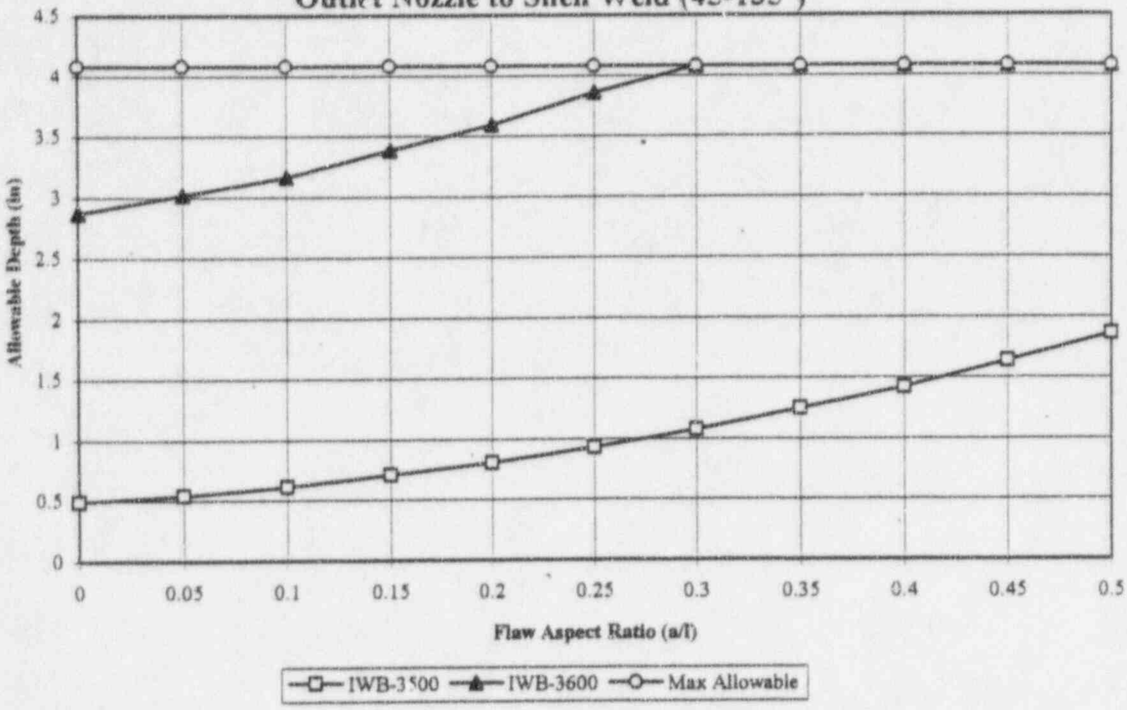
Circumferential Sub-Surface Flaw e/t = -0.35
Outlet Nozzle to Shell Weld (45-135°)



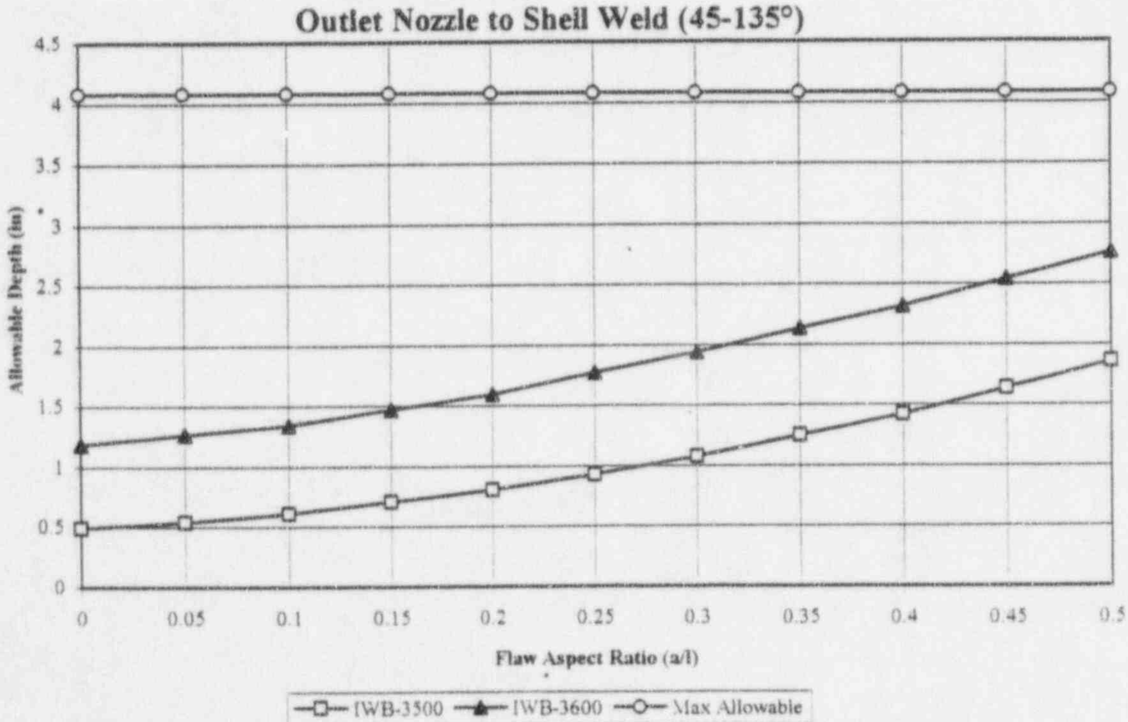
Axial Sub-Surface Flaw e/t = -0.35
Outlet Nozzle to Shell Weld (45-135°)

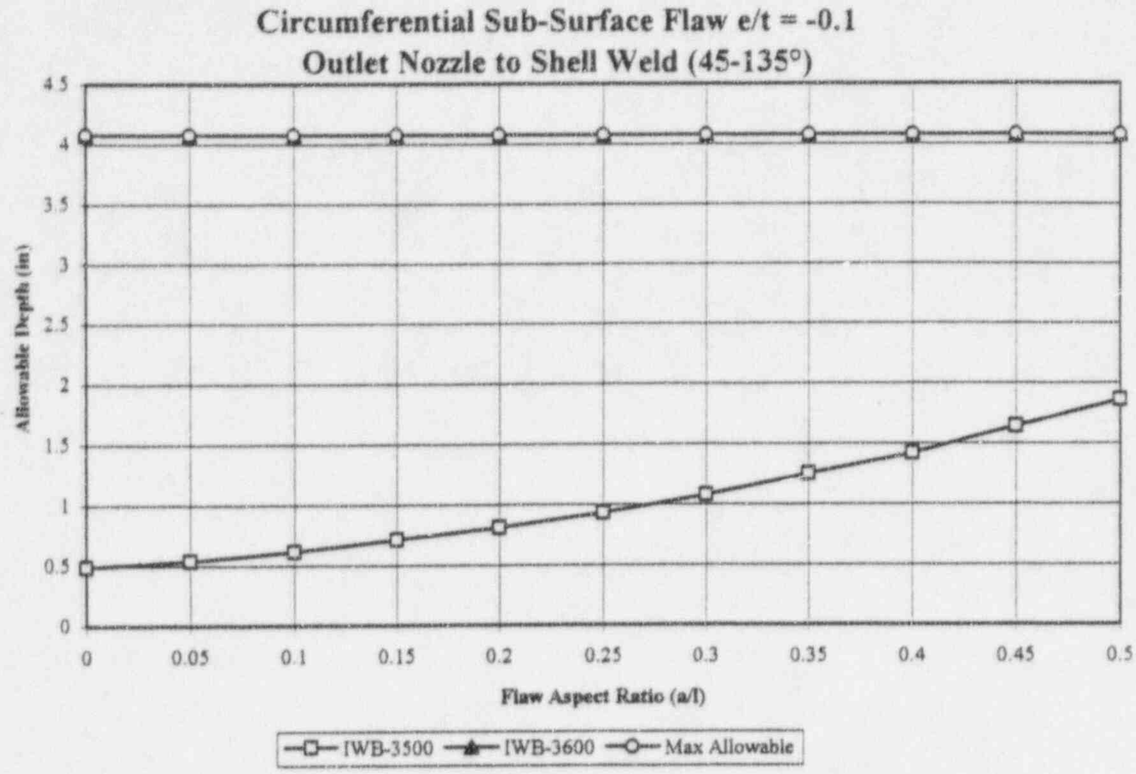


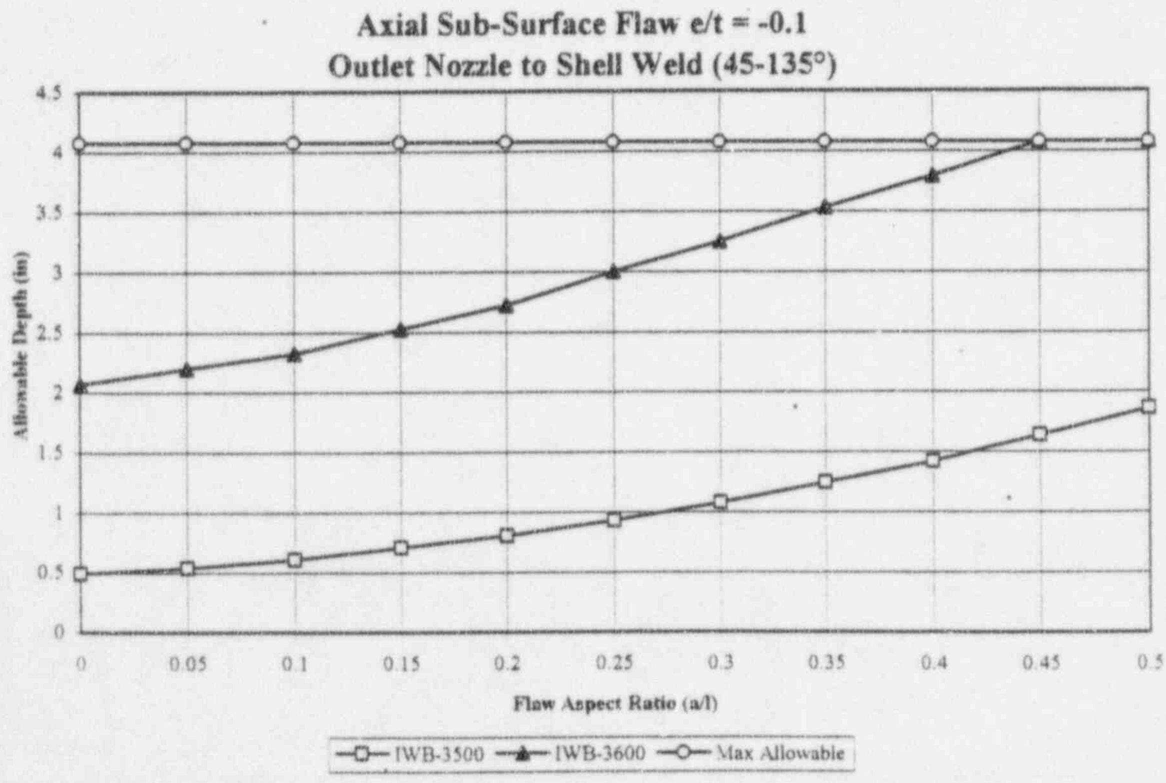
Circumferential Sub-Surface Flaw e/t = -0.25
Outlet Nozzle to Shell Weld (45-135°)



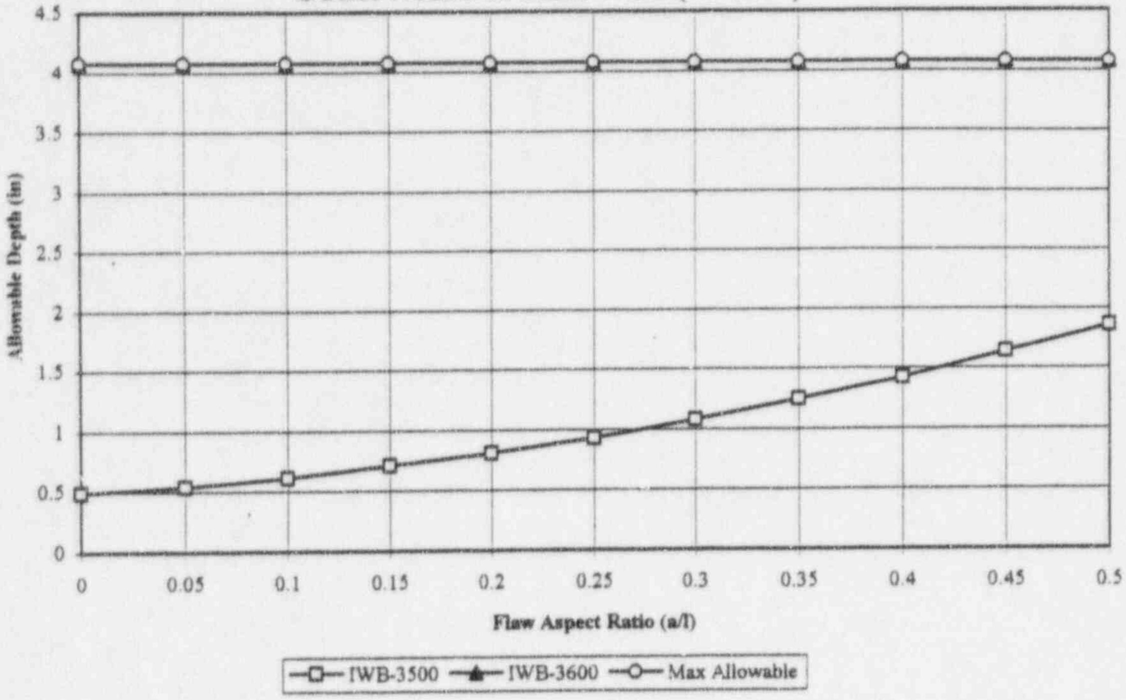
Axial Sub-Surface Flaw e/t = -0.25
Outlet Nozzle to Shell Weld (45-135°)



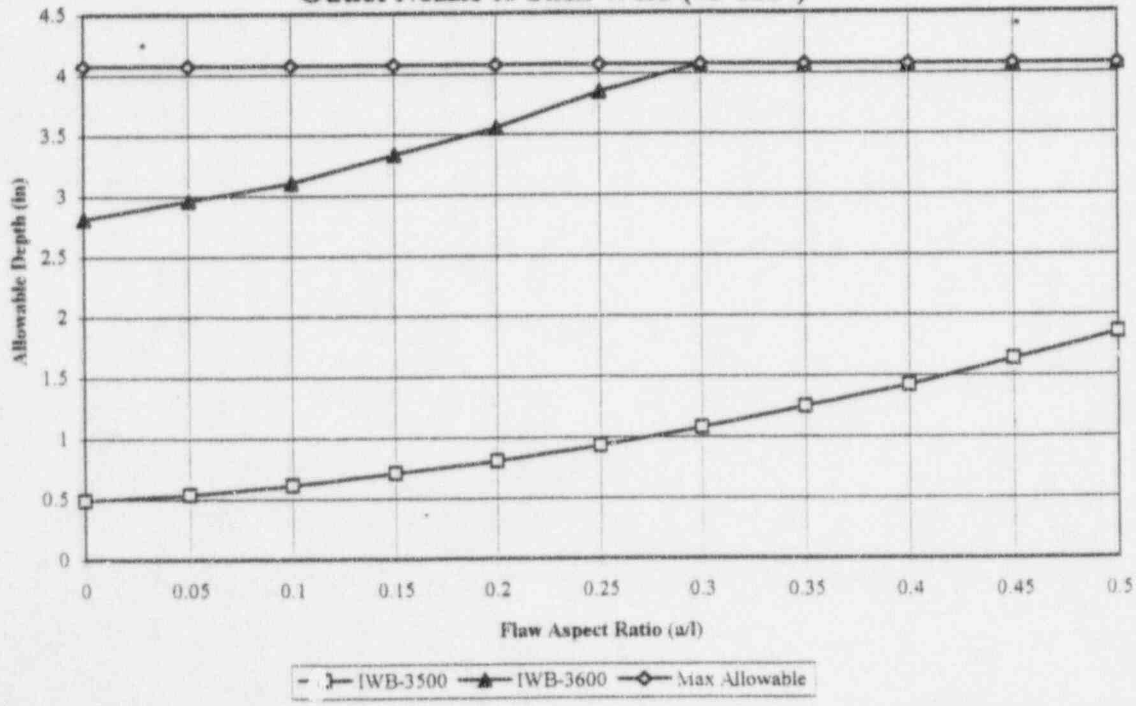

Circumferential Sub-Surface Flaw e/t = -0.1
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = -0.1
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

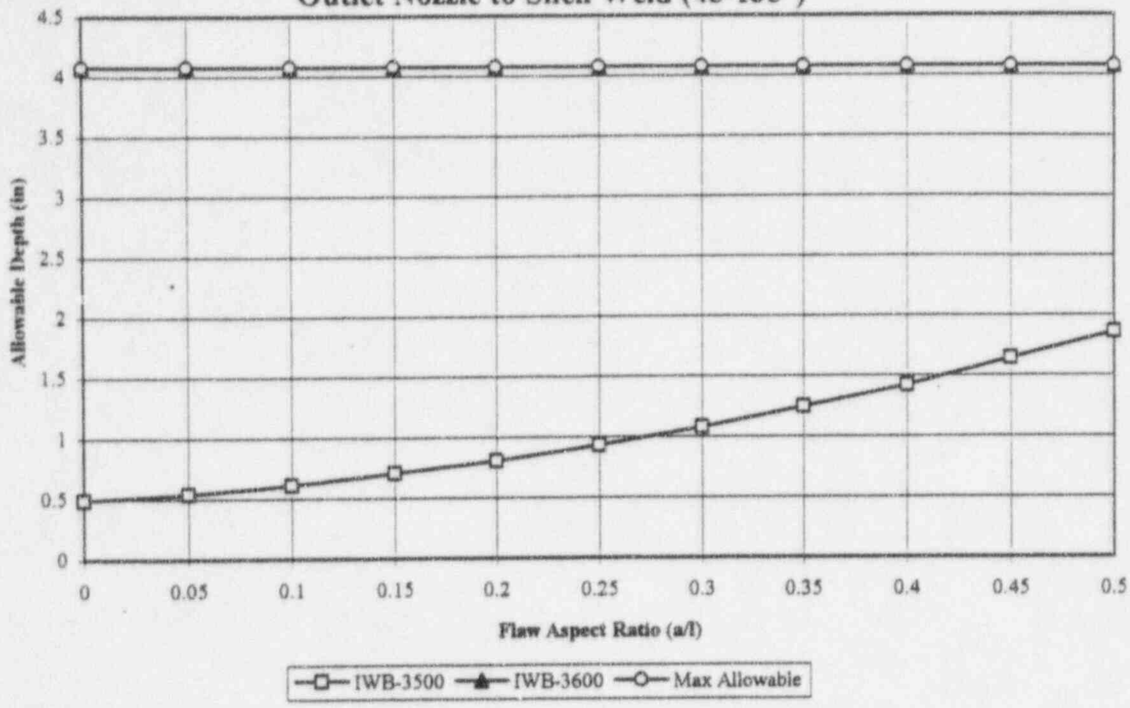
Circumferential Sub-Surface Flaw e/t = 0.0
Outlet Nozzle to Shell Weld (45-135°)



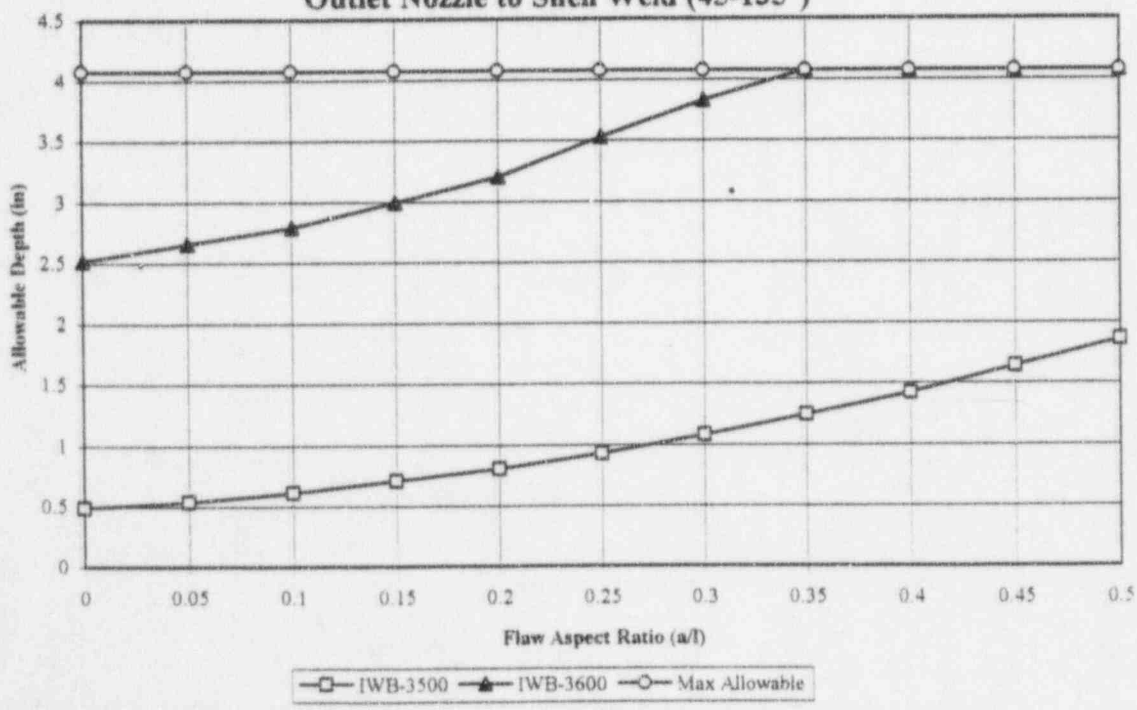
Axial Sub-Surface Flaw e/t = 0.0
Outlet Nozzle to Shell Weld (45-135°)



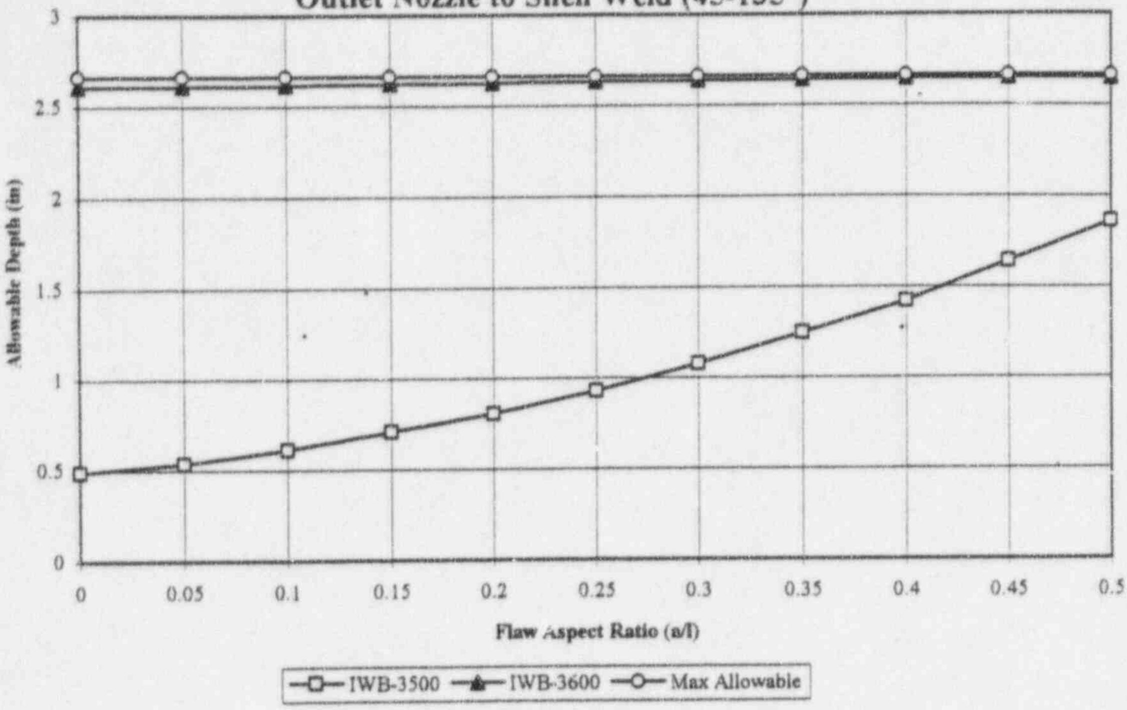
Circumferential Sub-Surface Flaw e/t = 0.2
Outlet Nozzle to Shell Weld (45-135°)



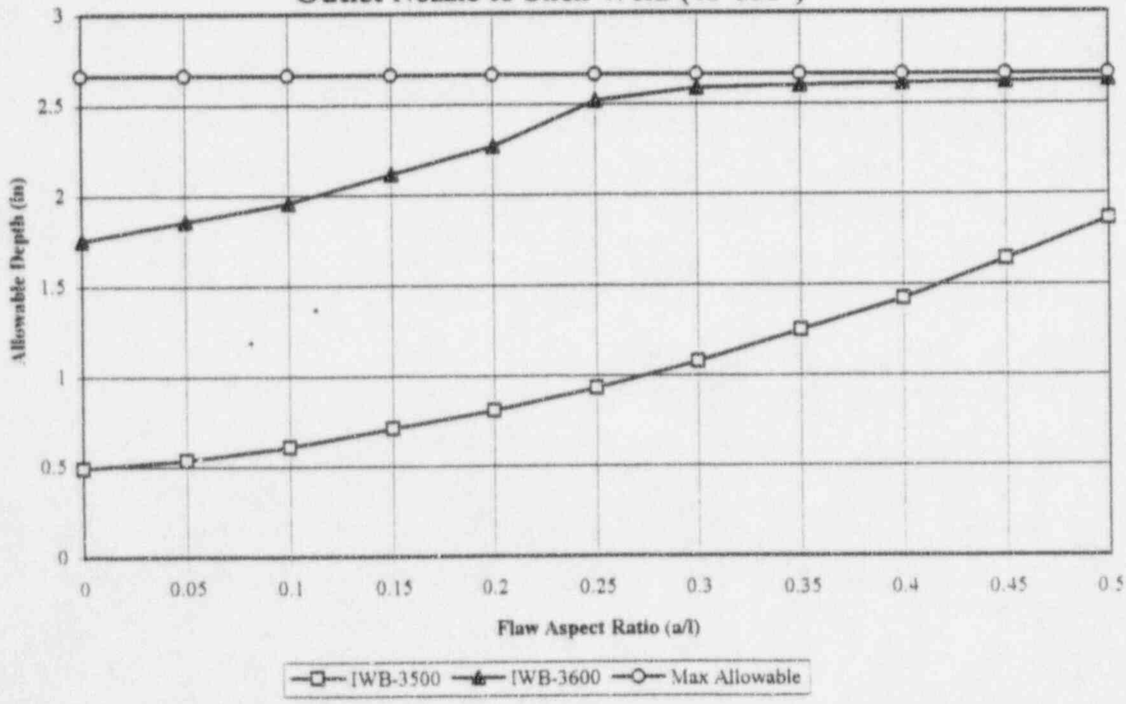
Axial Sub-Surface Flaw e/t = 0.2
Outlet Nozzle to Shell Weld (45-135°)

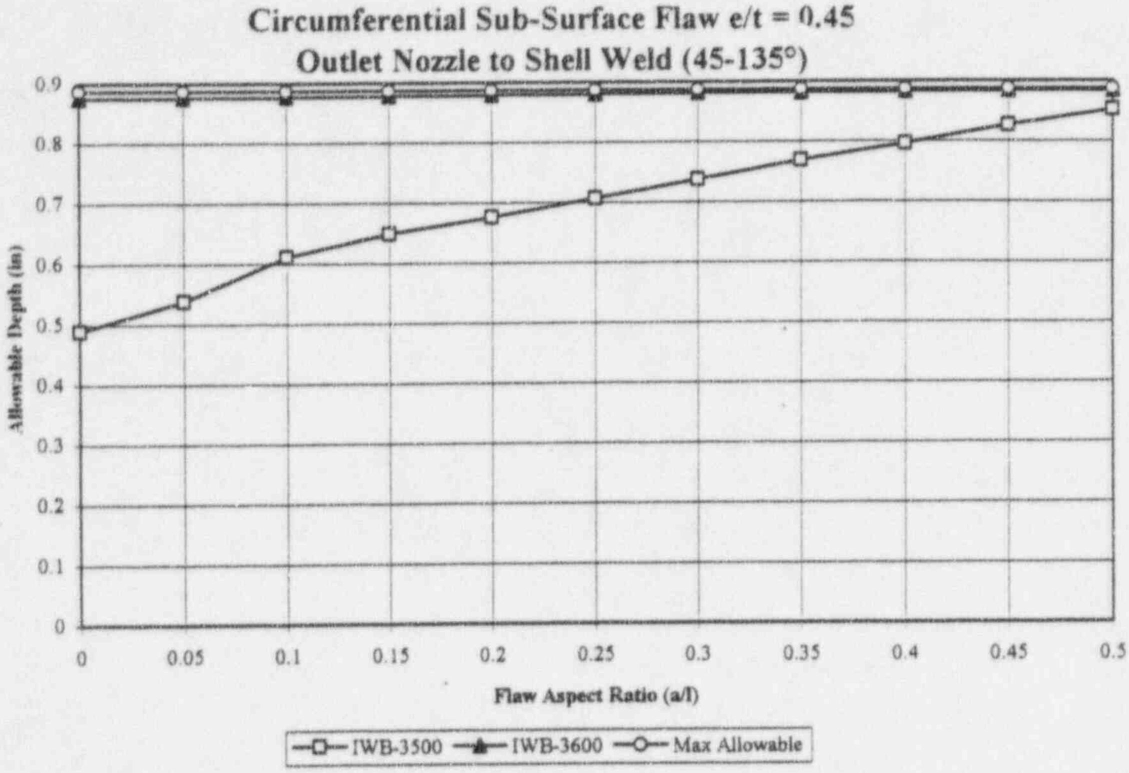


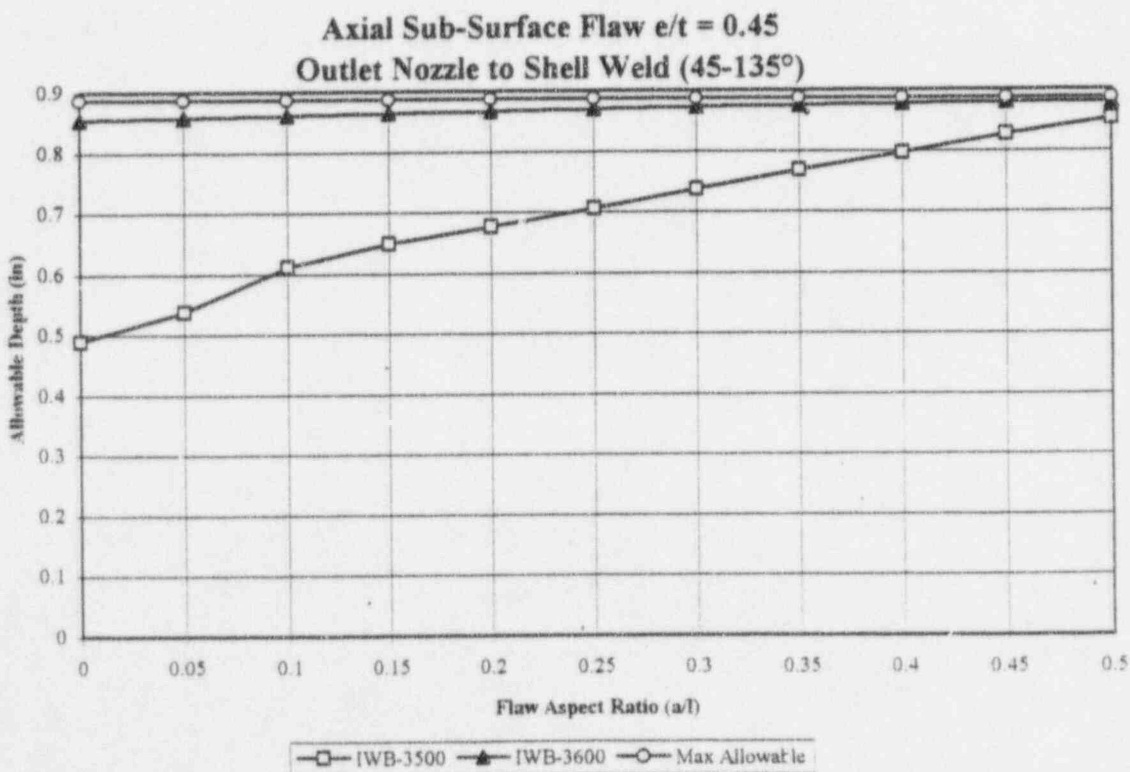
Circumferential Sub-Surface Flaw e/t = 0.35
Outlet Nozzle to Shell Weld (45-135°)



Axial Sub-Surface Flaw e/t = 0.35
Outlet Nozzle to Shell Weld (45-135°)




Circumferential Sub-Surface Flaw e/t = 0.45
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.45
Outlet Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

APPENDIX M

Flaw Acceptance Diagrams for Region M Materials

Diagrams on pages M-1 through M-10 are for 0°-45° and 135°-180° locations. Diagrams on pages M1-1 through M1-10 are for 45°-135° locations.

Region A includes:

- Upper Nozzle Shell
- Core Flood Nozzle (MK #17)
- Core Flood Nozzle to Shell Weld

Based on Minimum Thickness = 12.125"

Default Maximum Allowable Flaw Sizes for All Charts:

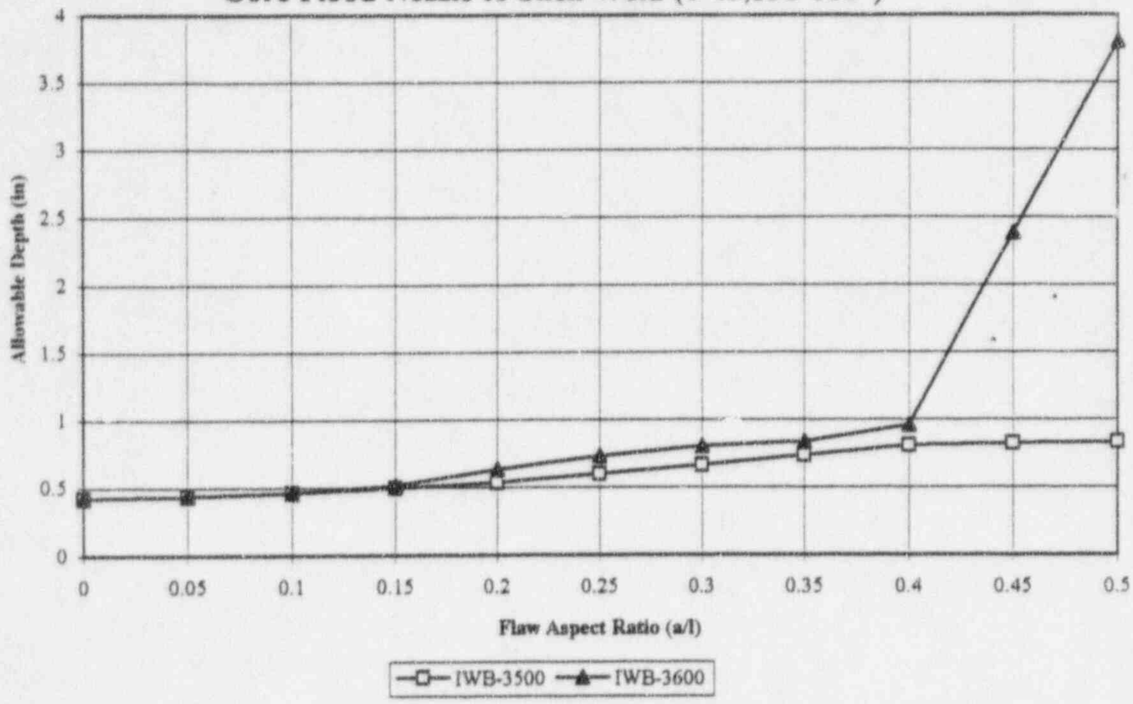
Axially (parallel to weld)-Oriented Flaws = 4.08"
Transverse-Oriented Flaws = 4.08"

Note: For all flaw acceptance diagrams in Appendix M, "axial" refers to flaws oriented axial to weld (as affected by hoop stresses) and "circumferential" refers to flaws oriented transverse to weld (as affected by radial stresses).

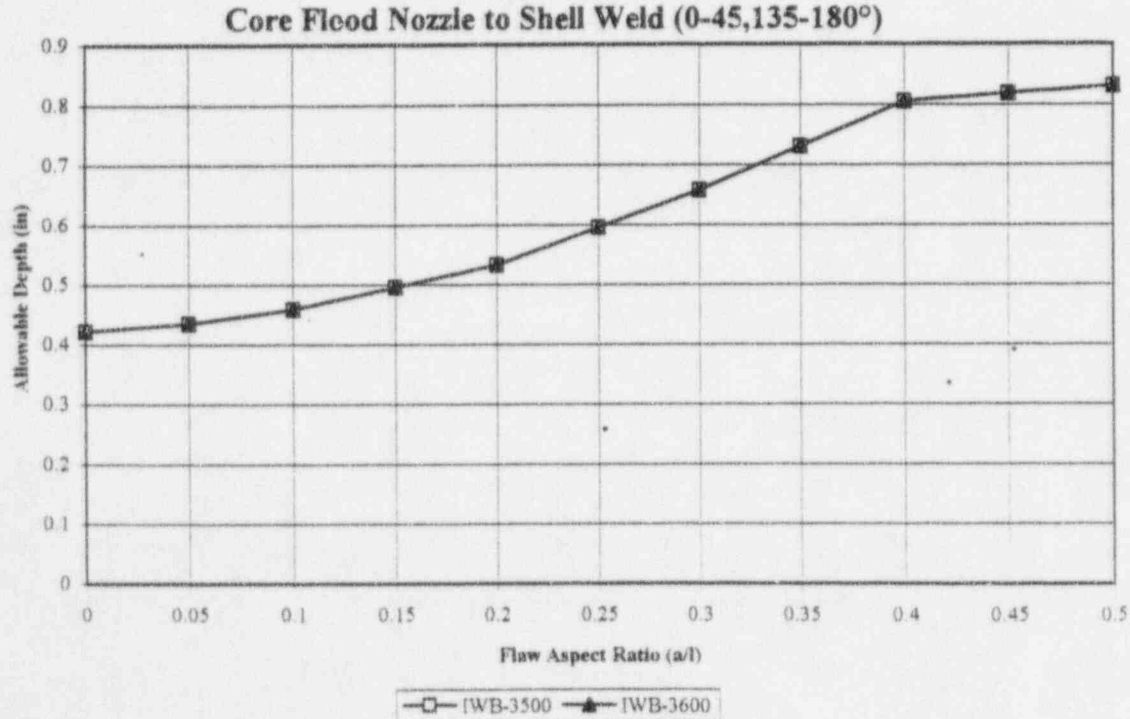
General Notes:

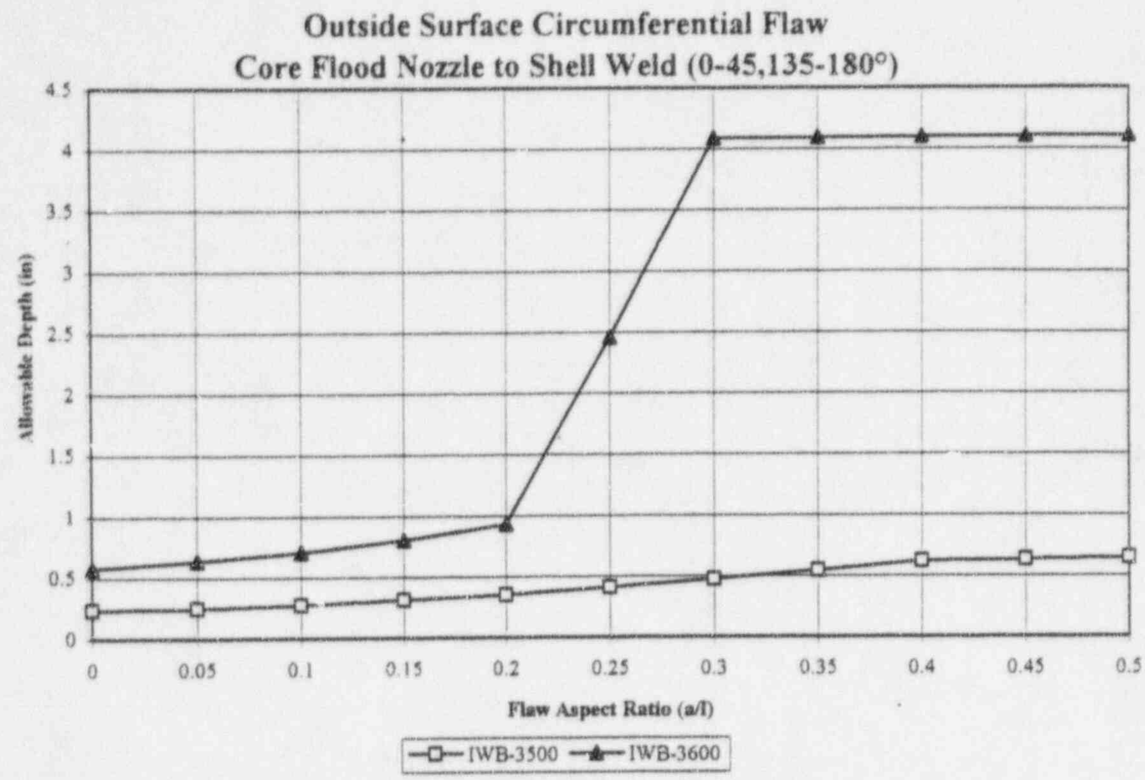
1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

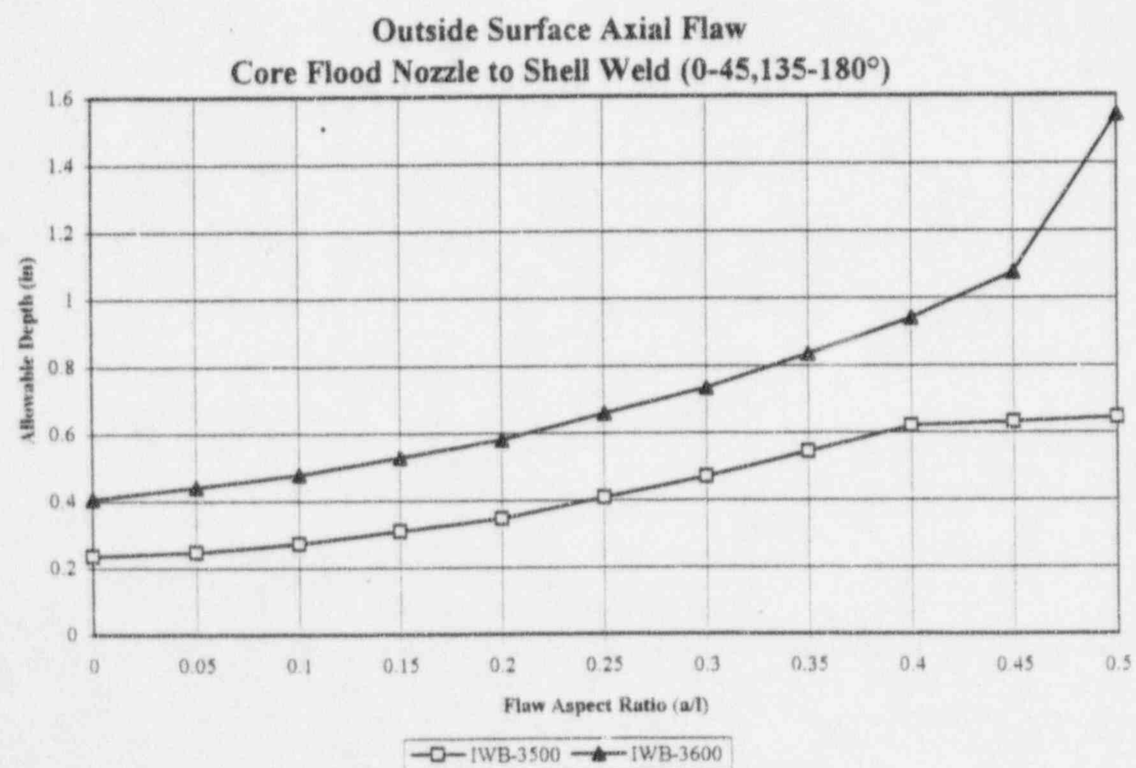
Inside Surface Circumferential Flaw
Core Flood Nozzle to Shell Weld (0-45,135-180°)

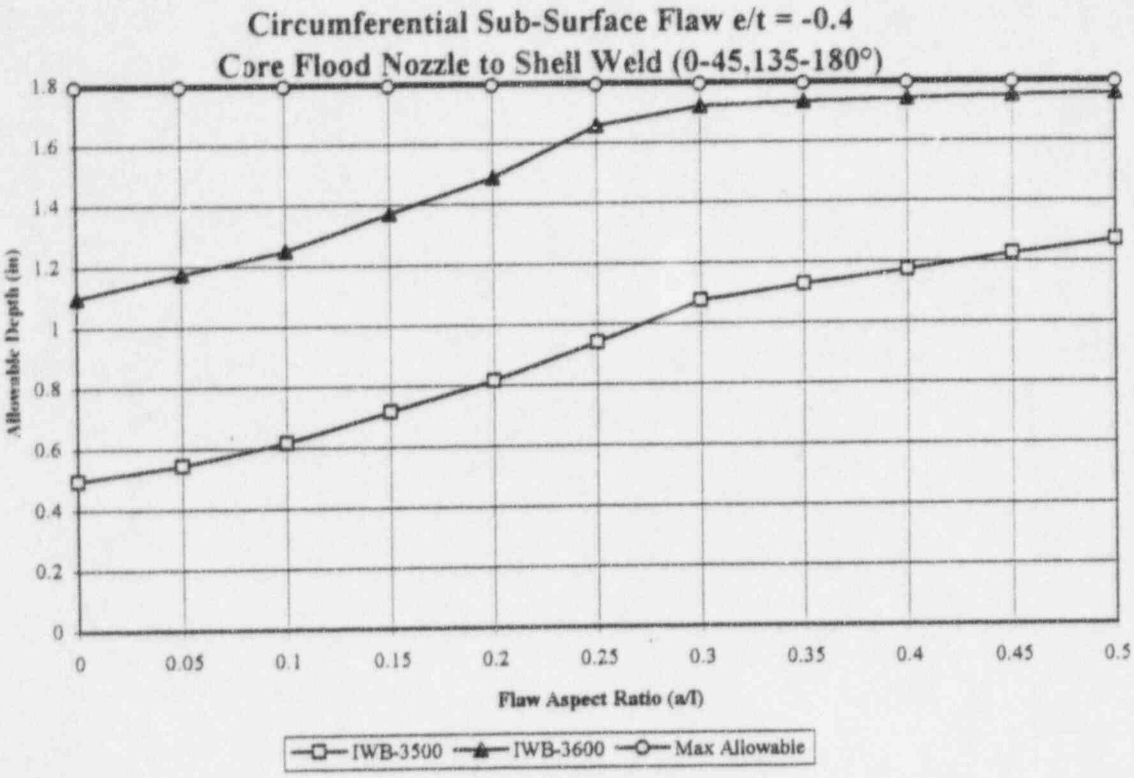


Inside Surface Axial Flaw
Core Flood Nozzle to Shell Weld (0-45,135-180°)

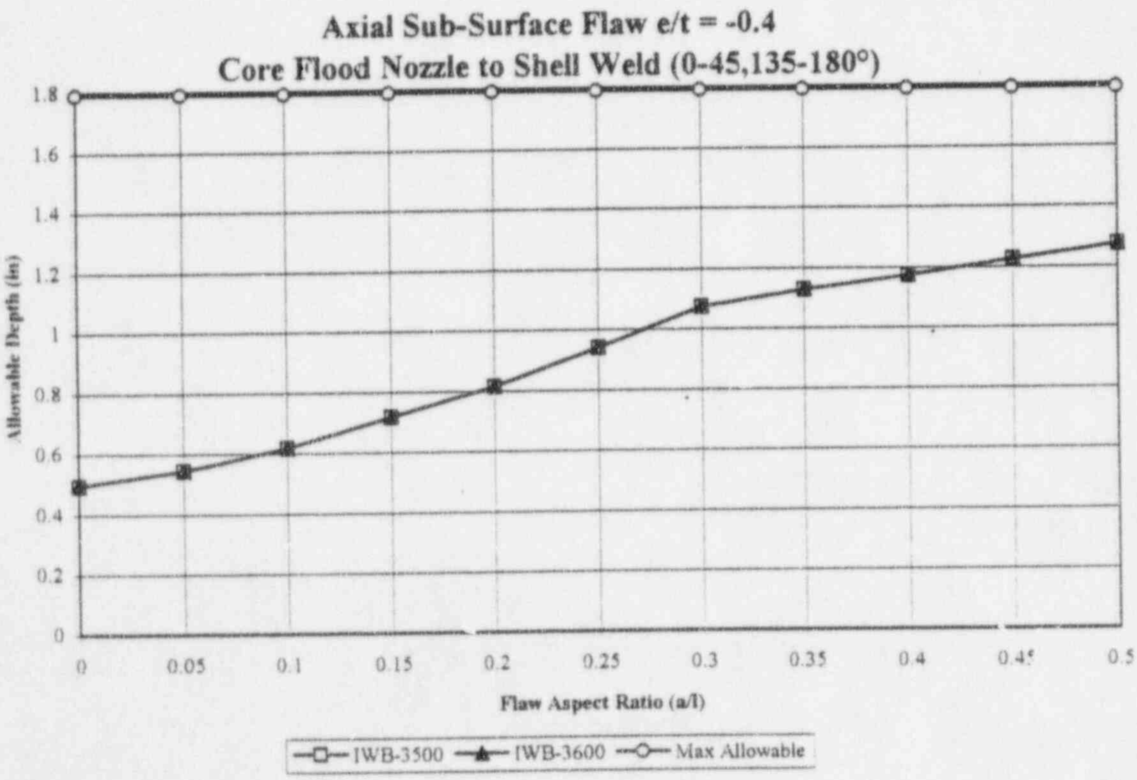



Outside Surface Circumferential Flaw
Core Flood Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600


Outside Surface Axial Flaw
Core Flood Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

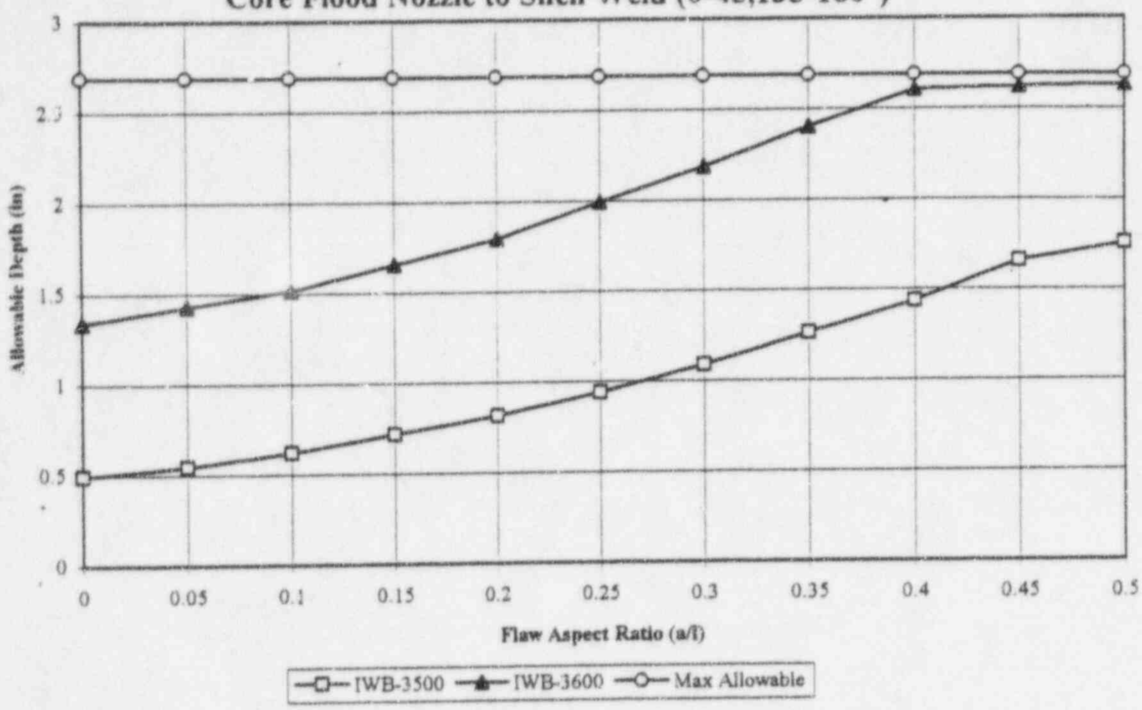


Circumferential Sub-Surface Flaw e/t = -0.4
Core Flood Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

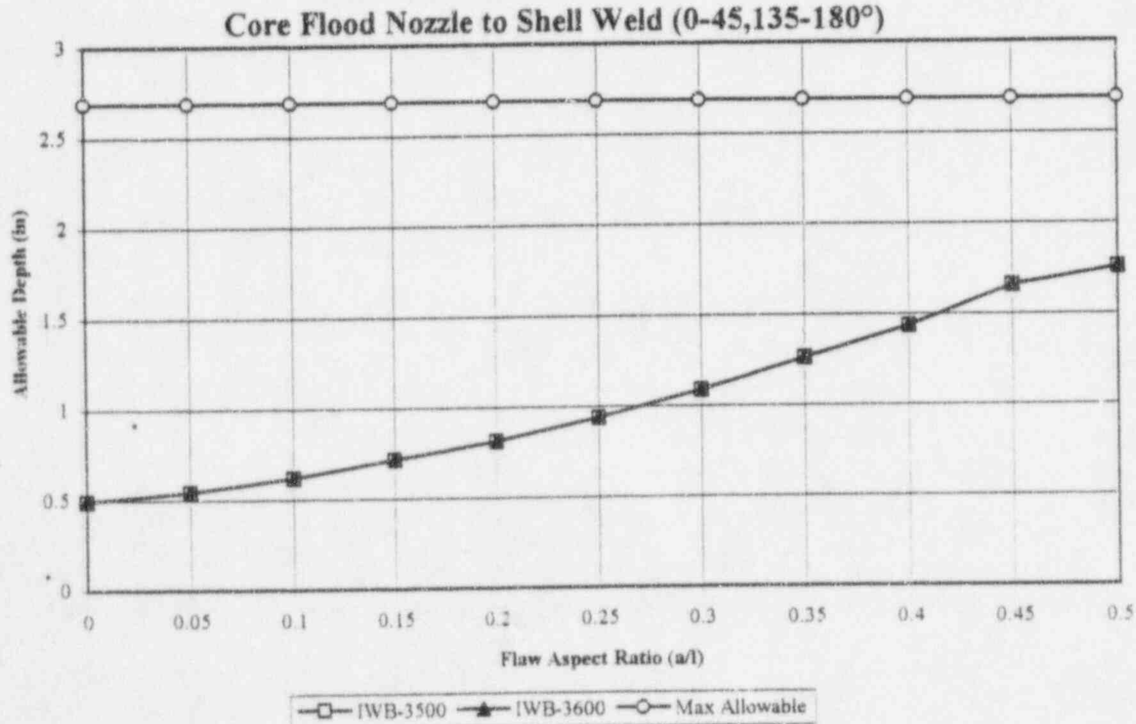


Axial Sub-Surface Flaw e/t = -0.4
Core Flood Nozzle to Shell Weld (0-45,135-180°)
Allowable Depth (in)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

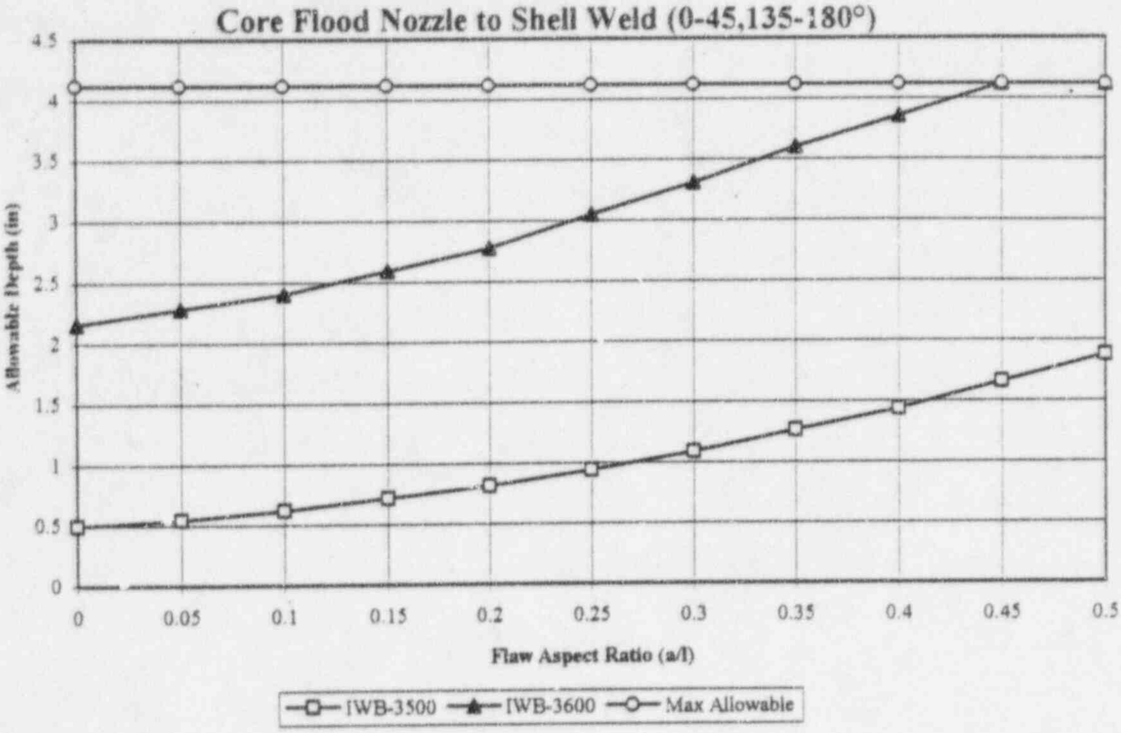
Circumferential Sub-Surface Flaw e/t = -0.35
Core Flood Nozzle to Shell Weld (0-45,135-180°)



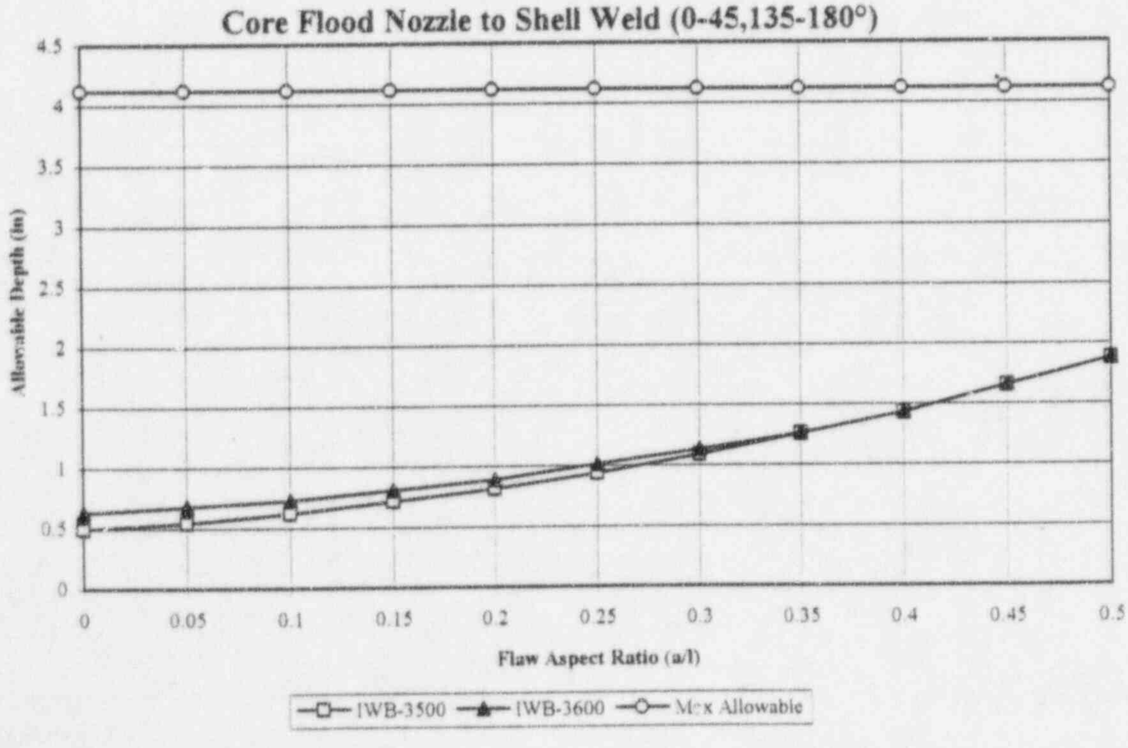
Axial Sub-Surface Flaw e/t = -0.35
Core Flood Nozzle to Shell Weld (0-45,135-180°)



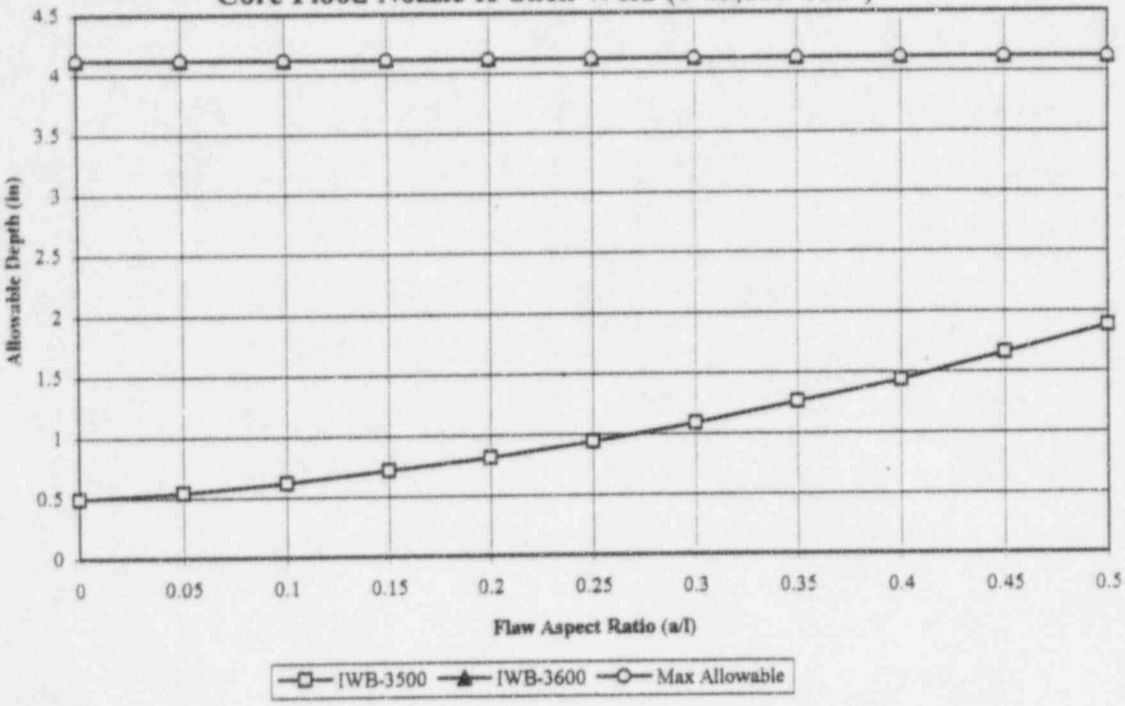
Circumferential Sub-Surface Flaw e/t = -0.25
Core Flood Nozzle to Shell Weld (0-45,135-180°)



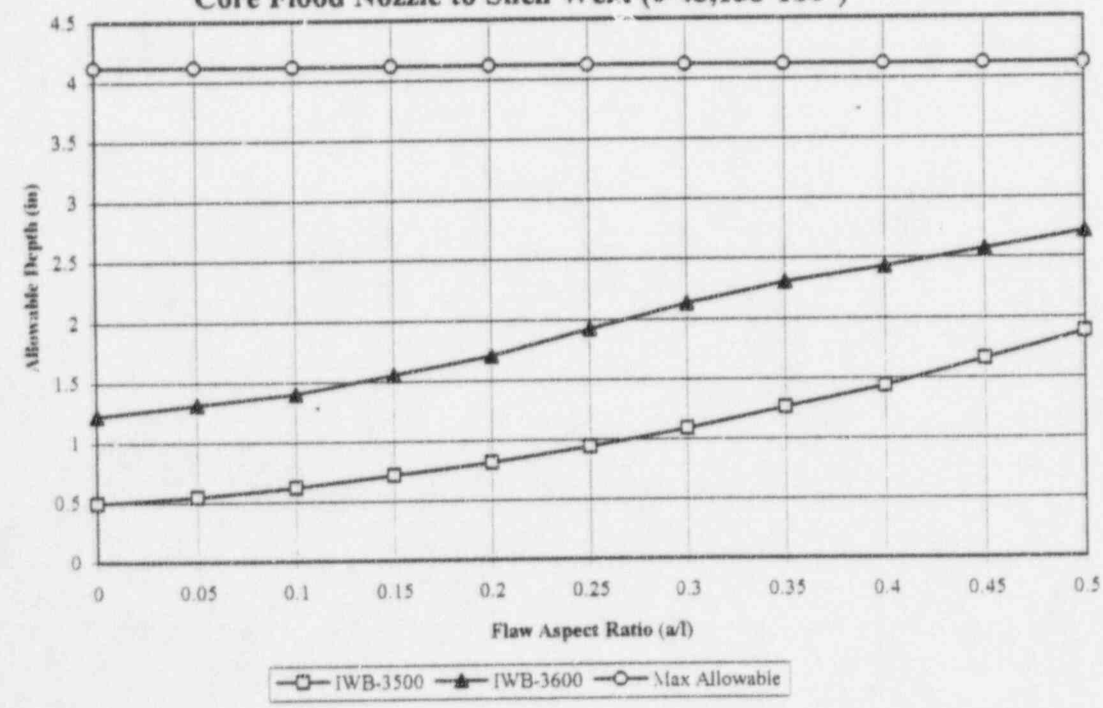
Axial Sub-Surface Flaw e/t = -0.25
Core Flood Nozzle to Shell Weld (0-45,135-180°)



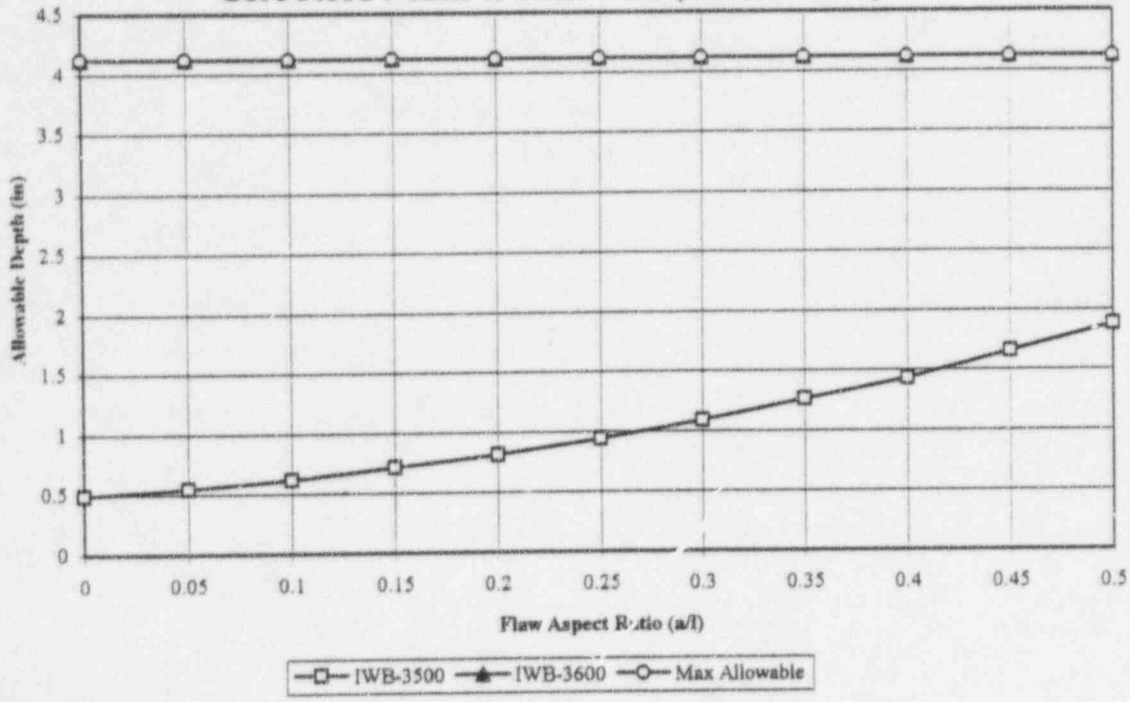
Circumferential Sub-Surface Flaw e/t = -0.1
Core Flood Nozzle to Shell Weld (0-45,135-180°)



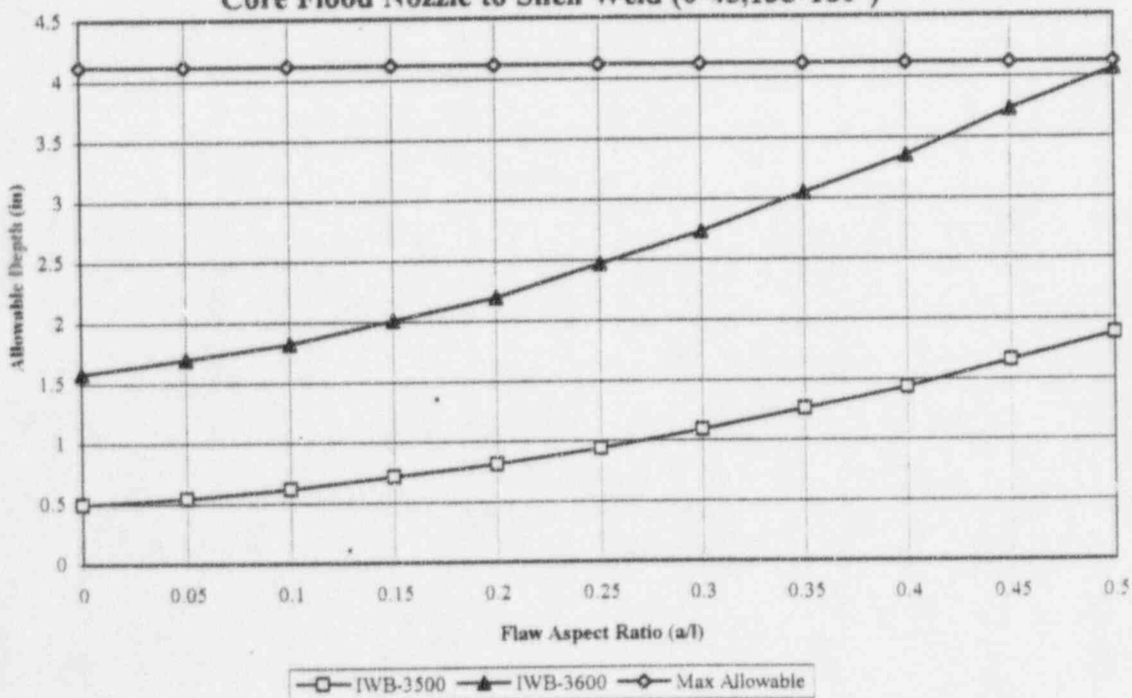
Axial Sub-Surface Flaw e/t = -0.1
Core Flood Nozzle to Shell Weld (0-45,135-180°)



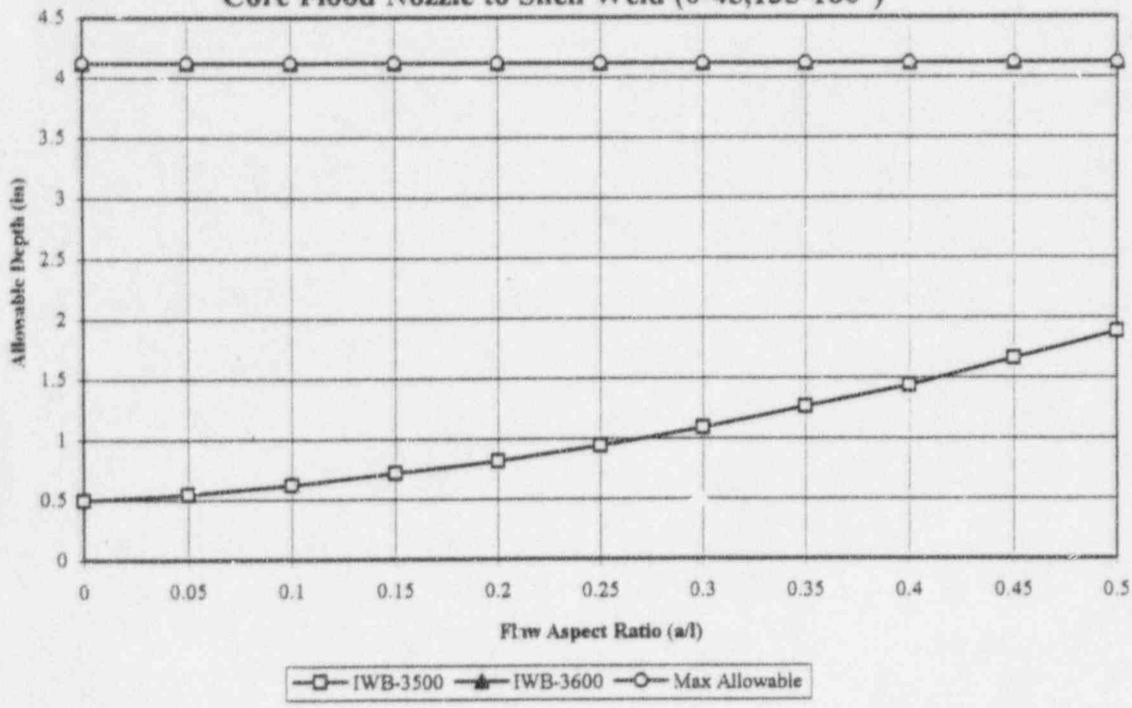
Circumferential Sub-Surface Flaw e/t = 0.0
Core Flood Nozzle to Shell Weld (0-45,135-180°)



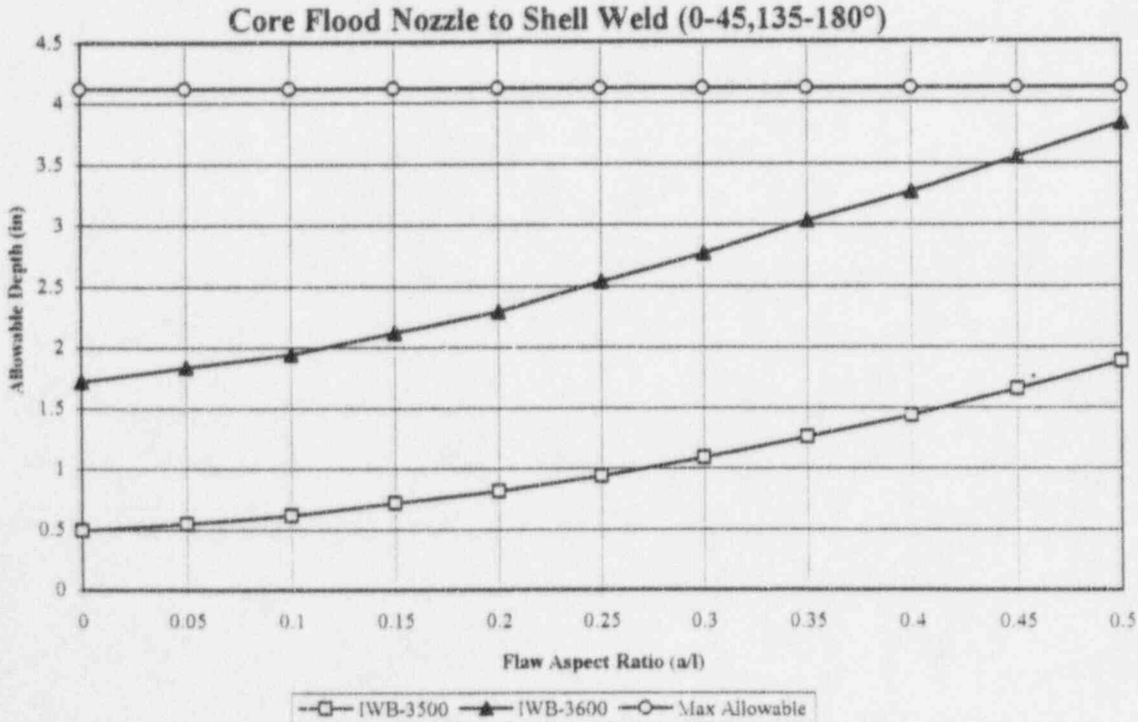
Axial Sub-Surface Flaw e/t = 0.0
Core Flood Nozzle to Shell Weld (0-45,135-180°)



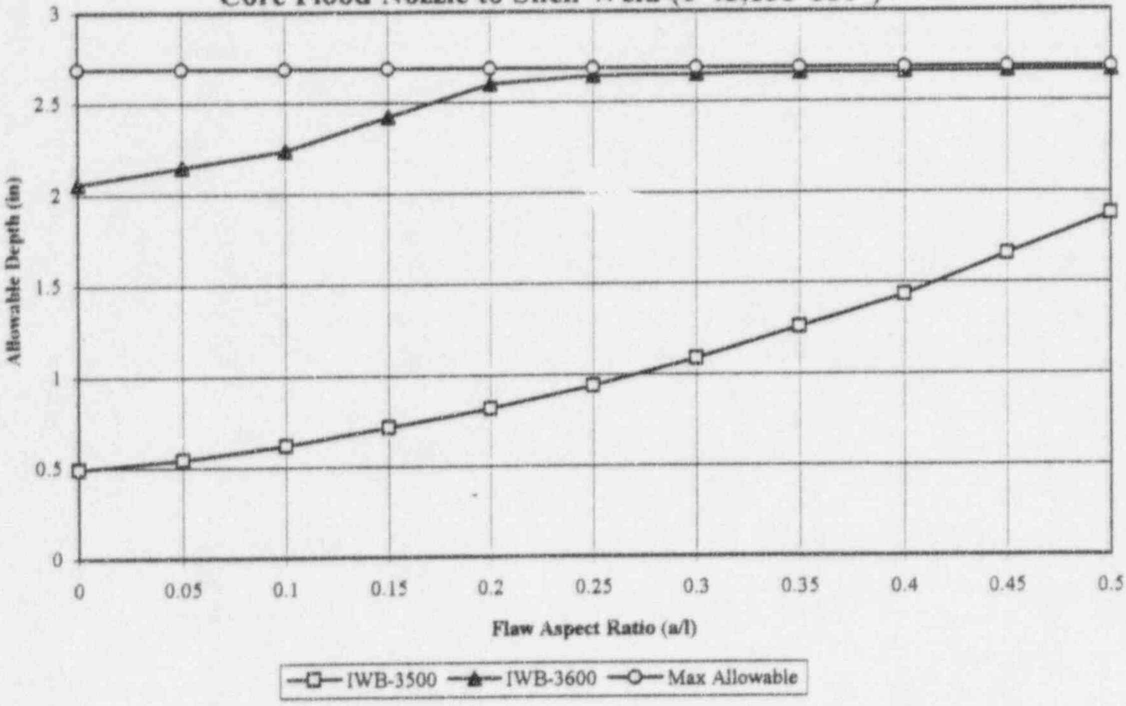
Circumferential Sub-Surface Flaw e/t = 0.2
Core Flood Nozzle to Shell Weld (0-45,135-180°)



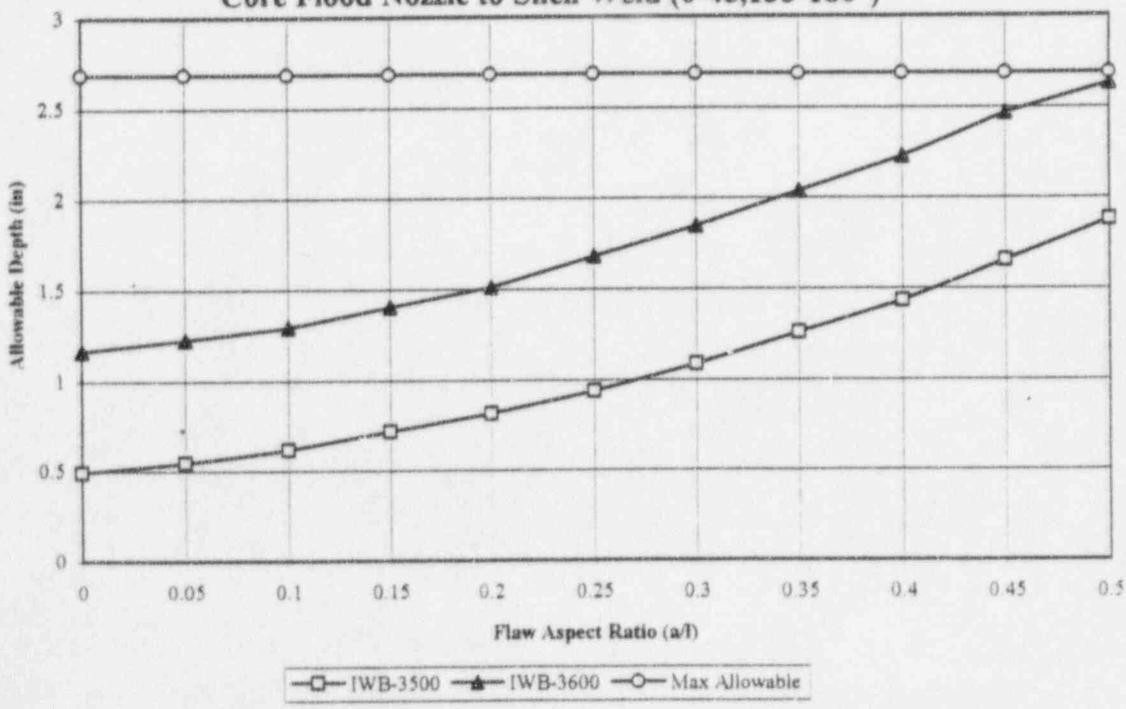
Axial Sub-Surface Flaw e/t = 0.2
Core Flood Nozzle to Shell Weld (0-45,135-180°)



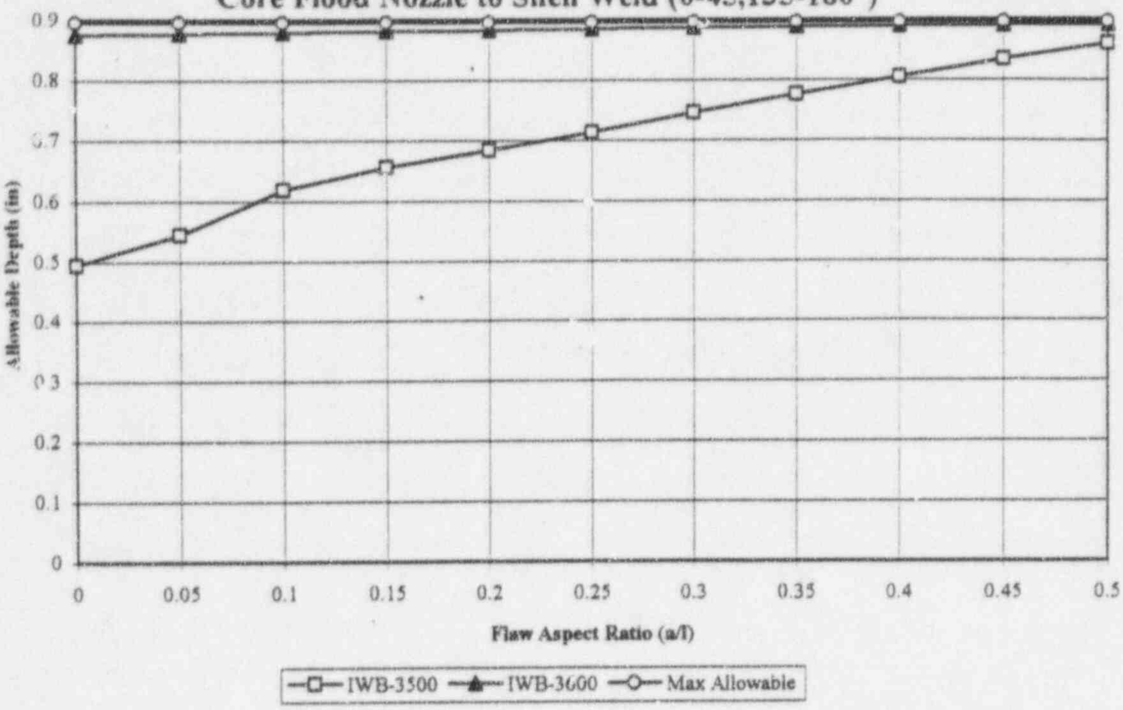
Circumferential Sub-Surface Flaw e/t = 0.35
Core Flood Nozzle to Shell Weld (0-45,135-180°)



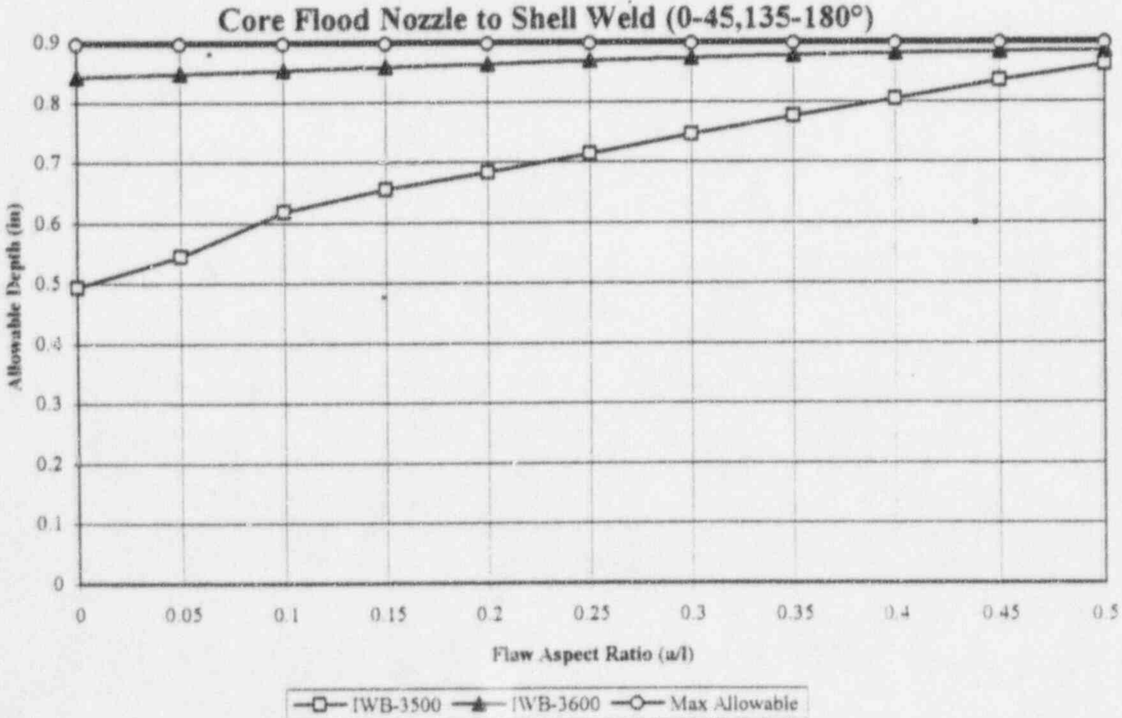
Axial Sub-Surface Flaw e/t = 0.35
Core Flood Nozzle to Shell Weld (0-45,135-180°)



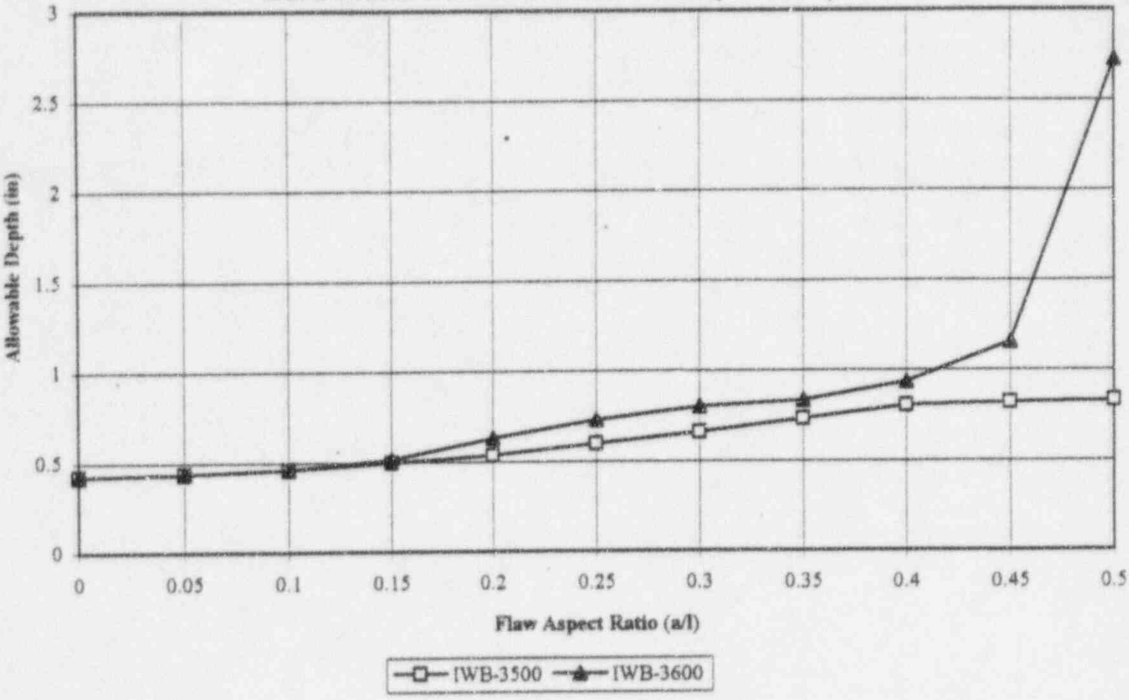
Circumferential Sub-Surface Flaw e/t = 0.45
Core Flood Nozzle to Shell Weld (0-45,135-180°)



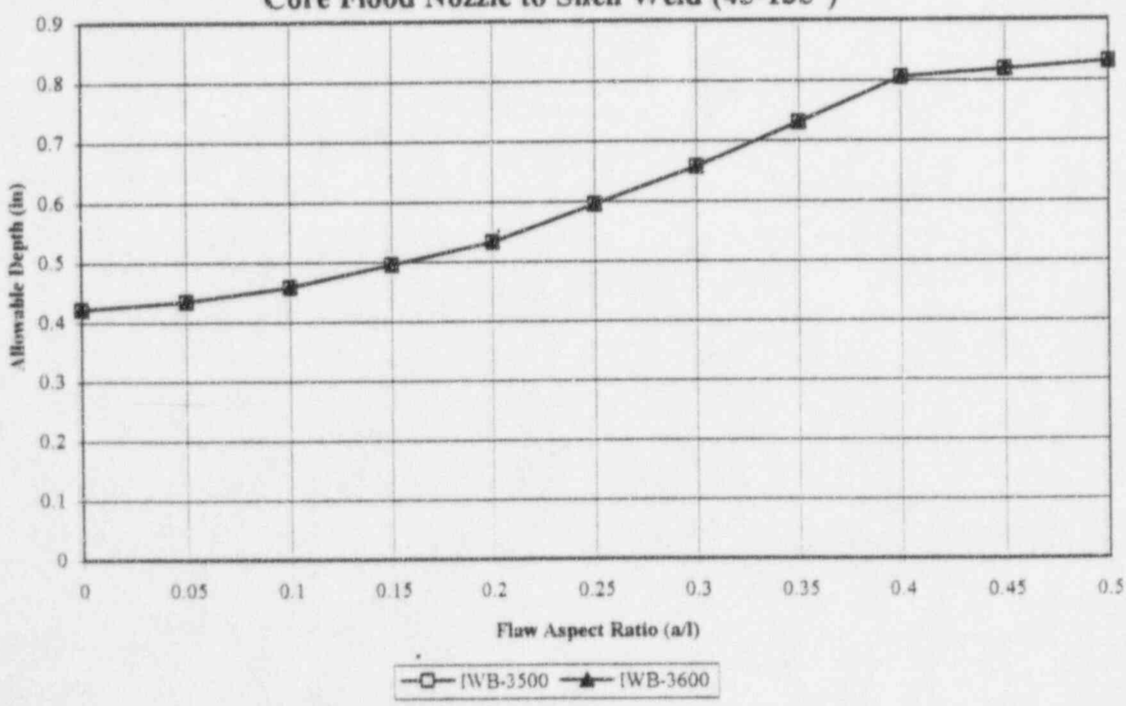
Axial Sub-Surface Flaw e/t = 0.45
Core Flood Nozzle to Shell Weld (0-45,135-180°)

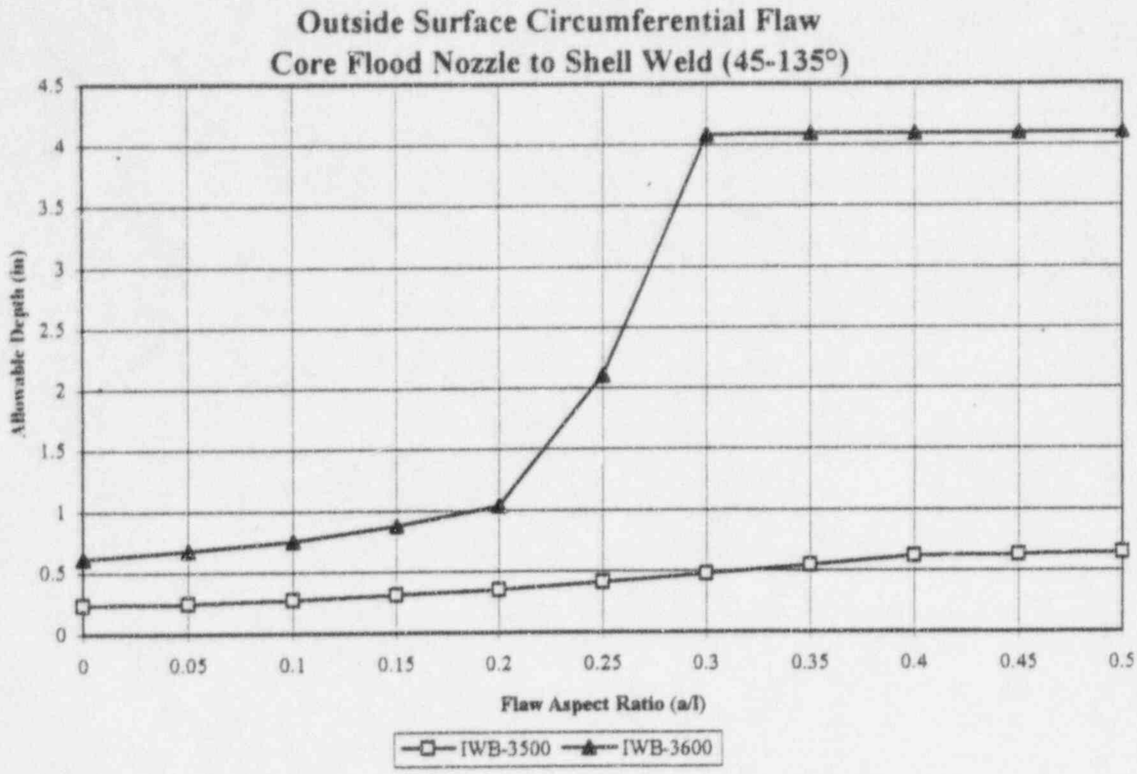


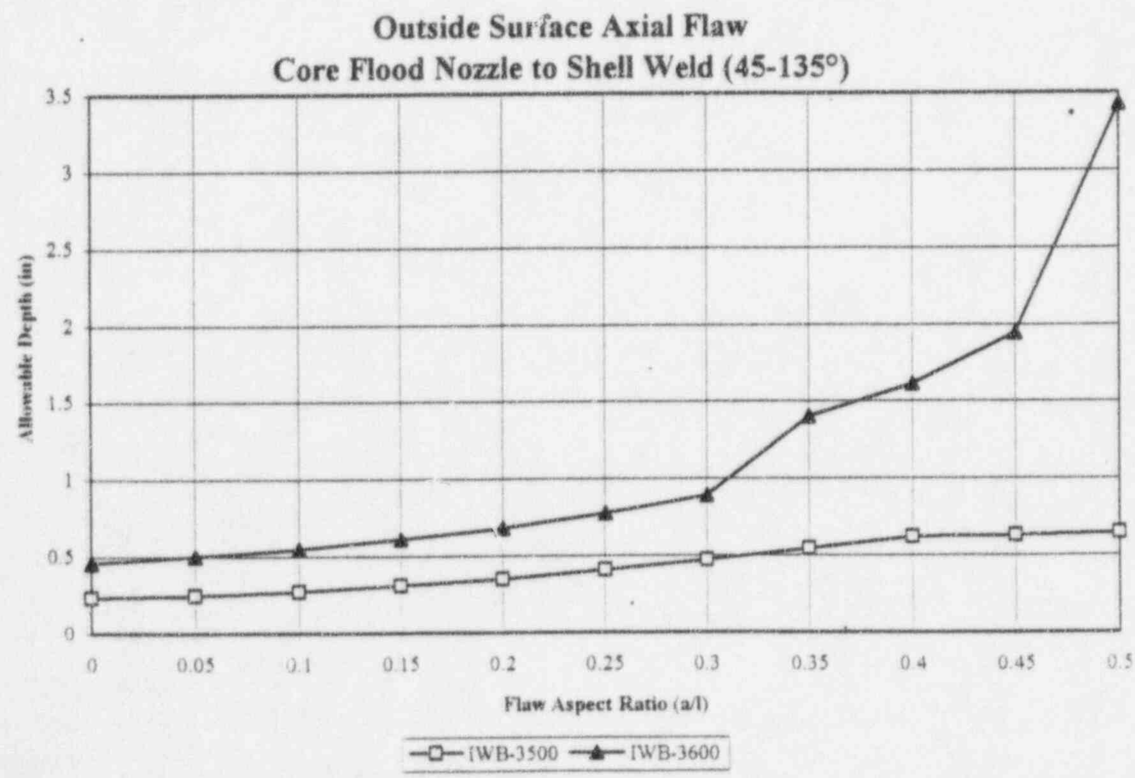
Inside Surface Circumferential Flaw
Core Flood Nozzle to Shell Weld (45-135°)



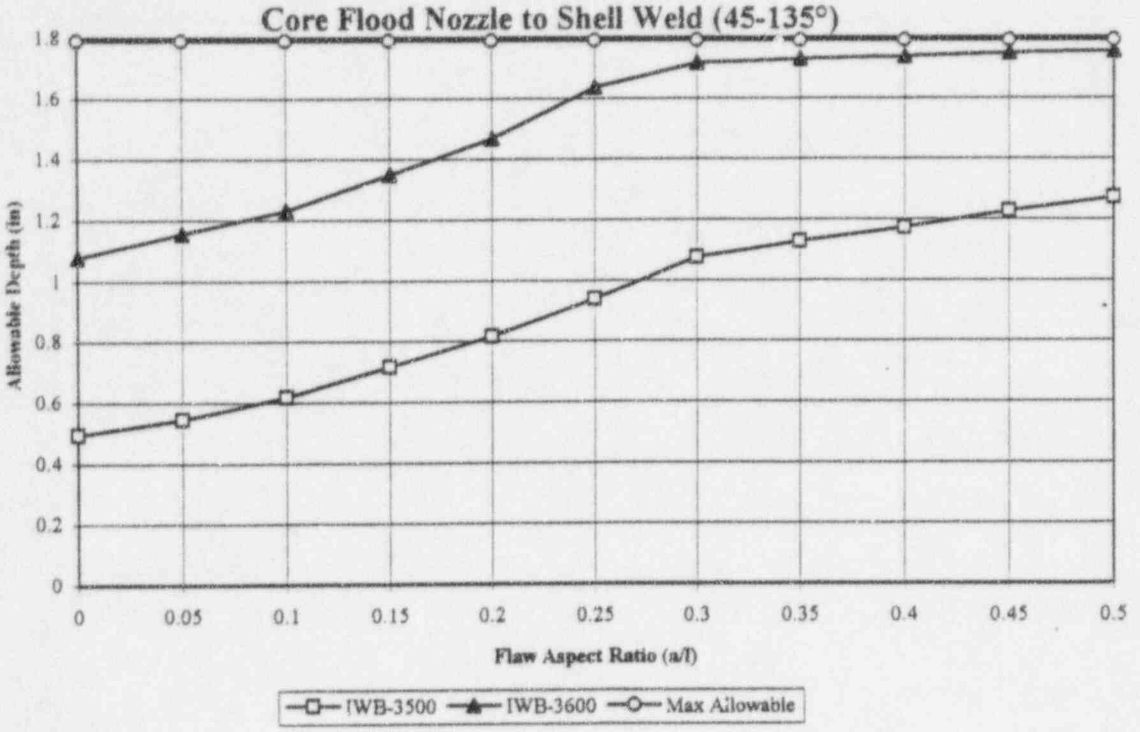
Inside Surface Axial Flaw
Core Flood Nozzle to Shell Weld (45-135°)



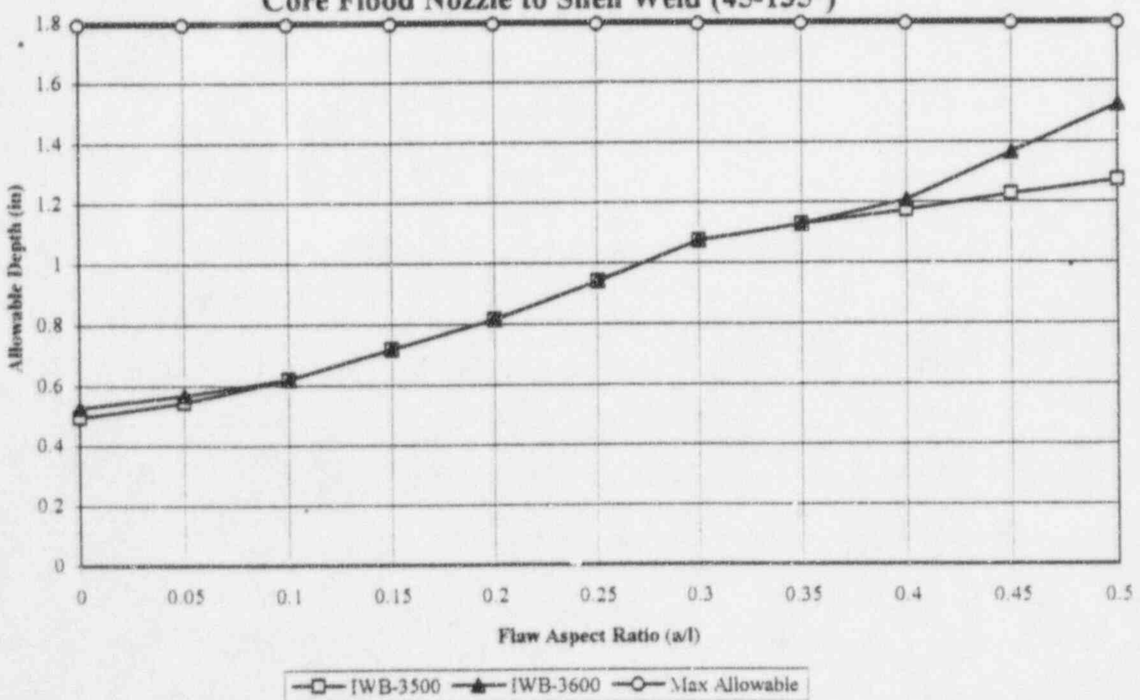

Outside Surface Circumferential Flaw
Core Flood Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600


Outside Surface Axial Flaw
Core Flood Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600

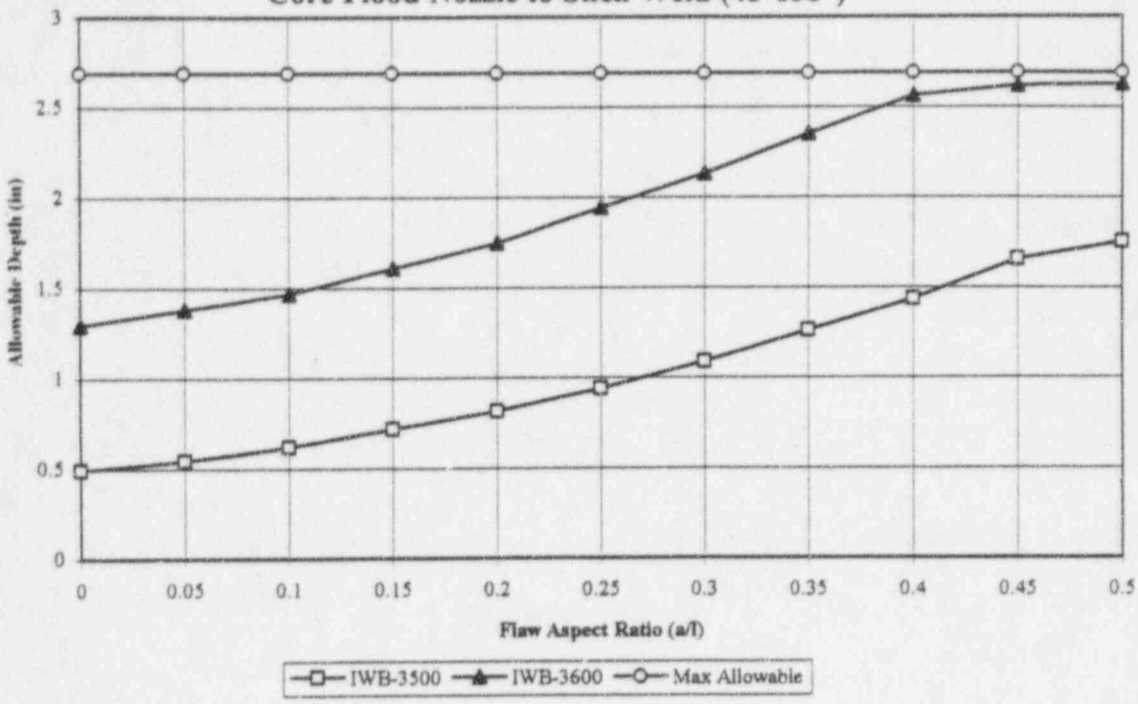
Circumferential Sub-Surface Flaw e/t = -0.4
Core Flood Nozzle to Shell Weld (45-135°)



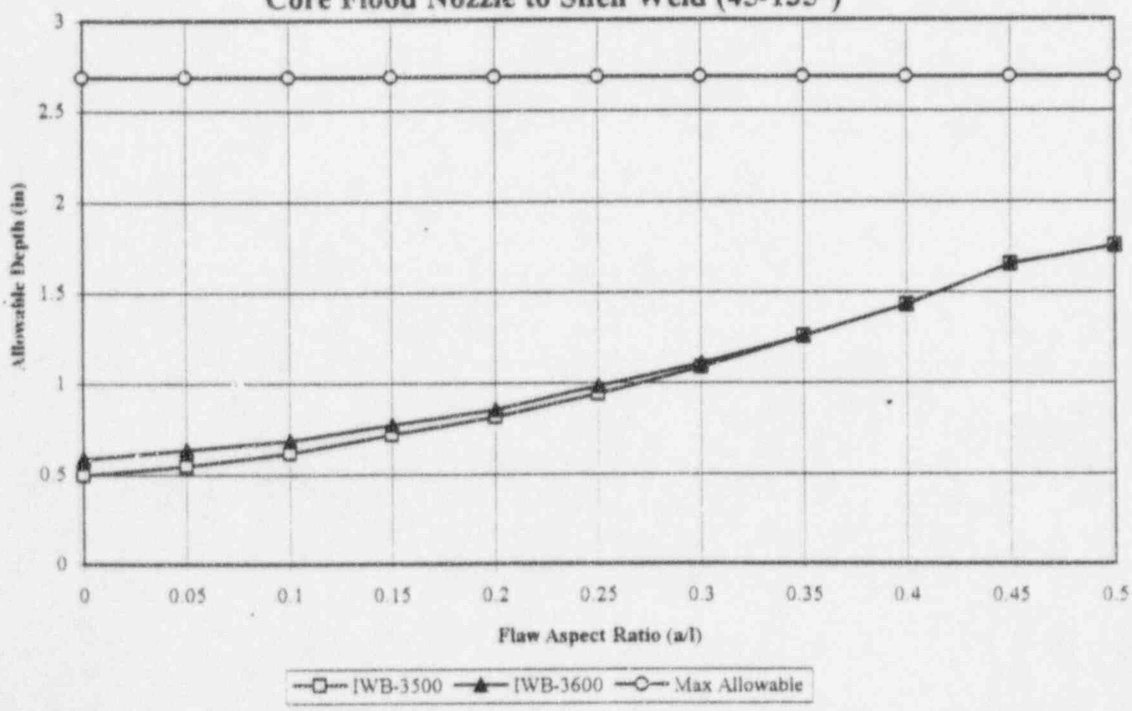
Axial Sub-Surface Flaw e/t = -0.4
Core Flood Nozzle to Shell Weld (45-135°)



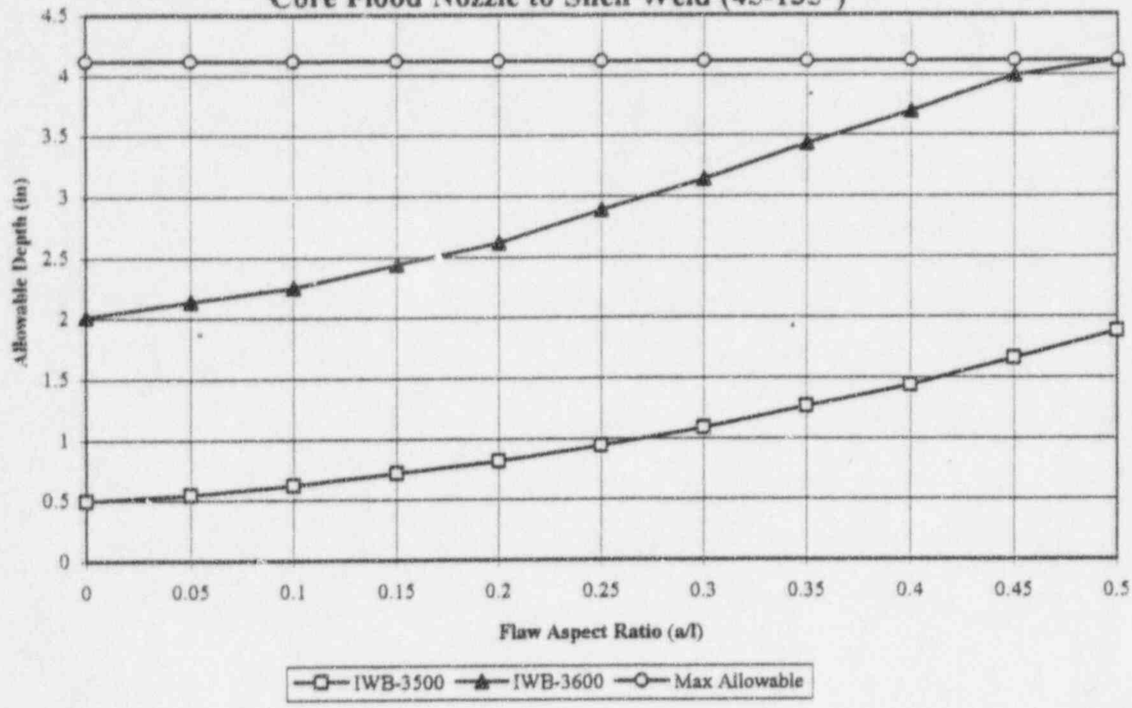
Circumferential Sub-Surface Flaw e/t = -0.35
Core Flood Nozzle to Shell Weld (45-135°)



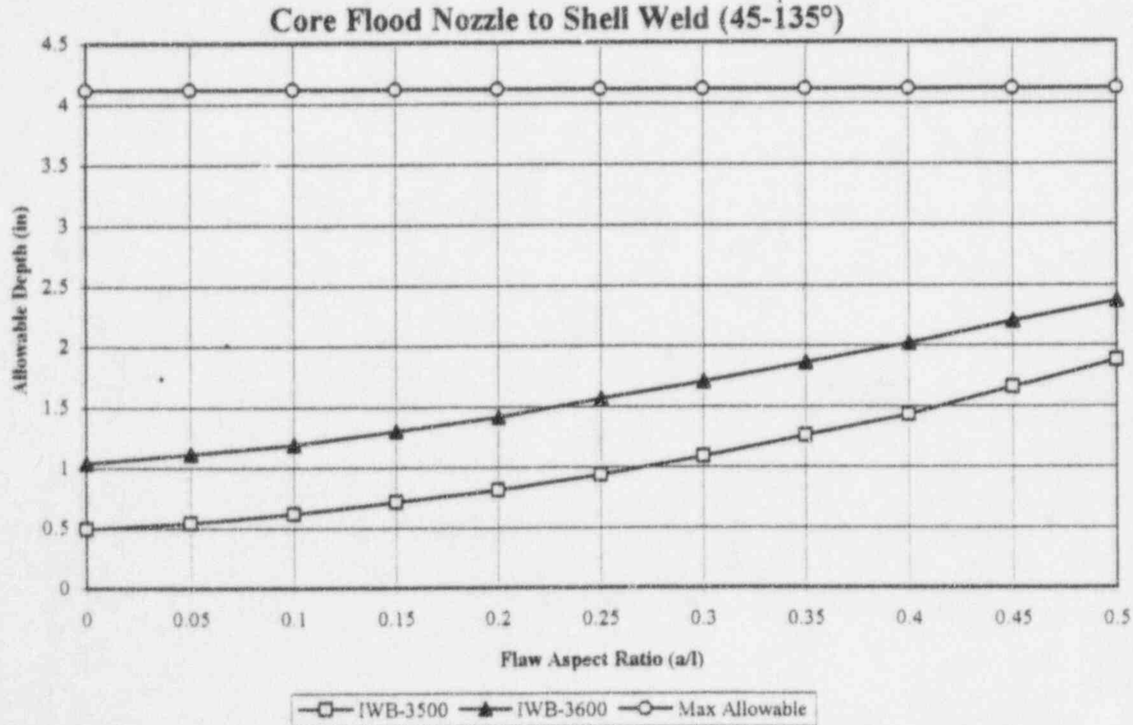
Axial Sub-Surface Flaw e/t = -0.35
Core Flood Nozzle to Shell Weld (45-135°)



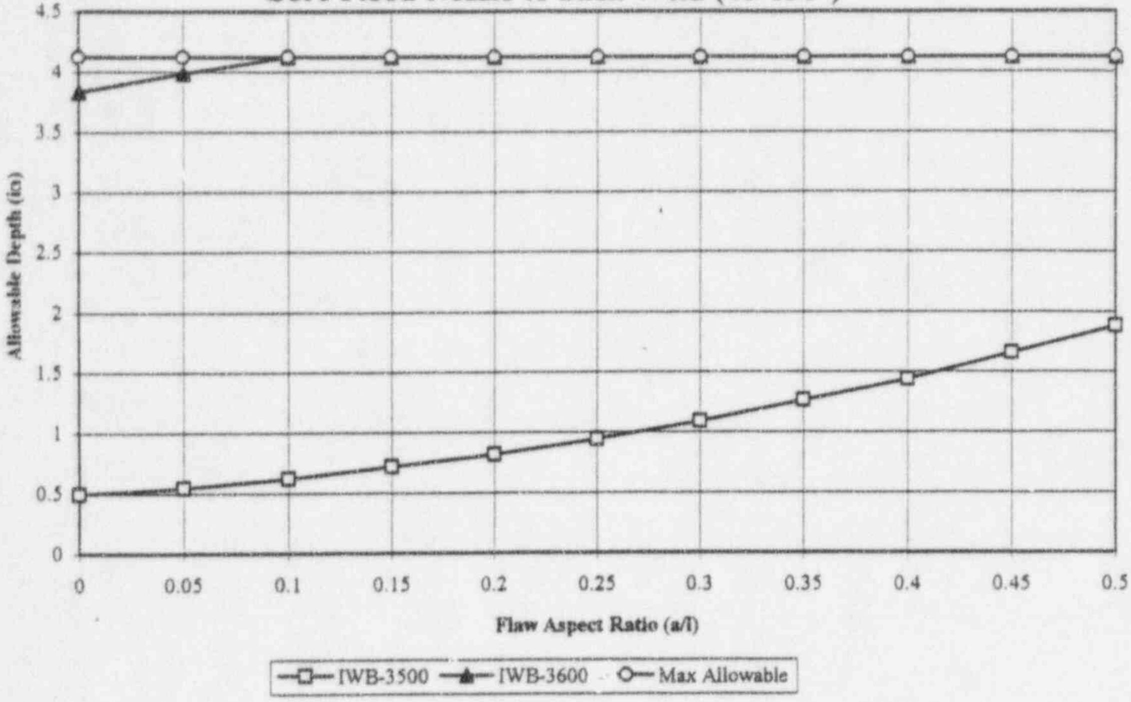
Circumferential Sub-Surface Flaw e/t = -0.25
Core Flood Nozzle to Shell Weld (45-135°)



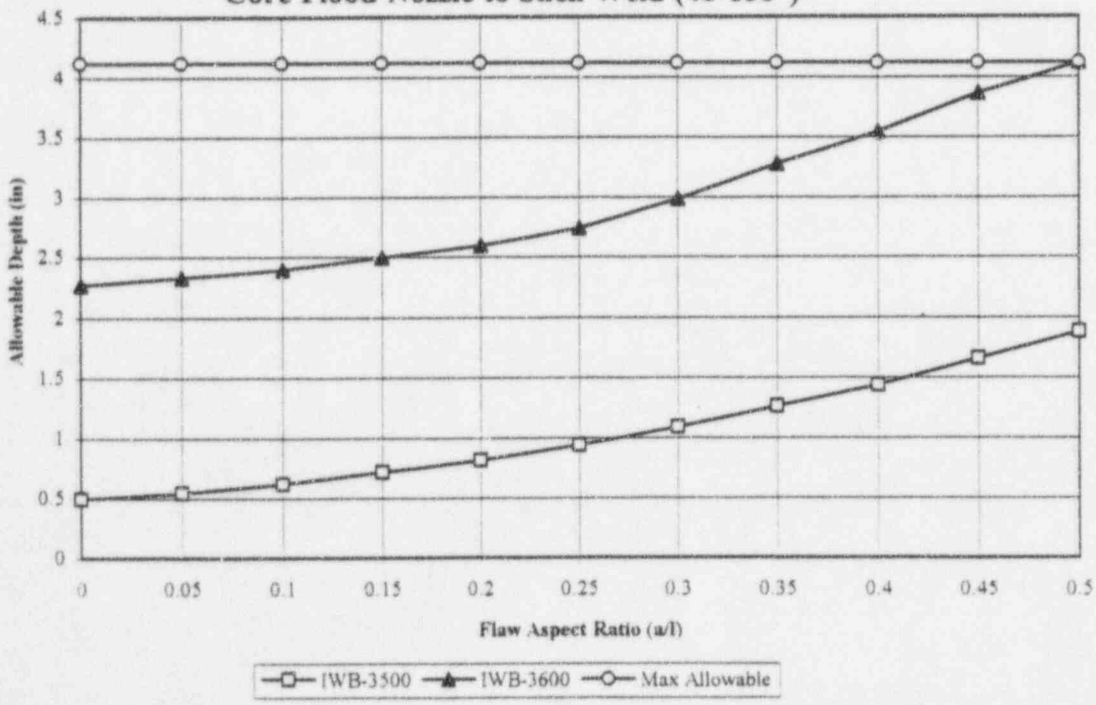
Axial Sub-Surface Flaw e/t = -0.25
Core Flood Nozzle to Shell Weld (45-135°)



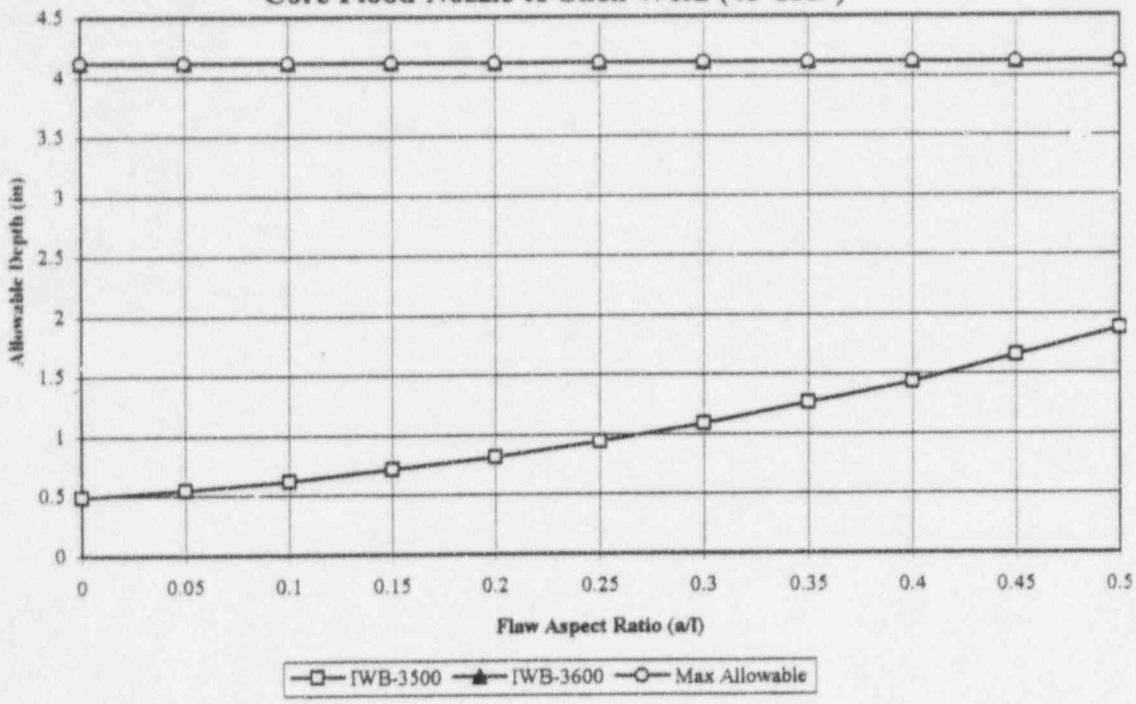
Circumferential Sub-Surface Flaw e/t = -0.1
Core Flood Nozzle to Shell Weld (45-135°)



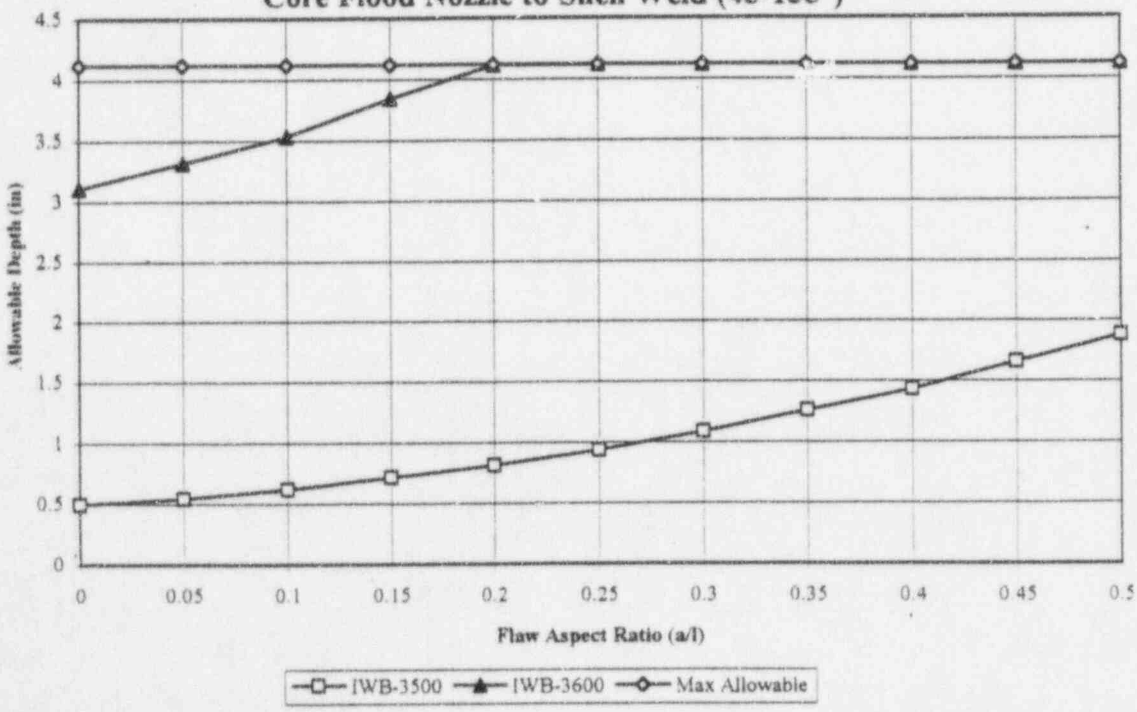
Axial Sub-Surface Flaw e/t = -0.1
Core Flood Nozzle to Shell Weld (45-135°)



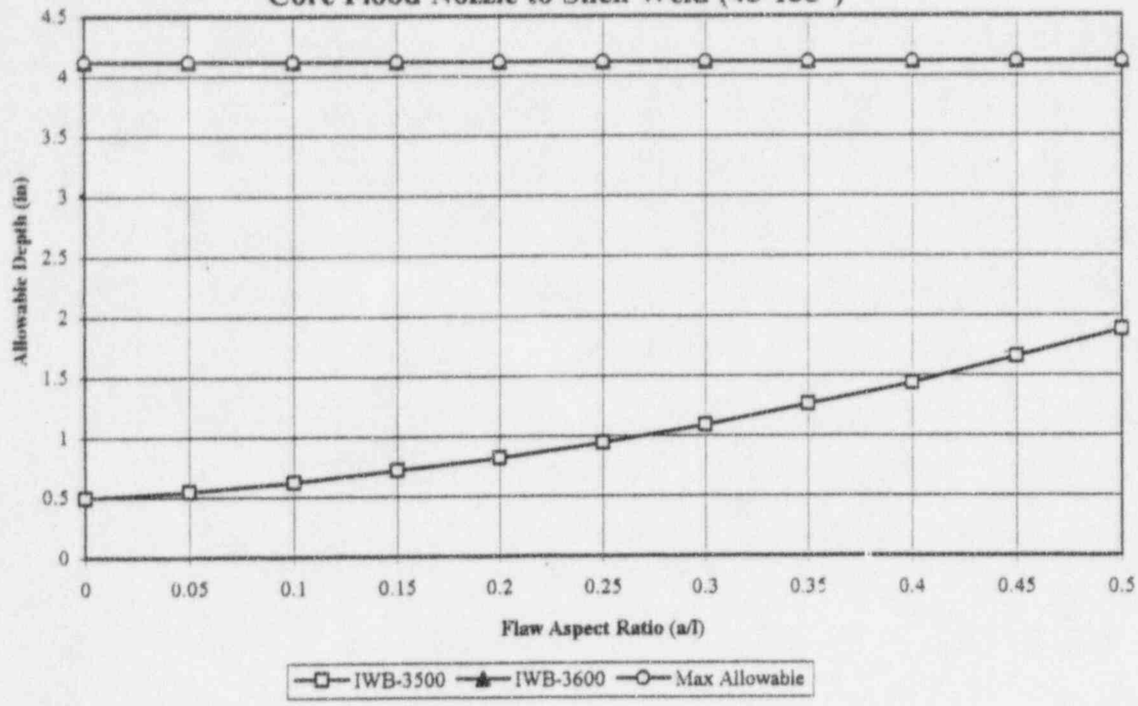
Circumferential Sub-Surface Flaw e/t = 0.0
Core Flood Nozzle to Shell Weld (45-135°)



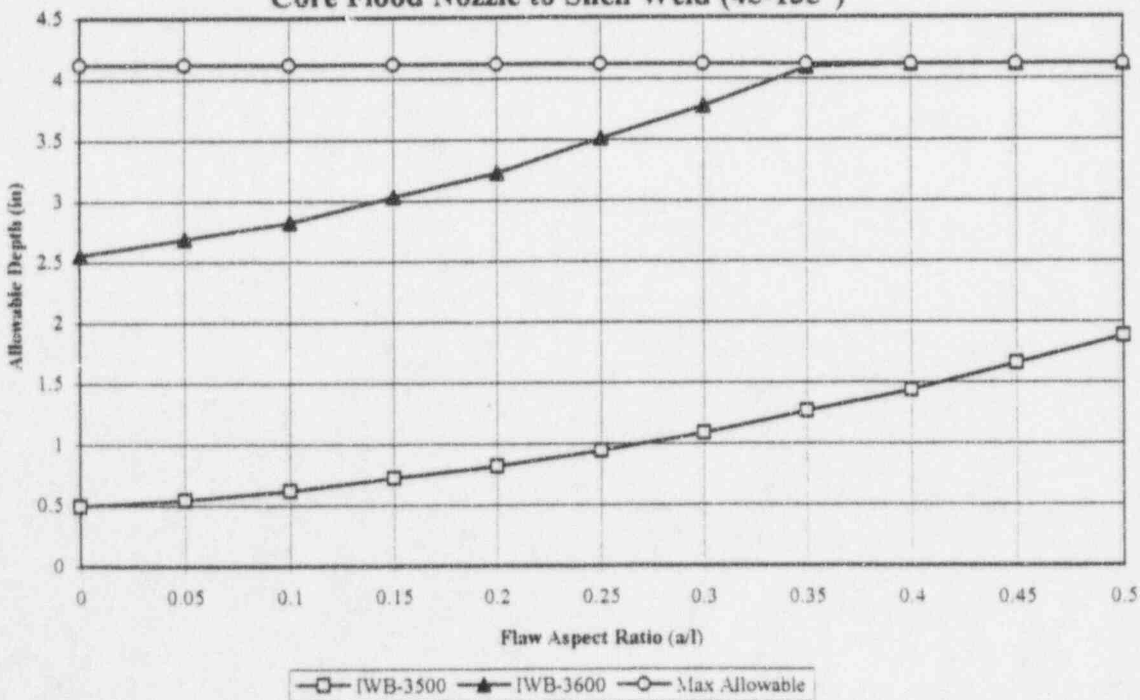
Axial Sub-Surface Flaw e/t = 0.0
Core Flood Nozzle to Shell Weld (45-135°)

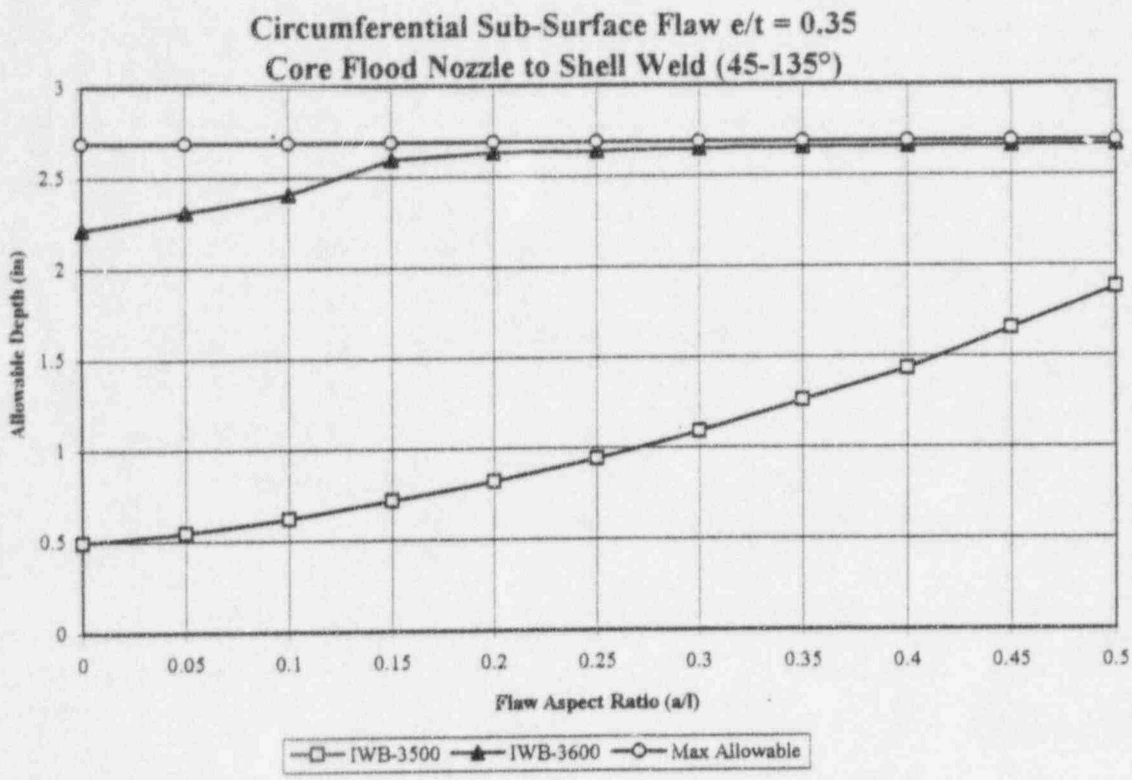


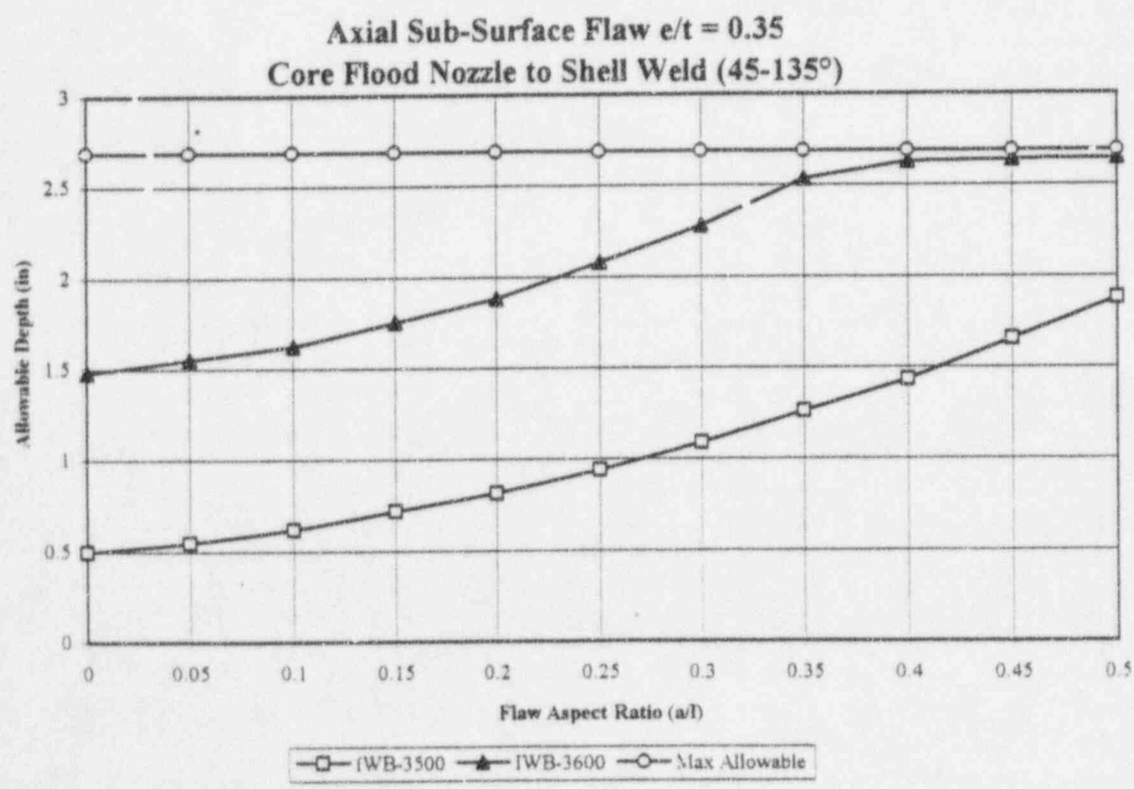
Circumferential Sub-Surface Flaw e/t = 0.2
Core Flood Nozzle to Shell Weld (45-135°)



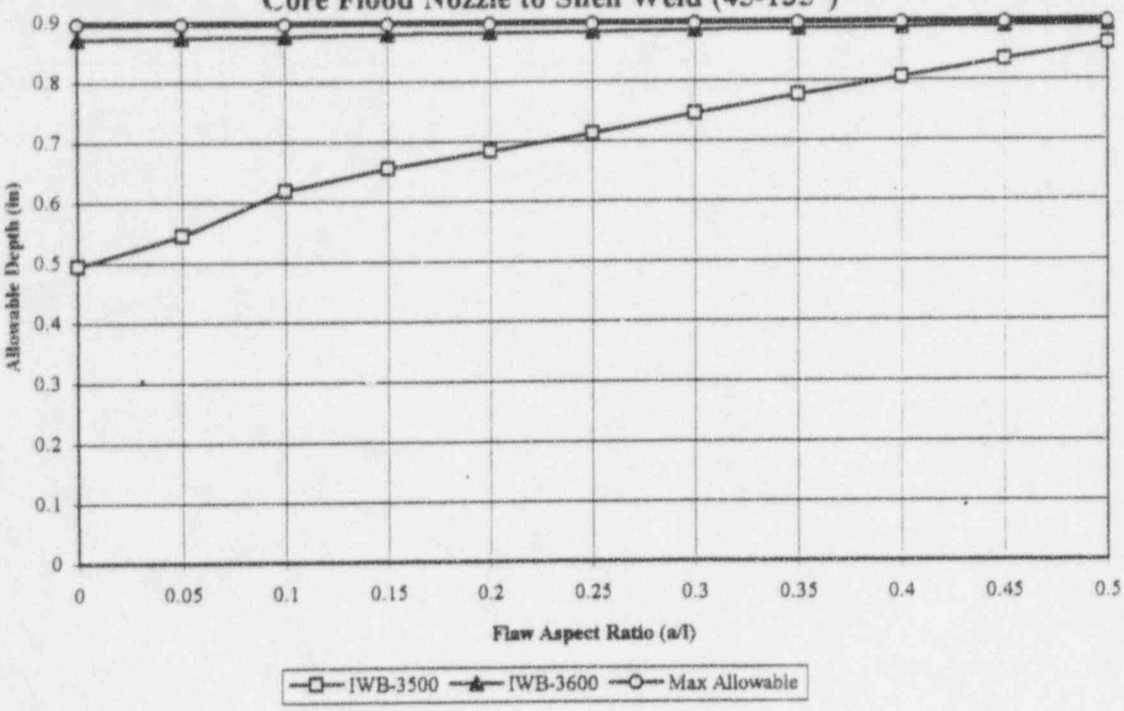
Axial Sub-Surface Flaw e/t = 0.2
Core Flood Nozzle to Shell Weld (45-135°)



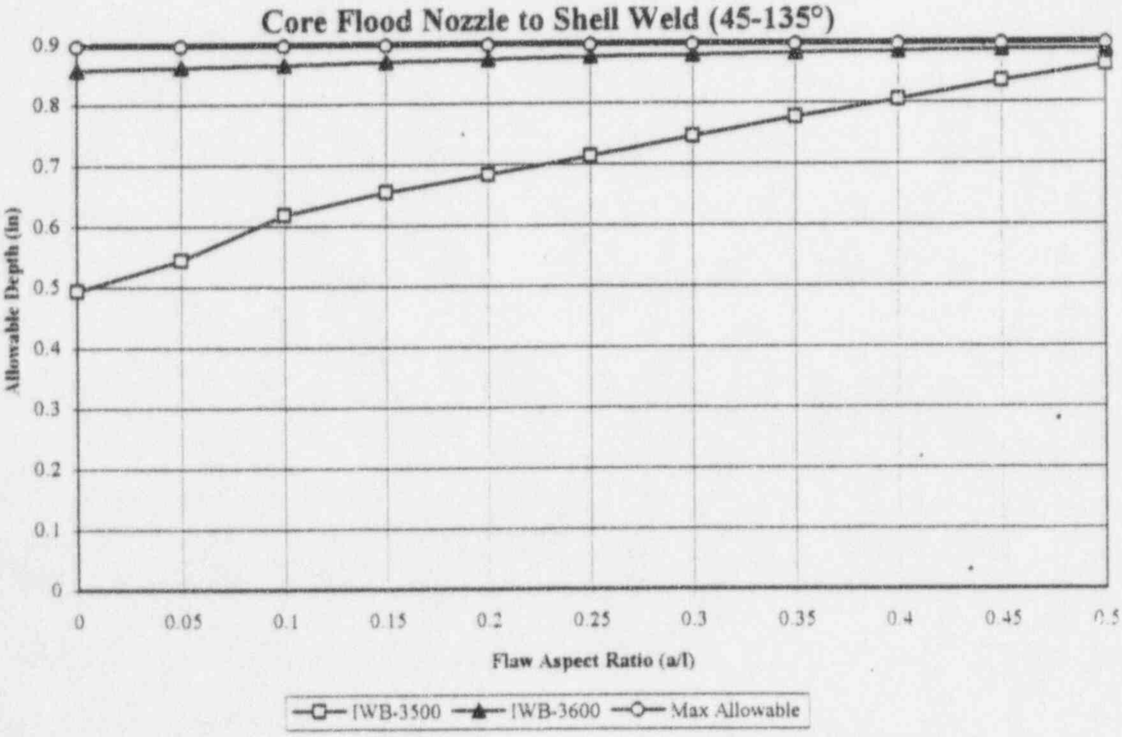

Circumferential Sub-Surface Flaw e/t = 0.35
Core Flood Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable


Axial Sub-Surface Flaw e/t = 0.35
Core Flood Nozzle to Shell Weld (45-135°)
Allowable Depth (in)
Flaw Aspect Ratio (a/l)
IWB-3500
IWB-3600
Max Allowable

Circumferential Sub-Surface Flaw e/t = 0.45
Core Flood Nozzle to Shell Weld (45-135°)



Axial Sub-Surface Flaw e/t = 0.45
Core Flood Nozzle to Shell Weld (45-135°)



APPENDIX N

Flaw Acceptance Diagrams for Region N Materials

Region N includes:

- Inlet Nozzle Forgings (MK#18)

Region O includes:

- Outlet Nozzle Forgings (MK#19)

Region P includes:

- Core Flood Nozzle Forgings (MK#17)

General Notes:

1. t = vessel wall thickness (including cladding thickness of 3/16").
2. e = distance from center of flaw to center of vessel wall (including cladding thickness of 3/16").
3. a = total radial depth of flaw, for surface flaws.
4. 2a = total radial depth of flaw, for subsurface flaws.
5. ℓ = length of flaw parallel to vessel wall.

Table N-1

	Location(1)	Flaw Size (in.)
Inlet Nozzle (Region N)	0° - 45°, 135° - 180° 45° - 135°	0.36 1.29
Outlet Nozzle (Region O)	0° - 45°, 135° - 180° 45° - 135°	0.35(2) 1.29
Core Flood Nozzle (Region P)	0° - 45°, 135° - 180° 45° - 135°	0.30(2) 0.30(2)

Note: (1) Location measured from top dead center of nozzle.
(2) Per Table IWB-3512-1 of ASME Section XI, a surface flaw depth of 2.5% of thickness is acceptable. This corresponds to a flaw depth of 0.30 inches for the core flood nozzle and 0.35 inches for the outlet nozzle.

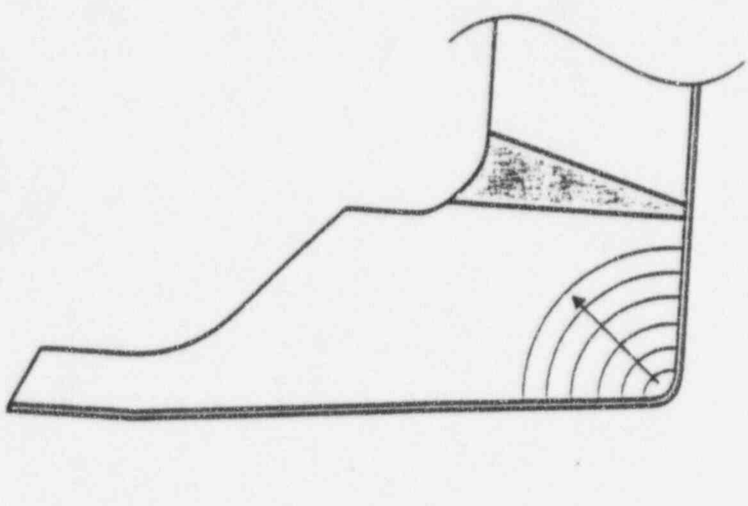


Figure N-1

Note: Allowable Flaw Sizes for Regions N, O and P measured from inside corner of inlet, outlet, and core flood nozzles.