NIAGARA MOHAWK POWER CORPORATION

NUCLEAR ENGINEERING REPORT
NINE MILE POINT UNIT 1

GE NUCLEAR ENERGY RPV FLAW EVALUATION HANDBOOK FOR NMP1, GENE-B13-01805-124

NER-1M-063, REV. 00

Prepared By: GE Nuclear Energy

Reviewed By: [signature] **Date:** 5/24/99
R. Corieri, Unit 1 Mechanical Design

Reviewed By: SEE ATTACHED **Date:** ______
Dr. M. P. Manahan, MPM Technologies

Approved By: [signature] **Date:** 5/25/99
L. P. Prunotto, Supervisor, Unit 1 Civil/Structural Design

Approved By: [signature] **Date:** 5/25/99
T. G. Mogren, Supervisor, Unit 1 Mechanical Design

Purpose:

The attached report was developed by GE Nuclear Energy for NMP1. The report provides a Structural Flaw Evaluation Handbook for the analysis of flaws detected in the NMP1 RPV welds in accordance with ASME XI, Subsection IWB-3600. The flaws were evaluated in NMPC Calculation S0VESSELM030, using the attached GE Flaw Handbook. Inputs for fluence and material property data for the RPV welds and base metal are from Nuclear Engineering Report NER-1M-065, "Updated NMP1 Vessel Weld Data for Flaw Evaluation Handbook (MPM-029934)". This report NER-1M-063, is issued as part of Configuration Change 1M00805. The Configuration Change was developed to evaluate flaws detected in RPV welds by ultrasonic exams performed during the 15th refueling outage (RFO15). The GE Flaw Handbook was independently reviewed by MPM Technologies, Inc., for NMPC. In addition, independent review comments by Structural Integrity, Inc., on the GE Flaw Evaluation Handbook prepared for the Cooper Nuclear Station were reviewed and addressed by GE, if the comments were also applicable for the NMP1 Flaw Handbook. Correspondence from B. Branlund (GE Nuclear Energy) to R. Corieri, dated April 29, 1999, includes all of the MPM comments, the applicable SIA comments, NMPC Engineering comments and the GE response to each comment (the 4/29/99 GE correspondence is included with Configuration Change Package 1M00805).

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Reviewed By: M P Manahan, Sr. (signature) **Date:** 5/24/99
Dr. M. P. Manahan, MPM Technologies

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GE Nuclear Energy

General Electric Company
175 Curtner Avenue, San Jose, CA 95125

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April 1999

NINE MILE POINT UNIT 1

RPV FLAW EVALUATION HANDBOOK

April 1999

Prepared for
Niagara Mohawk Power Corporation

Prepared by
GE Nuclear Energy

NINE MILE POINT UNIT 1

RPV FLAW EVALUATION HANDBOOK

Prepared by: [signature]
Aroon Herlekar, Principal Engineer
Structural Assessment and Mitigation

Verified by: T A Caine
T.A. Caine, Manager
Structural Assessment and Mitigation

Approved by: M. E. Harding for
J. F. Klapproth, ~~Manager~~
Engineering and Technology

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EXECUTIVE SUMMARY

A structural flaw evaluation was performed for Nine Mile Point Unit 1 in accordance with ASME Code Section XI (1983 Edition with Summer 1983 Addenda) for vertical welds in the vessel cylindrical shell region, as well as the beltline circumferential weld (RVWD-137) and circumferential vessel flange weld (RVWD-099). The BWRVIP (BWR Vessel and Internals Project) analysis ("BWR Reactor Pressure Vessel Shell Weld Inspection Recommendations," EPRI Report No. TR-105697, September 1995) indicated that flaws in the circumferential shell welds make essentially zero contribution to vessel failure probability; therefore, inspection of the entire circumferential shell welds may not be mandatory. However, a portion of each of the circumferential welds will be examined at the intersection of the vertical welds, so an evaluation of the beltline circumferential weld $\pm$3.3° of the vertical weld intersection was performed to allow disposition of any flaws found during inspection.

The flaw evaluation provided in this report includes fatigue crack growth and irradiation embrittlement for up to both 20.3 and 28 effective full power years (EFPY). In general, inside surface flaws were found to be limiting for vessel shell welds. Evaluations were also performed for subsurface flaws for all selected weld regions.

The analysis uses the most limiting loading for Normal (Level A), Upset (Level B), Emergency (Level C), Faulted (Level D), and Test conditions. The leak test and bolt up conditions, which involve the combination of low operating temperatures and high safety factors, are the most limiting operating conditions for vessel welds. Leak test conditions, and bolt up conditions at the flange regions, were considered for fracture analysis. The minimum specified leak test temperature is 247°F at 1195 psig for 20.3 EFPY and 260°F at 1195 psig for 28 EFPY. Bolt up conditions were analyzed at a service temperature of 100°F consistent with the pressure-temperature curves. Thermal transients during normal operation are bounded by the leak test and bolt up conditions, since the thermal stresses are more than offset by the associated higher fracture toughness values, K_{Ia}, due to higher metal service temperatures.

Loading associated with the analyses include:

- Membrane pressure stresses
- Bending Stress (near vessel flange)
- Weld residual bending stresses
- Clad residual stress (clad thickness = 7/32 in. nominal) on the inside surface only.

The analysis methods follow those prescribed in ASME Code Section XI IWB-3600. Applied stress intensity factors, K_I, were developed as a function of the flaw depth ratio, a/t (surface flaw) or 2a/t (subsurface), and aspect ratio, a/L. These were compared to the allowable fracture toughness, K_{Ia}, incorporating the Section XI safety factor of $\sqrt{10}$ for leak test, or $\sqrt{2}$ for bolt up, to determine allowable flaw sizes.

An upper bound on allowable flaw size was established at 1/3 depth of the LAS wall thickness to ensure that ASME Code Section III primary stress requirements were met. A lower bound for allowable flaw sizes is established by the minimum inspection standards of IWB-3500. If the flaw does not satisfy this standard, continued operation may still be justified if the flaw satisfies the IWB-3600 acceptance criteria, as developed in this report. However, for the latter case, there is a reinspection requirement imposed by the ASME Code.

Variation of neutron flux as a function of azimuth and elevation was considered to remove any undue conservatism in determining the allowable flaw sizes. In the beltline region, the allowable flaw sizes were calculated for the vertical welds with the highest adjusted RT_{NDT} values.

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1.0 INTRODUCTION

This report documents a generic flaw evaluation to determine allowable flaw sizes for vertical vessel welds in the cylindrical shell region, as well as the circumferential beltline weld and weld at the vessel flange region, of the reactor pressure vessel (RPV) at Nine Mile Point Unit 1. The time to disposition flaw indications found during inspections can be significantly minimized when the fracture mechanics assessment has been performed in advance. Furthermore, the allowable flaw size results can be used to guide UT inspections in a more efficient manner if indications or flaws are found.

The scope of this report includes the following:

- Assumed loading conditions, including pressure stresses, weld residual stresses and clad residual stresses.
- Analysis, per IWB-3500 and IWB-3600 Section XI of the ASME Code [Reference 1], of allowable surface and subsurface flaw sizes in the various weld regions, taking into consideration conservative estimates of fatigue crack growth and irradiation embrittlement up to both 20.3 and 28 EFPY.
- Flaw acceptance diagrams showing allowable surface and subsurface flaw depths (a or 2a, respectively) versus aspect ratio (a/L) for all selected weld regions.
- Procedure, including a flowchart and worksheet, for evaluating potential flaws found during inspections.

The various weld regions are shown in Figure 1-1. The beltline region includes plates G-307-4, G-307-3, G-307-10, G-8-3, G-8-4, and G-8-1; vertical welds at 105°, 225°, and 345° in the lower intermediate shell course assembly; vertical welds at 18°, 138°, and 258° in the lower shell course assembly; and the circumferential beltline weld ±3.3° from the vertical weld intersections. Although only a portion of the lower shell course plates and welds extend into the beltline region, all are conservatively classified as a beltline component. The labeling convention established in Figure 1-1 is consistently used throughout the handbook to identify specific plates or welds.

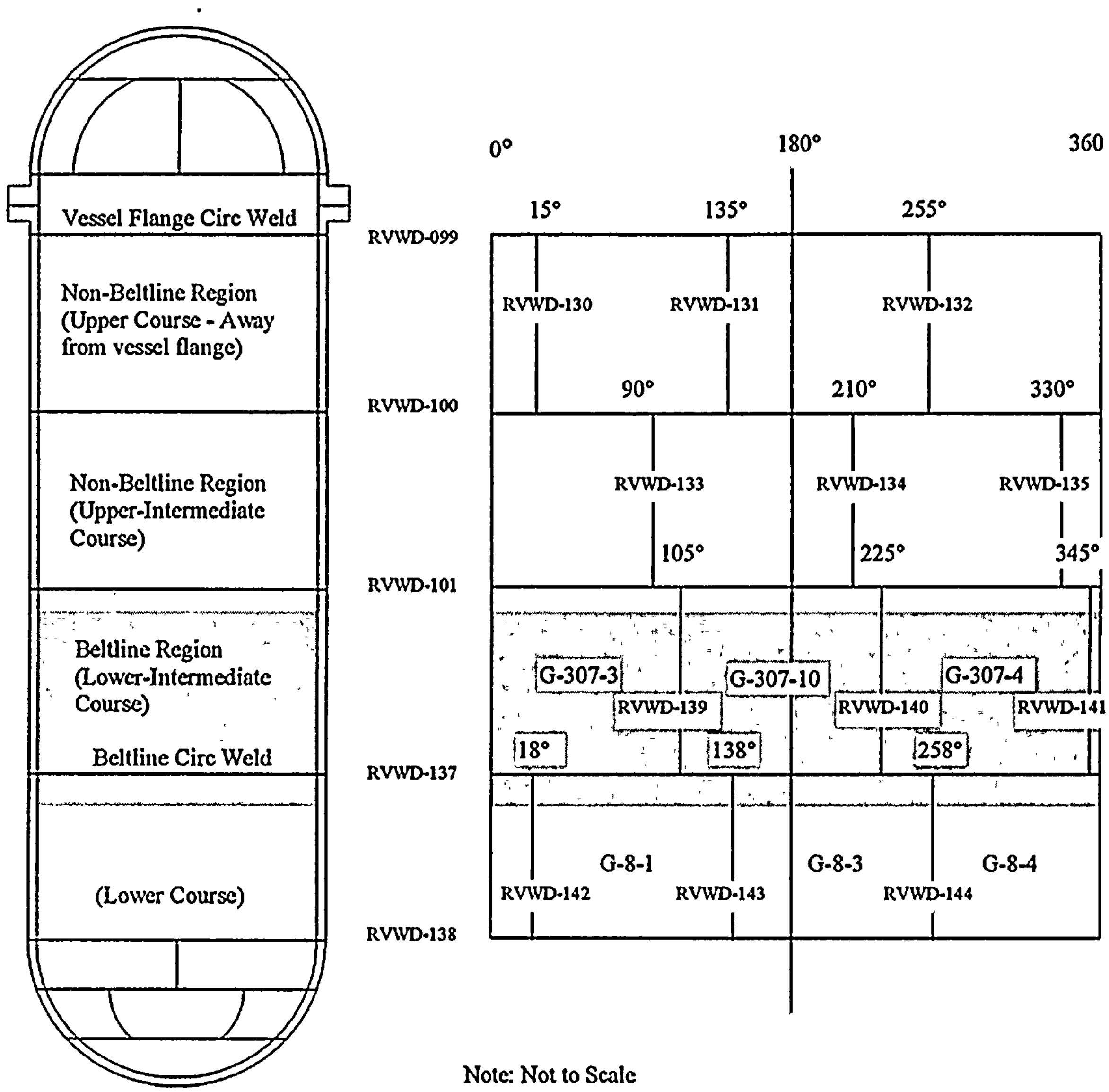


Figure 1-1. Nine Mile Point Unit 1 vessel weld regions for flaw evaluation.

2.0 ANALYSIS METHODS

2.1 Assumed Loading

The analysis uses the most limiting loading for Normal (Level A), Upset (Level B), Emergency (Level C), Faulted (Level D), and Test conditions. The leak test and bolt up conditions, which involve the combination of low operating temperatures and high safety factors, are the most limiting operating conditions for vessel welds. Thermal transients during normal operation are bounded by the leak test and bolt up conditions, since the thermal stresses are more than offset by the associated higher fracture toughness values, K_{Ic}, due to higher metal service temperatures.

Stresses in the region of each weld are assumed to be due to (i) clad residual stress, (ii) pressure stress, and (iii) weld residual stress. The applied stresses are summarized in Table A-5 of Appendix A. Since thermal stresses associated with the bolt up and leak test condition are insignificant, they are not included.

For welds adjacent to the closure flange region, the limiting load condition may be either the leak test condition, or the bolt up condition. For the remaining vessel welds, a previous analysis for a similar vessel [Reference 2] has shown that bolt preload stresses are fully attenuated at locations away from the flange region. Therefore, the limiting load condition at vessel welds away from the flange region is the leak test condition. A leak test condition of 1195 psig at 247°F for a leak test at 20.3 EFPY [Reference 14], and 1195 psig at 260°F for a leak test at 28 EFPY [Reference 15] are used for the analysis. The circumferential and longitudinal stresses at the vessel flange weld locations were obtained from the RPV stress report, [Reference 11]. Bolt up conditions were analyzed at a service temperature of 100°F consistent with the pressure-temperature curves.

2.1.1 Cladding Residual Stresses

After a stainless steel (SS) clad is applied to the low alloy steel (LAS) vessel shell plate, a post-weld heat treatment (PWHT) is performed at approximately 1150°F to relieve residual stresses. Consequently, cooling below the PWHT temperature results in residual clad stresses because of the difference in the coefficients of thermal expansion between the SS clad and LAS material. Cooling after PWHT causes tensile stresses in the clad which can reach yield

level (30-40 ksi) at room temperature. Rybicki, et.al., [Reference 4] have shown that the clad residual stress at room temperature, following PWHT and shop leak test, is approximately equal to the clad yield strength in both hoop and axial directions. Rybicki, et.al., [Reference 4] used a clad yield strength equal to 32 ksi at 70°F. Upon subsequent heating, the clad stress was found to decrease as a result of thermal expansion. Similar results have been obtained by Ganta, Ayres, and Hijeck [Reference 5], who have also reported clad residual stresses on the order of 30 ksi at room temperature, which, because of high temperature creep effects, are actually lower than the assumed yield strength of 45 ksi. Therefore, based on these results, it would be reasonable and conservative to assume a clad stress equal to an assumed yield strength of 35 ksi at 70°F for this analysis.

To validate this assumption, an analysis (see Appendix A) was performed to show that, upon cooling from 1150°F to 70°F (room temperature), the elastic residual clad stress does in fact exceed the clad yield strength. Therefore, a clad stress equal to an assumed yield strength of 35 ksi (at 70°F) will be used in this analysis. When the reactor is subsequently heated to the pressure test temperatures, the differences in the thermal expansion coefficients will reduce the tensile stresses in the clad (see Appendix A). At a leak test temperature of 247°F, corresponding to 20.3 EFPY, the residual clad stress reduces to 18.15 ksi due to thermal expansion. This result is consistent with Rybicki, et.al., [Reference 4], who reported a clad stress of approximately 26 ksi for a 0.125 inch thick clad at 200°F. The calculated clad residual stress at a leak test temperature of 260°F, corresponding to 28 EFPY, is 17.11 ksi.

Also, to maintain equilibrium, a slight compressive residual stress is induced in the LAS base metal. However, because of the differences in the thickness between the clad and the base metal, the compressive stress in the LAS material is small and will be conservatively neglected.

The clad stress is used to compute K_{clad} to be used in the Section XI fracture mechanics flaw assessment. The clad thickness is nominally 7/32 = 0.2188 inch at the inside surface of the vessel cylindrical region.

2.1.2 Pressure Stresses

Pressurization of the vessel results only in membrane stress. For axial flaws, the hoop stress is calculated according to the thin-walled pressure vessel formulation, PR/t, where R is the mean

vessel radius and P is the leak test pressure of 1195 psig. This approach is valid for Nine Mile Point Unit 1, since the limiting R/t = 15 (>10) in the vessel region.

2.1.3 Weld Residual Bending Stress

Weld residual stress due to the seam weld or the flange weld are reduced significantly as a result of PWHT. However, some weld residual stress still remains after PWHT. Based upon previous analysis for seam welds [References 6 & 7], a residual bending stress of 8 ksi is assumed for flaws oriented parallel to the weld line. This bending stress simulates the measured cosine stress distribution for welds with PWHT [Reference 6]. For flaws oriented perpendicular to the weld line, the weld residual stress is zero.

2.2 Section III Local Membrane Stress Limits

In addition to the fracture mechanics requirements of Section XI, structural requirements for primary local stress per Section III [Reference 1] must also be satisfied. The maximum primary membrane stress cannot exceed $1.5S_m$. Since it is assumed that the clad does not carry any part of the load, the part of the crack extending into the LAS must be limited to 1/3 the LAS wall thickness. However, for the purposes of this analysis, the net 1/3 wall thickness limit will be conservatively defined as:

$$t_{1/3\ limit} = 1/3\ t_{LAS} \qquad (2\text{-}1)$$

regardless of flaw classification (i.e. surface or subsurface). For inside surface flaws, the 1/3 limit is measured from the surface of the clad/LAS interface. This limit is used in conjunction with K_{allow} to determine allowable crack depths as a function of aspect ratio.

2.3 Section XI Fracture Margin Assessment

The assumed loads and clad residual stress from Section 2.1 were used to calculate stress intensity factors (K_I) versus crack depth ratio (a/t or 2a/t). Postulated subsurface flaws were conservatively analyzed for the most limiting proximity factors such that the allowable flaw depths are bounding for all subsurface flaws. The assumed flaw geometry for surface and subsurface defects are shown in Figure 2-1.

2.3.1 Fracture Toughness and Allowable Stress Intensity Factors

Fracture toughness values, K_{Ia}, were calculated per Appendix G of Section XI. K_{Ia} values are determined for each weld location based upon limiting RT_{NDT} values or adjusted reference temperatures (ART) , metal service temperatures, and irradiation embrittlement effects (refer to Appendix A). For beltline and non-beltline regions analyses were performed at the minimum leak test temperature of 247°F corresponding to 20.3 EFPY, and 260°F corresponding to 28 EFPY.

Allowable stress intensity factor limits, K_{allow}, were determined from the fracture toughness values per IWB-3612 by applying the following safety margin for leak test conditions,

$$K_{allow} = K_{Ia} / \sqrt{10} \qquad (2\text{-}2)$$

This value is used to determine the allowable crack depth ratios for each aspect ratio. Only for a few assumed flaw geometries in the vessel flange region, the bolt up condition was determined to be governing. The safety factor used in those cases was $\sqrt{2}$ instead of $\sqrt{10}$ indicated above.

2.3.2 Methods Specific to Irradiated (Beltline) Region

Due to irradiation embrittlement, the allowable stress intensity factor will decrease with increasing EFPYs. This effect is characterized by a shift in RT_{NDT} values based upon fluence levels at different EFPYs. The adjusted reference temperatures (ART) are used in place of the initial RT_{NDT} values in computing the allowable stress intensity factor as described in Section 2.3.1. The initial RT_{NDT} values are given in Reference 3 and the ART values were determined in accordance with the methods described in US NRC Regulatory Guide 1.99, Revision 2 (Rev. 2) [Reference 9]. The methodology for calculating ART is described in Section 2.3.3.

Only the allowable stress intensity factor, K_{allow}, calculated from the fracture toughness is directly affected by irradiation embrittlement. Applied stress intensities (as calculated per Section 2.3.4 below) are not dependent upon irradiation effects, and are only dependent upon applied loading.

2.3.3 Adjusted Reference Temperature Methodology

The effect on adjusted reference temperature (ART) due to irradiation in the beltline materials is determined according to the methods in Rev. 2 [Reference 9], as a function of neutron fluence and the element contents of copper (Cu) and nickel (Ni). The specific relationship from Rev. 2 [Reference 9] is:

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin}$$

where:

$$\Delta RT_{NDT} = CF\ f^{(0.28 - 0.1 \log f)}$$

$$\text{Margin} = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2}$$

CF =	chemistry factor from Tables 1 or 2 of Rev. 2 [Reference 9],
f =	fluence (n/cm^2) at the location of evaluation divided by 10^{19},
σ_I =	standard deviation on initial RT_{NDT}, which is taken to be 0°F.
σ_Δ =	standard deviation on ΔRT_{NDT}, 28°F for welds and 17°F for base material, except that σ_Δ need not exceed 0.50 times the ΔRT_{NDT} value. If 2 or more sets of credible surveillance data are used, σ_Δ is 1/2 the above values.

2.3.4 Applied Stress Intensity Factors

In determining applied stress intensity factors, the following assumptions were made:

- Vessel flaws can be modeled by flat plate analysis as described in Section XI of the ASME Code.
- Linear elastic fracture mechanics (LEFM) can be used to determine K_I.
- The effect of clad stress can be modeled as a point load applied to an edge (infinite) length flaw, which may be subsequently adjusted for finite length flaws.

Although there are several methods that can be used to determine K_I, the LEFM approach for flat plates was used per Appendix A of Section XI from the ASME Code [Reference 1].

Because of back wall bending, the use of flat plate theory has been shown to give conservative results for deep flaws [Reference 10] in cylindrical pressure vessels. Since all stresses, with the possible exception of clad stresses, are elastic, LEFM is expected to yield accurate results.

The applied stress intensities for the given stresses are calculated for surface flaw aspect ratios (a/L) and subsurface flaw aspect ratios (2a/L) of 0.0, 0.1, 0.2, 0.3, 0.4, and 0.5 according to the methods given in Appendix A of the ASME Code, Section XI [Reference 1].

The stress intensities due to applied membrane and bending stresses are calculated per IWB-3600 [Ref. 1] as follows:

$$K_m = \sigma_m M_m (\pi a/Q)^{0.5} \qquad (2\text{-}3)$$

$$K_b = \sigma_b M_b (\pi a/Q)^{0.5} \qquad (2\text{-}4)$$

where,

σ_m = total applied membrane stress

σ_b = total applied bending stress

a = flaw depth

Q = flaw shape parameter

M_m = membrane stress correction factor

M_b = bending stress correction factor

Although methods for calculating stress intensities for membrane and bending stresses are included in Section XI, no method is identified for determining K_{clad}.

The clad residual stress is a localized stress that only exists in the clad/LAS interface region. As such, the clad residual stress was modeled as a resultant force (equivalent point load) applied at the mid-thickness of the clad on each face of the crack opening. This model, which is valid only for surface defects, is described by the following equation given by Tada [Reference 17]:

$$K_{\infty,clad} = 2 * 1.297 * \sigma_{clad}\, t_{clad} / (\pi c)^{0.5} \qquad (2\text{-}5)$$

where,

σ_{clad} = clad residual stress

$c = a - 0.5\ t_{clad}$

This value is then corrected for a finite length crack,

$$K_{clad} = K_{\infty,clad}\,(Q_{\infty}/Q)^{0.5} \qquad (2\text{-}6)$$

where,

Q_{∞} = shape factor for infinite length flaw

Q = shape factor for analyzed finite length flaw

The shape factors are identical to those obtained from Section XI of the ASME Code for membrane and bending stresses. The net effect of clad stresses for subsurface flaws is insignificant.

The individual stress intensity contributions due to membrane stress, bending stress, and clad point load stress can be combined by method of superposition, as shown in Figure 2-2. The applied stress intensity factor is, therefore, calculated as the sum of individual stress intensity factors,

$$K_I = K_m + K_b + K_{clad} \qquad (2\text{-}7)$$

This calculation is performed for each aspect ratio as a function of flaw depth (i.e. a/t or 2a/t) to determine the limiting flaw depths (not including fatigue allowances).

2.3.5 Allowable Flaw Depths (Not Including Fatigue)

To illustrate how the allowable flaw depths are calculated, sample results showing K_I versus crack depth ratio are shown in Figures 2-3 and 2-4. Figure 2-3 shows typical K_I results for a surface flaw. The limiting flaw depth ratio (a/t) is defined at the point where the applied stress intensity is equal to the allowable stress intensity, provided that the upper bound 1/3 wall thickness limit is not exceeded. Similar example results are shown in Figure 2-4 for subsurface flaws.

2.3.6 Fatigue Crack Growth Allowances

The limiting crack depths calculated above do not include fatigue crack growth, and must therefore be adjusted to include an additional allowance for crack growth up to the desired number of effective full power years.

A fatigue crack growth allowance is conservatively calculated for the limiting flaw sizes. Since the limiting flaw sizes will have an applied stress intensities equal to or less than the allowable stress intensity, K_{allow} , the applied stress intensity range, ΔK, used to compute fatigue crack growth will be conservatively based upon a maximum stress intensity level of $K_{max} = K_{allow}$. Therefore,

$$\begin{aligned} \Delta K &= K_{max} - K_{min} \\ &= K_{allow} - 0 \end{aligned} \qquad (2\text{-}8)$$

The minimum stress intensity is conservatively assumed to be $K_{min} = 0$. Fatigue crack growth for all inside surface flaws is calculated for a reactor water environment. The limiting fatigue crack growth rate (for a stress intensity ratio of $R = K_{min}/K_{max} > 0.65$) is computed as follows [Reference 1],

$$da/dN = 0.252(\Delta K)^{1.95} \quad (\mu\text{-in./cycle}) \qquad (2\text{-}9)$$

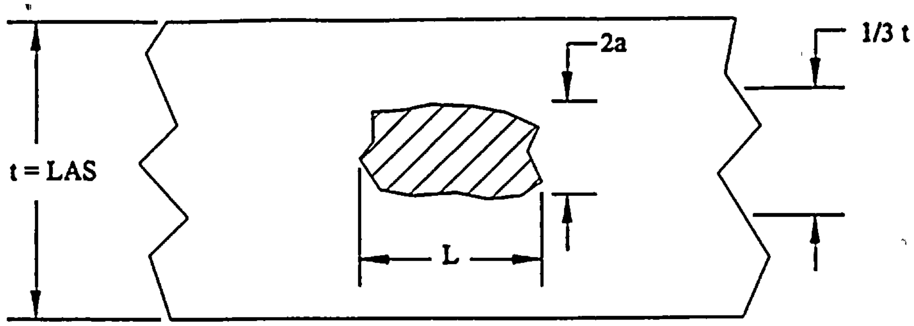
where,

ΔK = maximum stress intensity factor range (ksi$\sqrt{\text{in}}$).

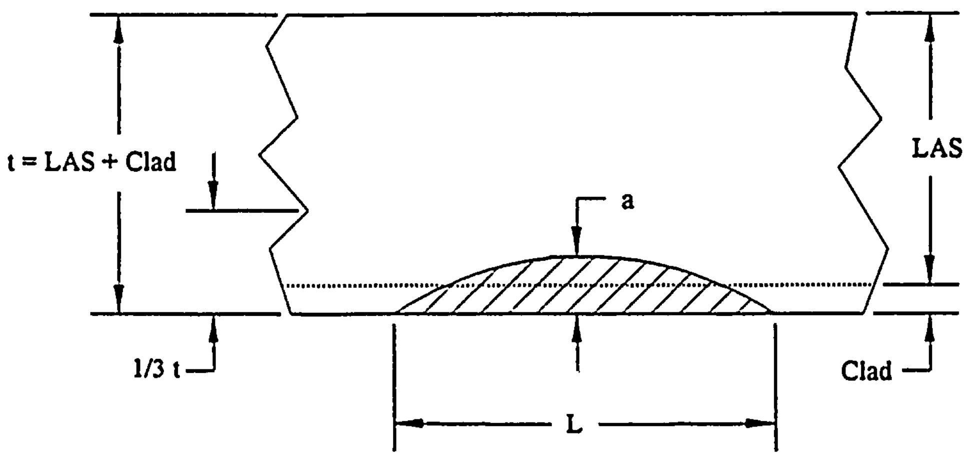
Fatigue crack growth for outside surface flaws and subsurface flaws is computed based upon an air environment [Reference 1]:

$$da/dN = 0.0267(10^{-3})/(\Delta K)^{3.726} \quad (\mu\text{-in/cycle}) \qquad (2\text{-}10)$$

Approximately 18 cycles per EFPY is conservatively assumed. Nine Mile Point Unit 1 is assumed to be at 18.3 EFPY currently. Therefore, for 20.3 EFPY operation fatigue crack growth allowances were calculated relative to 2.0 EFPY. Similarly, for 28 EFPY operation fatigue crack growth allowances were calculated relative to 9.7 EFPY. The fatigue crack growth allowances, Δa_{fcg} or $2\Delta a_{fcg}$, are used to adjust the limiting flaw sizes obtained from the LEFM analysis to develop the acceptance criteria.



Subsurface Flaw



Surface Flaw

Figure 2-1. Flaw geometry for typical planar surface and subsurface defects.

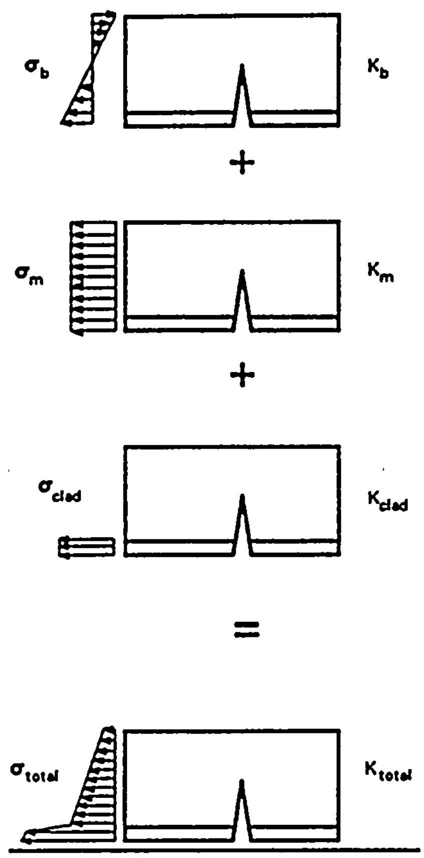


Figure 2-2. Method of superposition for fracture mechanics problem.

Stress intensities due to localized clad stresses, membrane stress, and bending stress can be combined using this method.

Figure 2-3 Sample Results of K_I vs a/t for a Surface Flaws

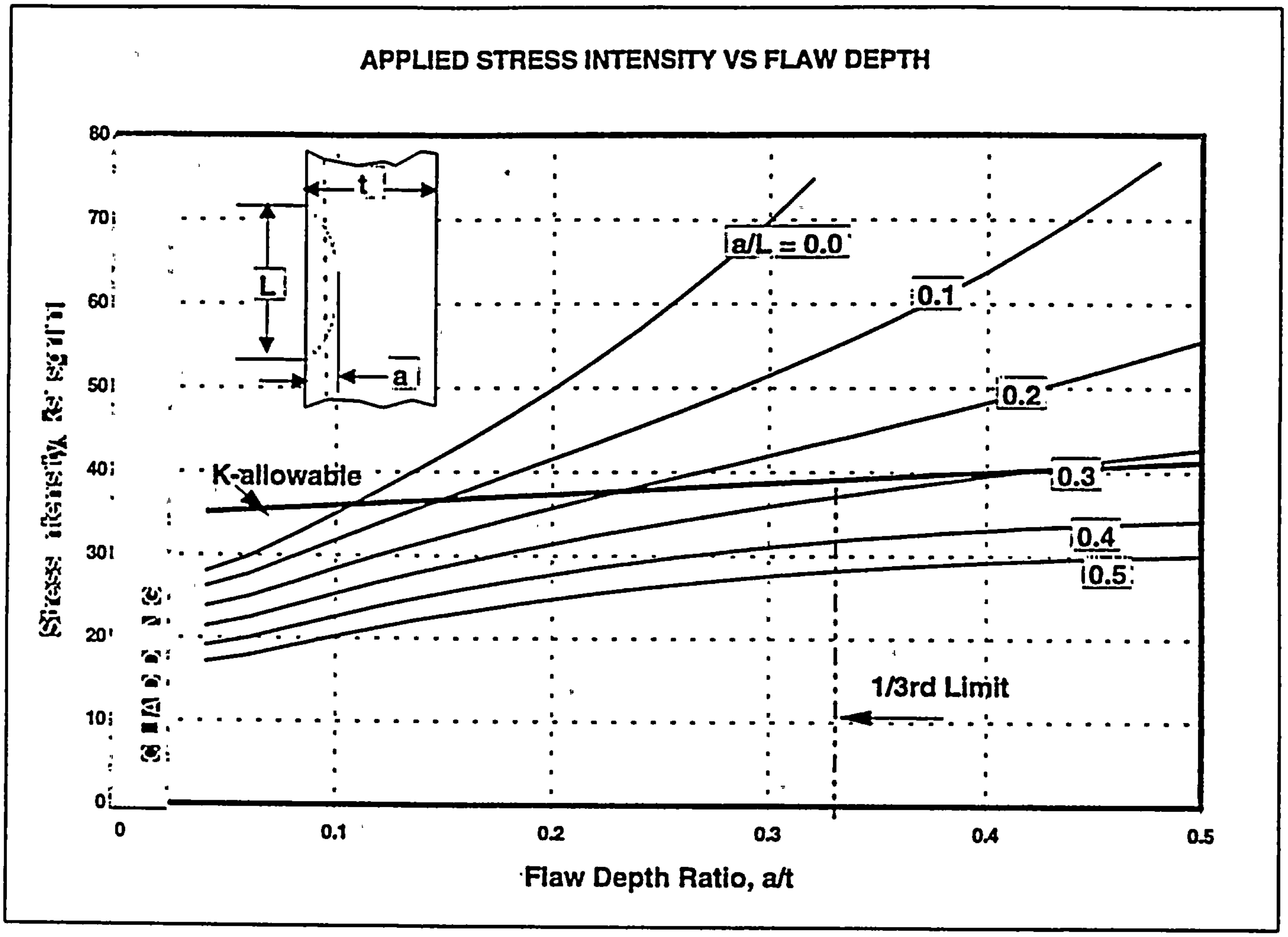
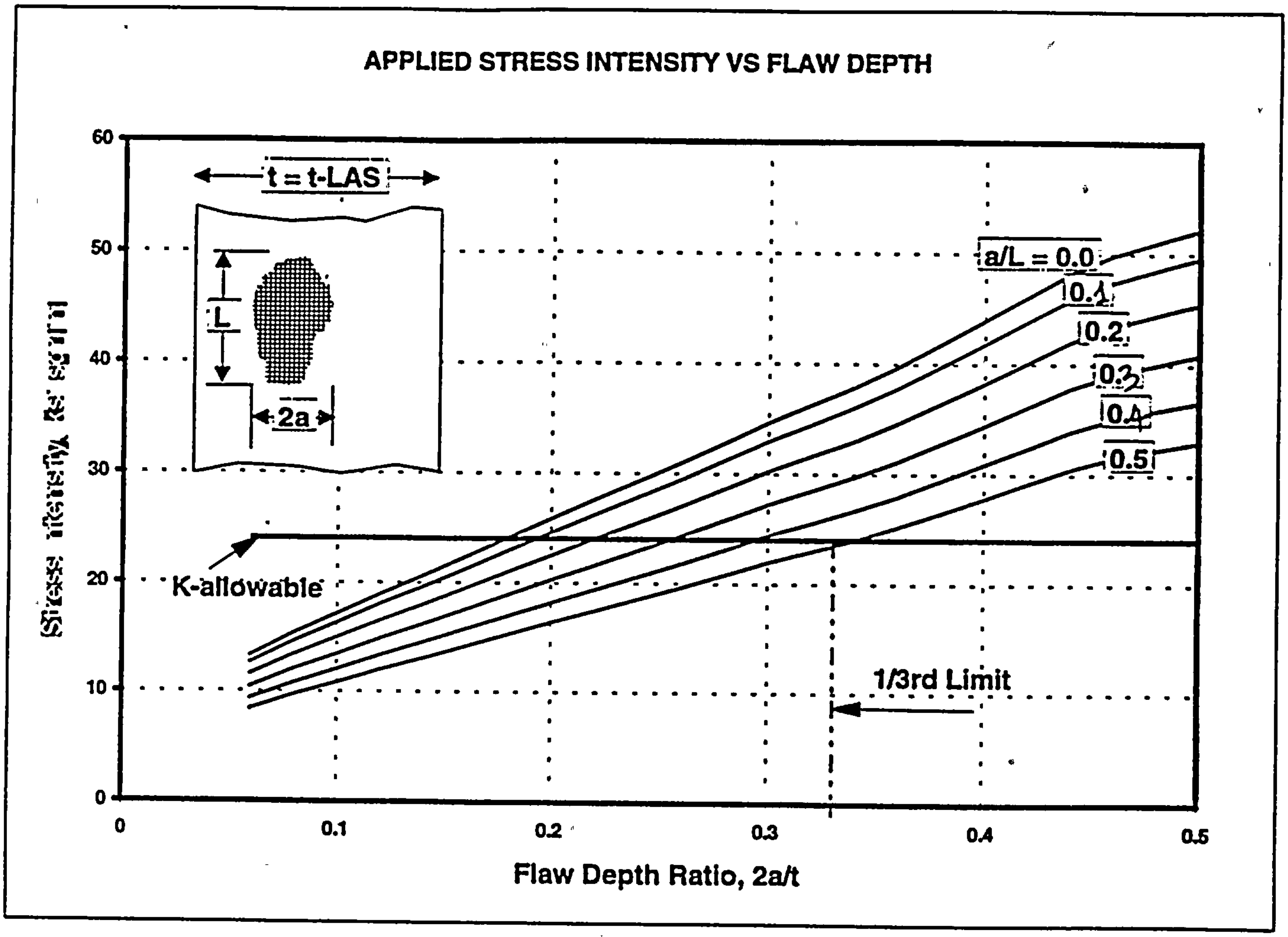


Figure 2-4 Sample Results of K_I vs 2a/t for a Subsurface Flaws



3.0 FLAW ACCEPTANCE DIAGRAMS

3.1 Flaw Acceptance Criteria

3.1.1 IWB-3500 Acceptance Standards for Examination

The ASME Code, Section XI, IWB-3510.1 [Reference 1], outlines the standards for examination for surface and subsurface planar flaws in pressure retaining vessel weld regions. It should be noted that the IWB-3500 acceptance standards for surface flaws are measured relative to the LAS/clad interface. This is because any flaw found entirely within the clad is considered acceptable per IWB-3500. Since the inspection standards specified in the Code do not include clad thickness, the allowables for inside surface flaws are adjusted such that the allowable flaw depth may be measured relative to the surface of the clad rather than the LAS/clad interface.

Subsurface allowables were calculated based upon a proximity factor of $Y = S/a = 1.0$, which is typical of a mid-plane flaw. For flaws where $Y < 0.4$, the flaw must be classified as a surface defect according to the proximity rules of IWA-3300. The IWB-3500 curves in the figures in Appendix C and D are provided for comparison and a detailed calculation based upon actual S/a proximity factors should be performed to ensure that the IWB-3500 inspection standards are satisfied.

Flaws detected during inspection must satisfy the requirements of IWB-3500 standards to justify continued operation. However, if a flaw does not satisfy these requirements, additional analysis may be performed in accordance with IWB-3600, which allows for the use of analytical procedures to evaluate flaws to justify continued operation.

3.1.2 IWB-3600 Analytical Acceptance Criteria

Per IWB-3600 [Reference 1], the analytical techniques described in Section 2.3 of this report can be used to establish acceptance criteria for flaws which may not necessarily satisfy IWB-3500 acceptance standards.

To justify continued operation, fatigue crack growth and irradiation embrittlement with time were considered. These effects have been conservatively evaluated up to both 20.3 and 28 EFPY. These allowances were used to adjust the allowables calculated per Section 2.3.4

above to establish a flaw acceptance criteria, such that, if a flaw satisfies the acceptance criteria, continued operation is justified up to the specified EFPY.

3.2 Development of Acceptance Diagrams

The results from Section 2.3 are used in conjunction with the above evaluation to develop flaw acceptance diagrams showing allowable flaw depth (a or 2a) versus aspect ratio (a/L) for each flaw orientation and location. The limiting flaw depth per IWB-3600 is bounded by either K_{allow} or the 1/3t limit, which ever is more limiting. These limiting values are reduced by an amount Δa_{fcg} for surface flaws and $2\Delta a_{fcg}$ for subsurface flaws to account for fatigue crack growth to compute the IWB-3600 acceptance standard as follows:

$$a_{allow} = a - \Delta a_{fcg} \qquad \text{(surface flaw)} \qquad (3\text{-1a})$$

or

$$2a_{allow} = 2a - 2\Delta a_{fcg} \qquad \text{(subsurface flaw)} \qquad (3\text{-1b})$$

For some cases, allowable flaw sizes were found to be relatively small for the minimum specified test temperatures. But since the leak test condition is limiting for vessel weld regions, the allowable flaw sizes can be increased by increasing the test temperature. Therefore, to ensure added margin for flaw acceptability, the system leak test may be performed at higher temperatures.

Flaw acceptance diagrams for postulated axial and circumferential flaws at all selected locations are shown in the figures in Appendix C for 20.3 EFPY and Appendix D for 28 EFPY. These curves are limiting for all normal and upset operating conditions. During operation, the metal service temperature will be on the order of 400-550°F, which will always yield fracture toughness values higher than those computed for leak test.

The use of the figures in Appendix C for 20.3 EFPY and Appendix D for 28 EFPY is described in further detail in Appendix B, where a flaw evaluation procedure, worksheet, and flowchart are provided.

4.0 SUMMARY

A structural flaw evaluation was performed in accordance with ASME Code Section XI (1983 Edition with Summer 1983 Addenda) for vertical welds in the vessel cylindrical regions, as well as the horizontal weld in the vessel flange region. The analysis uses the most limiting loadings for normal, upset and faulted operation. The flaw evaluation provided in this report includes fatigue crack growth and irradiation embrittlement for up to both 20.3 and 28 effective full power years (EFPY). The minimum specified leak test temperature is 247°F at 1195 psig for 20.3 EFPY and 260°F at 1195 psig for 28 EFPY. In general, inside surface flaws were found to be limiting for vessel shell welds. Evaluations were also performed for subsurface flaws for all selected weld regions. Figure 1-1 of Section 1.0 identifies all the weld regions selected for analysis.

Loading was assumed to be due to:

- Membrane pressure stresses
- Weld residual bending stresses
- Clad residual stress (clad thickness = 7/32 inches nominal) on the inside surface only.

The analysis methods follow those prescribed in ASME Code Section XI IWB-3600. Applied stress intensity factors, K_I, were developed as a function of the flaw depth ratio, a/t (surface flaw) or 2a/t (subsurface), and aspect ratio, a/L. These were compared to the allowable fracture toughness, K_{Ia}, reduced by the Section XI safety factor of $\sqrt{10}$ for leak test and $\sqrt{2}$ for bolt up, to determine allowable flaw sizes.

An upper bound on allowable flaw size was established at 1/3 depth of the LAS wall thickness to ensure that ASME Code Section III primary stress requirements were met. A lower bound for allowable flaw sizes is established by the minimum inspection standards of IWB-3500. If the flaw, however, does not satisfy this standard, continued operation may still be justified if the flaw satisfies the IWB-3600 acceptance criteria, as developed in this report. For the latter case, there is a reinspection requirement imposed by the Code.

The allowable flaw curves presented in this report are based on conservative assumptions of possible loadings and flaw location. If a specific flaw were to be found, which did not meet the IWB-3600 allowable in this report, a more specific analysis of the flaw may show

continued operation to be acceptable. If flaw-specific analysis to IWB-3600 criteria were not met, it would likely be possible to show continued operation to be acceptable on the condition that the pressure test temperature be increased. In an extreme case, either flaw removal or weld repair might be necessary.

5.0 REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Section III and XI, 1983 Edition with Summer 83 Addenda.

[2] Swift, T.J., "Structural Evaluation of Head Flange Weld, Vessel Flange Weld and Upper Shell Weld at Quad Cities Nuclear Power Station, Unit 2", GE Nuclear Energy, SASR 90-82, December 1990

[3] "Updated Nine Mile Point Unit 1 Vessel Weld Data for Flaw Evaluation Handbook", Report No. MPM-029934, by MPM Technologies, Inc., State College, PA dated February, 22 1999.

[4] Rybicki, Shadley, Sandhu, and Stonesifer, "Experimental and computational Residual Stress Evaluation of a Weld Clad Plate and Machined Test Specimens", Journal of Engineering Materials and Technology Vol. 110, October 1988, pp.297-304.

[5] Ganta, Ayres, and Hijeck, "Cladding Stresses in a Pressurized Water Reactor Vessel Following Application of the Stainless Steel Cladding, Heat Treatment and Initial Service", PVP-Vol. 213/MPC-Vol.32, Pressure Vessel Integrity, ASME 1991.

[6] Ferrill, D.A., et. al., "Measurement of Residual Stresses in Heavy Weldment", Welding Journal Research Supplement Vol. 45, November 1966.

[7] Landerman, E., and Grotke, G., "Residual Stress Considerations in Weldments for the Nuclear Industry," Weldments: Physical Metallurgy and Failure Phenomena, General Electric, 1977.

[8] ASME Boiler and Pressure Vessel Code, Section I, 1959 Edition with Summer 1963 Addenda.

[9] US Nuclear Regulatory Commission, Regulatory Guide 1.99, Revision 2, May 1988.

[10] Paris and Sih, "Stress Analysis of Cracks", ASTM Special Technical Publication No. 381, Fracture Toughness Testing and Its Applications, 1965.

[11] "Analytical Report for Niagara Mohawk Reactor Vessel", Combustion Engineering Report No. CENC-1142, VPF# 1236-153-1.

[12] "Response to NRC Generic Letter 92-01 for Nine Mile Point Unit 1," Niagara Mohawk Power Corporation Project 03-9425, June 12, 1992.

[13] "Reactor Pressure Vessel Stress Report", GE Document No. 24A6426, Revision 4.

[14] NMPC Nine Mile Point Unit 1 In-service Test Pressure Tests, N1-IST-LK-101, Revision 03, dated December 16, 1998.

[15] NMPC Nine Mile Point Unit 1 Amendment No. 164 to Technical Specification (Table 3.2.2.e).

[16] "Reactor Pressure Vessel Stud Replacement Stress Report", GE Document No. 22A6561, Revision 0.

[17] Hiroshi Tada with cooperation of Paul C. Paris and George R. Irwin, "The Stress Analysis of Cracks Handbook, Second Edition," Paris Productions Incorporated, St. Louis, Missouri, 1985.

APPENDIX A - MATERIALS DATABOOK AND CALCULATIONS

A. MATERIALS DATABOOK AND CALCULATIONS

A-1. Vessel Geometry

Vessel dimensions at each of weld location are listed in Table A-1. The clad thickness in the vessel region is 7/32 = 0.2188 inch nominally. Figure 1-1 of Section 1.0 identifies the location of the various shell plates and the welds. A LAS wall thickness of 7.125 inches was used in all of the cylindrical shell locations.

A-2. Limiting Initial RT_{NDT}

The initial RT_{NDT} values for the vessel shell plates and welds are summarized in Reference [3]. For each weld location, the most limiting RT_{NDT} of either the weld or adjacent shell materials was used. The limiting initial RT_{NDT} values used in the analysis are listed in Table A-2.

A-3. Limiting RT_{NDT} for Non-Beltline Regions

For the non-beltline regions, the base and weld material RT_{NDT} values are summarized in Table A-2. Conservative initial RT_{NDT} values are assumed because actual values are unavailable. Because irradiation embrittlement is insignificant in these regions, any shift in RT_{NDT} is negligible.

A-4. Adjusted Reference Temperatures (ART) for Beltline Regions

The ART values were calculated, in accordance with US NRC Regulatory Guide 1.99 [Ref. 9], using fluence value for each location. The more limiting ART of either the shell (course) or the weld material was used in the analysis. Values of ART for both 20.3 and 28 EFPY at 1/4 t depth are summarized in Table A-3a and A-3b, respectively. In addition, Table A-3c documents the chemical composition for the beltline materials. The 1/4T depth values of ART are reported in Tables A3a & A3b because these are generally used in P-T curves. However, the ART values used for the evaluation of surface flaws are based on the fluence at the location of the crack tip. The ART values used for the evaluation of subsurface flaws are conservatively based on the inside surface fluence.

A-5. Fracture Toughness, K_{Ia}

Fracture toughness values are calculated per Appendix G of Section XI from the ASME Code [Ref. 1] using the following expression,

$$K_{Ia} = 26.78 + 1.223e^{[0.0145(T-RT_{NDT}+160)]} \text{ ksi}\sqrt{in} \qquad \text{(A-5)}$$

where,

T (°F) = metal service temperature (i.e. test temperature)

For beltline regions, the ART value is substituted for the RT_{NDT}. Fracture toughness values for both 20.3 and 28 EFPY at 1/4 t depth are summarized in Table A-4a and A-4b respectively. The maximum calculated value was limited to 200 ksi$\sqrt{in}$. Table A-4c lists the LAS material yield strength at various temperatures used in this analysis.

A-6. Vessel Test Pressures and Metal Temperatures

The vessel temperatures and pressures used in the analysis correspond to the hydro test and bolt up conditions. For the hydro test condition at 20.3 EFPY, the temperature and pressure are 247°F and 1195 psig respectively [Reference 14]; for 28 EFPY, the temperature and pressure are 260°F and 1195 psig [Reference 15] respectively. The bolt up condition was analyzed at a temperature of 100°F.

A-7. Bolt Preload and Shroud Repair & Stud Replacement Stresses

Bolt up stresses are assumed negligible for the beltline vessel welds since stresses are fully attenuated. Beyond a 10 inch region of the flange discontinuity, flange stresses have been shown to be fully attenuated [Reference 2], and as such, the analysis for locations other than VFW does not include any bolt up stresses. The circumferential and longitudinal stress at the vessel flange weld locations were obtained from Reference 11 and are shown in Table A-5.

The circumferential and longitudinal stresses resulting from the shroud repair hardware implementation at Nine Mile Point 1 (Reference 13) are added for the leak test condition at all welds except the vessel flange weld as shown in Table A-5.

The stresses resulting from the stud replacement at Nine Mile Point 1 (Reference 16) do not invalidate the existing stresses per Reference 11 (CENC-1142 report) and none are included at the vessel flange weld and all other locations were included in the values shown in Table A-5.

A-8. Cladding Residual Stresses

A stainless steel (SS) clad was applied to the inner surface of the vessel. Based on the simulated post-weld heat treatment (PWHT) data reported for the welds, a PWHT temperature of 1150°F is assumed. For the purposes of this analysis, the cladding is assumed to have zero stress at 1150°F. At temperatures other than the PWHT temperature, clad stresses are difficult to predict, since they depend on the PWHT and the clad yield strength.

For room temperature conditions the elastic clad residual stress is initially estimated at

$$\sigma_{c,70°F} = E_{70} (\Delta\alpha) (\Delta T) / (1-\mu) = 118 \text{ ksi} > S_{y,70°F}$$

where,

E_{70} = 28,300 ksi, modulus of elasticity for SS at room temperature (Table I-6.0, Section III of ASME Code [Ref. 1]).

μ = 0.3, Poisson's ratio.

ΔT = (1150-70) = 1080°F.

$\Delta\alpha$ = Difference in coefficient of thermal expansion between SS and LAS, 2.7 x10^{-6} in/in-°F [Ref. 5]

$S_{y,70°F}$ = 35 ksi, assumed SS yield strength.

However, because the elastic stress is greater than reported yield strengths for stainless steel clad, a clad stress of 35 ksi will be used at room temperature. This value is consistent with typical yield strength values reported for 304SS clad materials.

The clad residual stress for the leak test condition at 247°F (for all regions excluding the bottom head) is estimated as,

$$\sigma_{c,247°F} = \sigma_{c,70°F} + E_{247} (\Delta\alpha) (\Delta T)/(1-\mu) = \underline{18.15 \text{ ksi}}$$

where,

E_{247} = 27,318 ksi, modulus at 247°F

ΔT = (70-247) = -177°F (leak test @ 247°F)

$\Delta\alpha$ = 2.44×10^{-6} in/in-°F

$\sigma_{c,70°F} = S_{y,70°F} = 35$ ksi

The clad residual stress for the leak test condition at 260°F (for all regions excluding the bottom head) is estimated as,

$\sigma_{c,260°F} = \sigma_{c,70°F} + E_{260} (\Delta\alpha) (\Delta T)/(1-\mu) = \underline{17.11 \text{ ksi}}$

where,

E_{260} = 27,240 ksi, modulus at 260°F

ΔT = (70-260) = -190°F (leak test @ 260°F)

$\Delta\alpha$ = 2.42×10^{-6} in/in-°F

$\sigma_{c,70°F} = S_{y,70°F} = 35$ ksi

Table A-1

Vessel Geometry

Component I.D.	Shell Course	Maximum I.D. [in]	Min. LAS Thickness [in]	Clad Thickness [in]	Distance from flange [in]
All Plates and Vertical Welds	Upper	213.438	7.125	0.2188	< 10
All Plates and Vertical Welds	Upper-Intermediate	213.438	7.125	0.2188	> 10
G-307-3 G-307-4 G-307-10	Lower-Intermediate	213.438	7.125	0.2188	> 10
Weld RVWD-139 @ 105° Weld RVWD-140 @ 225° Weld RVWD-141 @ 245°	Lower-Intermediate	213.438	7.125	0.2188	> 10
G-8-1 G-8-3 G-8-4	Lower	213.438	7.125	0.2188	> 10
Weld RVWD-142 @ 18° Weld RVWD-143 @ 138° Weld RVWD-144 @ 258°	Lower	213.438	7.125	0.2188	> 10
Circumferential Weld RVWD-137	Lower/ Lower-Intermediate	213.438	7.125	0.2188	> 10

NOTE: For components >10 inches away from the flange, bolt up stresses are fully attenuated (Ref. 2).

Table A-2

Limiting Initial RT_{NDT}

Weld Region	Shell Course	Weld Material.* [°F]	Base Material. [°F]	Limiting RT_{NDT} including $2\sigma_I$ [°F]
All Vertical Welds	Upper	40	40**	40
All Vertical Welds	Upper-Intermediate	40	40**	40
Weld @ 105°	Lower-Intermediate	-50	28	28
Weld @ 225°	Lower-Intermediate	-50	40	40
Weld @ 345°	Lower-Intermediate	-50	40	40
Weld @ 18°	Lower	-50	36	36
Weld @ 138°	Lower	-50	36	36
Weld @ 258°	Lower	-50	-3	-3
Circum. Weld RVWD 137	Lower/ Lower-Intermediate	-50	40	40

* Values from Reference 3.

** Conservatively assumed values for non-beltline plates

Table A-3a
Adjusted Reference Temperature (ART) Information
for Beltline Regions @ 20.3 EFPY

Shell Course	Weld Region	Fluence at 1/4 t [n/cm^2]	Limiting $ART_{1/4t}$ based on fluence [°F]
Lower Inter.	Weld @ 105°	9.26×10^{17}	116 $^{(p)}$
	Weld @ 225°	3.21×10^{17}	114 $^{(p)}$
	Weld @ 345°	9.26×10^{17}	144 $^{(p)}$
Lower	Weld @ 18°	6.327×10^{17}	144 $^{(p)}$
	Weld @ 138°	2.187×10^{17}	110 $^{(p)}$
	Weld @ 258°	5.743×10^{17}	72 $^{(p)}$
Lower/ Lower-Intermediate	Weld RVWD 137	6.357×10^{17}	132 $^{(p)}$

$^{(w)}$ Weld material is limiting

$^{(p)}$ Plate material is limiting

Table A-3b

Adjusted Reference Temperature (ART) Information
for Beltline Regions @ 28 EFPY

Shell Course	Weld Region	Fluence at 1/4 t [n/cm^2]	Limiting $ART_{1/4t}$ based on fluence [°F]
Lower Inter.	Weld @ 105°	1.27×10^{18}	125 (p)
	Weld @ 225°	4.43×10^{17}	122 (p)
	Weld @ 345°	1.27×10^{18}	155 (p)
Lower	Weld @ 18°	8.73×10^{17}	156 (p)
	Weld @ 138°	3.02×10^{17}	119 (p)
	Weld @ 258°	7.92×10^{17}	79 (p)
Lower/ Lower-Intermediate	Weld RVWD 137	8.789×10^{17}	142 (p)

(w) Weld material is limiting

(p) Plate material is limiting

Table A-3c

Best Estimate Chemistry for Beltline Materials

Shell (Course) Identification	Chemical Composition (Wt. %)*		Chemistry Factor (Deg)**
	Cu	Ni	
G-307-3	0.20	0.48	134.6
G-307-4	0.27	0.53	174.0
G-307-10	0.22	0.51	148.9
G-8-1	0.23	0.51	221.3***
G-8-3	0.18	0.56	130.2
G-8-4	0.18	0.56	130.2
All Welds	0.22	0.20	112.0

*Note: Based on Reference 12.

**Note: Table 1 (weld) or Table 2 (Shell) of Reg. Guide 1.99 [Reference 9]

***Note: This is chemistry factor for Plate G-8-1 used to develop the P-T curves [Reference 3]

Table A-4a
Fracture Toughness, K_{Ia}
per Appendix G, Section XI of ASME Code
Beltline Regions @ 20.3 EFPY

Weld Region	Test Temp [°F]	$ART_{1/4t}$ [°F]	$K_{Ia\ 1/4t}$ [$ksi\sqrt{in}$]
Non-Beltline	247	40*	200
Weld @ 105°	247	116	111
Weld @ 225°	247	114	113
Weld @ 345°	247	144	82
Weld @ 18°	247	144	82
Weld @ 138°	247	110	118
Weld @ 258°	247	72	186
Weld RVWD 137	247	132	93

* Note: Limiting RT_{NDT} is used.

Table A-4b
Fracture Toughness, K_{Ia}
per Appendix G, Section XI of ASME Code
Beltline Regions @ 28 EFPY

Weld Region	Test Temp [°F]	$ART_{1/4t}$ [°F]	$K_{Ia\ 1/4t}$ [ksi $\sqrt{in}$]
Weld @ 105°	260	125	116
Weld @ 225°	260	122	120
Weld @ 345°	260	155	84
Weld @ 18°	260	156	83
Weld @ 138°	260	119	123
Weld @ 258°	260	79	200
Weld RVWD 137	260	142	96

Table A-4c

Yield Stress for LAS Vessel Wall Material (Ref. 8)

Source of Temperature from Pressure-Temperature Curves	Temperature (°F)	Yield Stress (ksi)
Bolt up	100	50
Leak Test at 20.3 EFPY with pressure of 1195 psig	247	46.26
Leak Test at 28 EFPY with pressure of 1195 psig	260	46.01

Table A-5
Stress Values Used in the Flaw Evaluation

Location	Loading Condition	Flaw Orientation	Pressure Stress [ksi] ***	Other (**)Loading [ksi] σ_m	σ_b*	Weld Residual [ksi]	Clad Residual [ksi] 20.3 EFPY	28 EFPY
Non-Beltline (near flange)	Bolt up	Axial	$\sigma_\theta = 0.0$	1.7	7.8	8	35.0	35.0
		Circumf.	$\sigma_a = 0.0$	0.0	26.0	0	35.0	35.0
Non-Beltline (near flange)	Leak Test	Axial	$\sigma_\theta = 18.51$	0.3	6.9	8	18.15	17.11
		Circumf.	$\sigma_a = 9.26$	0.3	21.9	0	18.15	17.11
Non-Beltline (away from flange)	Leak Test	Axial	$\sigma_\theta = 18.51$	0.3	0.5	8	18.15	17.11
		Circumf.	$\sigma_a = 9.26$	0.3	0.5	0	18.15	17.11
Vertical Welds Beltline	Leak Test	Axial	$\sigma_\theta = 18.51$	0.3	0.5	8	18.15	17.11
		Circumf.	$\sigma_a = 9.26$	0.3	0.5	0	18.15	17.11
Circumferential weld Beltline	Leak Test	Axial	$\sigma_\theta = 9.26$	0.3	0.5	0	18.15	17.11
		Circumf.	$\sigma_a = 18.51$	0.3	0.5	8	18.15	17.11

* Calculated at surface of vessel wall.

** Includes 0.3 ksi (membrane) and 0.5 ksi (bending) from Reference 13 along with other stress from Reference 11 for appropriate transient condition.

** Calculated by formula of PR/t (hoop) and PR/2t (axial), where P = 1.195 ksi (leak test) and 0 ksi (bolt up), R = Mean radius = 110.28 in, and t = 7.125 in.

APPENDIX B - FLAW EVALUATION PROCEDURE

B. FLAW EVALUATION PROCEDURE

This section describes the procedure to be followed to evaluate a flaw should one be found in the reactor pressure vessel. The attached worksheet is to be used to record the flaw evaluation for each flaw. Figure B-1 may be used to sketch the flaw. Figure B-2 is a flowchart which outlines the detail evaluation procedure described below.

The following procedure should be used in conjunction with the flaw acceptance diagrams (Figures in Appendix C and D), the attached worksheet and flaw evaluation flowchart to determine flaw sizes and evaluate the acceptability of flaws.

B-1. Determine Region and Orientation of Flaw

Particular flaw locations not considered in this handbook are listed below. Flaws in any of these locations shall be listed as region 0 in step 1 of the worksheet. These flaws must be addressed with a flaw specific analysis not covered by this handbook.

a) Flaws in or near (within 1 plate thickness of) attachment welds,
b) Flaws in or near (within $\sqrt{Rt}$ = 28 inches of) the shroud support plate to vessel weld,
c) Flaws in or near (within $\sqrt{Rt}$ = 28 inches of) the vessel support skirt to vessel weld,
d) Flaws in vessel studs or nuts,
e) Flaws in nozzles or nozzle-to-vessel blend radii,
f) Flaws in reactor internals,
g) Flaws in nozzle safe ends or piping,
h) Flaws in vessel tophead or bottomhead.

The various vessel welds considered in this handbook are shown in Figure 1-1. Flaws should be classified as either inside surface, outside surface, or subsurface per the proximity rules of Section XI of the ASME Code. The correct weld region identification is to be recorded on step 1 of the worksheet. If the flaw is contained in two regions or if it is not possible to definitely determine in which region the flaw is located, the flaw is to be evaluated against the acceptance criteria for the more limiting region.

The flaw orientation shall be classified as circumferential if the plane of the flaw is within 30° of horizontal. A flaw which is greater than 30° from horizontal shall be classified as axial.

B-2. Flaw Geometry and Classification

The geometry of the flaw or group of flaws in close proximity are first to be sketched. This sketch should be attached to the worksheet. Figure B-1 may be used for this sketch which shall include:

a) The measured thickness, 't', of the low alloy steel vessel wall in the region containing the flaw. If the measured thickness is not available, the design thickness from Table A-1 shall be used.

b) The measured clad thickness, 't_{clad}', in the region of the flaw. If the clad thickness can not be determined, the nominal clad design thickness of 0.2188 inch is to be used per paragraph IWA-3320 of Section XI of the ASME Code.

c) The location of the flaw with respect to the surface and to other flaws is to be sketched and dimensioned in accordance with IWA-3300 of Section XI, ASME Code.

d) The flaw shape and measurements of proximity parameters in accordance with the proximity rules of IWA-3300 of Section XI, ASME Code.

e) Combine any flaws in close proximity to other flaws or to the surface according to the rules contained in section IWA-3300. Flaws need not be combined unless they are in parallel planes within 1/2-inch of each other.

Upon applying proximity rules, planar flaws will be classified as follows:

1) inside surface flaws (measured from clad surface).
2) outside surface flaws (no clad).
3) subsurface flaws.

The appropriate classification should be recorded in step 3 of the worksheet.

B-3. Flaw Size and Aspect Ratio

The final flaw dimensions are next recorded in step 5 of the worksheet. Note that for subsurface flaws, the flaw depth is measured as 2a. The flaw aspect ratio is calculated as a/L, where 'a' represents the half-depth in the case of subsurface flaws.

B-4. IWB-3500 Flaw Evaluation

The detected flaw is first evaluated in accordance with paragraph IWB-3500 of the ASME Code, Section XI. Note that the subsurface IWB-3500 curves have been calculated only for a typical mid-plane flaw with a proximity factor of Y = 1.0. The allowable flaw depth should be calculated in accordance with IWB-3510 based upon the actual measured flaw location to show acceptability. The subsurface IWB-3500 evaluation provided in this handbook are only valid for Y = S/a = 1.0.

B-5. IWB-3600 Flaw Evaluation

If the flaw does not satisfy the requirements of IWB-3500, the Site Corrective Action Program Activity is required and the IWB-3600 allowables may be used to justify continued operation up to the EFPY(s) evaluated in the flaw handbook; however, reinspection will be required.

B-6. Section III Evaluation (1/3 Limit)

If the flaw does not satisfy the allowable per IWB-3600 analysis, either flaw removal (1/3 limit satisfied) or weld repair (1/3 limit exceeded) will be necessary, unless a further flaw-specific evaluation can show the flaw to be acceptable. Refer to Figure B-2 and the attached worksheet for further details.

B-7. Further Evaluation

If a flaw can not be shown to be acceptable according to the flaw acceptance diagrams given in this report, it is possible that a flaw-specific analysis can be completed to show acceptance of this flaw with no repair. Because this analysis considers most of the Nine Mile Point Unit 1 vessel, some conservative assumptions were made to make the results bounding for various regions of the vessel. Some conservative assumptions which were made in the IWB-3600 fracture analysis include:

1. The most limiting (highest) RT_{NDT} for any material within the adjacent shell segments is assumed for the entire weld region.

2. The largest bending stresses for the closure flange regions are assumed to occur over the entire region.

3. Subsurface flaws are evaluated based upon surface fluence values and bounding proximity effects.

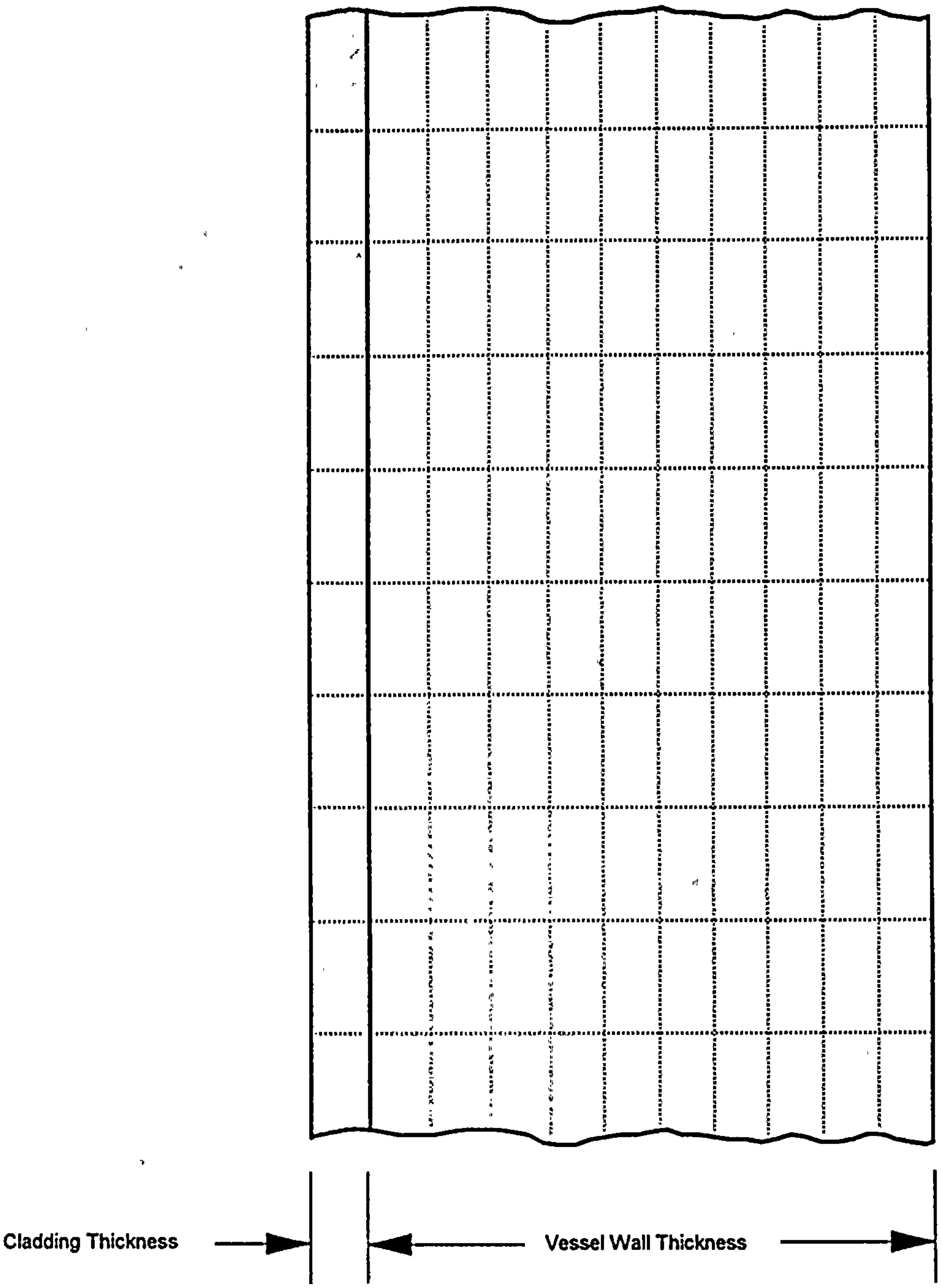
Although these assumptions do not add much conservatism to the analysis in most cases, a flaw-specific analysis should first be conducted to eliminate these conservatisms. Another possible alternative is to increase the leak test temperature. This may increase the material toughness during the most severe loading in terms of fracture and increase the allowable flaw depths. In this case, allowable flaws for operating conditions would have to be determined.

If the local stress limit (1/3 thickness) region of the acceptance curve is exceeded (the flat portion of the curve) the assumptions made above will not affect the flaw depth limit. For this case, a finite element analysis will likely be able to show additional margin.

If a flaw-specific analysis is not able to resolve the detected flaw, the flaw may have to be ground out or in extreme situations weld repaired (see flowchart of Figure B-2).

Vessel Flaw Sketch

Flaw ID: ________



t_{clad} = ______ t_{LAS} = ______

Figure B-1. Form for Vessel Flaw Sketches.

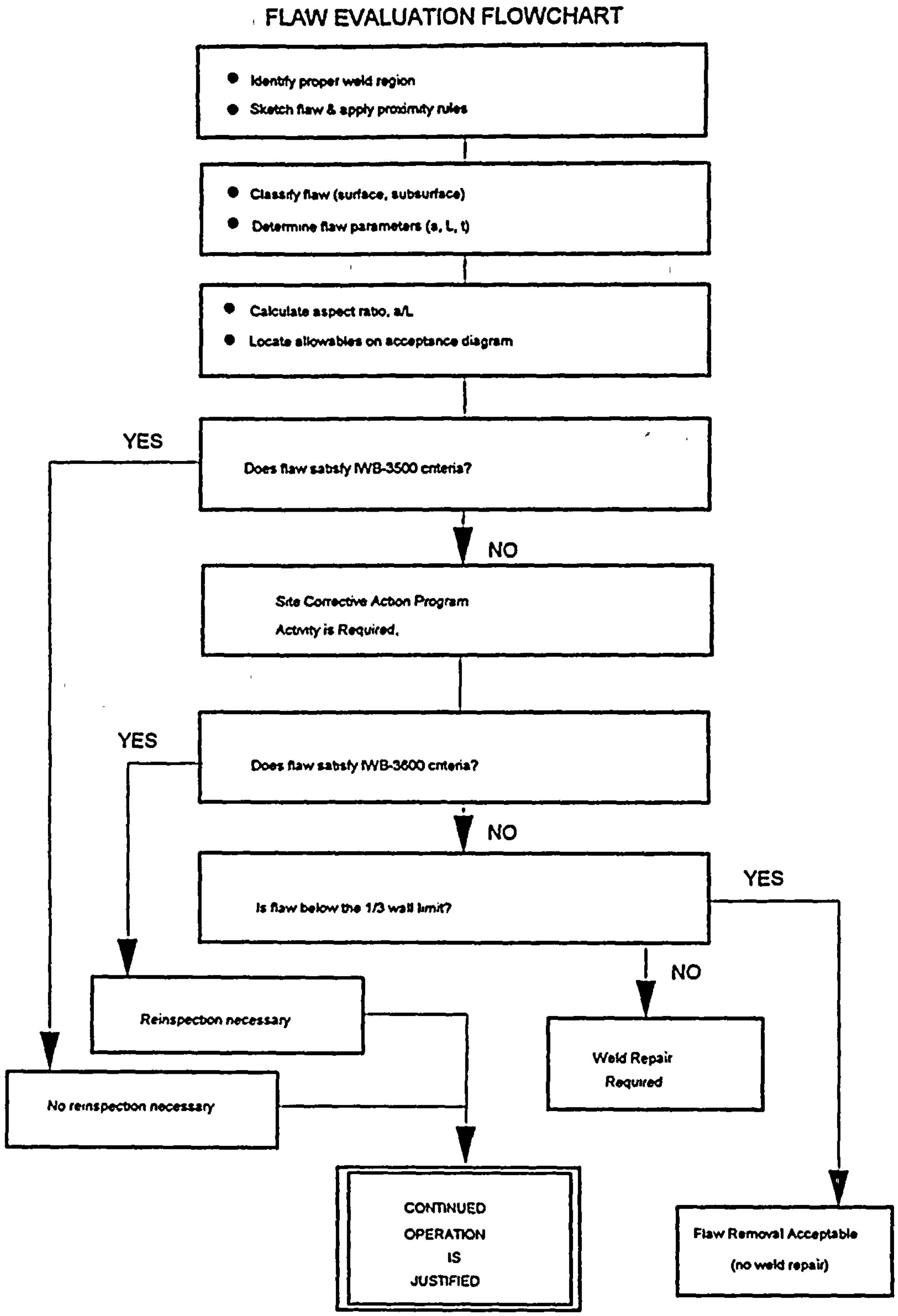


Figure B-2. Flowchart of flaw evaluation process.

NINE MILE POINT UNIT 1 FLAW EVALUATION WORKSHEET

Flaw ID:_______________

1. Determine Region and Orientation of Flaw. The weld region should be identified by the nearest weld. The orientation is either [A]xial or [C]ircumferential. If the flaw is at a junction between two welds, the region with the more limiting acceptance criteria should be conservatively used.

   Region: _______
   Orientation: _______

2. Sketch Flaw Geometry. Use the attached flaw sketch to draw the flaw.

3. Classify Flaw. Combine flaws in close proximity to other flaws and to the surface per the proximity rule of IWA-3300, Section XI of the ASME Code. Classify flaw as either:

   Inside Surface _______
   Outside Surface _______
   Subsurface _______

4. Determine Vessel Wall Geometry. If the flaw is classified as subsurface or outside surface, input 0 for clad thickness, else enter the analysis value for clad thickness as listed in Table A-1 of Appendix A for the specified weld region.

   Cladding Thickness, t_{clad} = _________ (in)
   Low Alloy Steel Thickness, t_{LAS} = _________ (in)
   Total thickness, $t = t_{clad} + t_{LAS}$ = _________ (in)

(Nine Mile Point Unit 1 Flaw Evaluation Worksheet cont'd)

Flaw ID:____________

5. Size Flaw. Calculate flaw depth, including any portion of the flaw extending into the cladding.

Surface Flaws:
Flaw Depth, a = ________ (in)
Flaw Length, L = ________ (in)

Subsurface Flaws:
Flaw Depth, 2a = ________ (in)
Half Depth, a = ________ (in)
Flaw Length, L = ________ (in)
Distance to Surface as defined in IWA-3300, S = ________ (in)

6. Calculate Aspect Ratio of Flaw.

Flaw Aspect Ratio, a/L = ________

7. IWB-3500 Flaw Evaluation. For the given a/L aspect ratio, determine the allowable flaw depth, a (surface) and 2a (subsurface), in accordance with IWB-3510 of the Code and record the value below. If the flaw depth recorded in step 5 is below the allowable value, check the box "Acceptable per IWB-3500" below. Otherwise, check the box "Unacceptable per IWB-3500" and continue to step 8.

Inside Surface Flaw:
IWB-3500 Allowable Depth = a = ________ (in)

Outside Surface Flaw (top head, head flange, vessel flange regions only):
IWB-3500 Allowable Depth = a = ________ (in)

Subsurface Flaw:
IWB-3500 Allowable Depth = 2a = ________ (in)

(Nine Mile Point Unit 1 Flaw Evaluation Worksheet cont'd)

Flaw ID:____________

ACCEPTABILITY:

_____ Acceptable per IWB-3500.

_____ Unacceptable per IWB-3500. (Site Corrective Action Program Activity required)

8. IWB-3600 Flaw Evaluation. Record the appropriate flaw acceptance diagram Figure number from Section 3.0. Record the allowable flaw depth, a or 2a, from the appropriate curve for the specified orientation. If the flaw depth recorded in step 5 is below the allowable value, check the box "Acceptable per IWB-3600" below. Otherwise, check the box "Unacceptable per IWB-3600", and proceed to step 9.

   NOTE: Outside surface flaws for vessel and bottom head regions are not considered limiting. Flaw specific analysis would be required if outside surface flaws were found in any region below the vessel flange.

   Figure # ______

   Inside Surface Flaw:

   IWB-3600 Allowable Depth = a = ________ (in)

   Outside Surface Flaw (top head, head flange, vessel flange regions only):

   IWB-3600 Allowable Depth = a = ________ (in)

   Subsurface Flaw:

   IWB-3600 Allowable Depth = 2a = ________ (in)

(Nine Mile Point Unit 1 Flaw Evaluation Worksheet cont'd)

Flaw ID:____________

ACCEPTABILITY:

____ Acceptable per IWB-3600. (for __ EFPY)
____ Unacceptable per IWB-3600.

9. From figure identified above, record the 1/3 wall thickness limit below. If flaw depth is below 1/3 limit, flaw removal is acceptable. Otherwise, weld repair is necessary.

1/3 Limit = ________ (in)

From step 5 above:

Flaw depth = a = ________ (surface)
2a +s - (clad thickness, if applicable) = ________ (subsurface)

Flaw depth < 1/3 Limit: **Flaw removal acceptable (No weld repair)**
Flaw depth > 1/3 Limit: **Weld repair required**

APPENDIX C - ALLOWABLE FLAW SIZE FOR 20.3 EFPY

This Appendix contains Figures C-1 through C-22

Figure C-1. Non-Beltline, Vessel Flange Horizontal Weld I. D. Flaw @ 20.3 EFPY

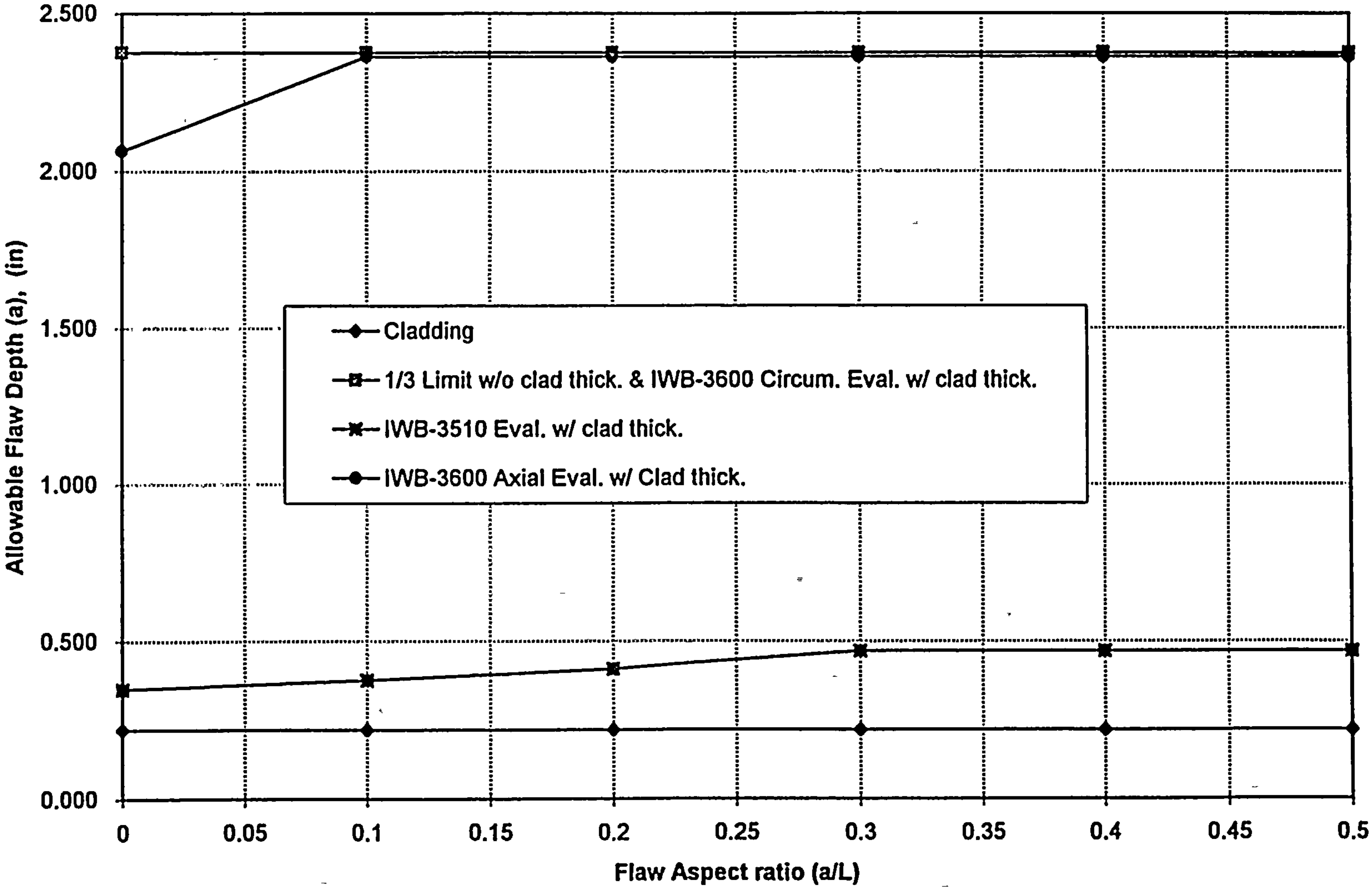


Figure C-2. Non-Beltline, Vessel Flange Horizontal Weld O. D. Flaw @ 20.3 EFPY

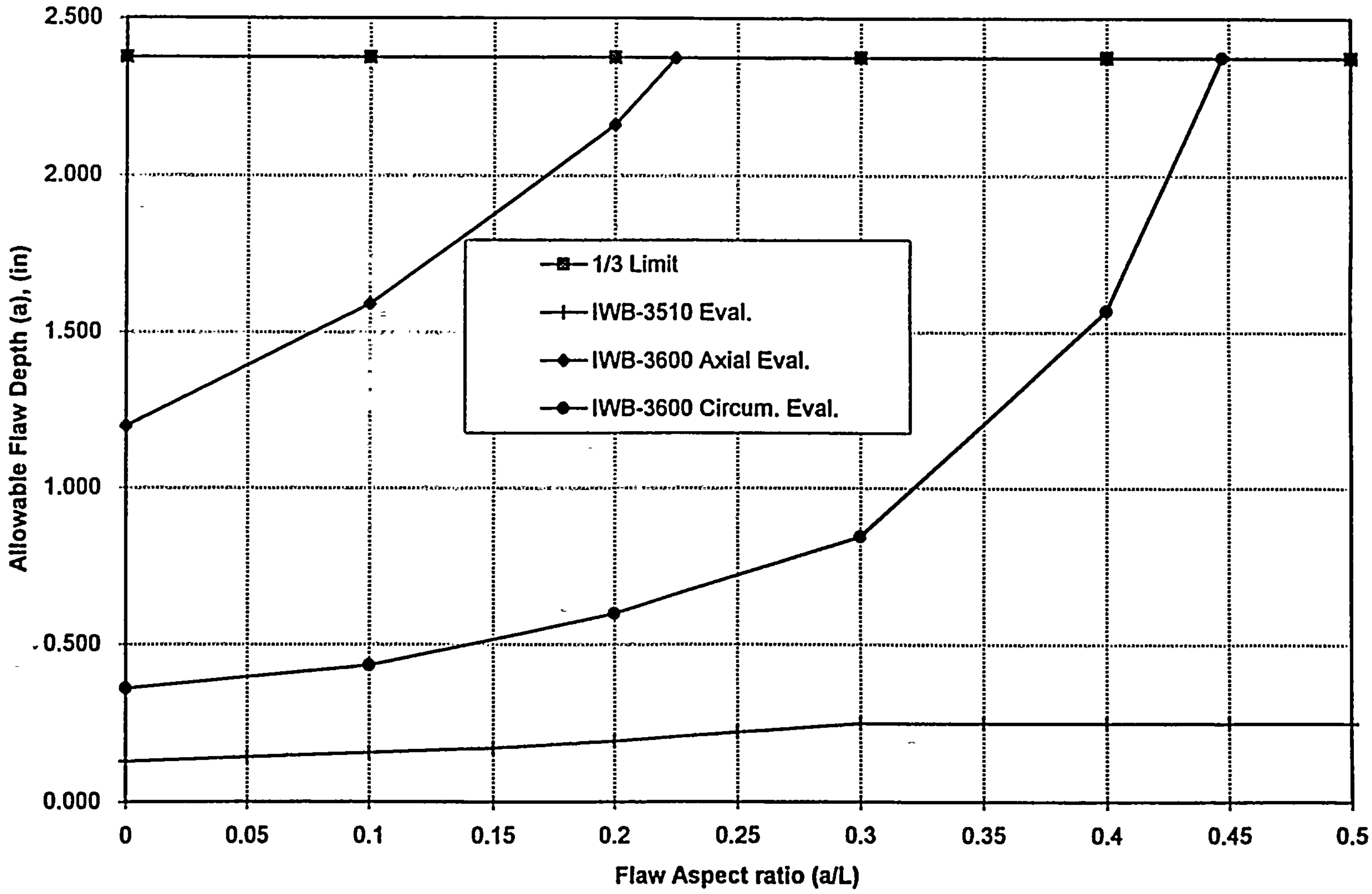


Figure C-3. Non-Beltline, Vessel Flange Horizontal Weld Subsurface Flaw @ 20.3 EFPY

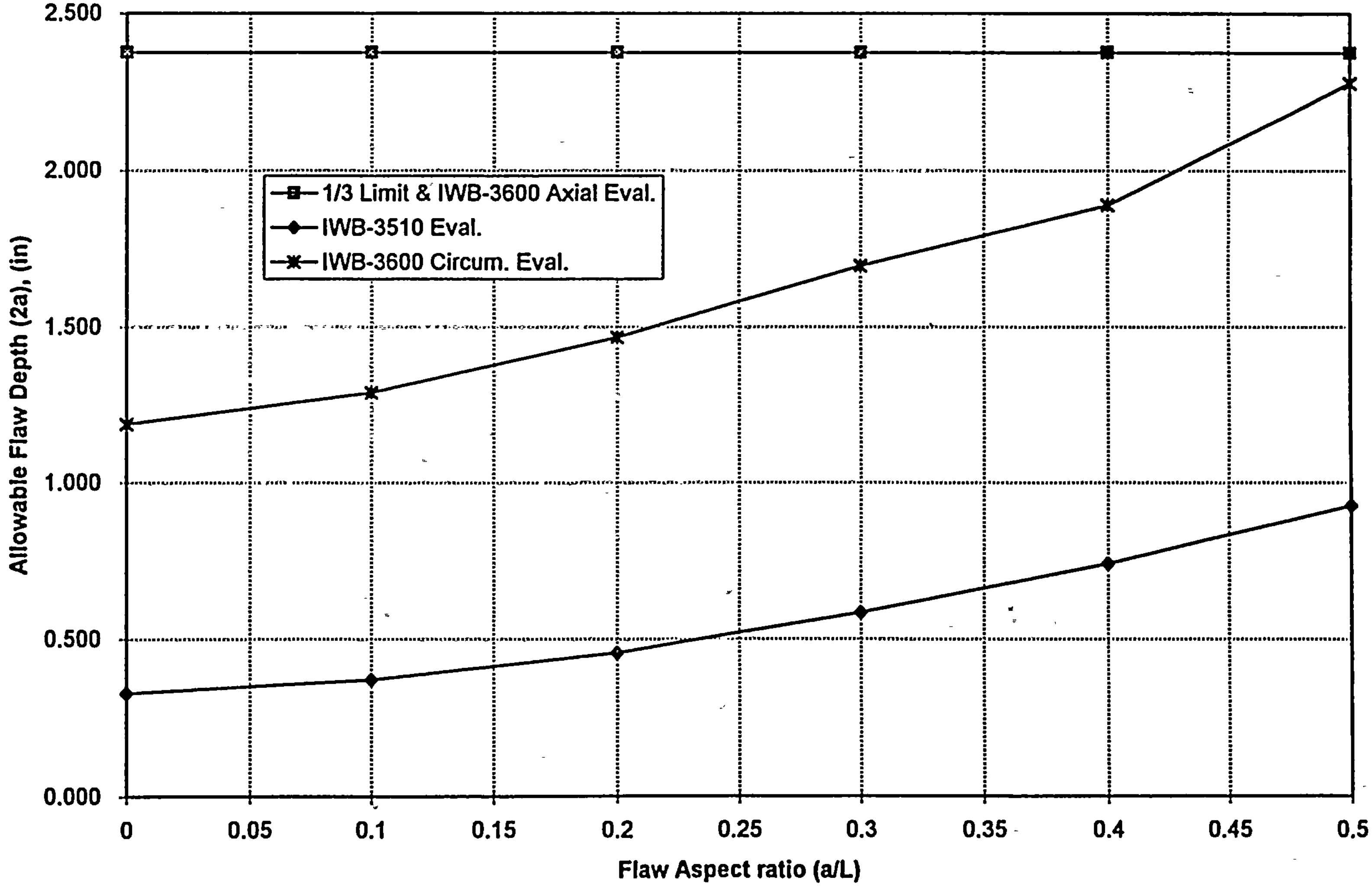


Figure C-4. Non-Beltline, Near the Vessel Flange I. D. Flaw
@ 20.3 EFPY

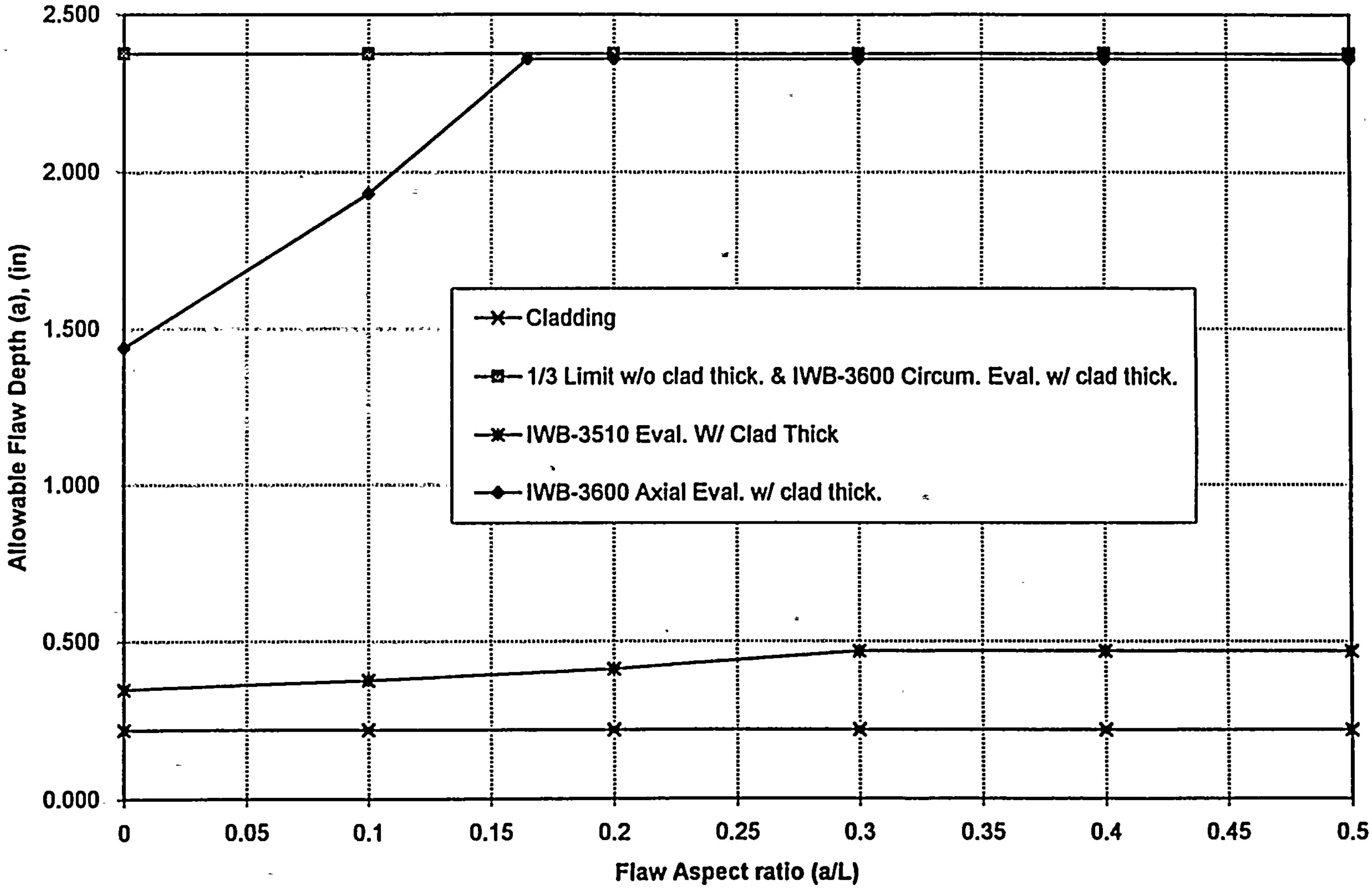


Figure C-5. Non-Beltline, Near the Vessel Flange O. D. Flaw
@ 20.3 EFPY

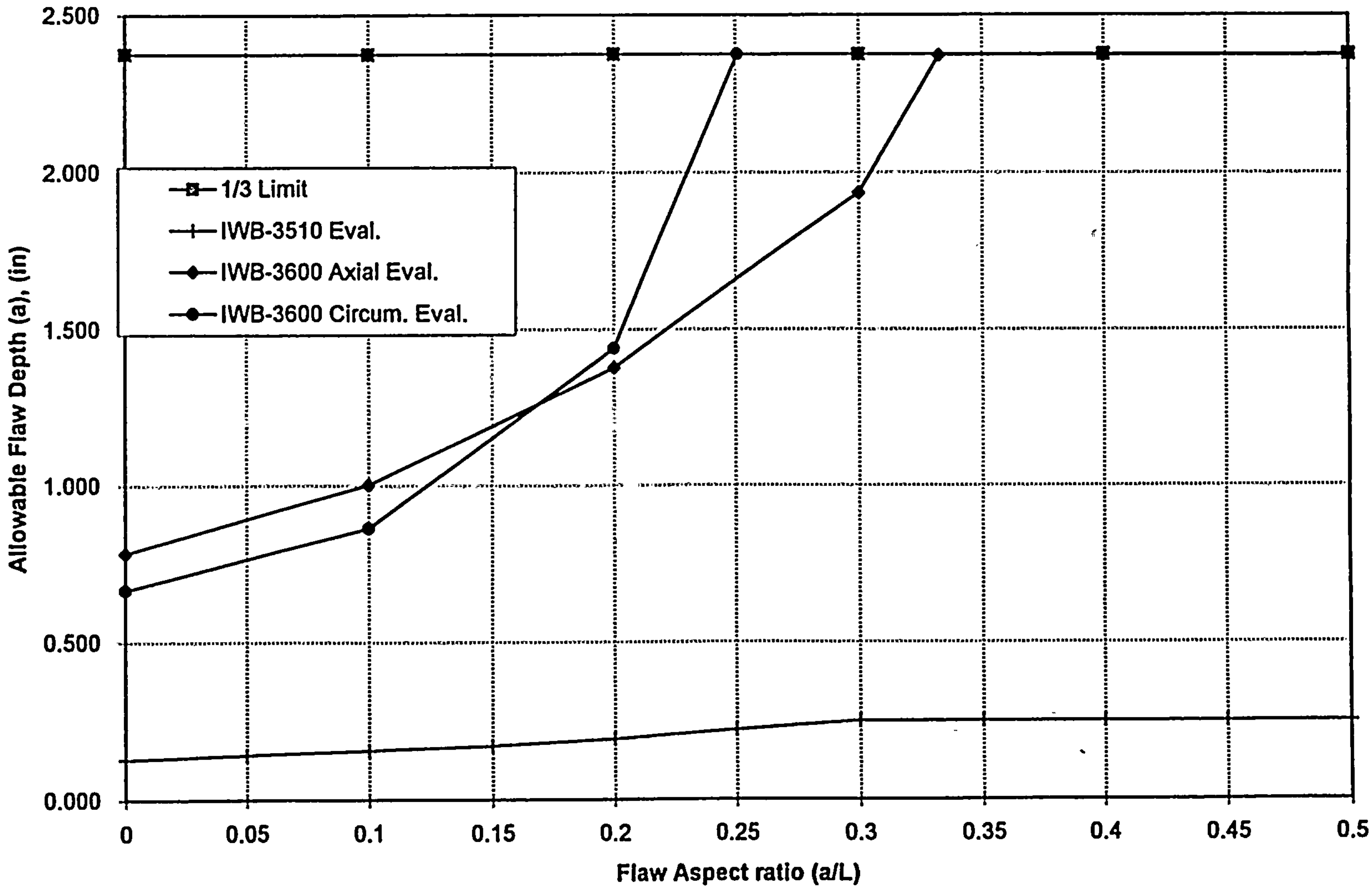


Figure C-6. Non-Beltline,Near the Vessel Flange Subsurface Flaw @ 20.3 EFPY

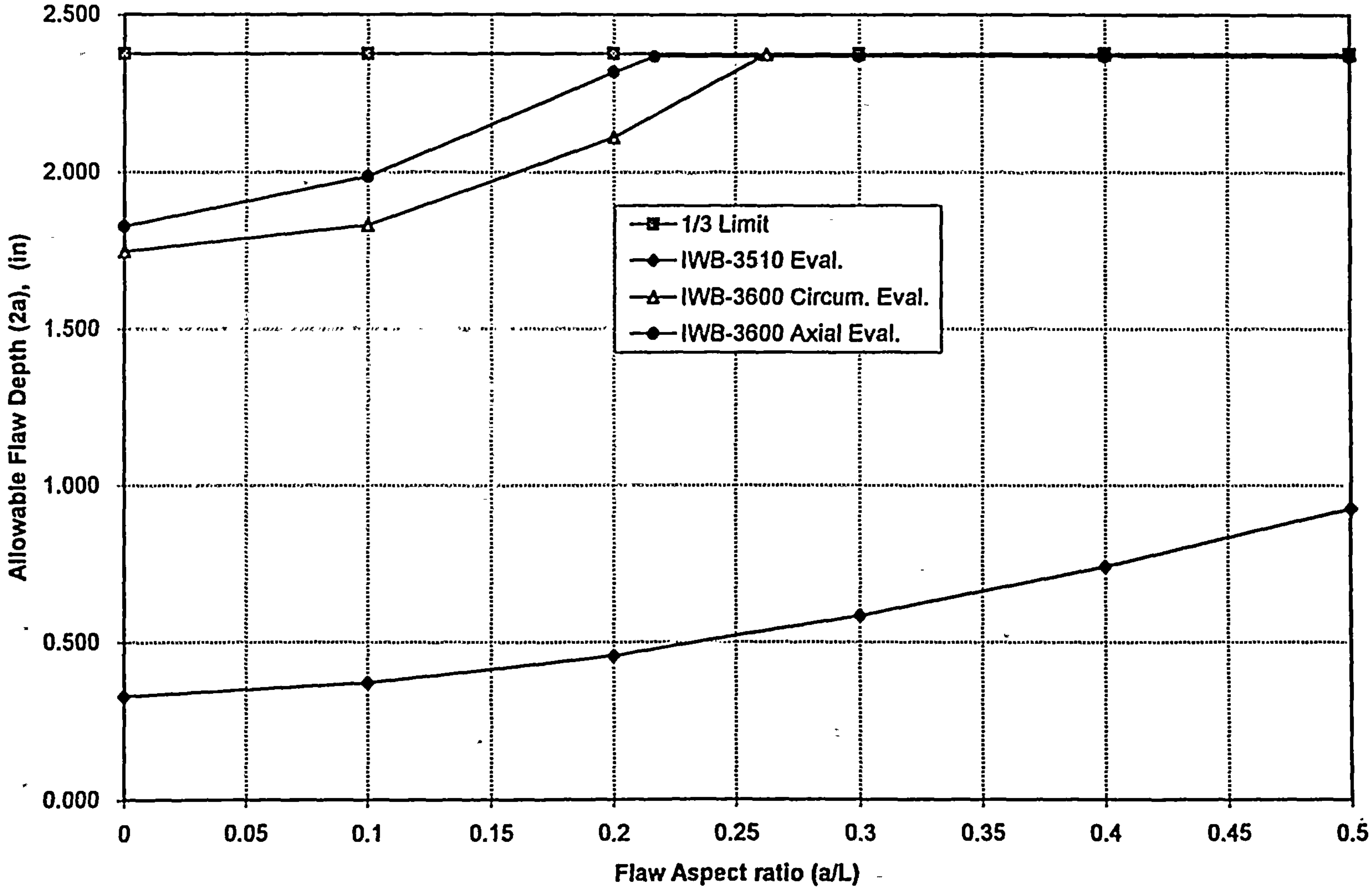


Figure C-7. Non-Beltline, Lower Course Surface Flaw @ 20.3 EFPY

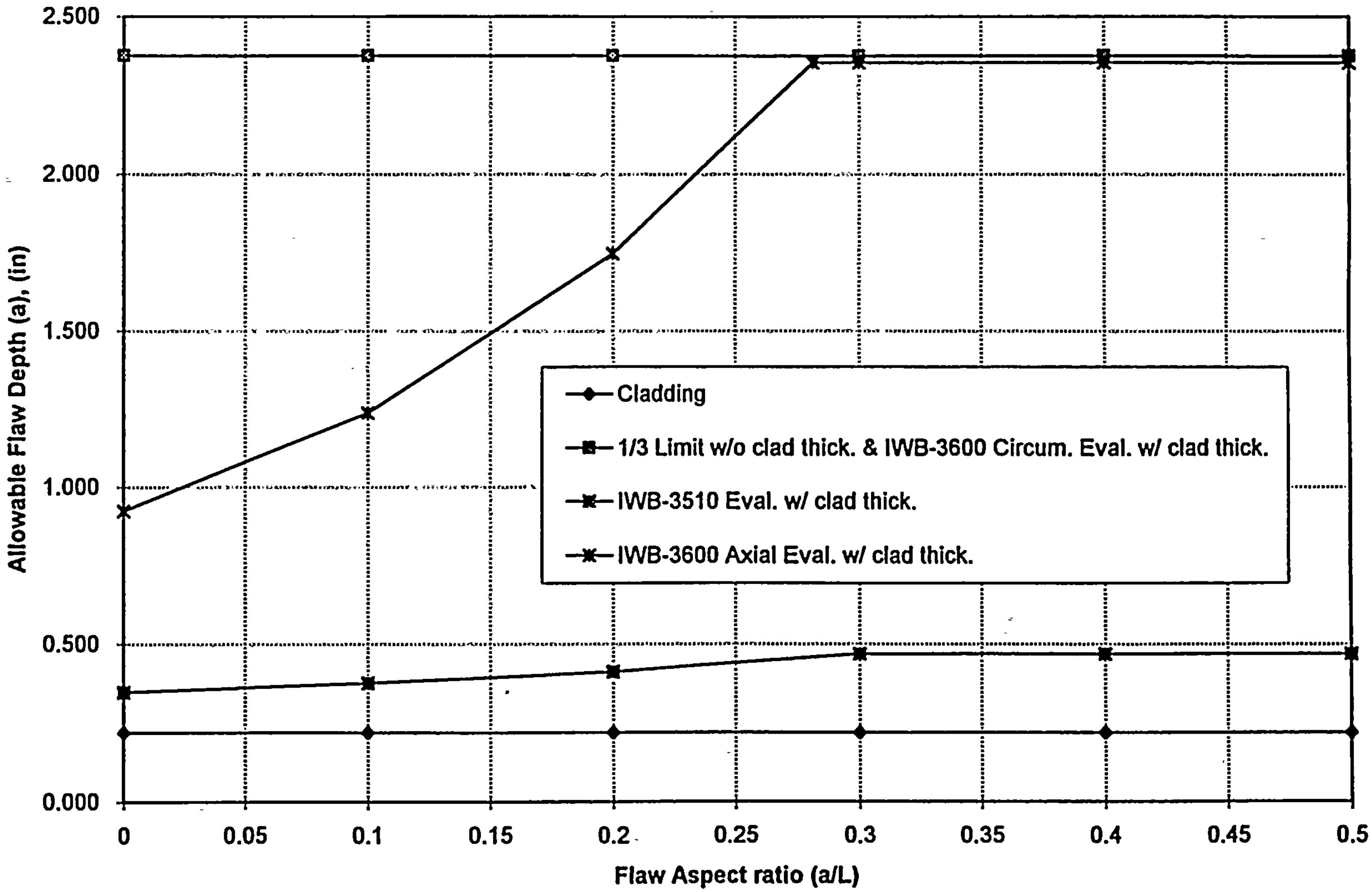


Figure C-8. Non-Beltline, Lower Course Subsurface Flaw @ 20.3 EFPY

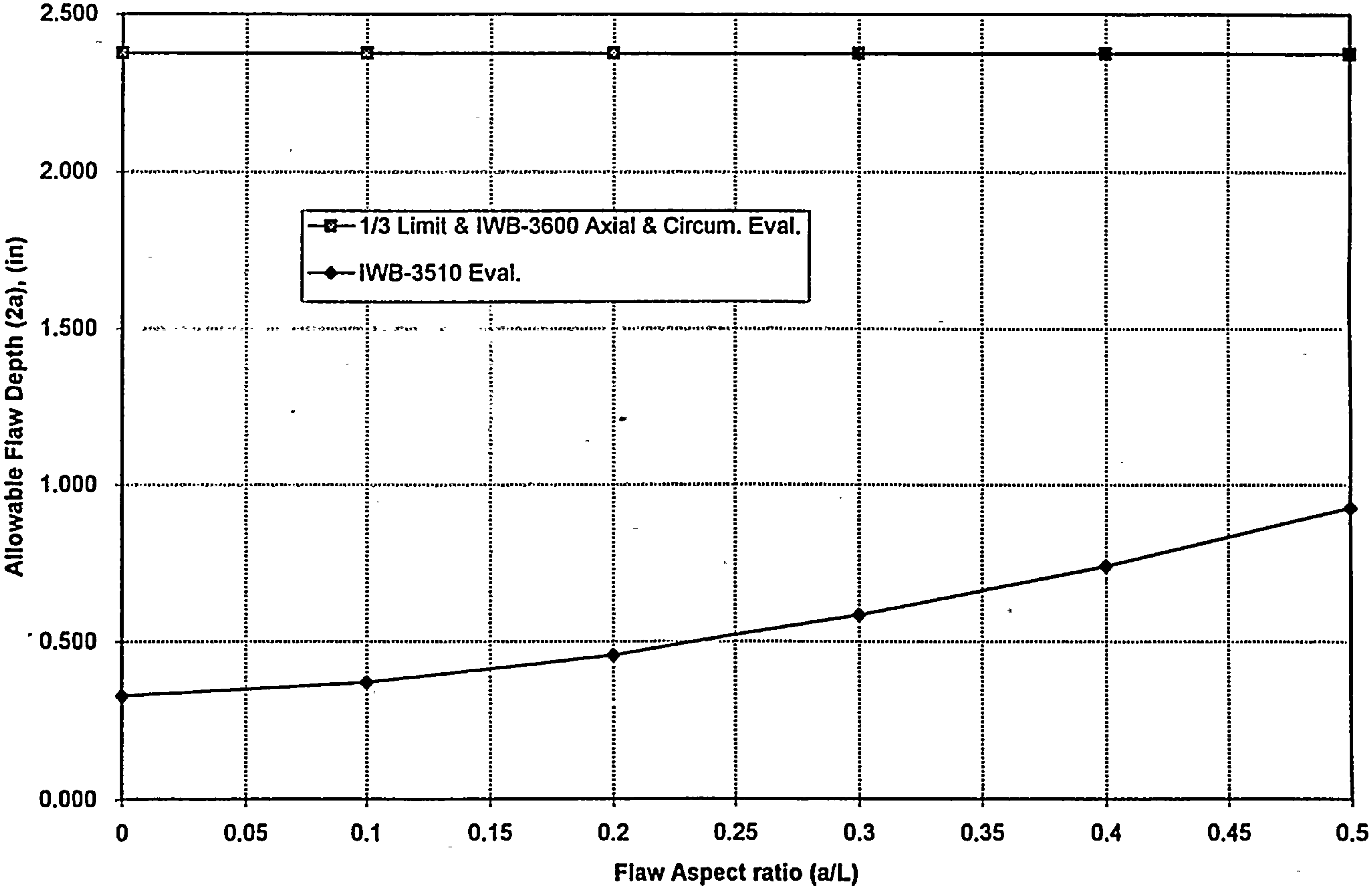


Figure C-9. Lower-Intermediate Course at 105 Deg, Surface Flaw @ 20.3 EFPY

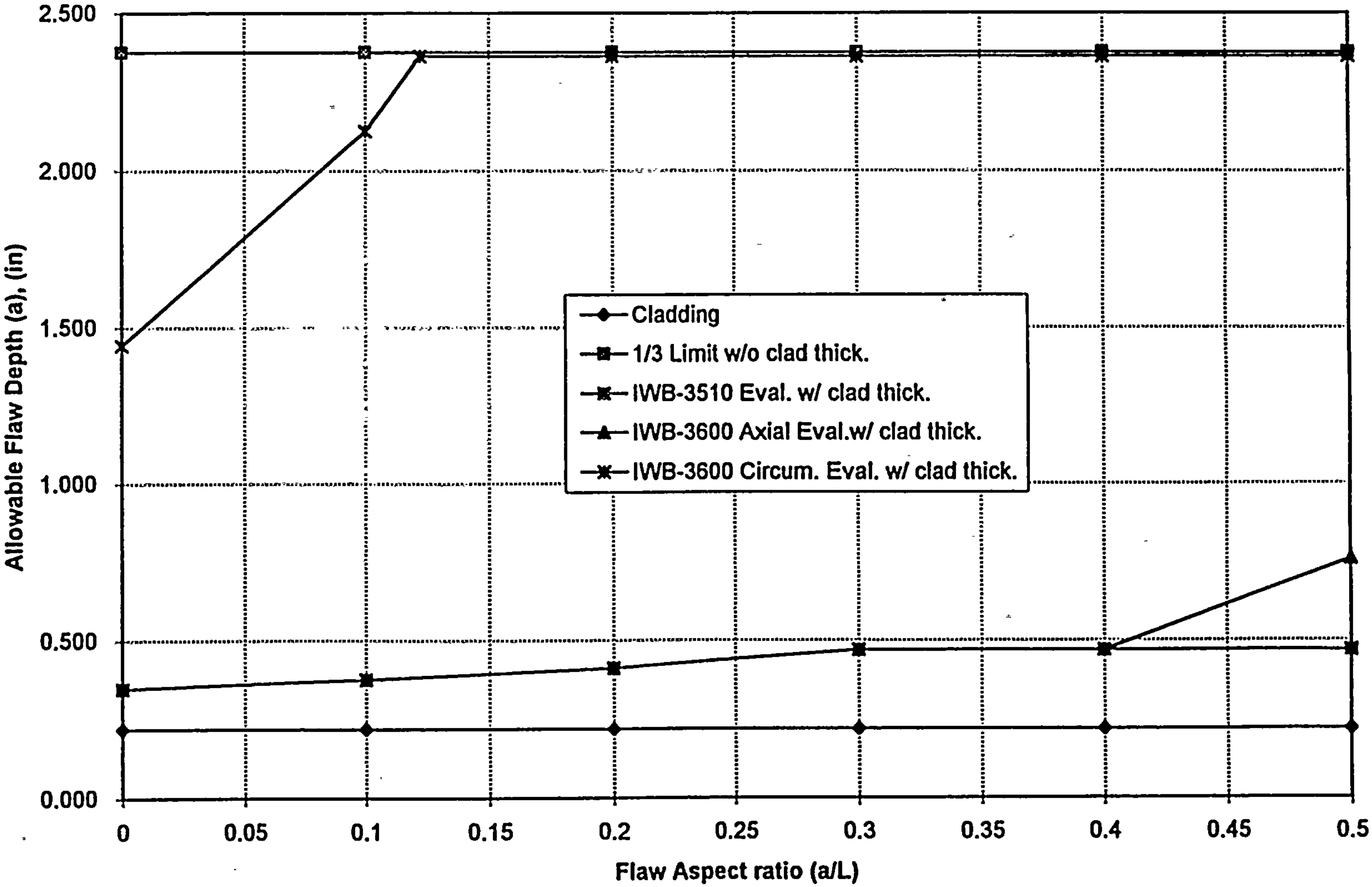


Figure C-11. Lower-Intermediate Course at 225 Deg, Surface Flaw @ 20.3 EFPY

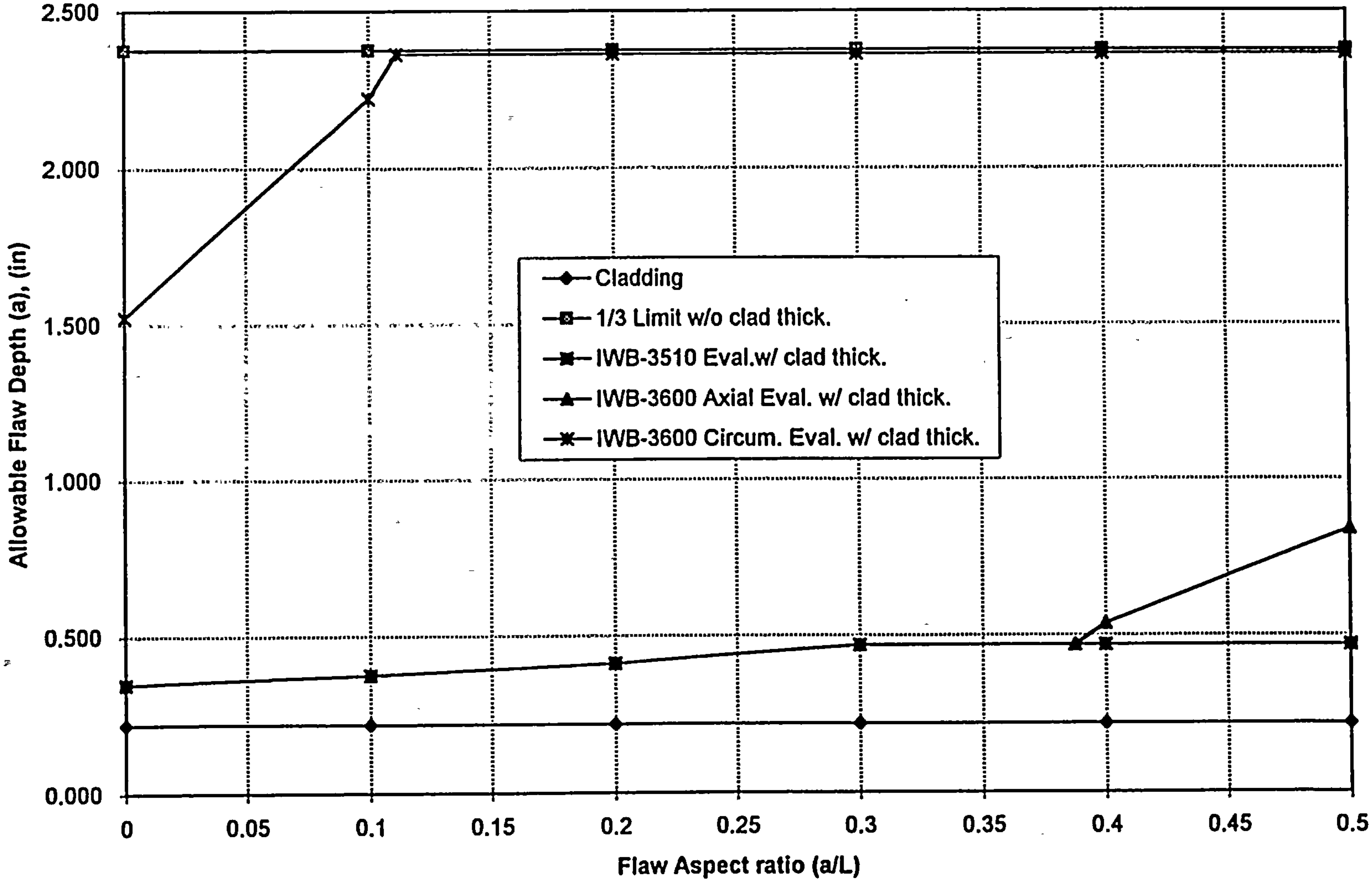


Figure C-12. Lower-Intermediate Course at 225 Deg, Subsurface Flaw @ 20.3 EFPY

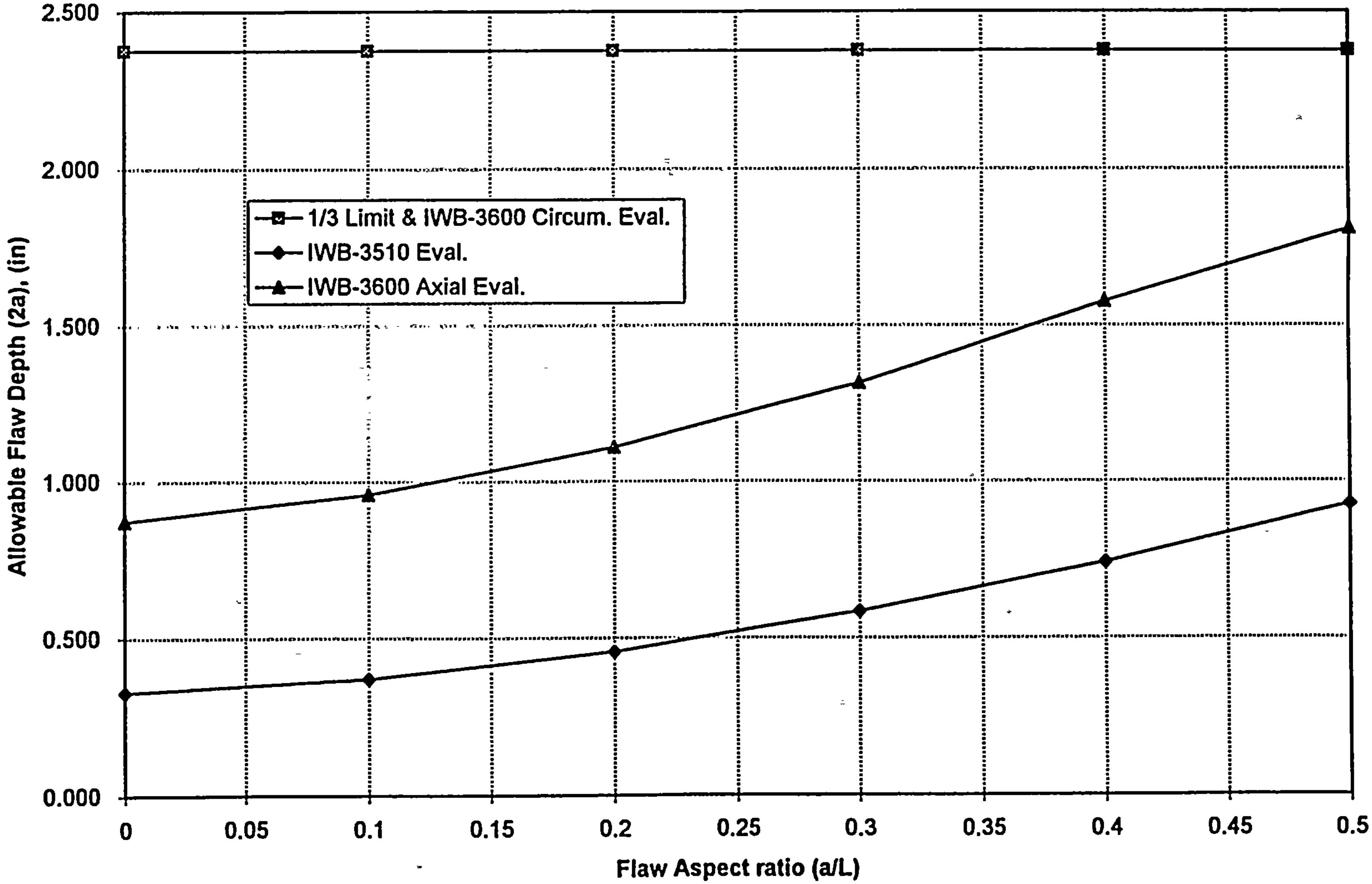


Figure C-13. Lower-Intermediate Course at 345 Deg, Surface Flaw @ 20.3 EFPY

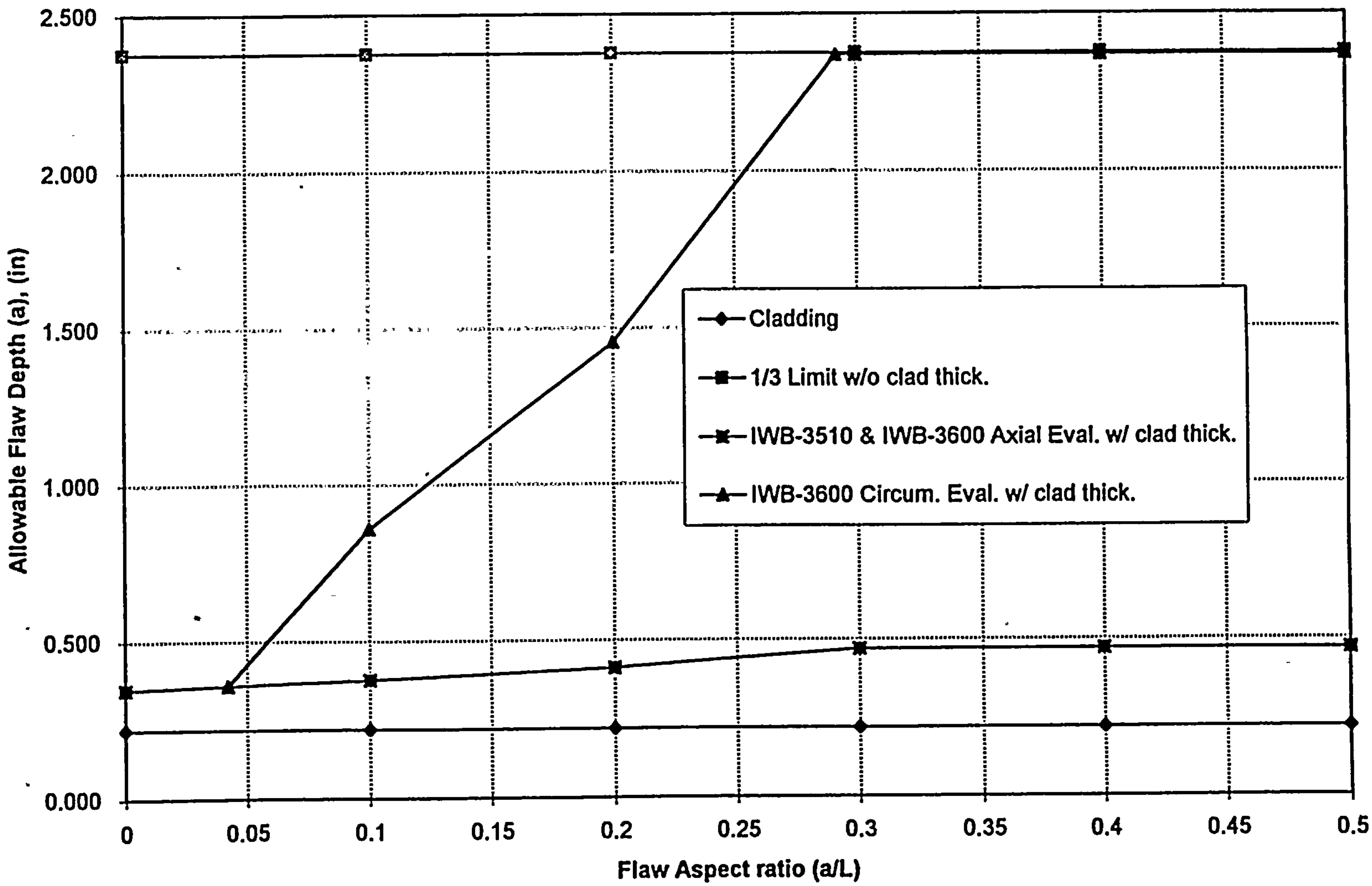


Figure C-14. Lower-Intermediate Course at 345 Deg, Subsurface Flaw @ 20.3 EFPY

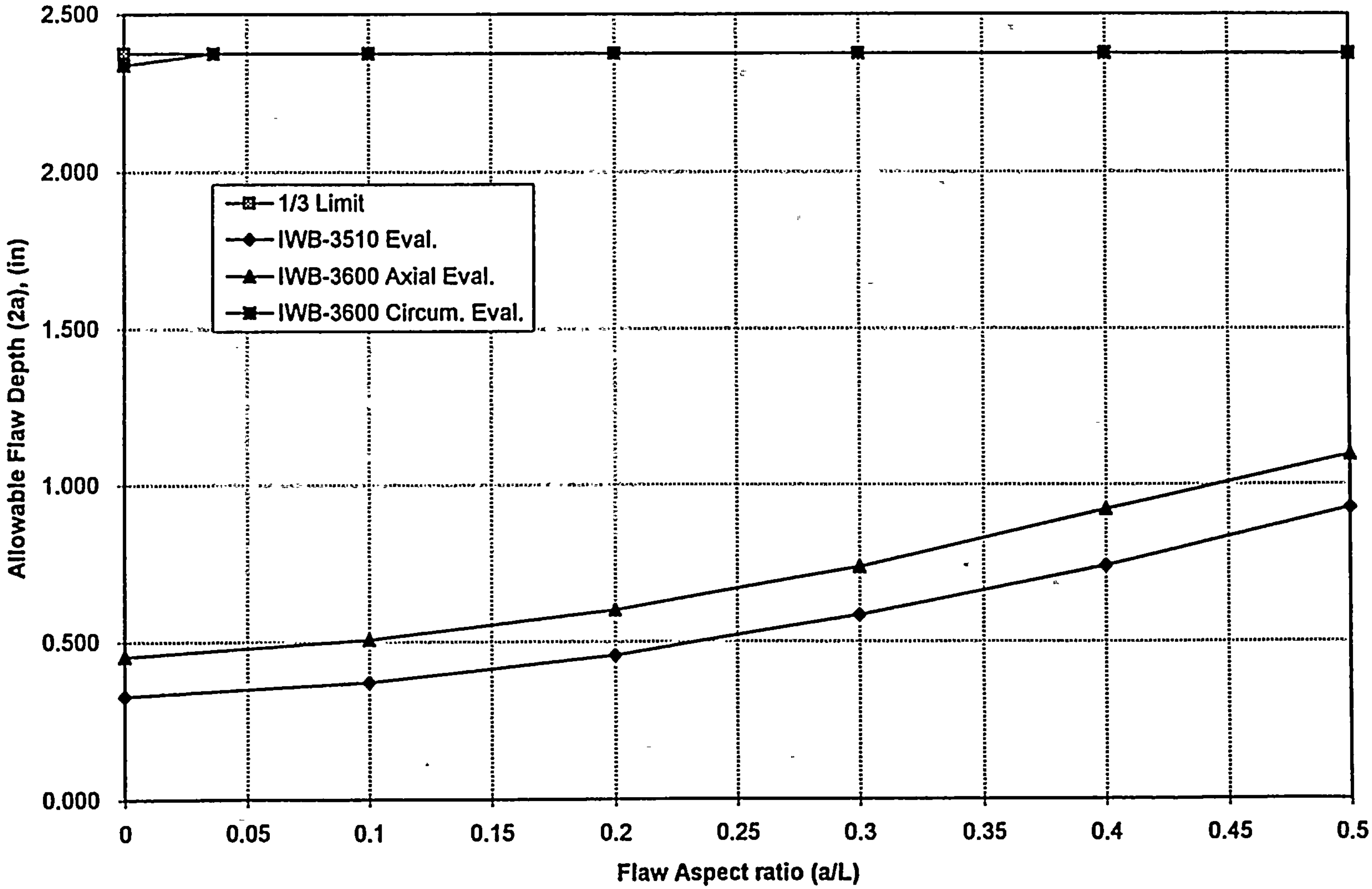


Figure C-15. Lower Course at 18 Deg, Surface Flaw
@ 20.3 EFPY

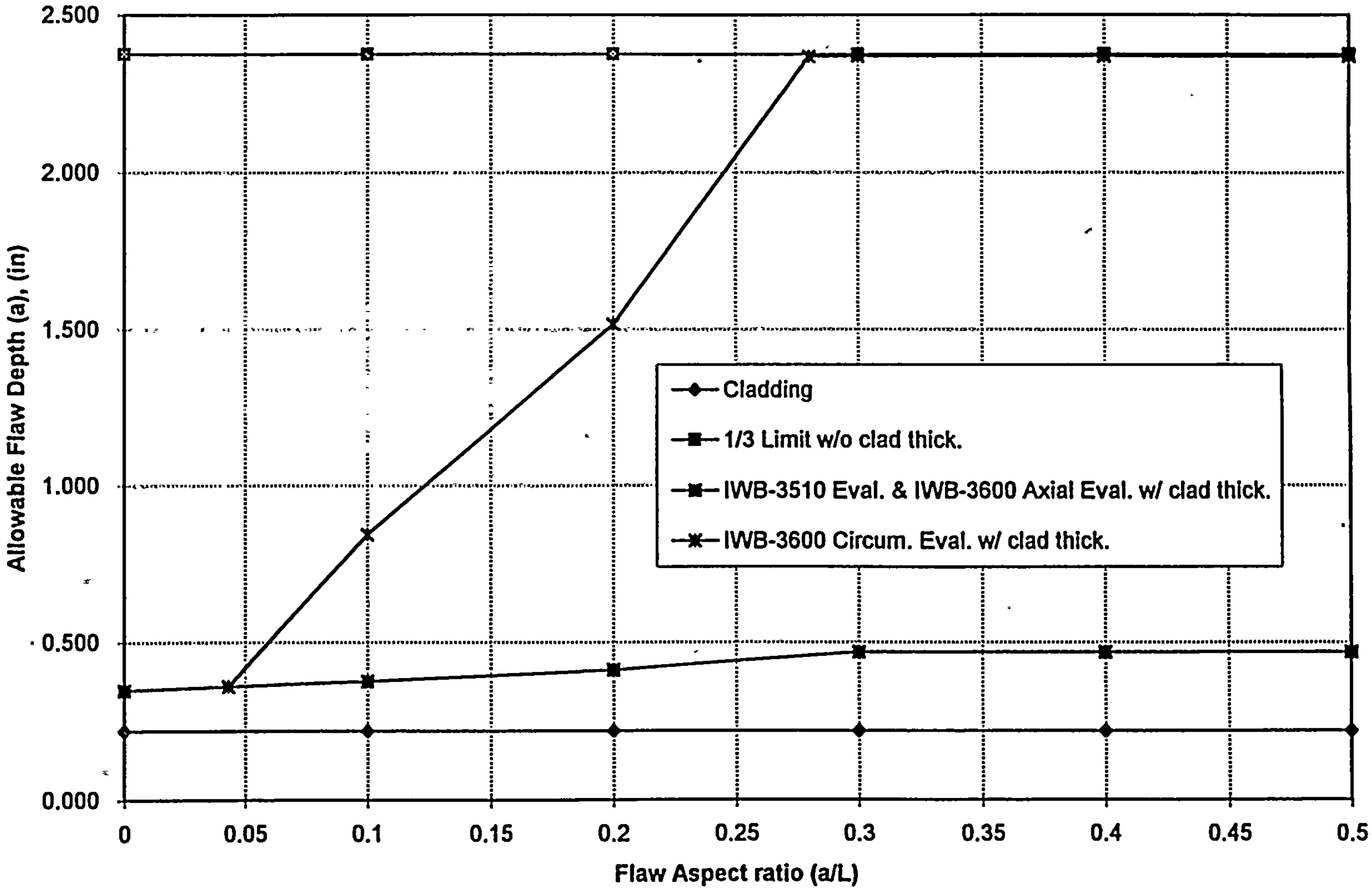


Figure C-17. Lower Course at 138 Deg, Surface Flaw @ 20.3 EFPY

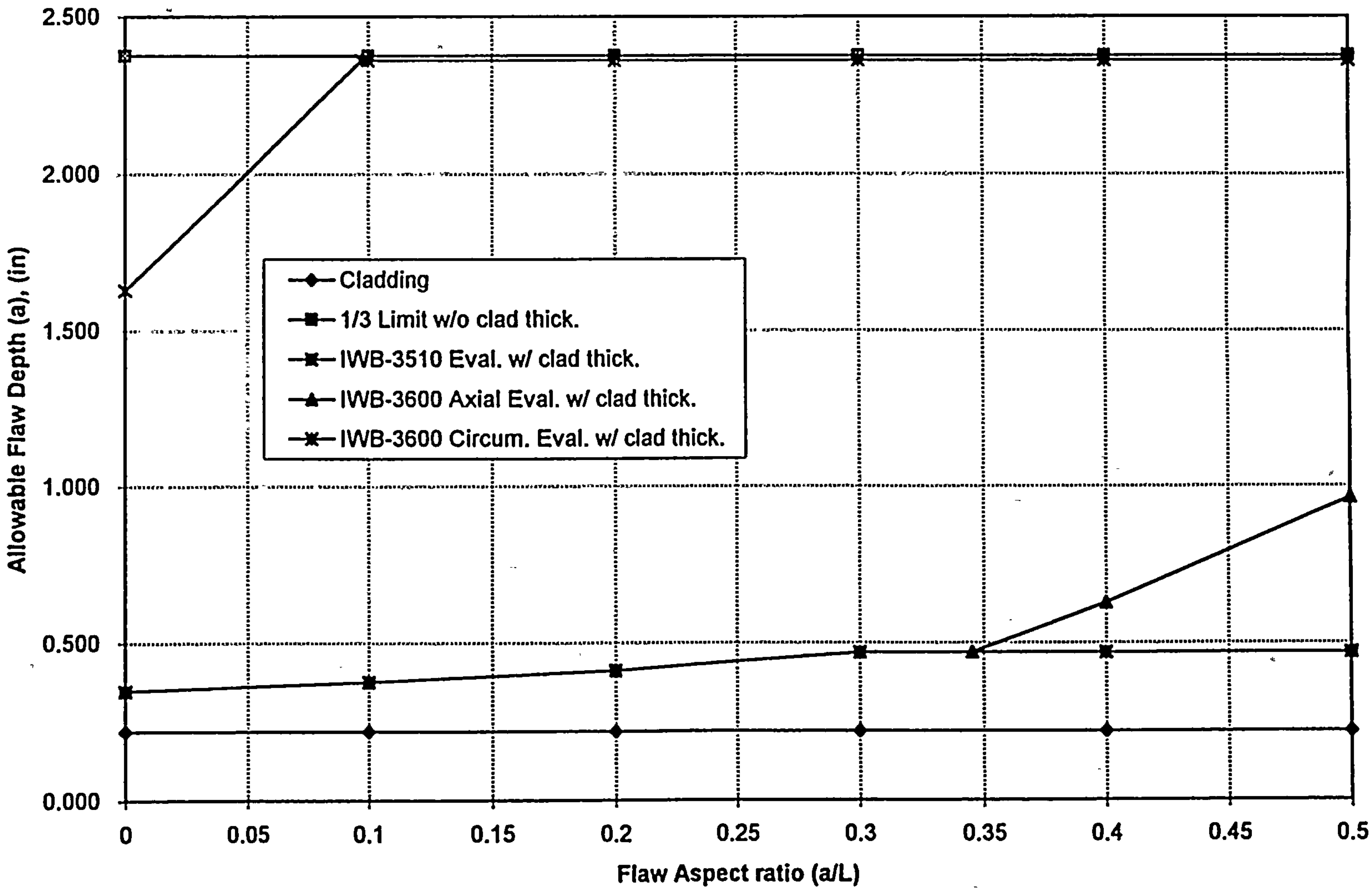


Figure C-18. Lower Course at 138 Deg, Subsurface Flaw @ 20.3 EFPY

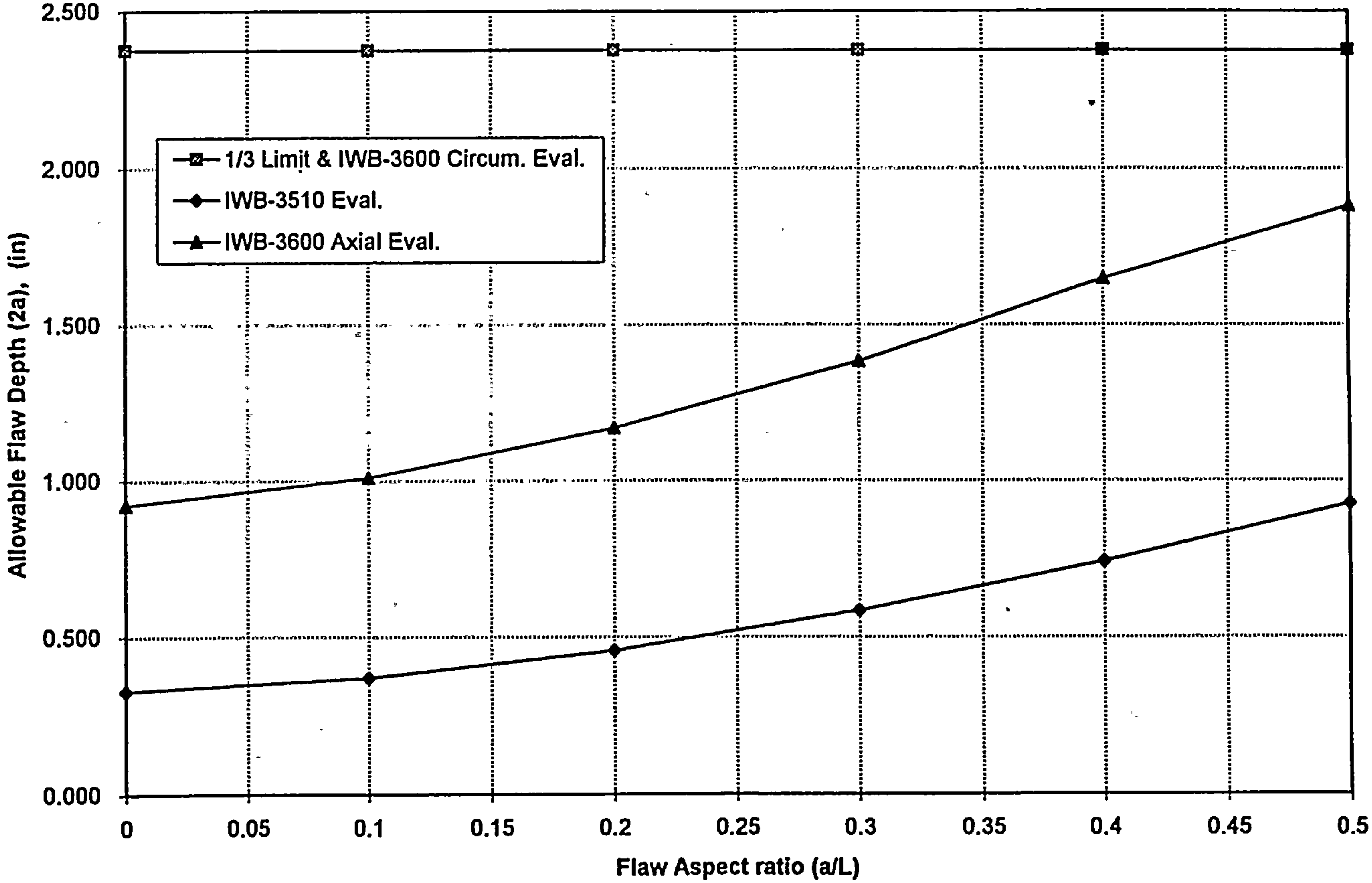


Figure C-19. Lower Course at 258 Deg, Surface Flaw
@ 20.3 EFPY

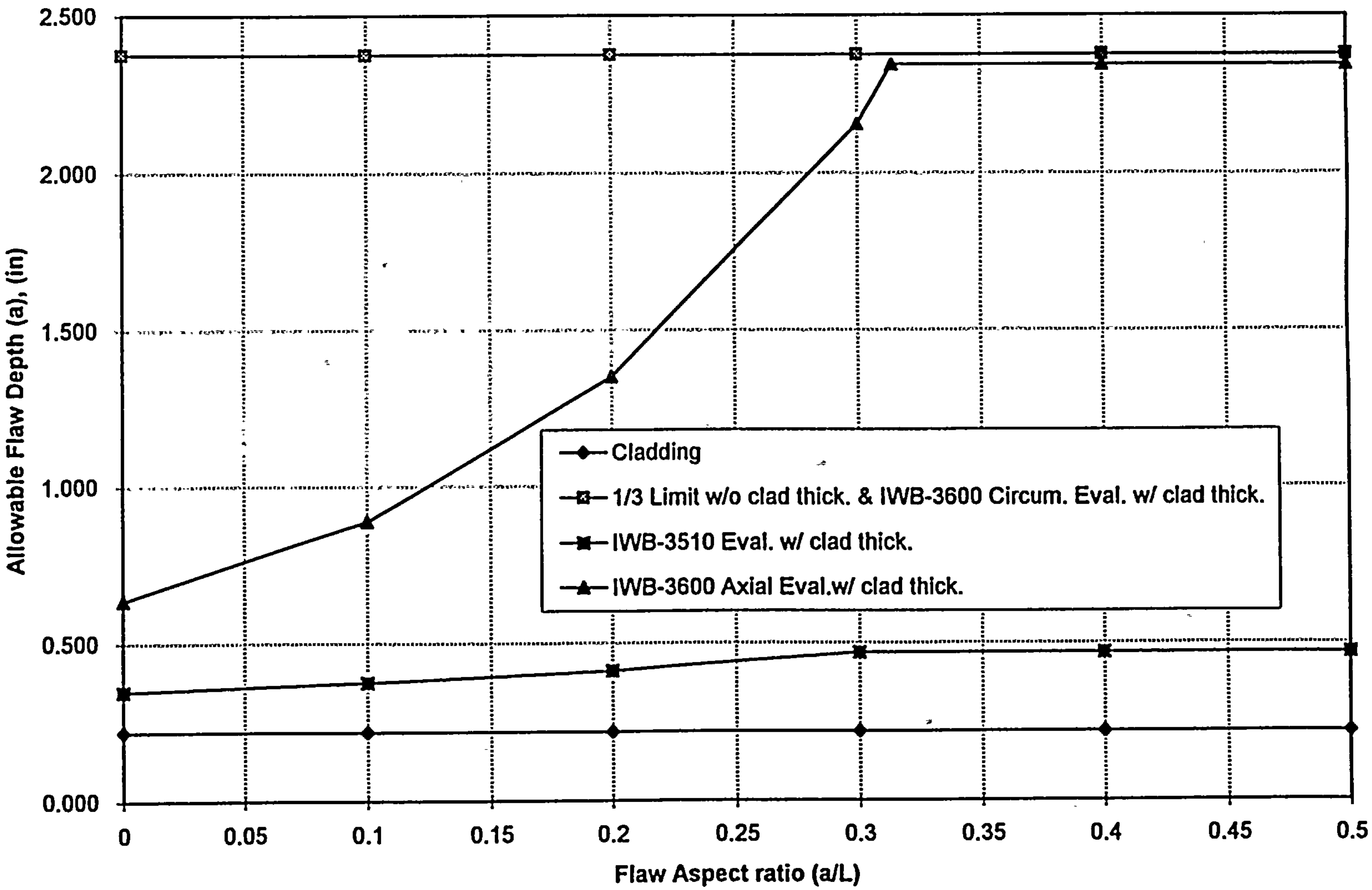


Figure C-20. Lower Course at 258 Deg, Subsurface Flaw @ 20.3 EFPY

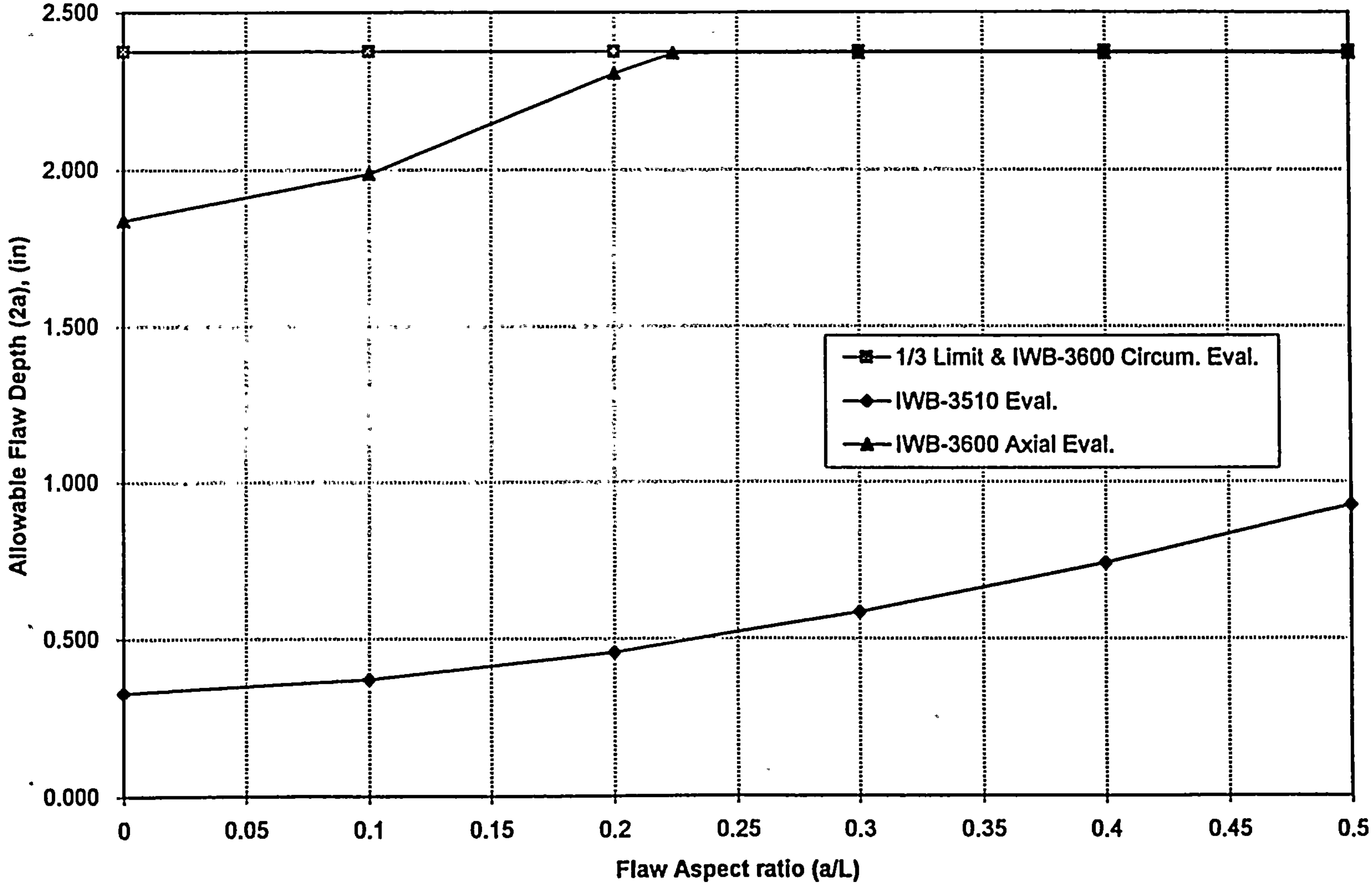


Figure C-21. Beltline Circum. Weld RVWD 137, Surface Flaw @ 20.3 EFPY

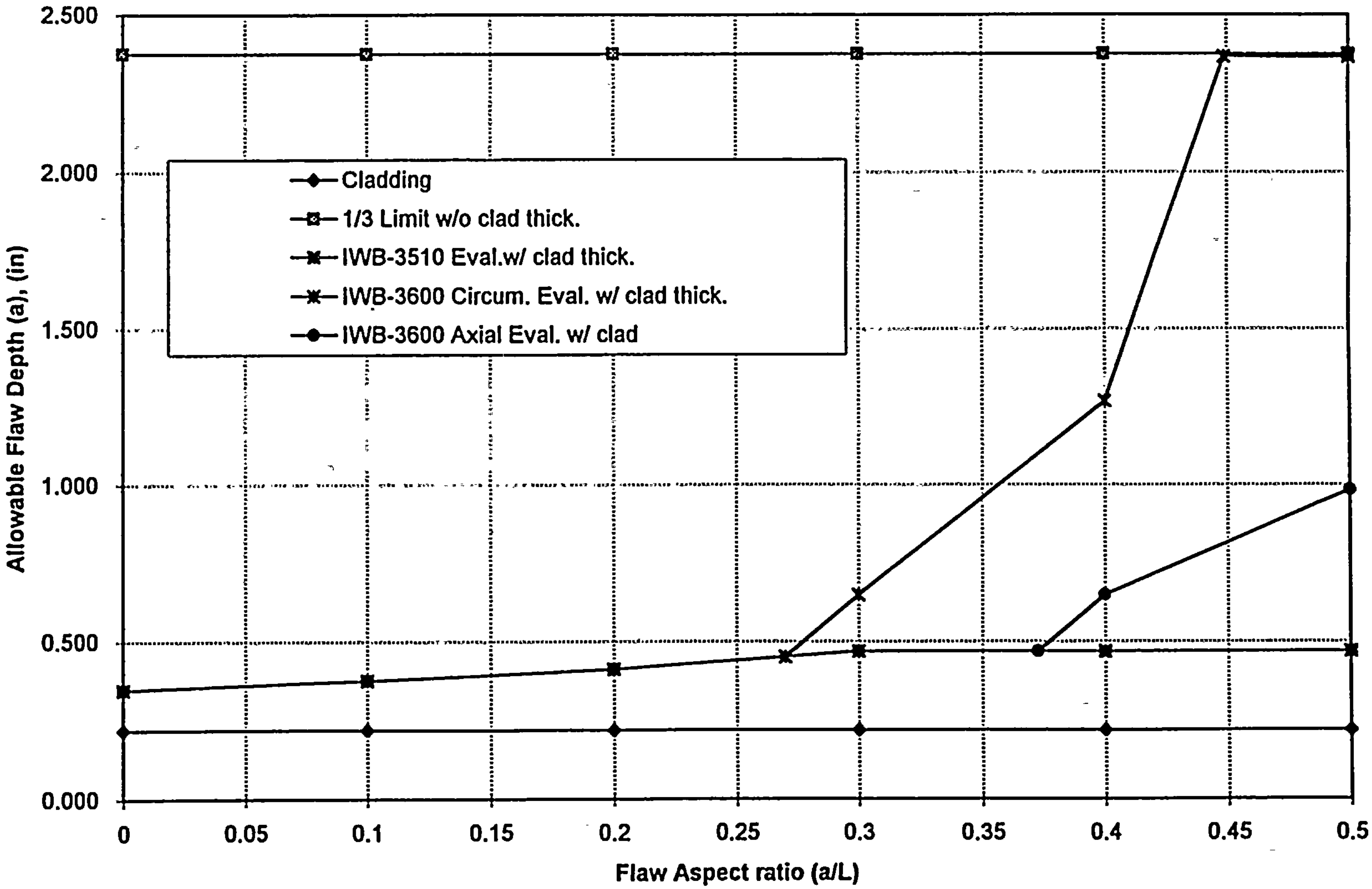


Figure C-22. Beltline Circum. Weld RVWD 137, Subsurface Flaw @ 20.3 EFPY

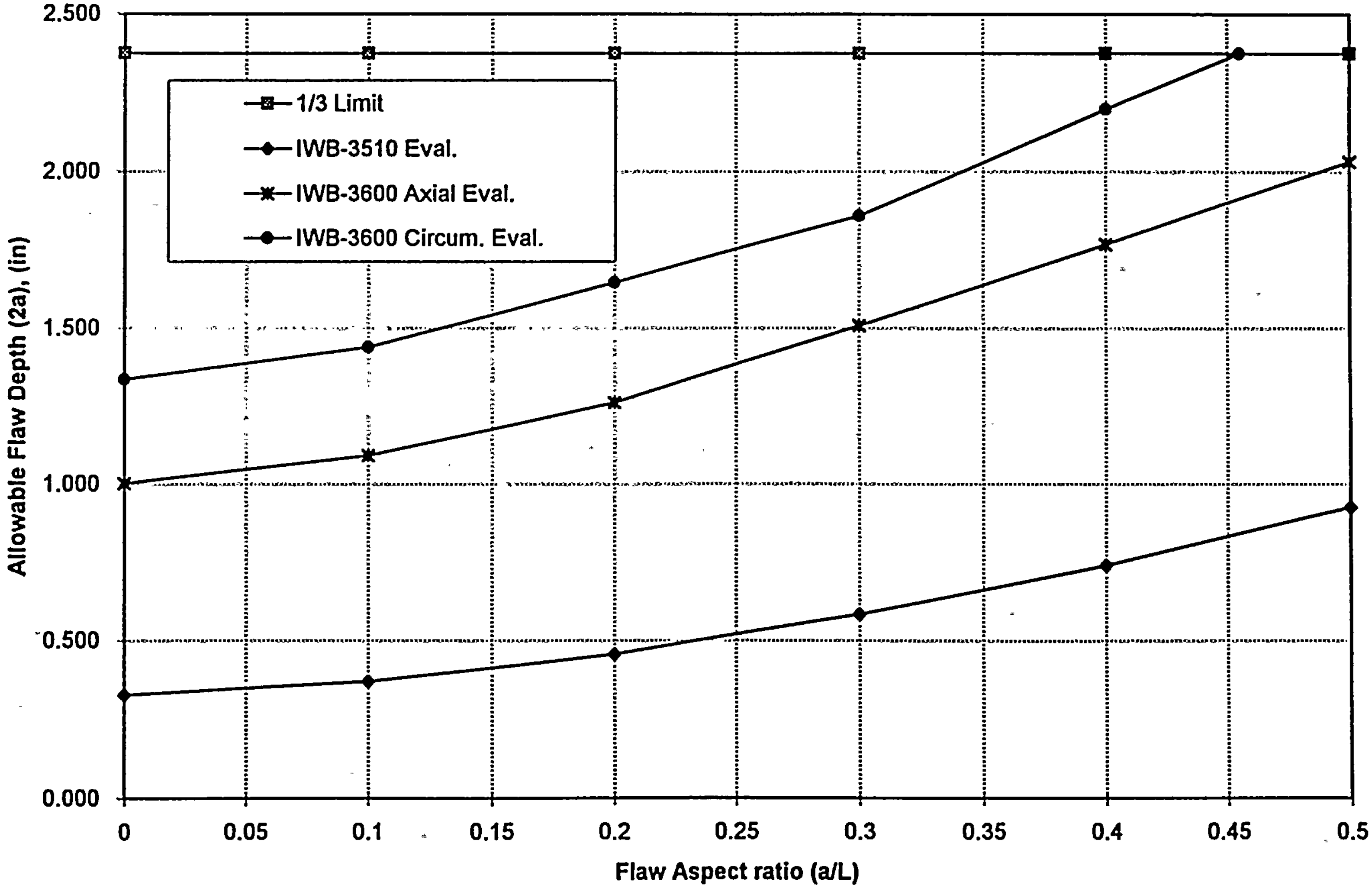


Figure C-10. Lower-Intermediate Course at 105 Deg, Subsurface Flaw @ 20.3 EFPY

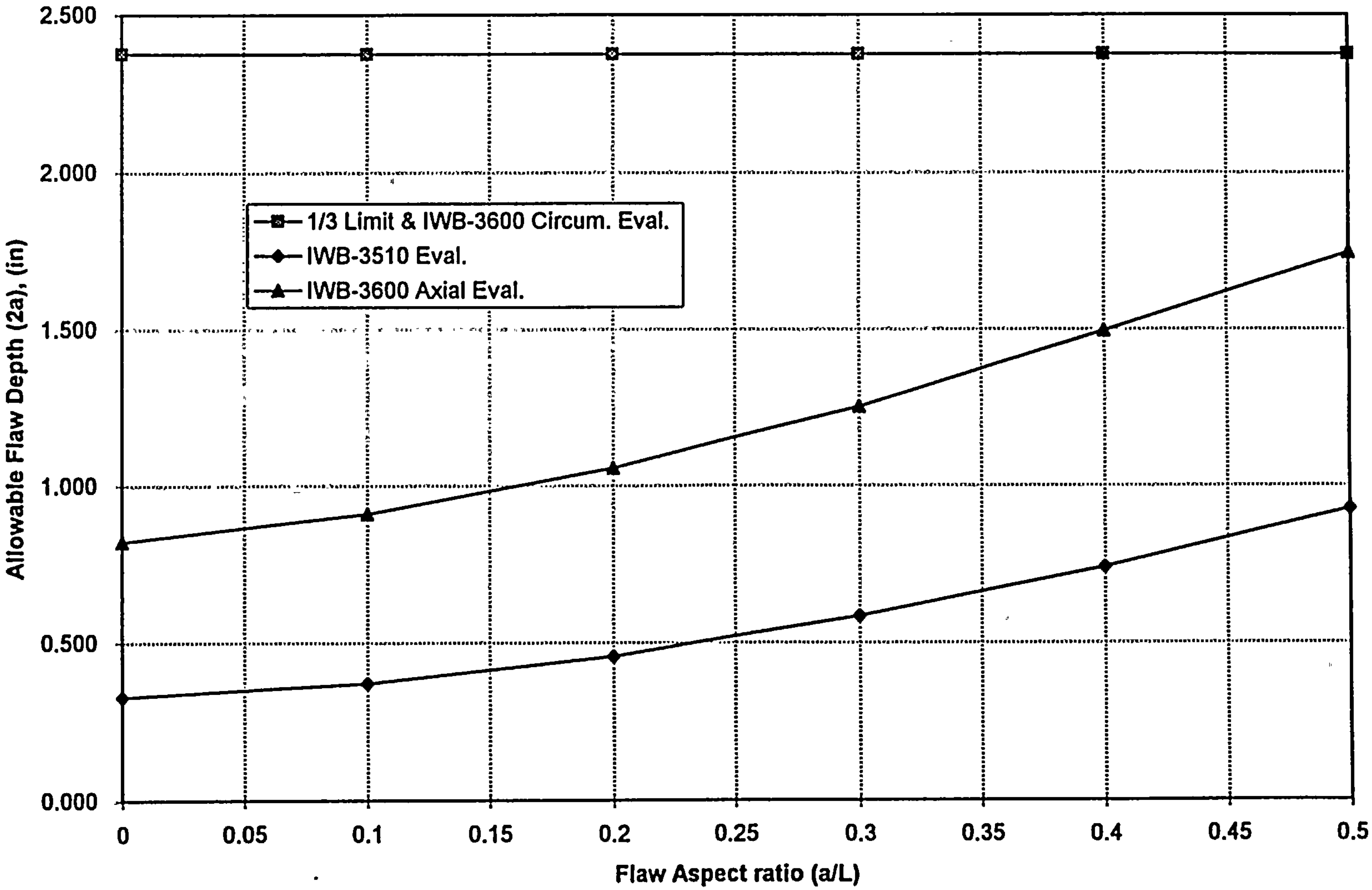
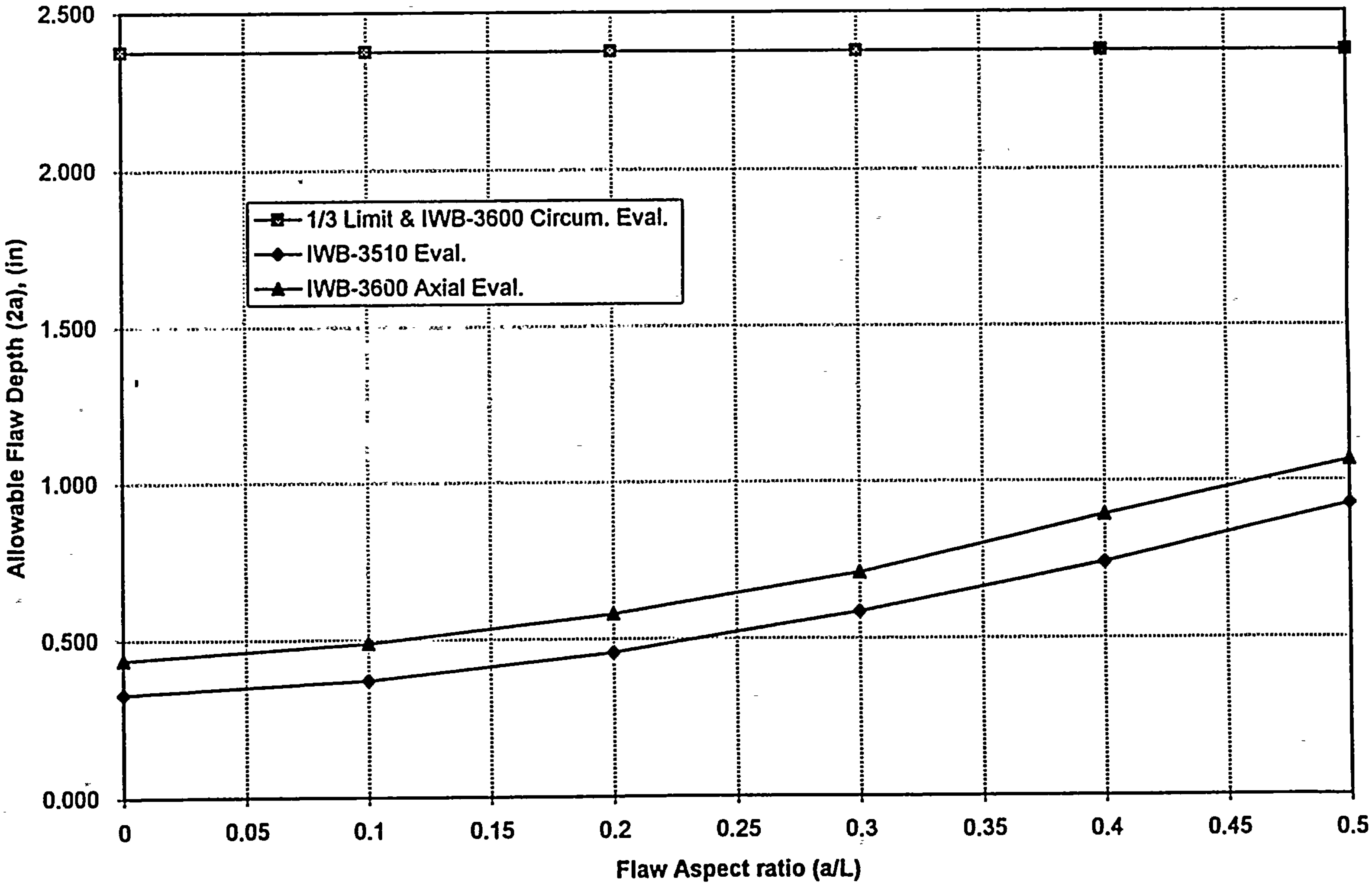


Figure C-16. Lower Course at 18 Deg, Subsurface Flaw @ 20.3 EFPY



APPENDIX D - ALLOWABLE FLAW SIZE FOR 28 EFPY

This Appendix contains Figures D-1 through D-22

Figure D-1. Non-Beltline, Vessel Flange Horizontal Weld I. D. Flaw @ 28 EFPY

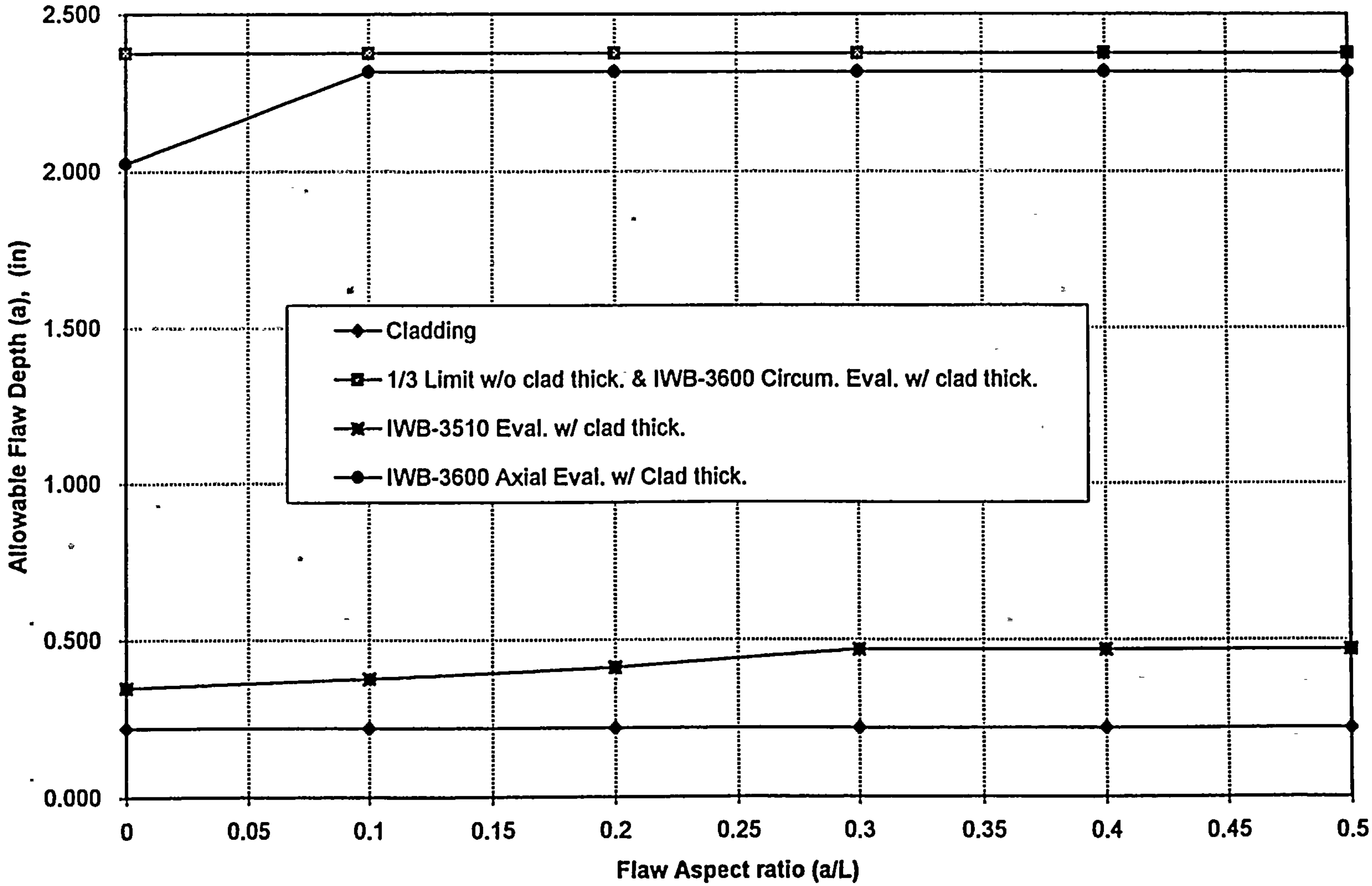


Figure D-2. Non-Beltline, Vessel Flange Horizontal Weld O. D. Flaw @ 28 EFPY

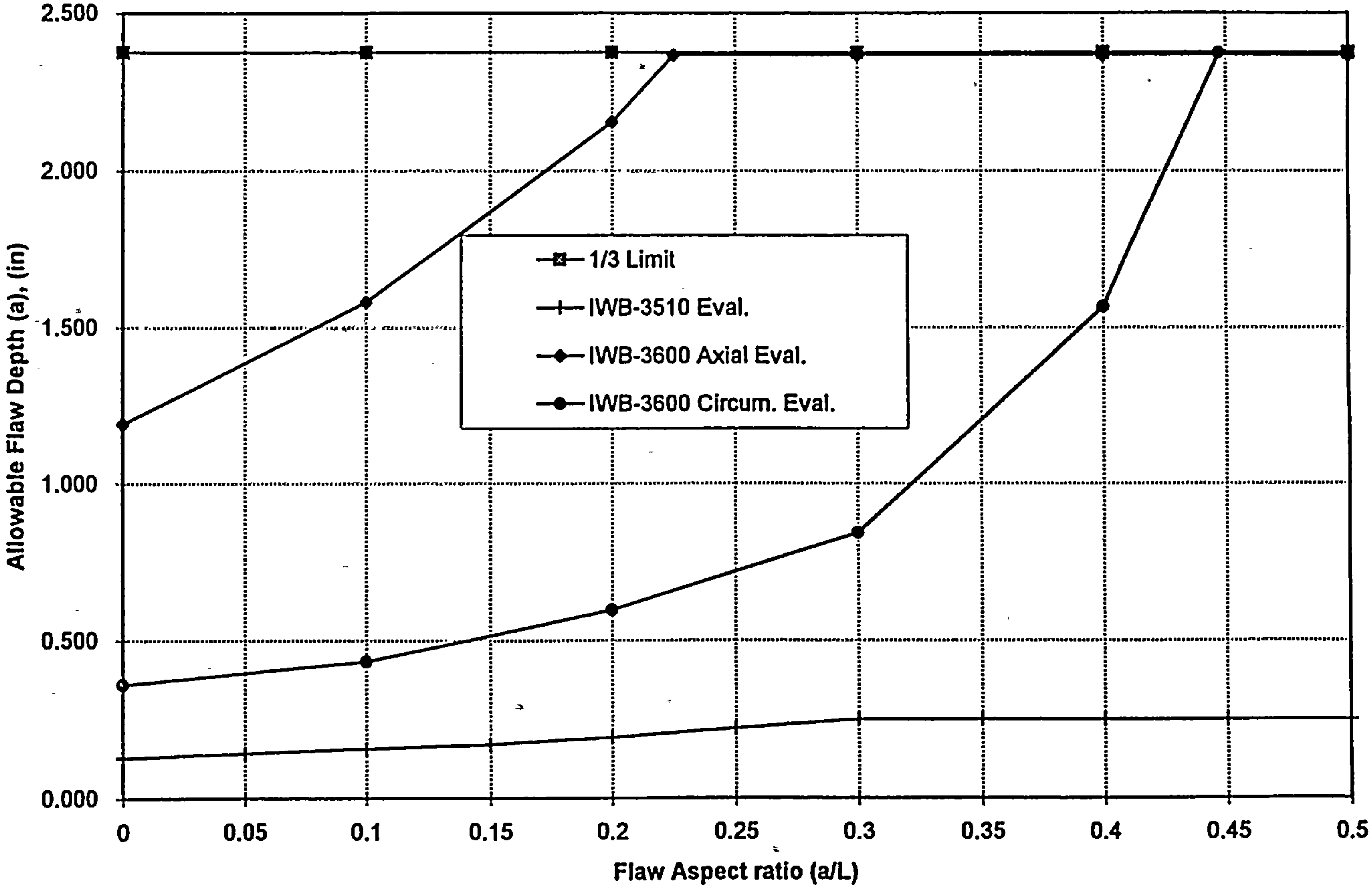


Figure D-3. Non-Beltline, Vessel Flange Horizontal Weld Subsurface Flaw @ 28 EFPY

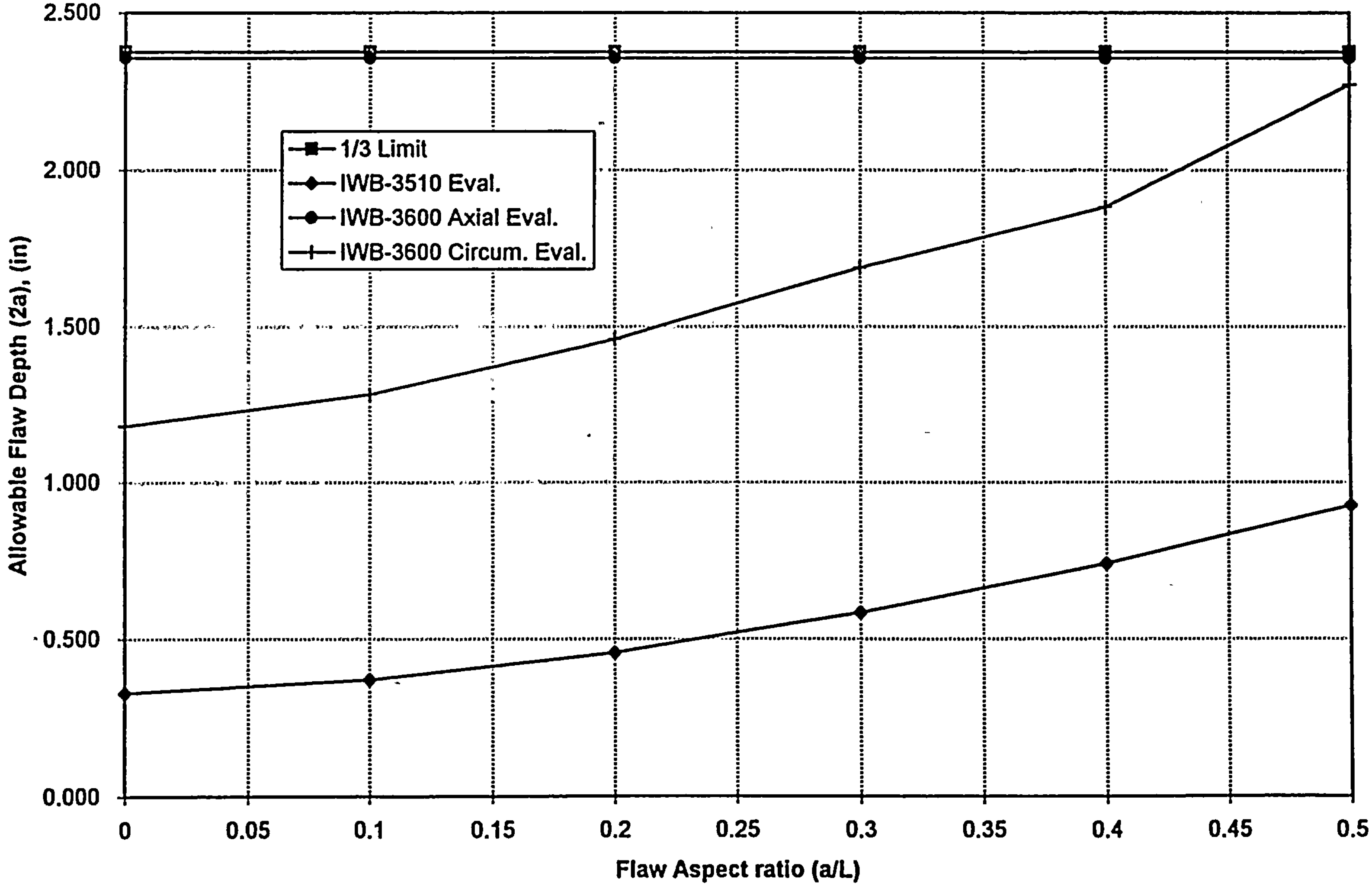


Figure D-4. Non-Beltline, Near the Vessel Flange I. D. Flaw @ 28 EFPY

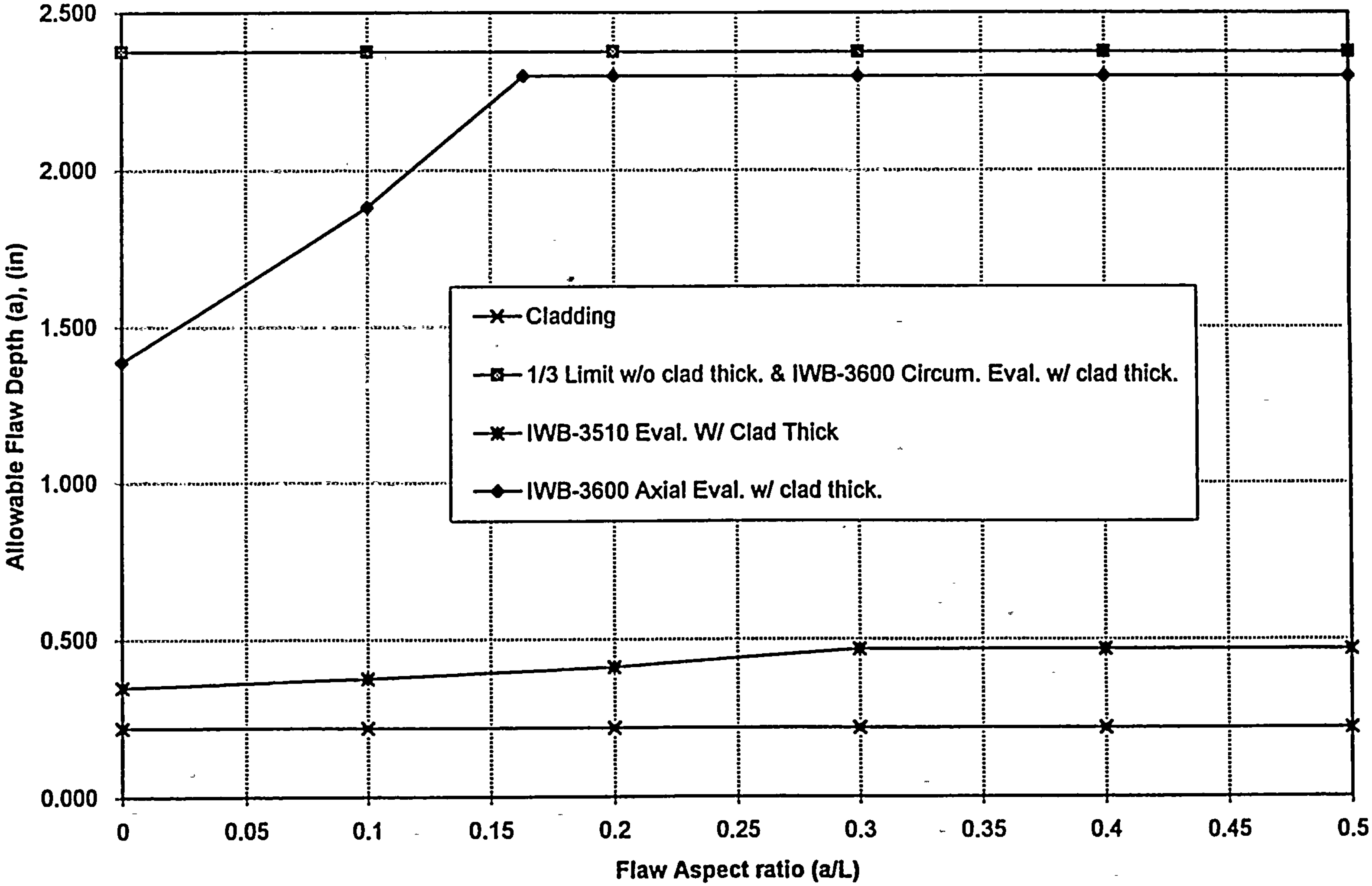


Figure D-5. Non-Beltline, Near the Vessel Flange O. D. Flaw @ 28 EFPY

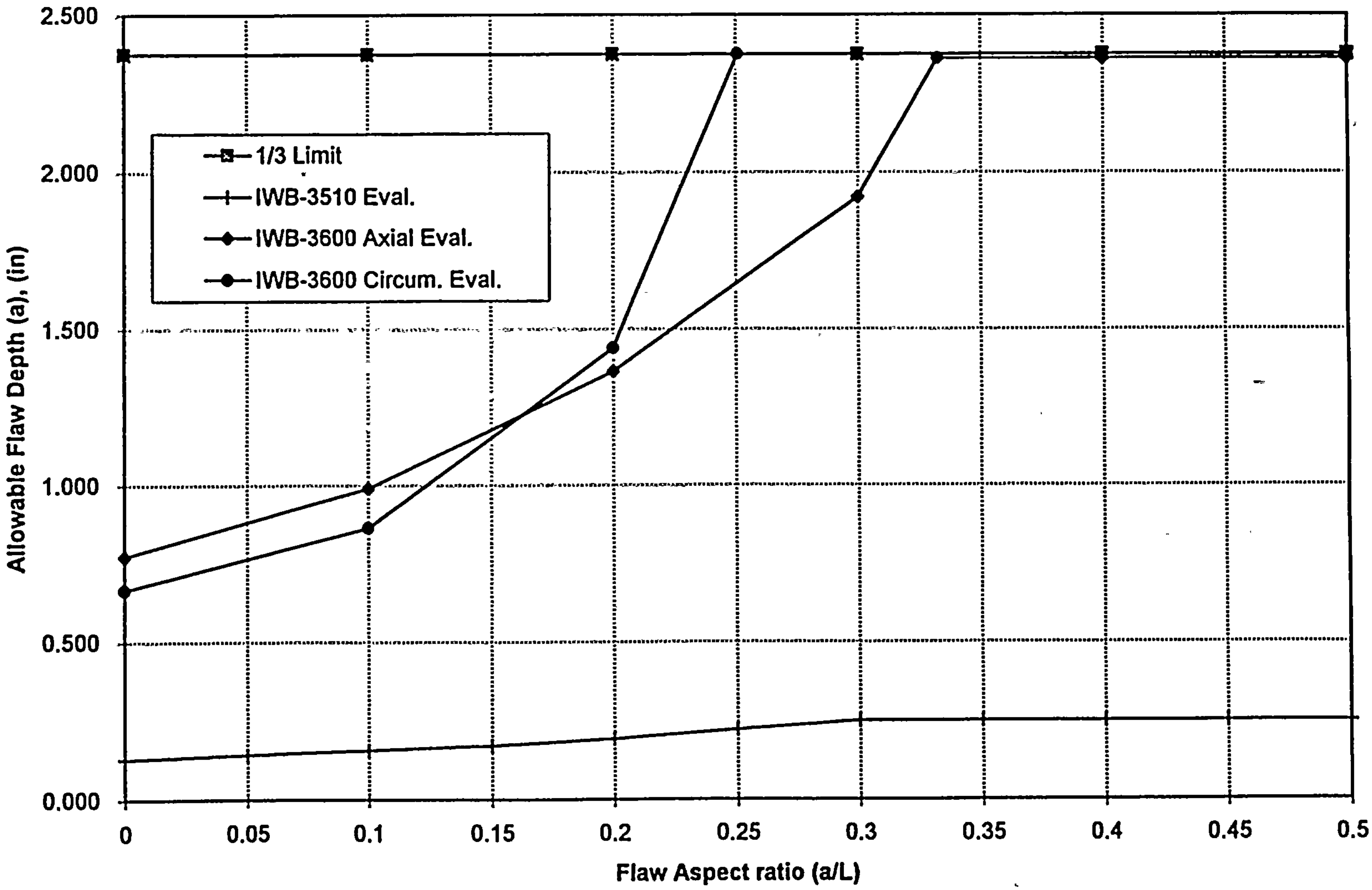
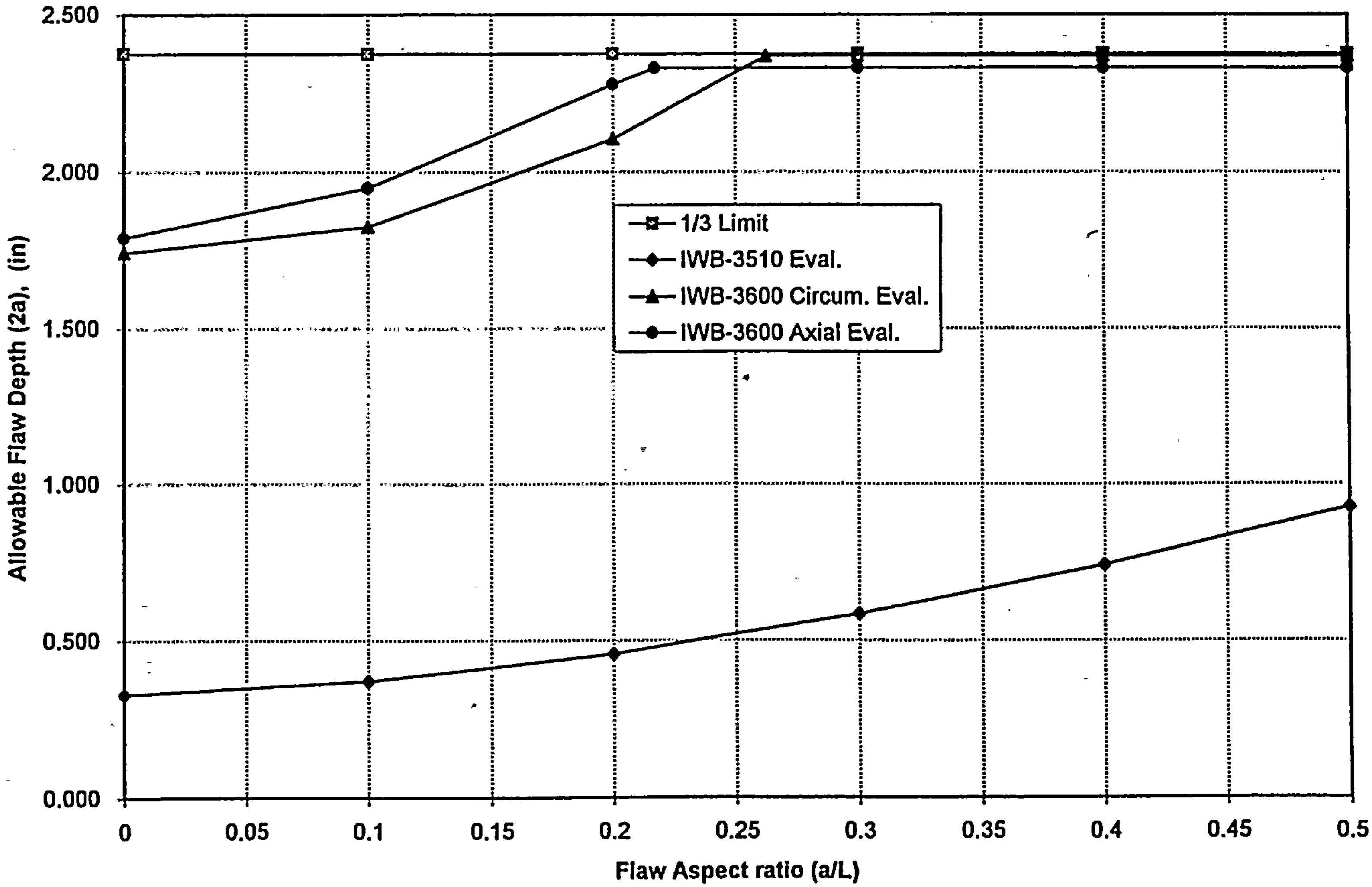


Figure D-6. Non-Beltline,Near the Vessel Flange Subsurface Flaw
@ 28 EFPY



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[illegible]

[illegible]

Figure D-7. Non-Beltline, Lower Course Surface Flaw
@ 28 EFPY

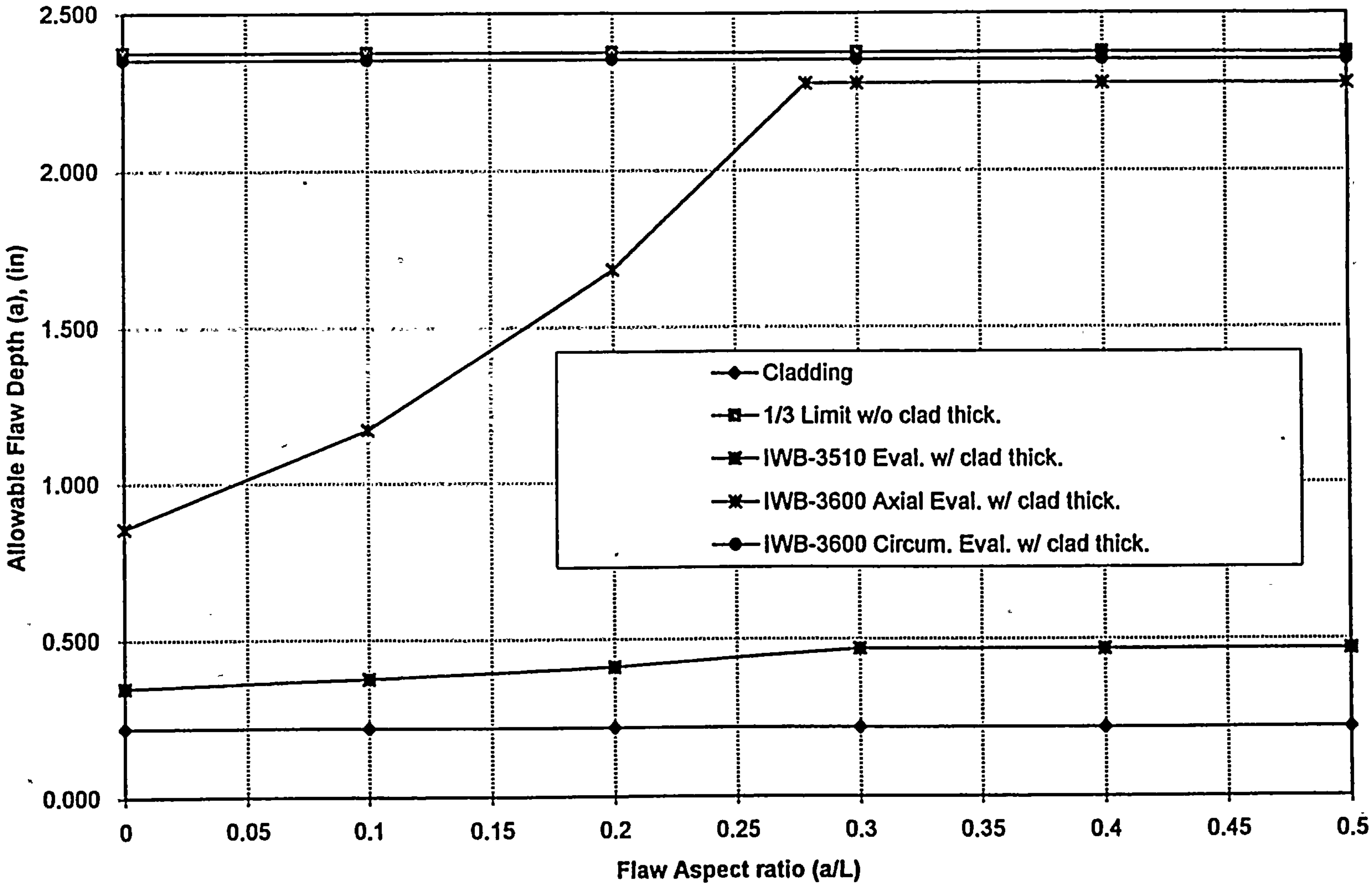


Figure D-8. Non-Beltline, Lower Course Subsurface Flaw @ 28 EFPY

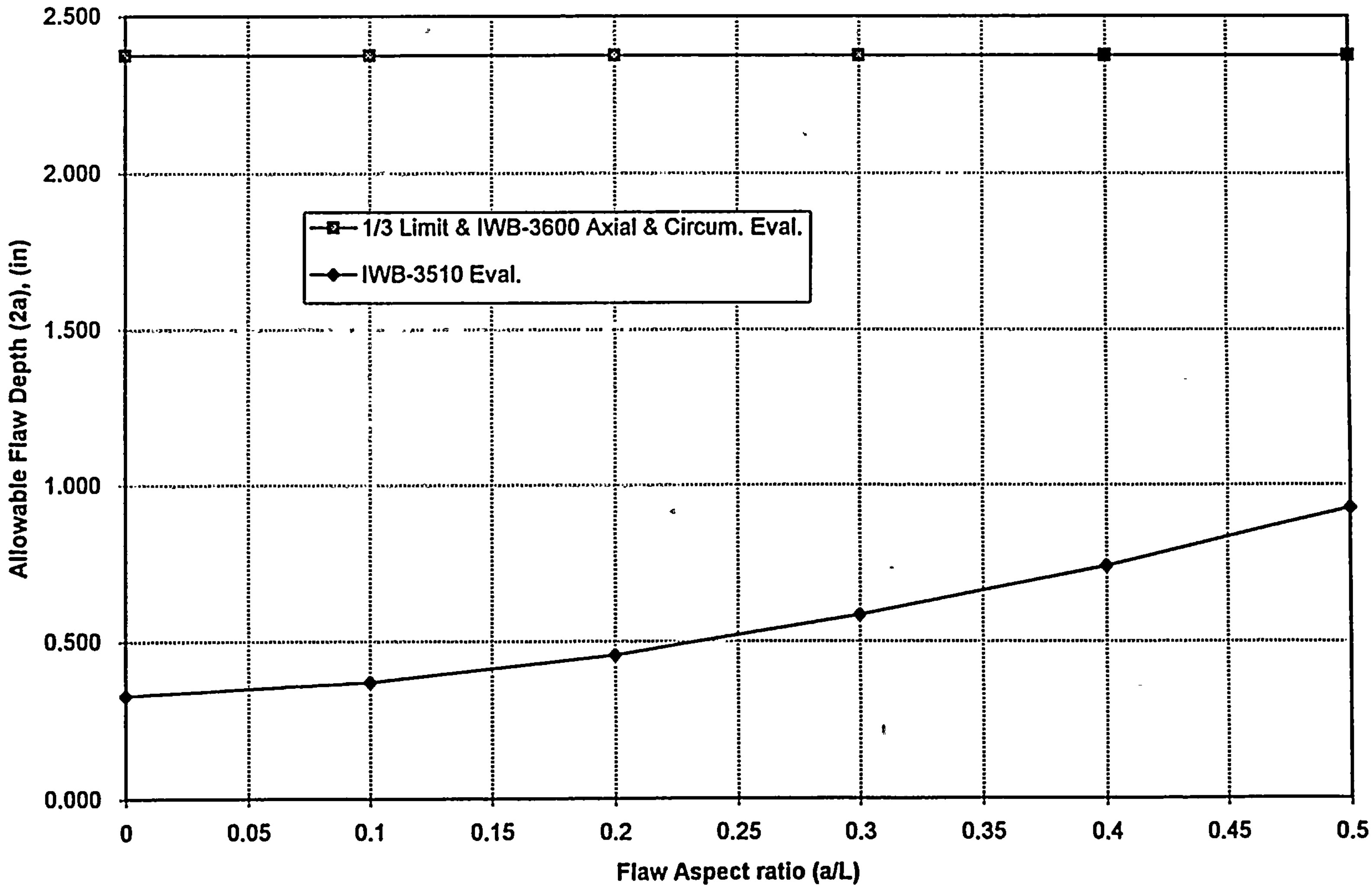


Figure D-9. Lower-Intermediate Course at 105 Deg, Surface Flaw @ 28 EFPY

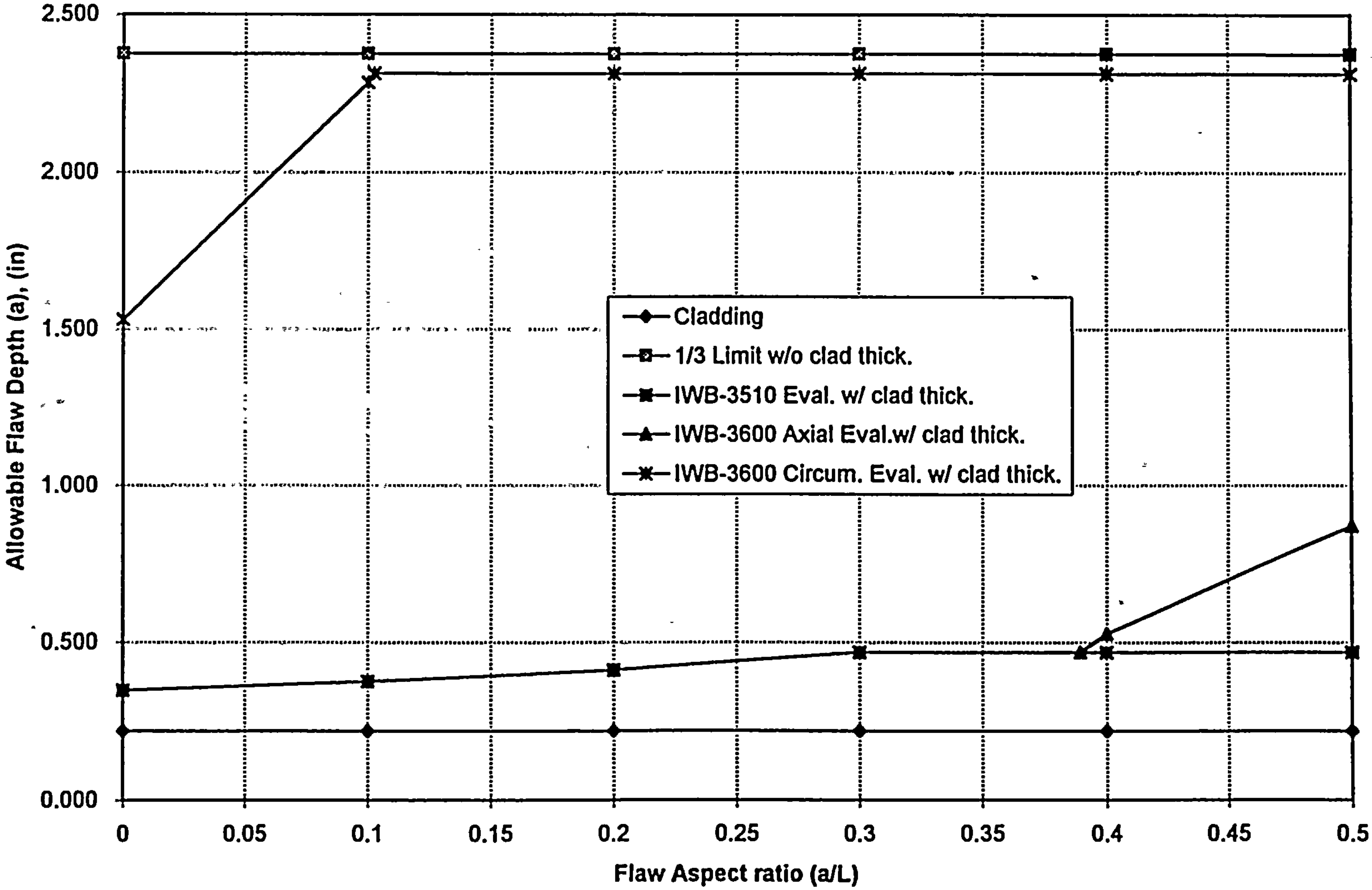


Figure D-10. Lower-Intermediate Course at 105 Deg, Subsurface Flaw @ 28 EFPY

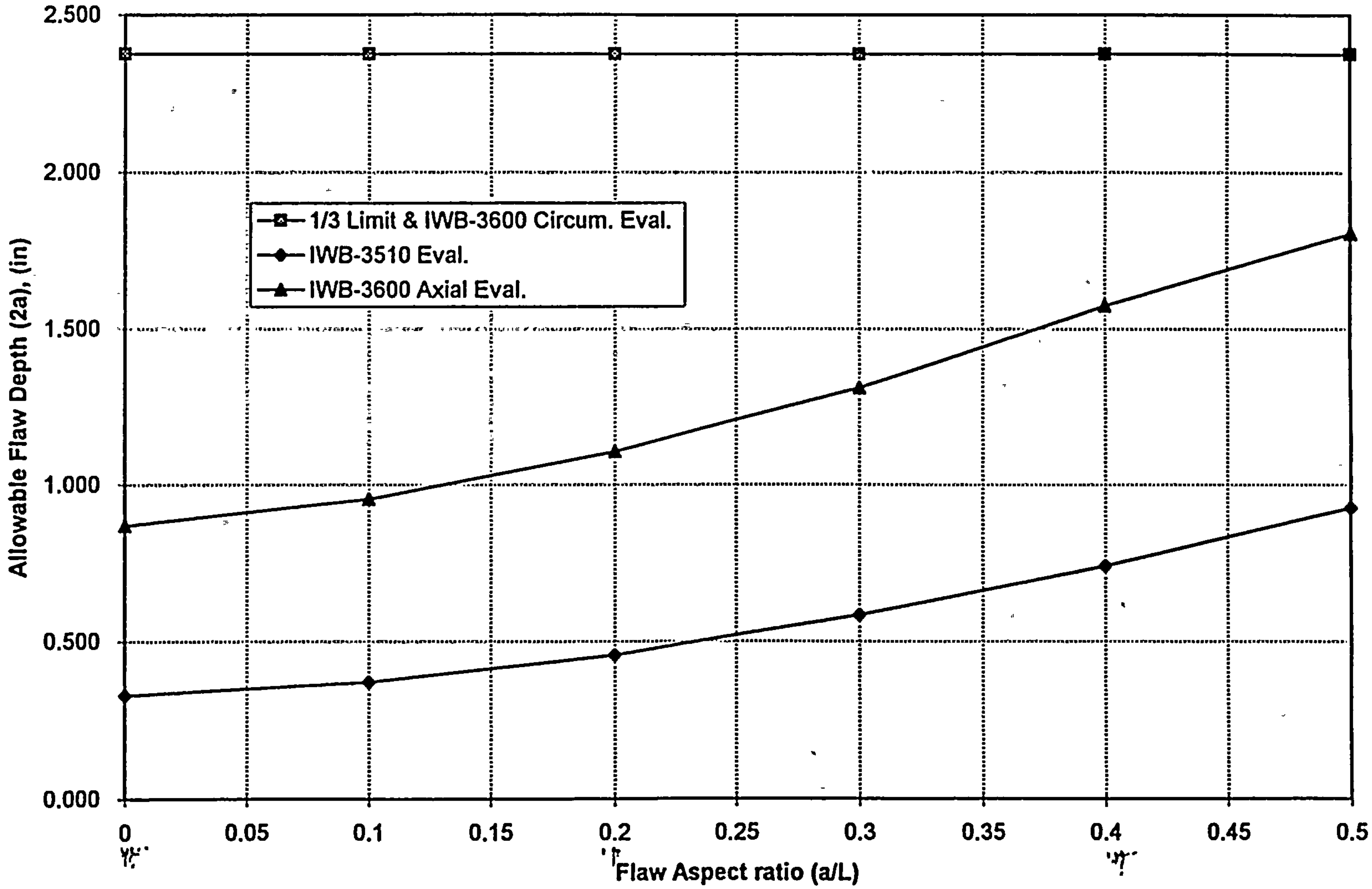


Figure D-11. Lower-Intermediate Course at 225 Deg, Surface Flaw @ 28 EFPY

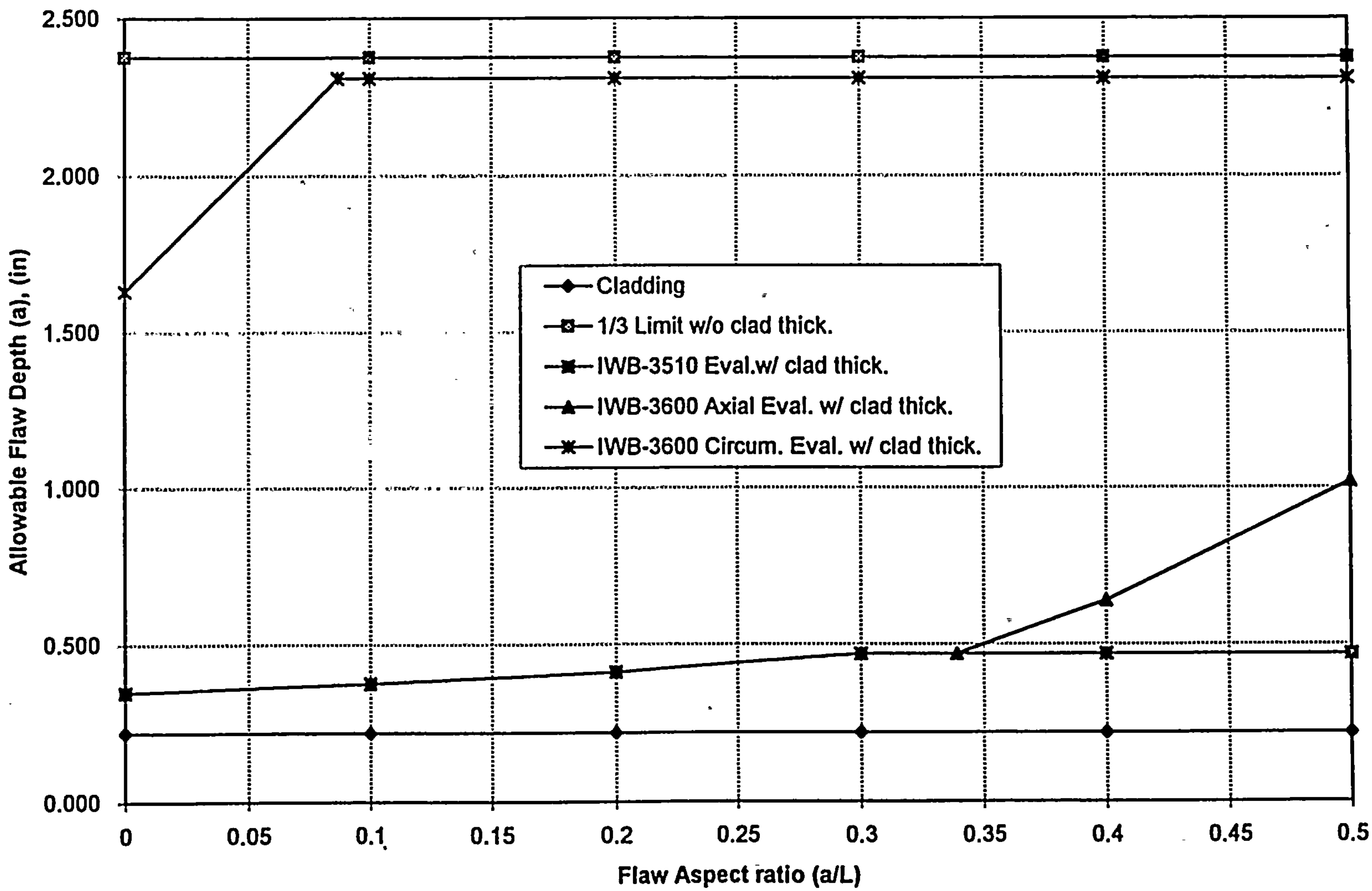


Figure D-12. Lower-Intermediate Course at 225 Deg, Subsurface Flaw @ 28 EFPY

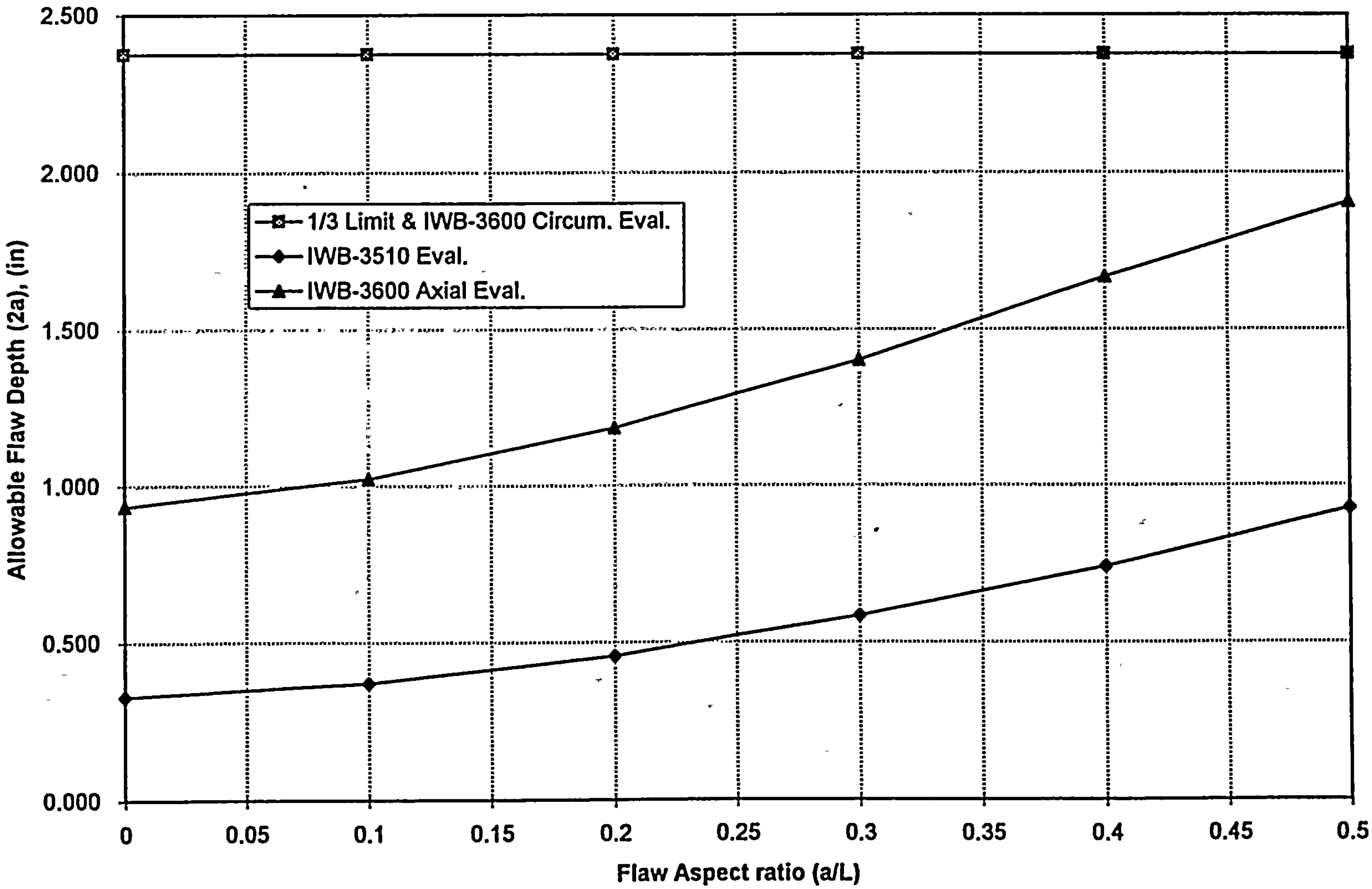


Figure D-13. Lower-Intermediate Course at 345 Deg, Surface Flaw @ 28 EFPY

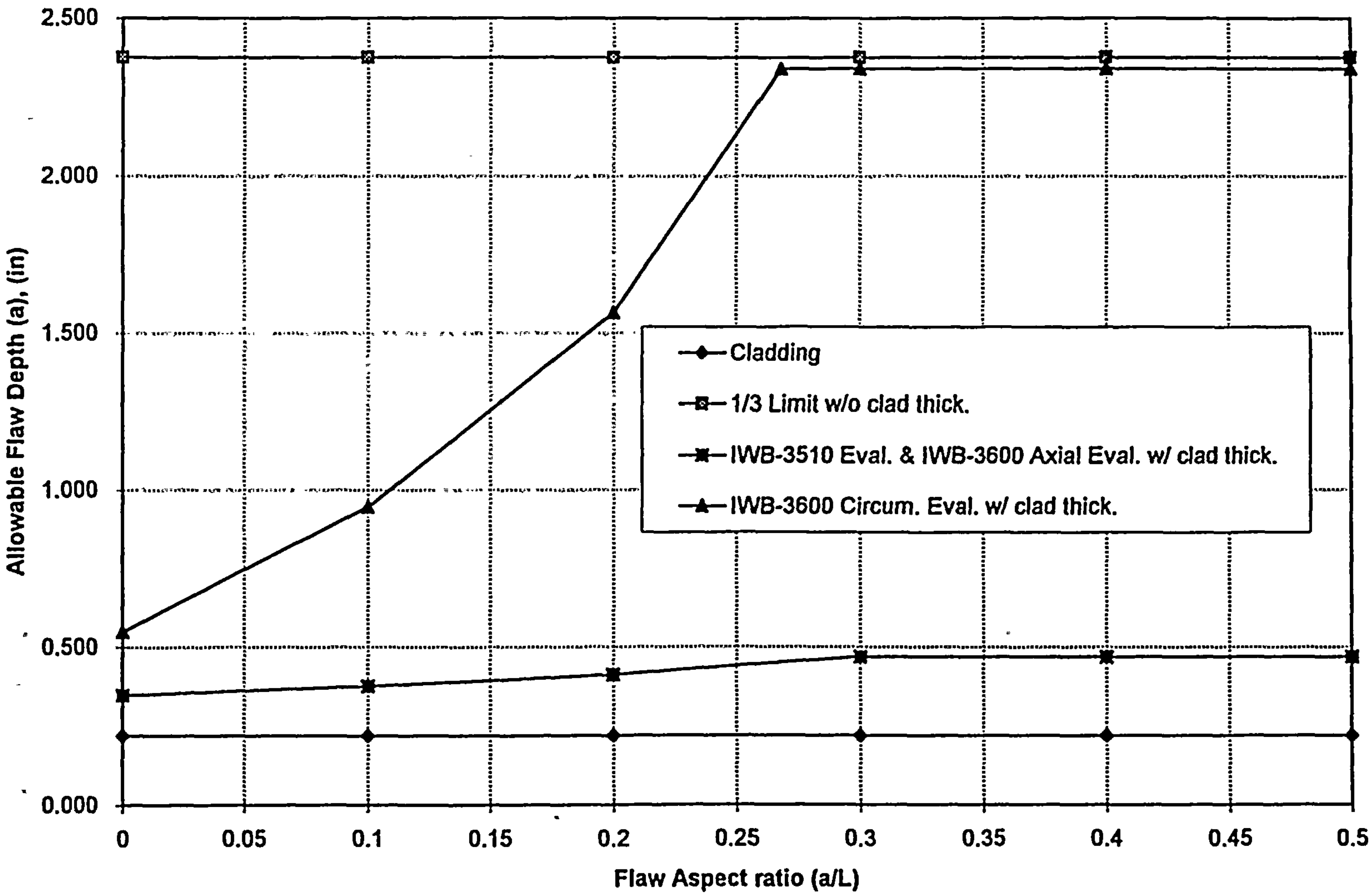


Figure D-14. Lower-Intermediate Course at 345 Deg, Subsurface Flaw @ 28 EFPY

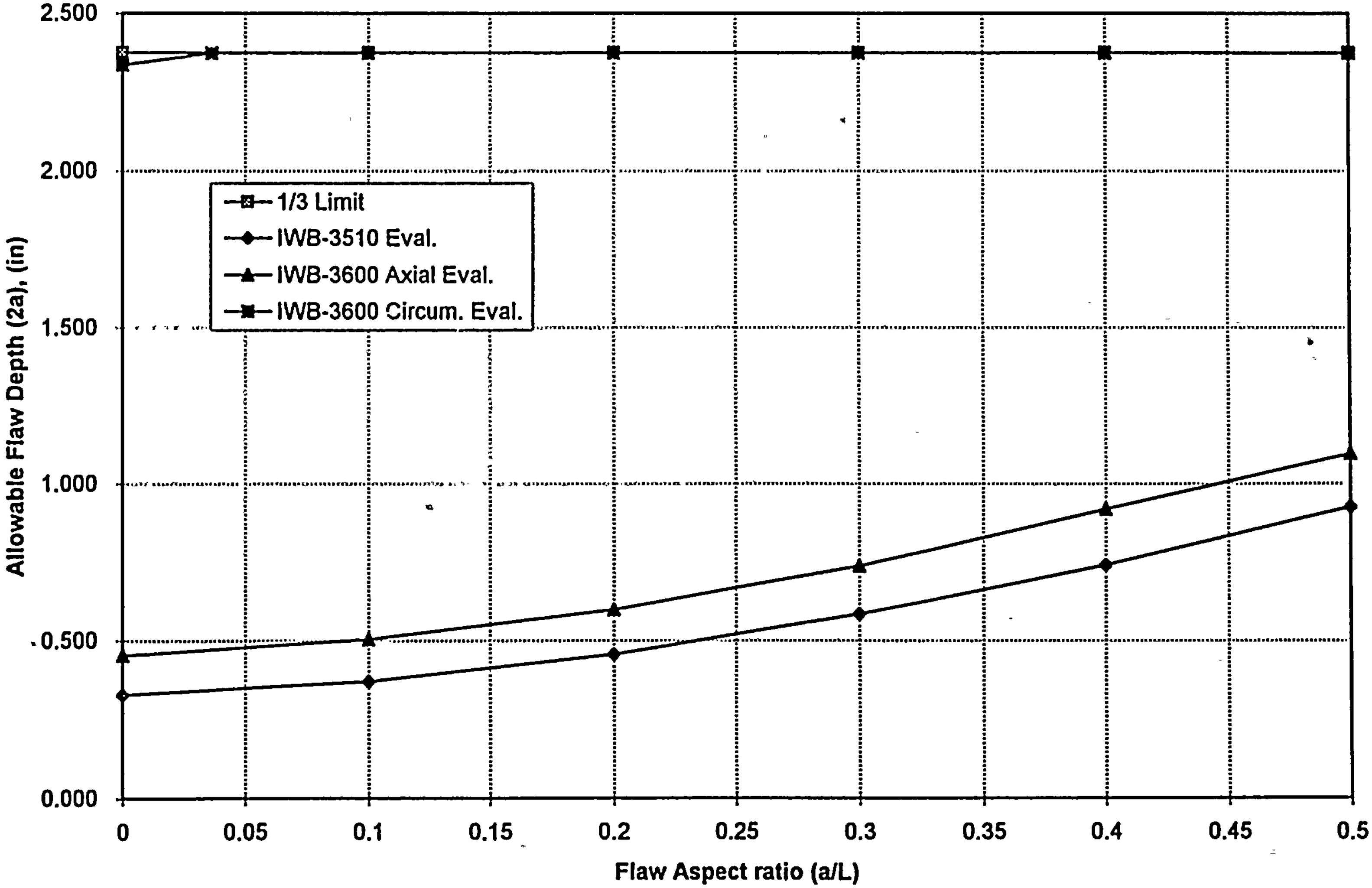


Figure D-15. Lower Course at 18 Deg, Surface Flaw @ 28 EFPY

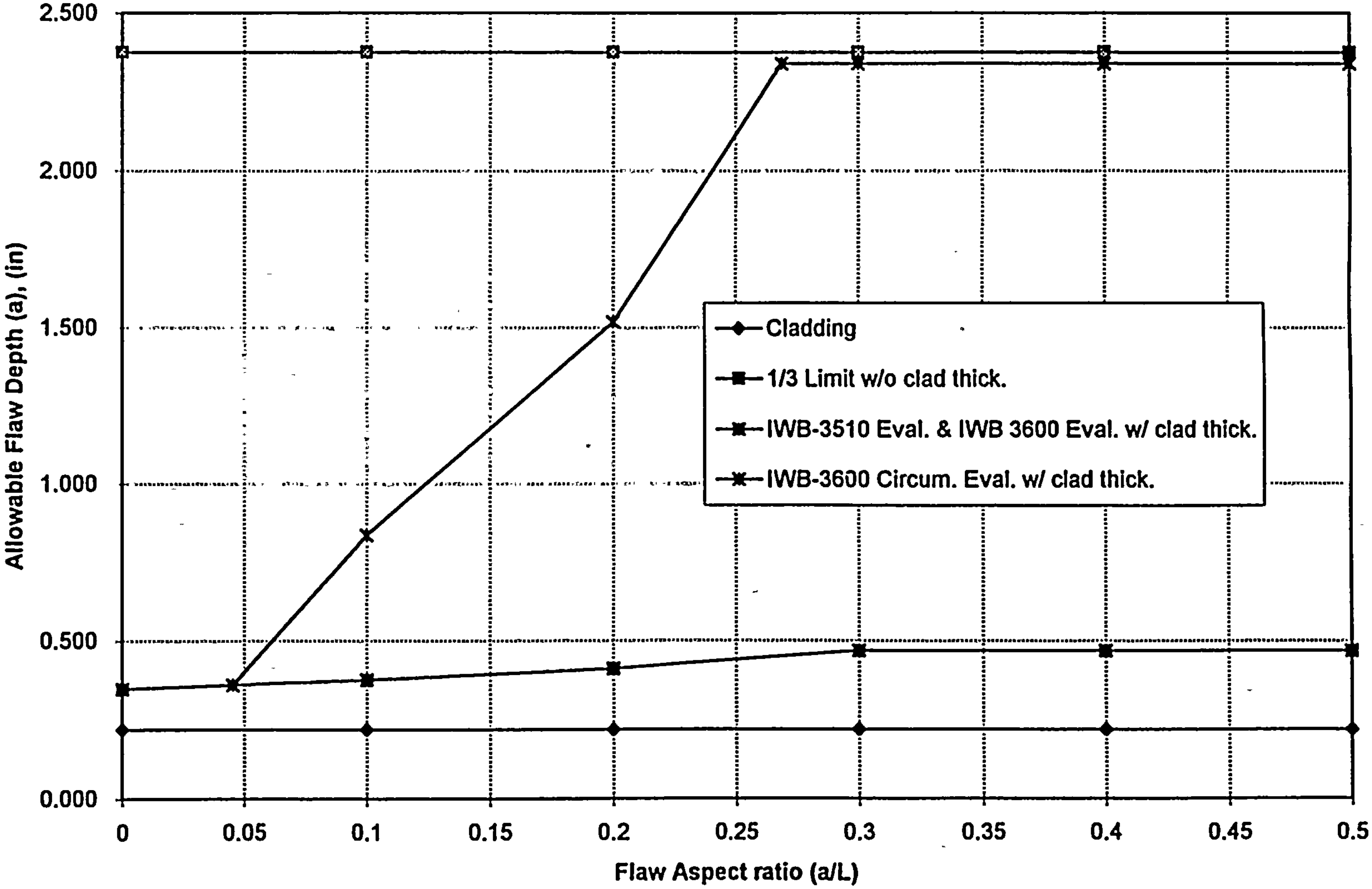


Figure D-16. Lower Course at 18 Deg, Subsurface Flaw @ 28 EFPY

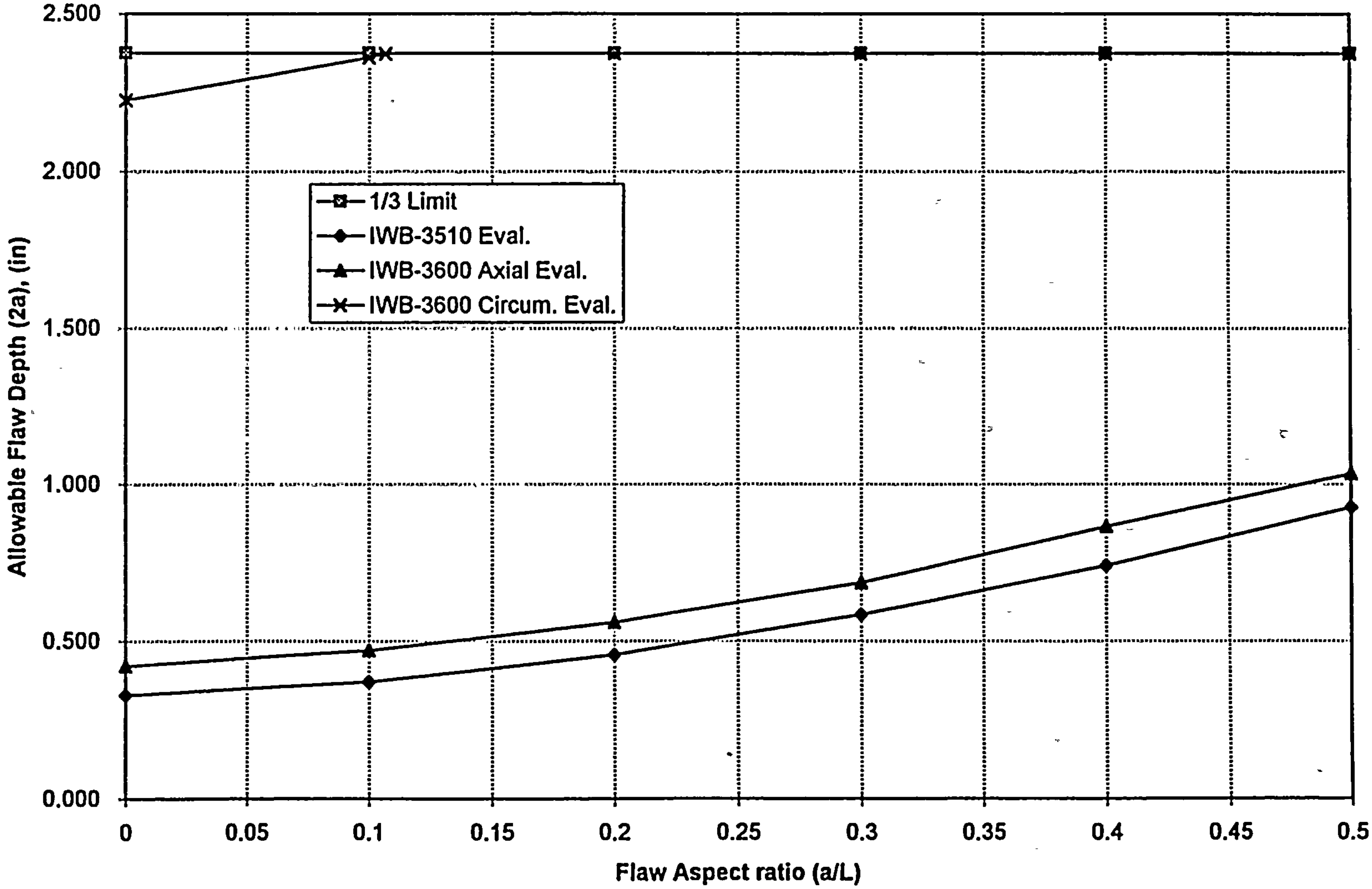


Figure D-17. Lower Course at 138 Deg, Surface Flaw @ 28 EFPY

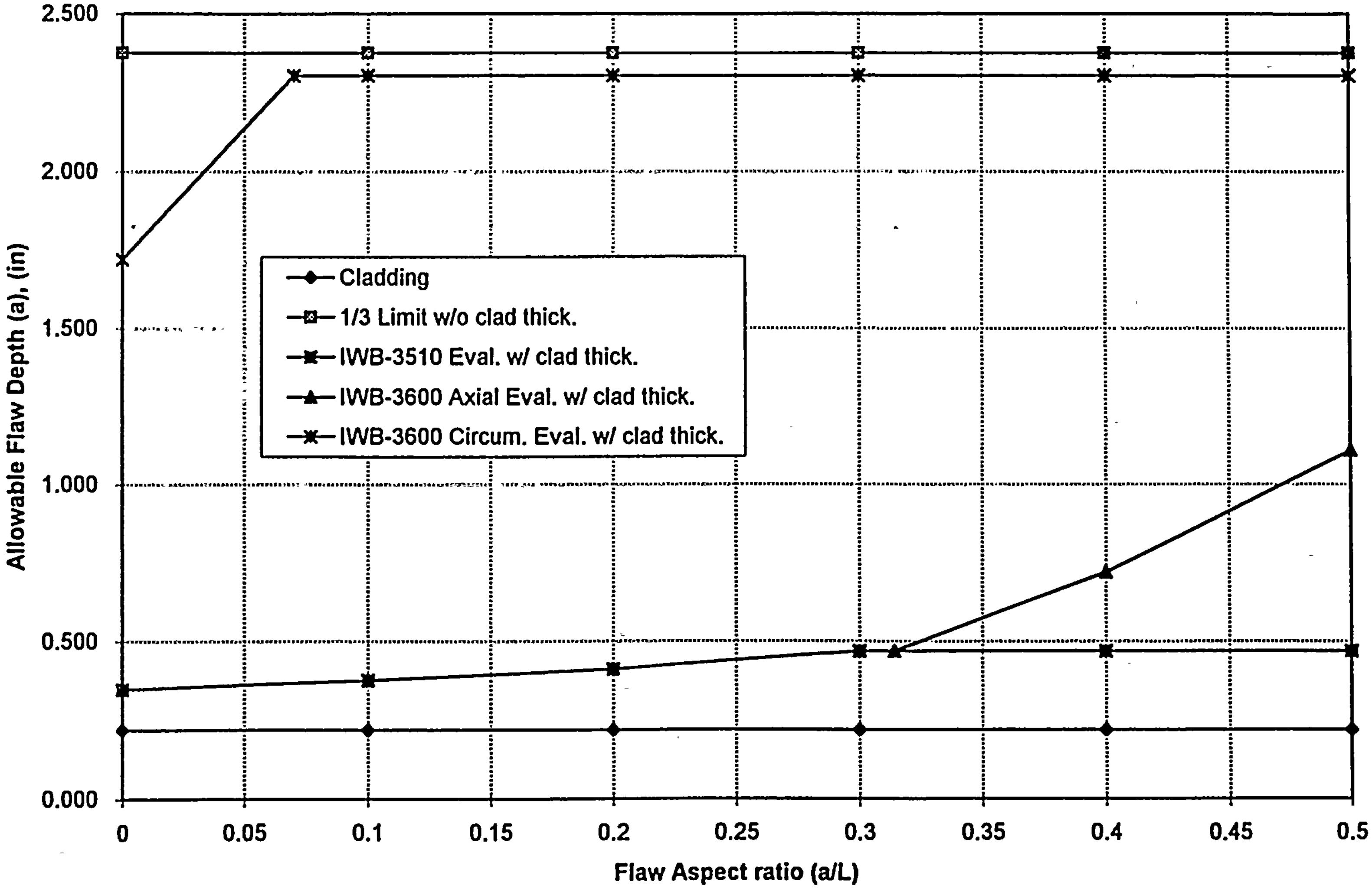


Figure D-18. Lower Course at 138 Deg, Subsurface Flaw @ 28 EFPY

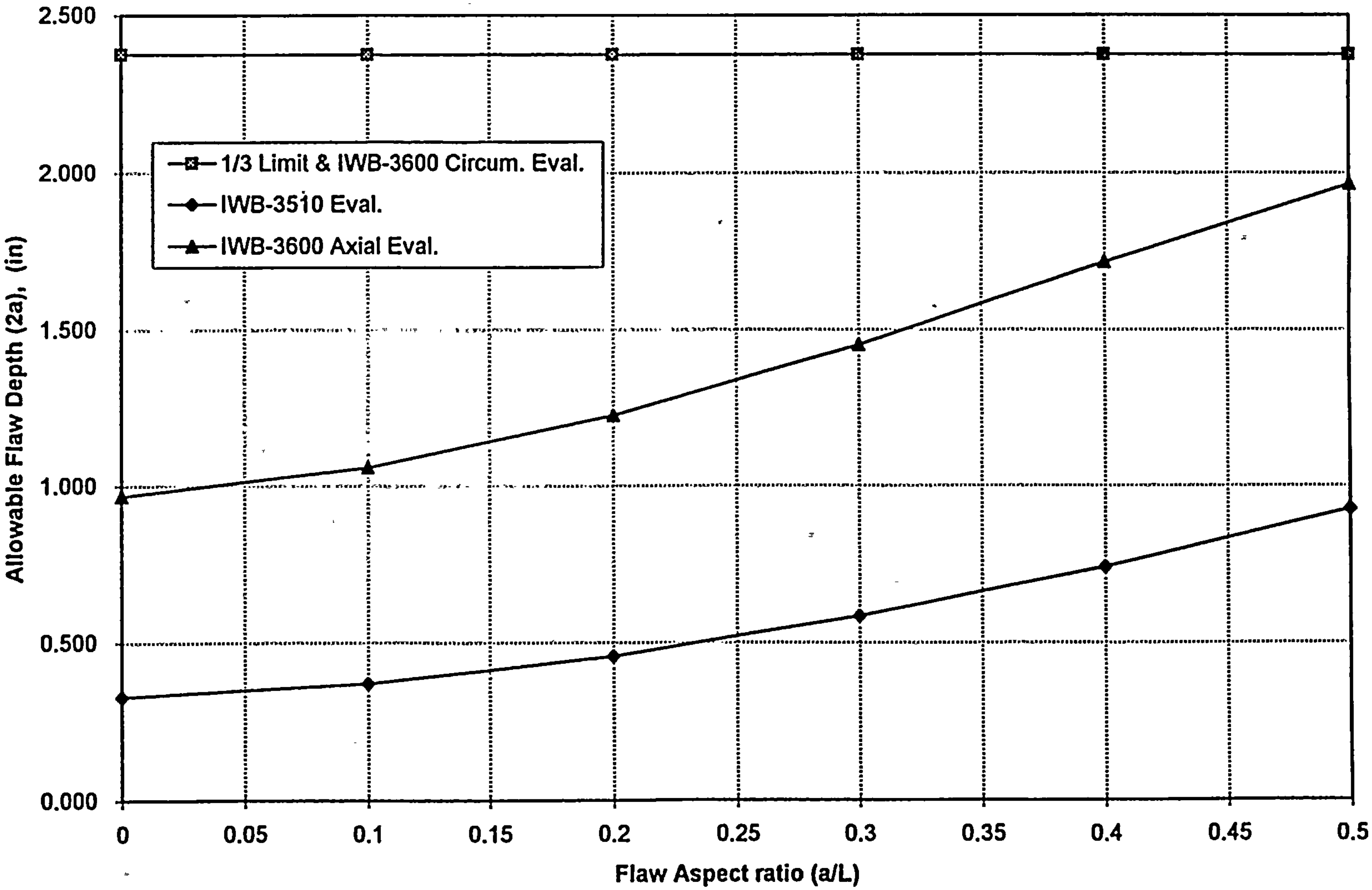


Figure D-19. Lower Course at 258 Deg, Surface Flaw @ 28 EFPY

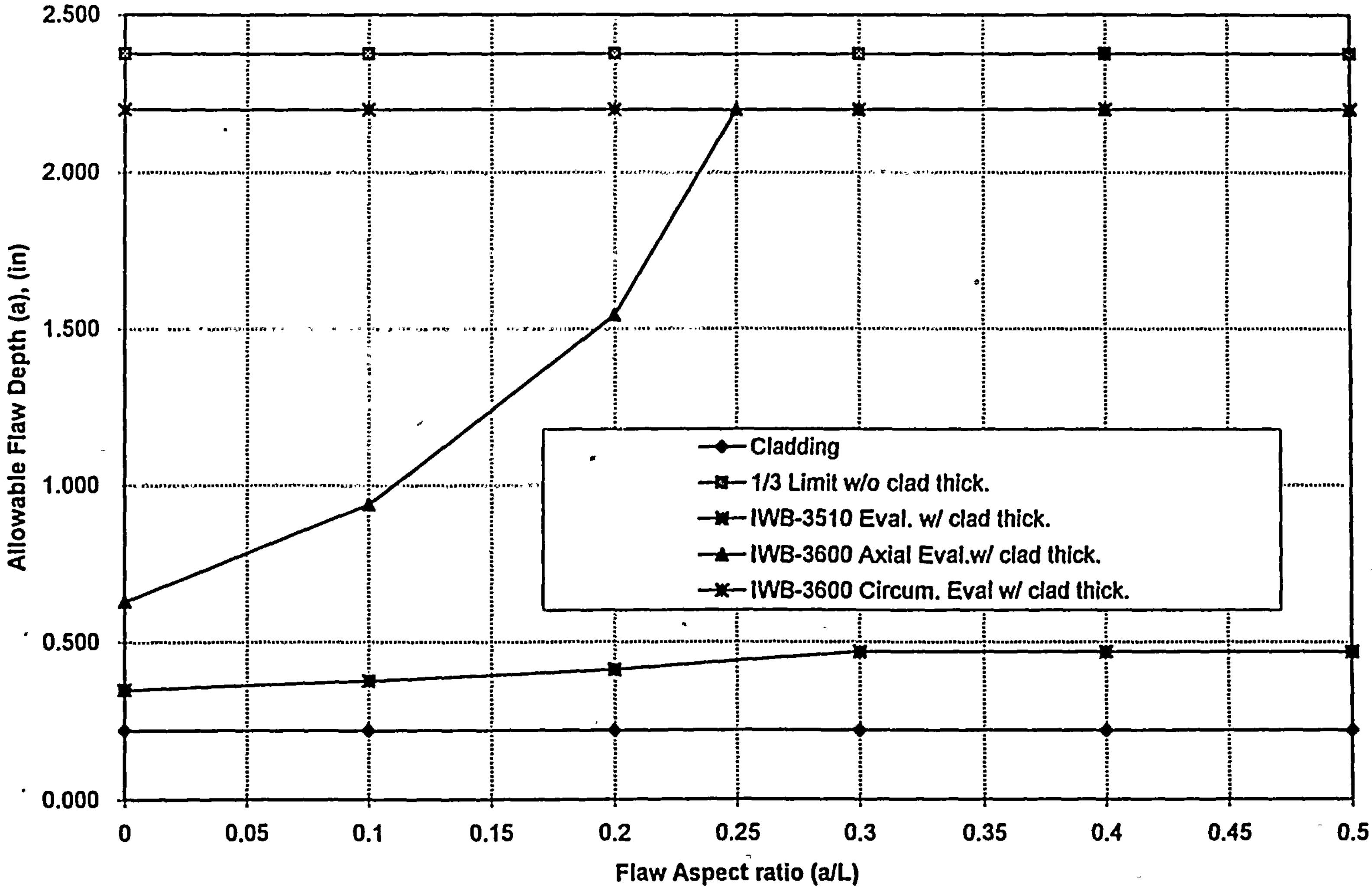


Figure D-20. Lower Course at 258 Deg, Subsurface Flaw @ 28 EFPY

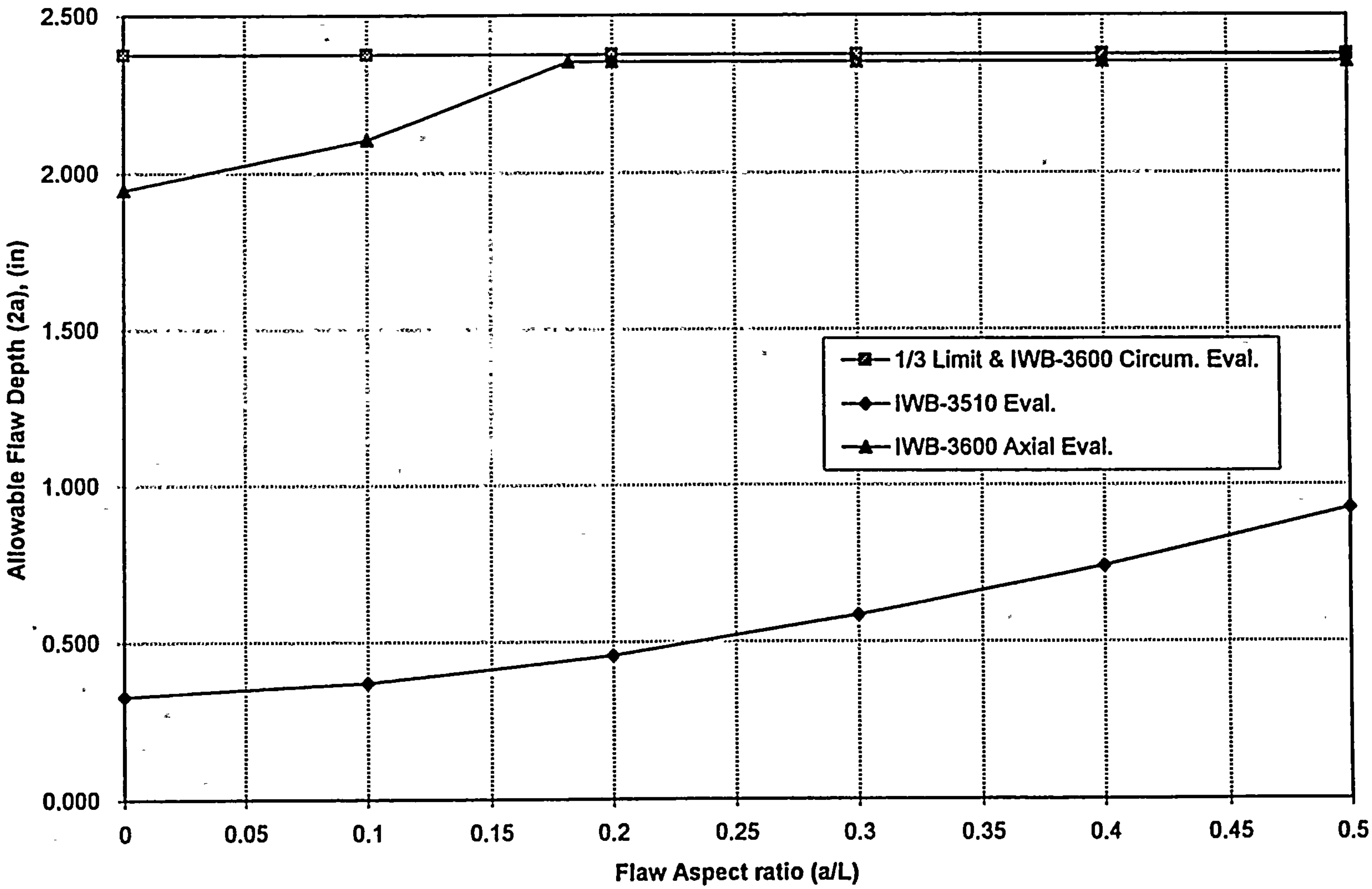


Figure D-21. Beltline Circum. Weld RVWD 137, Surface Flaw @ 28 EFPY

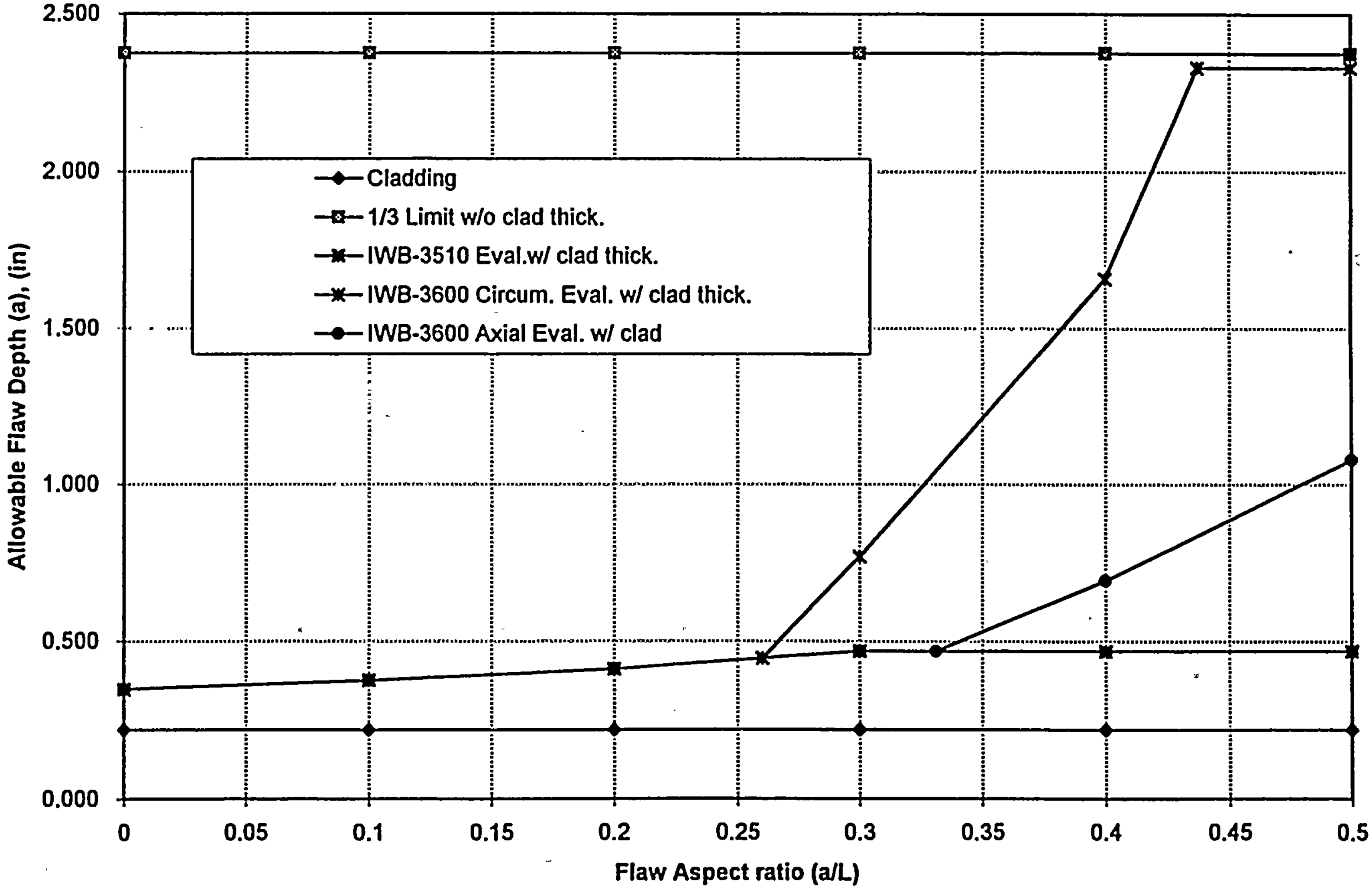
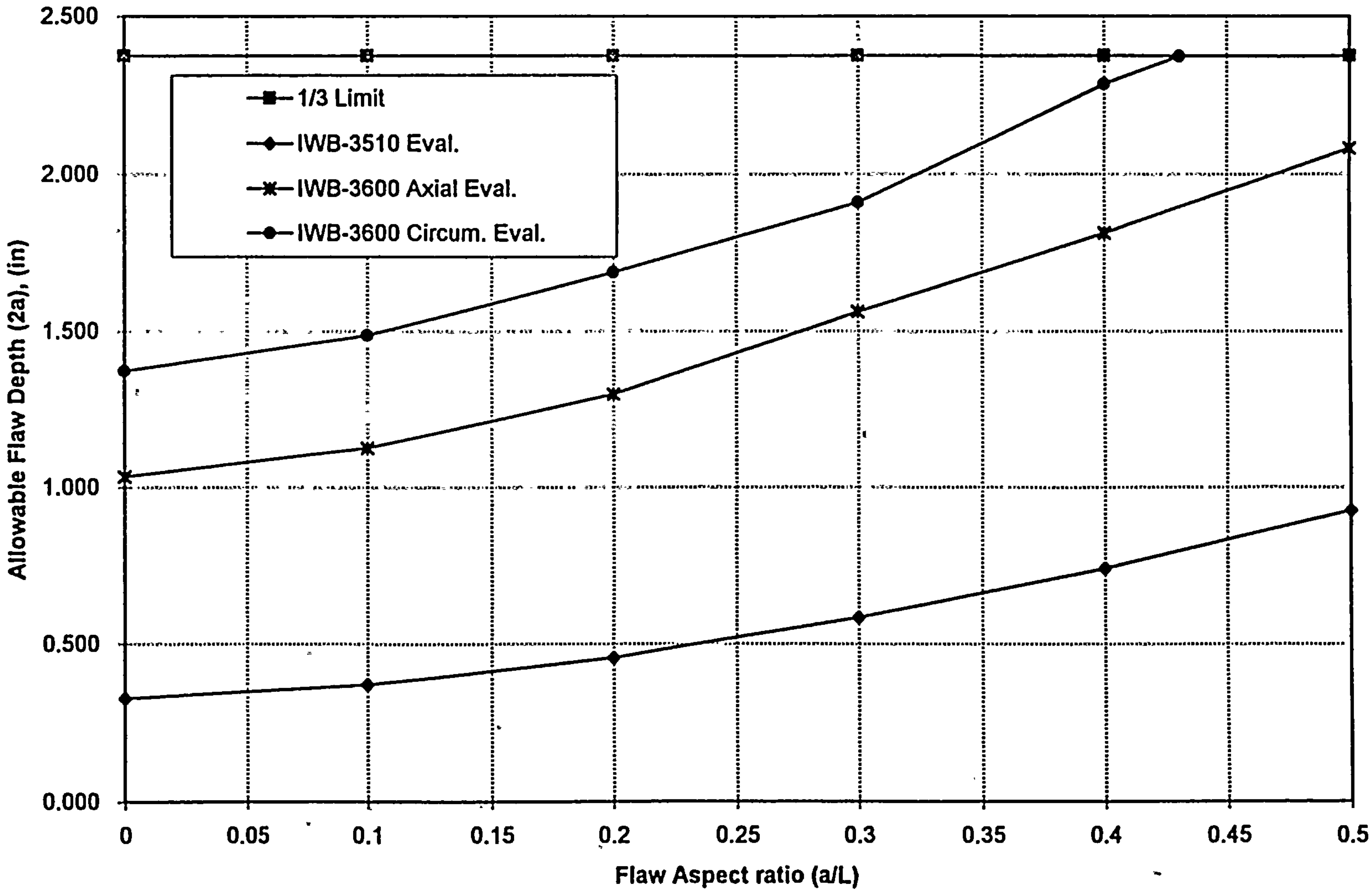


Figure D-22. Beltline Circum. Weld RVWD 137, Subsurface Flaw @ 28 EFPY



ATTACHMENT 2B