H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2

WCAP-15621-NP, REVISION 1, "HANDBOOK ON FLAW EVALUATION FOR THE H.B. ROBINSON UNIT 2 REACTOR VESSEL," AUGUST 2008

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15621-NP
Revision 1

August 2008

Handbook on Flaw Evaluation for the H. B. Robinson Unit 2 Reactor Vessel

Westinghouse

WCAP-15621-NP

Revision 1

Handbook on Flaw Evaluation for the H. B. Robinson Unit 2 Reactor Vessel

A. Udyawar

August 2008

Reviewer: S. F. Hankinson*
Piping Analysis & Fracture Mechanics

Approved: S. A. Swamy*
Manager, Piping Analysis & Fracture Mechanics

*Electronically approved records are authenticated in the Electronic Document Management System.

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

© 2008 Westinghouse Electric Company LLC
All Rights Reserved

REVISION RECORD

Revision Number	Date	Description
0	March 2001	Original Issued Document
1	August 2008	Updated the crack growth laws at the Reactor Vessel Inlet and Outlet nozzle safe end weld regions.

**** NOTE ****

The information contained in WCAP-15621-NP Revision 1 pertaining to the reactor vessel closure head is obsolete because it does not reflect the configuration of the current reactor vessel head that was installed in 2005. Additional evaluation and/or reconciliation are necessary to update WCAP-15621-NP Revision 1 to reflect the new reactor vessel head configuration.

TABLE OF CONTENTS

REVISION RECORD iii

LIST OF TABLES vii

LIST OF FIGURES ix

EXECUTIVE SUMMARY xiii

1 INTRODUCTION 1-1
1.1 CODE ACCEPTANCE CRITERIA: FERRITIC REGIONS 1-2
1.1.1 Criteria Based on Flaw Size 1-2
1.1.2 Criteria Based on Stress Intensity Factor 1-3
1.1.3 Primary Stress Limits 1-4
1.2 ASME CODE ACCEPTANCE CRITERIA: AUSTENITIC PIPING 1-4
1.3 GEOMETRY 1-4

2 LOAD CONDITIONS 2-1
2.1 TRANSIENTS FOR THE REACTOR VESSEL 2-1

3 SUBCRITICAL CRACK GROWTH 3-1
3.1 FATIGUE CRACK GROWTH 3-1
3.2 STRESS CORROSION CRACK GROWTH 3-2

4 CRITICAL FLAW SIZE CALCULATIONS 4-1
4.1 INTRODUCTION 4-1
4.2 STRESS INTENSITY FACTOR CALCULATIONS 4-1
4.3 FRACTURE TOUGHNESS 4-1
4.4 CRITICAL FLAW SIZE BASED ON LIMIT LOAD 4-2
4.5 RESULTS 4-2

5 REFERENCES 5-1
A-1 BELTLINE (INCLUDING CIRCUMFERENTIAL AND LONGITUDINAL SEAM WELDS) A1-1
A-1.1 Surface Flaws A1-1
A-1.2 Embedded Flaws A1-1
A-2 NOZZLE SHELL TO INTERMEDIATE SHELL WELD A2-1
A-2.1 Surface Flaws A2-1
A-2.2 Embedded Flaws A2-2
A-3 INLET NOZZLE TO SHELL WELD A3-1
A-3.1 Surface Flaws A3-1
A-3.2 Embedded Flaws A3-2
A-4 INLET NOZZLE INNER RADIUS (CORNER) A4-1
A-4.1 Surface Flaws A4-1
A-5 INLET NOZZLE SAFE-END WELD REGIONS A5-1
A-5.1 Surface Flaws A5-1
A-5.2 Embedded Flaws A5-2

A-6 OUTLET NOZZLE TO SHELL WELD A6-1
A-6.1 Surface Flaws A6-1
A-6.2 Embedded Flaws A6-2
A-7 OUTLET NOZZLE INNER RADIUS (CORNER) A7-1
A-7.1 Surface Flaws A7-1
A-8 OUTLET NOZZLE SAFE-END WELD REGIONS A8-1
A-8.1 SURFACE FLAWS A8-1
A-8.2 Embedded Flaws A8-2
A-9 LOWER HEAD TO SHELL WELDS (INCLUDES DOLLAR WELD) A9-1
A.9-1 Surface Flaws A9-1
A-9.2 Embedded Flaws A9-2
A-10 TOP HEAD TO FLANGE WELD (INCLUDES TORUS TO DOME WELD) A10-1
A-10.1 Surface Flaws A10-1
A-10.2 Embedded Flaws A10-2
A-11 LOWER FLANGE TO SHELL WELD (INCLUDES DOLLAR WELD) A11-1
A-11.1 Surface Flaws A11-1
A-11.2 Embedded Flaws A11-2

LIST OF TABLES

TABLE 2-1 Summary of Reactor Vessel Transients 2-2

LIST OF FIGURES

Figure 1-1 Schematic Representation of Appendix A Flaw Evaluation Process 1-5

Figure 1-2 Reactor Vessel Welds and Geometry: H. B. Robinson Nuclear Power Plant 1-6

Figure 1-3 Upper Head and Lower Head Regions: H. B. Robinson Nuclear Power Plant 1-7

Figure 1-4 Geometry of Reactor Vessel Inlet and Outlet Nozzles: H. B. Robinson Nuclear Power Plant 1-8

Figure 1-5 Geometry of Reactor Vessel Inlet and Outlet Nozzle Safe-end Regions 1-9

Figure 1-6 Typical Notation for Surface and Embedded Flaw Indications 1-10

Figure A-1 Example of Surface Flaw Evaluation A-9

Figure A-2 Example of Embedded Flaw Evaluation A-10

Figure A-3 Acceptance Standards for Embedded Flaws, for Section Thickness 4 Inches and Greater (From Tables IWB 3510 and IWB 3512) A-11

Figure A-4 Acceptance Standards for Embedded Flaws, for Section Thicknesses Less than 4 Inches (From Tables IWB 3510 and IWB 3512) A-12

Figure A-1.1 Geometry and Terminology for Flaws in the Beltline A1-3

Figure A-1.2 Evaluation Chart for Reactor Vessel Beltline A1-4

Figure A-1.3 Evaluation Chart for Reactor Vessel Beltline (RT_{NDT} < 245°F) A1-5

Figure A-1.4 Evaluation Chart for Reactor Vessel Beltline (RT_{NDT} < 260°F) A1-6

Figure A-1.5 Evaluation Chart for Reactor Vessel Beltline A1-7

Figure A-1.6 Evaluation Chart for Reactor Vessel Beltline A1-8

Figure A-2.1 Geometry and Terminology for Flaws at the Nozzle Shell to Intermediate Shell Weld A2-3

Figure A-2.2 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld A2-4

Figure A-2.3 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld A2-5

Figure A-2.4 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld A2-6

Figure A-2.5 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld A2-7

Figure A-2.6 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld A2-8

Figure A-2.7 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld A2-9

LIST OF FIGURES (Cont.)

Figure A-3.1 Geometry and Terminology for Flaws at the Inlet Nozzle to Shell Weld A3-3

Figure A-3.2 Evaluation Chart for Inlet Nozzle to Shell Weld A3-4

Figure A-3.3 Evaluation Chart for Inlet Nozzle to Shell Weld A3-5

Figure A-3.4 Evaluation Chart for Inlet Nozzle to Shell Weld A3-6

Figure A-3.5 Evaluation Chart for Inlet Nozzle to Shell Weld A3-7

Figure A-3.6 Evaluation Chart for Inlet Nozzle to Shell Weld A3-8

Figure A-3.7 Evaluation Chart for Inlet Nozzle to Shell Weld A3-9

Figure A-4.1 Geometry and Terminology for Flaws at the Inlet Nozzle Inner Radius (Corner) A4-2

Figure A-4.2 Evaluation Chart for Inlet Nozzle Inner Radius (Corner) A4-3

Figure A-5.1 Geometry and Terminology for Flaws at the Inlet Nozzle Safe-End Weld Region A5-4

Figure A-5.2 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A5-5

Figure A-5.3 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A5-6

Figure A-5.4 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A5-7

Figure A-5.5 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A5-8

Figure A-5.6 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A5-9

Figure A-5.7 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A5-10

Figure A-5.8 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A5-11

Figure A-5.9 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A5-12

Figure A-6.1 Geometry and Terminology for Flaws at the Outlet Nozzle to Shell Weld A6-3

Figure A-6.2 Evaluation Chart for Outlet Nozzle to Shell Weld A6-4

Figure A-6.3 Evaluation Chart for Outlet Nozzle to Shell Weld A6-5

Figure A-6.4 Evaluation Chart for Outlet Nozzle to Shell Weld A6-6

Figure A-6.5 Evaluation Chart for Outlet Nozzle to Shell Weld A6-7

Figure A-6.6 Evaluation Chart for Outlet Nozzle to Shell Weld A6-8

Figure A-6.7 Evaluation Chart for Outlet Nozzle to Shell Weld A6-9

Figure A-7.1 Geometry and Terminology for Flaws at the Outlet Nozzle Inner Radius (Corner) A7-2

Figure A-7.2 Evaluation Chart for Outlet Nozzle Inner Radius (Corner) A7-3

LIST OF FIGURES (Cont.)

Figure A-8.1 Geometry and Terminology for Flaws at the Outlet Nozzle Safe-End Weld Region ... A8-4
Figure A-8.2 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A8-5
Figure A-8.3 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A8-6
Figure A-8.4 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A8-7
Figure A-8.5 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A8-8
Figure A-8.6 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A8-9
Figure A-8.7 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel) A8-10
Figure A-8.8 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A8-11
Figure A-8.9 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182) A8-12
Figure A-9.1 Geometry and Terminology for Flaws at the Lower Head to Shell Weld A9-3
Figure A-9.2 Evaluation Chart for Lower Head to Shell Weld A9-4
Figure A-9.3 Evaluation Chart for Lower Head to Shell Weld A9-5
Figure A-9.4 Evaluation Chart for Lower Head to Shell Weld A9-6
Figure A-9.5 Evaluation Chart for Lower Head to Shell Weld A9-7
Figure A-9.6 Evaluation Chart for Lower Head to Shell Weld A9-8
Figure A-9.7 Evaluation Chart for Lower Head to Shell Weld A9-9
Figure A-10.1 Geometry and Terminology for Flaws at the Top Head to Flange Weld A10-3
Figure A-10.2 Evaluation Chart for Top Head to Flange Weld A10-4
Figure A-10.3 Evaluation Chart for Top Head to Flange Weld A10-5
Figure A-10.4 Evaluation Chart for Top Head to Flange Weld A10-6
Figure A-10.5 Evaluation Chart for Top Head to Flange Weld A10-7
Figure A-10.6 Evaluation Chart for Top Head to Flange Weld A10-8
Figure A-11.1 Surface and Embedded Flaw Indications at the Lower Flange to Shell Weld A11-3
Figure A-11.2 Evaluation Chart for Lower Flange to Shell Weld A11-4
Figure A-11.3 Evaluation Chart for Lower Flange to Shell Weld A11-5
Figure A-11.4 Evaluation Chart for Lower Flange to Shell Weld A11-6
Figure A-11.5 Evaluation Chart for Lower Flange to Junction Shell Weld A11-7
Figure A-11.6 Evaluation Chart for Lower Flange to Shell Weld A11-8

EXECUTIVE SUMMARY

This handbook has been prepared to allow quick, yet accurate, assessment of indications which may be discovered during inservice inspections of the H. B. Robinson Unit 2 reactor vessel. This assessment capability is provided in the form of charts for each region of the vessel, and these are contained in Appendix A of this document. Appendix A begins with a simple example demonstrating use of the evaluation charts, followed by a section for each region of the reactor vessel. Details of the derivation of the charts are provided in the technical basis document [1]*. The main body of the handbook provides brief summaries of the various calculations carried out in developing the charts. To evaluate the acceptability of an indication, the user may proceed directly to Appendix A.

Revision 1 of this report updates the surface and embedded flaw evaluation charts for the Inlet and Outlet Nozzles safe end weld regions only. The updated charts are presented in Sections A-5 and A-8 for the Inlet and Outlet nozzles respectively. These revised charts utilize the latest crack growth rates for the nickel base alloy and the austenitic stainless steel weld materials as discussed in Section 3.0 of the technical basis document [1]. Revision bars are added in the left-hand side margins of this document to reflect these technical changes.

It should be noted that the information contained in WCAP-15621-NP Revision 1 pertaining to the reactor vessel closure head is obsolete because it does not reflect the configuration of the current reactor vessel head that was installed in 2005. Additional evaluation and/or reconciliation are necessary to update WCAP-15621-NP Revision 1 to reflect the new reactor vessel head configuration.

*Numbers in brackets indicate references contained in Section 5.

1 INTRODUCTION

This flaw evaluation handbook has been designed for the evaluation of indications which may be discovered during inservice inspection of the H. B. Robinson reactor vessel. The tables and charts provided in Appendix A of this report allow the evaluation of any indication discovered in the regions listed below, without further fracture mechanics calculations. The fracture analysis work has been done in advance, in accordance with the criteria of ASME Code Section XI, and is documented in a companion background and technical basis report [1]. Use of the handbook will allow the acceptability of larger indications than would be allowable by only using the standards tables of Section XI [2]. A schematic representation of the flaw evaluation process of Section XI Appendix A is provided in Figure 1-1.

This flaw evaluation handbook has been developed as a direct implementation of the analytical requirements of Section XI. In all cases the most accurate material properties and analytical criteria have been used. The material properties and analytical criteria for Revision 0 of this report were based on ASME Section XI 1983 Edition with Winter 1985 Addendum and 1989 Editions as referenced in Revision 0 of the background and technical basis report (WCAP-15620). In preparation for the Fall 2008 inspection of the reactor vessel inlet and outlet nozzle dissimilar metal butt welds, Revision 1 of this report updated the flaw evaluation charts for the reactor vessel inlet and outlet nozzle safe end weld regions in accordance with the latest crack growth laws and the ASME Section XI 1995 Edition with 1996 Addendum requirements. This handbook has been designed for use throughout the operating lifetime of the plants, during which time the applicable edition of Section XI will change a number of times.

It should be noted that the information contained in WCAP-15621-NP Revision 1 pertaining to the reactor vessel closure head is obsolete because it does not reflect the configuration of the current reactor vessel head that was installed in 2005. Additional evaluation and/or reconciliation are necessary to update WCAP-15621-NP Revision 1 to reflect the new reactor vessel head configuration.

The handbook is applicable to the following locations in the H. B. Robinson Nuclear Power Plant Unit 2 reactor vessel:

- Beltline (core region) [Note that this region includes all the core region welds]
- Inlet nozzle: nozzle to shell weld, safe end weld regions, and inner radius (corner)
- Outlet nozzle: nozzle to shell weld, safe end weld regions, and inner radius (corner)
- Lower head ring to lower shell weld (including lower head to ring weld)
- Lower flange to shell weld
- Top head ring to flange weld (including top head torus to dome weld) **(Original Vessel Head)**

The geometry of each of these regions is shown in Figures 1-2 through 1-5, and repeated in the appropriate section of Appendix A for convenience.

The highlight of the handbook is the design of a series of flaw evaluation charts for both surface flaws and embedded flaws. Since the characteristics of the two types of flaws are different, separate evaluation charts are designed for each flaw type. Flaw charts have been developed for surface flaws as well as embedded flaws, in all the regions of the reactor vessel which will require inspection. Postulated flaws in both longitudinal and circumferential orientations are considered in each region, except the inlet and outlet nozzle inner radius regions, where only longitudinal surface flaws are considered.

The flaw evaluation charts are provided in Appendix A of this document, and have been developed using the methodology discussed in the technical basis document [1]. For flaw evaluation of an indication discovered in an inspection, turn directly to Appendix A.

Revision 1 of this report updates the surface and embedded flaw evaluation charts for the Inlet and Outlet Nozzles safe end weld regions only. The updated charts are presented in Sections A-5 and A-8 for the Inlet and Outlet nozzles respectively. These revised charts utilize the applicable Fatigue Crack Growth (FCG) rates for both austenitic stainless steel and nickel base alloy weld materials while the applicable Primary Water Stress Corrosion Crack (PWSCC) growth rates are considered for the nickel base alloy weld material. These crack growth rates are discussed in Section 3.0 of the technical basis document [1].

1.1 CODE ACCEPTANCE CRITERIA: Ferritic Regions

There are two alternate sets of flaw acceptance criteria for continued service without repair in paragraph IWB-3600 of ASME Code Section XI:

1. Acceptance Criteria Based on Flaw Size (IWB-3611)
2. Acceptance Criteria Based on Stress Intensity Factor (IWB-3612)

For the surface flaw evaluation charts, analyses were performed for each region using both of the acceptance criteria. To illustrate, one evaluation was performed using the flaw size acceptance criteria, in order to determine the smallest allowable flaw size for all the design transients. Then a second analysis was performed using the criteria based on stress intensity factor, as described in Section 1.1.2 to find the smallest acceptable flaw size for all the design transients. The results of these two sets of analyses were then compared, and the more beneficial criteria (allowing the largest flaw) were used.

Both criteria are comparable for thick sections. Acceptance criteria in Section 1.1.2 have been assessed by past experience to be less restrictive for thin sections, and for outside surface flaws in many cases.

All of the embedded flaw evaluation charts in this handbook were constructed using acceptance criteria in Section 1.1.2, for ease of use, as well as to obtain the maximum benefit, since these criteria will generally be less restrictive for embedded flaws.

1.1.1 Criteria Based on Flaw Size

The code acceptance criteria are stated in Paragraph IWB-3611 of Section XI:

$a_f < 0.1\ a_c$ For normal conditions (upset & test conditions inclusive)

and $a_f < 0.5\ a_i$ For faulted conditions (emergency condition inclusive)

where

a_f = The maximum size to which the detected flaw is calculated to grow at the end of the next inspection time, as applicable.

a_c = The minimum critical flaw size under normal operating conditions (upset and test conditions inclusive).

a_i = The minimum critical flaw size for initiation of nonarresting growth under postulated faulted conditions (emergency conditions inclusive).

To determine whether a flaw indication is acceptable for continued service without repair, both criteria must be met. Both criteria have been considered in the construction of the charts.

1.1.2 Criteria Based on Stress Intensity Factor

The term stress intensity factor (K_I) is defined as the driving force on a crack. It is a function of the size of the crack and the applied stresses, as well as the overall geometry of the structure. In contrast, the fracture toughness (K_{Ia}, K_{Ic}) is a measure of the resistance of the material to propagation of a crack. It is a material property, and a function of temperature.

The criteria with respect to K_I used for the evaluation of embedded flaws, surface flaws of the nozzle safe-end, and most outside surface flaws are from IWB-3612 of Section XI. The criteria are:

$$K_I < \frac{K_{Ia}}{\sqrt{10}}$$ For normal conditions (upset & test conditions inclusive)

$$K_I < \frac{K_{Ic}}{\sqrt{2}}$$ For faulted conditions (emergency conditions inclusive)

where

K_I = The maximum applied stress intensity factor for the flaw size a_f to which a detected flaw will grow, during the conditions under consideration, to the next inspection.

K_{Ia} = Fracture toughness based on crack arrest for the corresponding crack tip temperature.

K_{Ic} = Fracture toughness based on fracture initiation for the corresponding crack tip temperature.

To determine whether a surface flaw is acceptable for continued service without repair, both criteria must be met. Both criteria have been considered in the construction of the charts.

1.1.3 Primary Stress Limits

In addition to satisfying the fracture criteria, it is required that the primary stress limits of ASME Code Section III, paragraph NB-3000 be satisfied. A local area reduction of the pressure retaining membrane must be used, equal to the area of the indication, and the stresses increased to reflect the smaller cross section. All of the flaw acceptance tables provided in this handbook have included this consideration, as demonstrated in the technical basis document [1].

1.2 ASME CODE ACCEPTANCE CRITERIA: Austenitic Piping

The evaluation procedures and acceptance criteria for indications in austenitic piping are contained in paragraph IWB-3640 of ASME Section XI [2]. The evaluation procedure is applicable to all the materials in the piping system. However, the only regions covered in this handbook are the nozzle safe-end weld regions.

The evaluation process begins with a flaw growth analysis, including the requirements for fatigue and stress corrosion cracking. The methodology for the subcritical crack growth analysis is described in detail in Section 3.

Next, the calculated maximum flaw dimensions for the specified interval are compared with the maximum allowable flaw dimensions for both normal/upset conditions and emergency/faulted conditions, to determine acceptability for continued service.

In paragraph IWB-3640 of the Code [2], the allowable flaw sizes are defined in the tables based on failure load safety margins. The calculated failure loads are different for the base metal and the flux welds, which have different fracture toughness values, as discussed in Section 4. The failure loads, and consequently the allowable flaw sizes, are larger for the base metal than for the stainless steel welds.

1.3 GEOMETRY

The geometry of the reactor vessel is shown in Figures 1-2 through 1-5. The cladding on the inside surface of the vessel has been neglected in the stress analysis. However, in the heat transfer calculations, for both normal/upset and emergency/faulted conditions, the cladding has been accounted for by adjusting the film coefficient. The outside surfaces have been assumed to be insulated. The notation used for both surface and embedded flaws in this work is illustrated in Figure 1-6, and repeated in each of the sections of Appendix A.

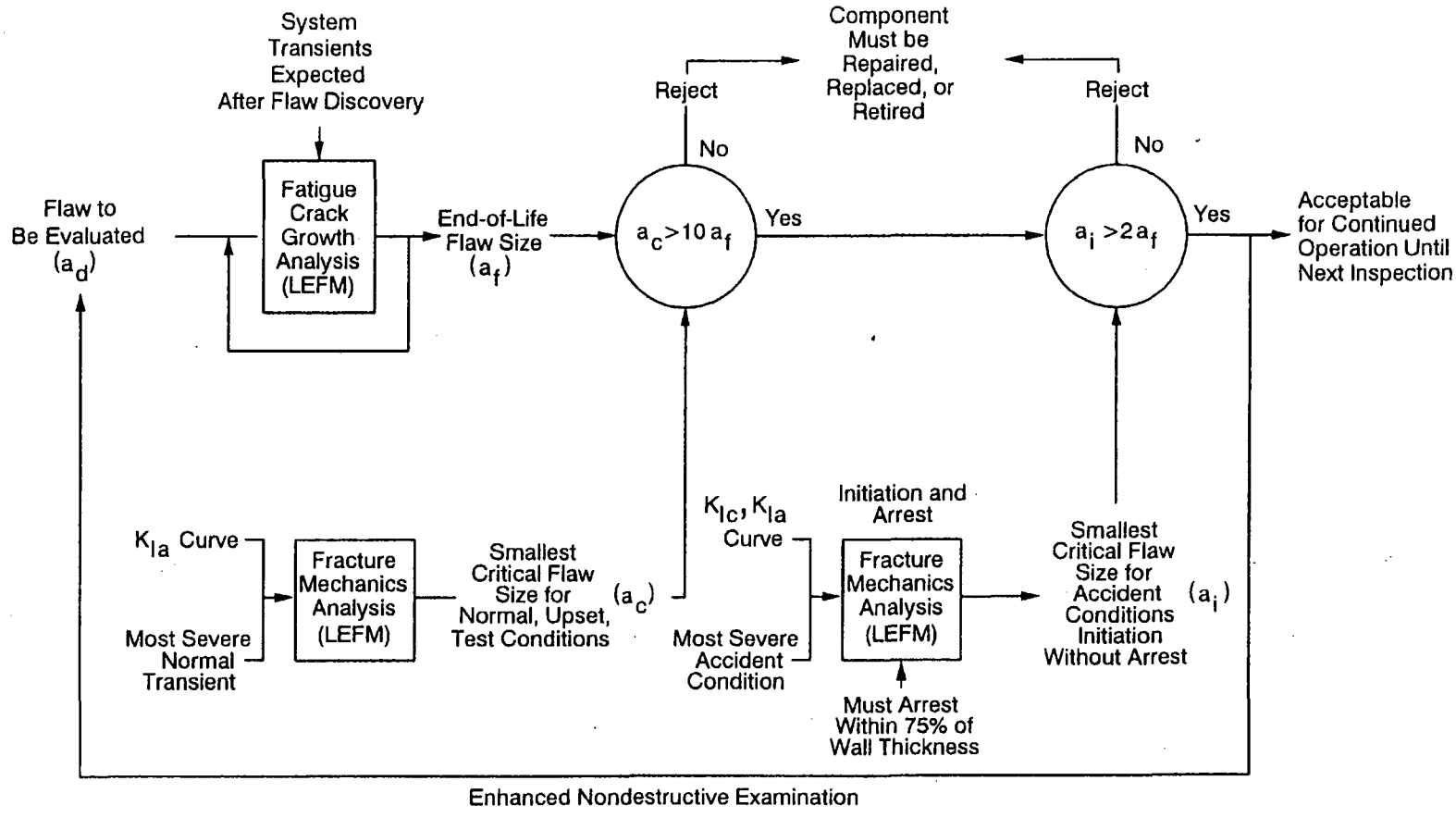


Figure 1-1 Schematic Representation of Appendix A Flaw Evaluation Process

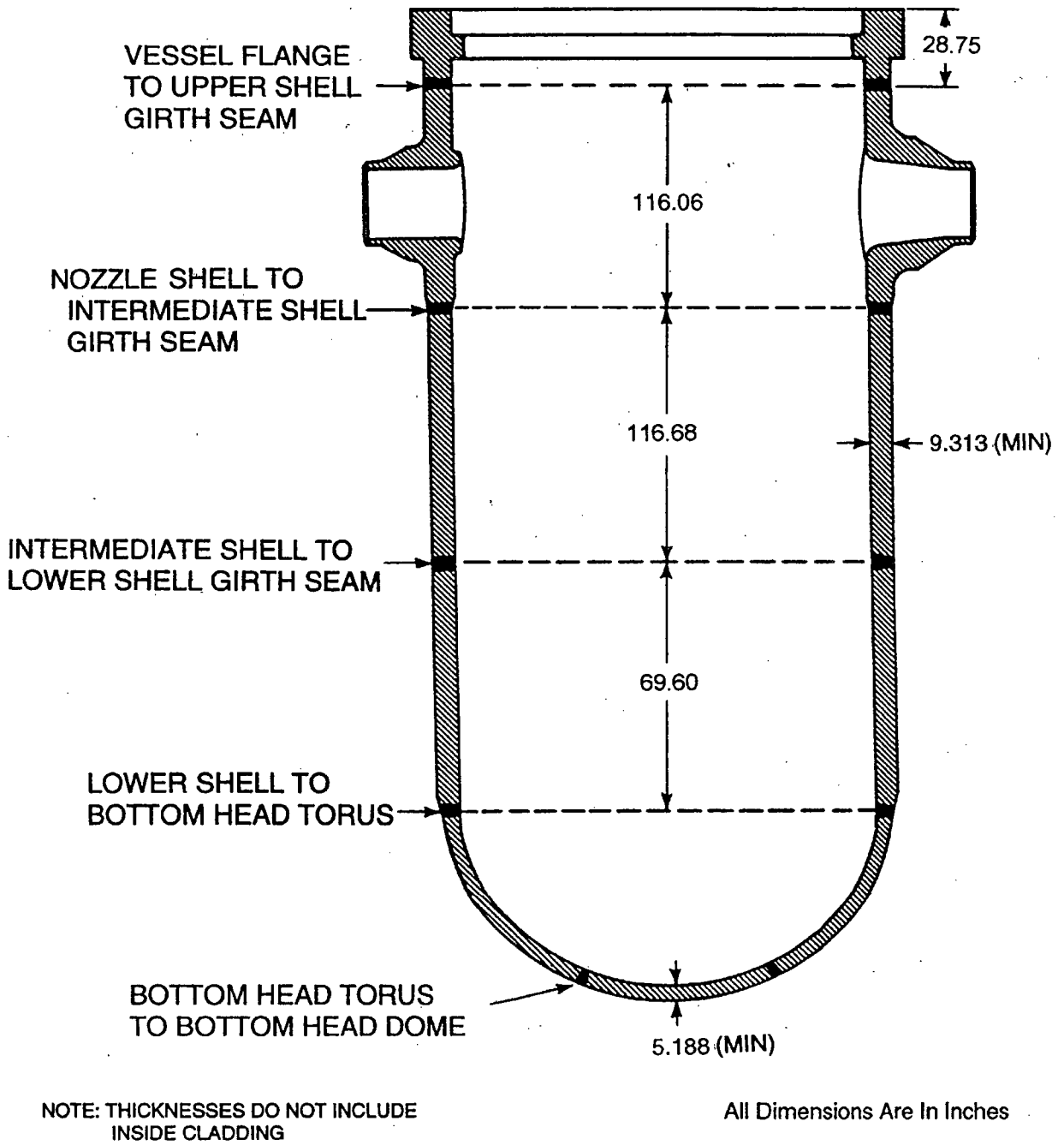
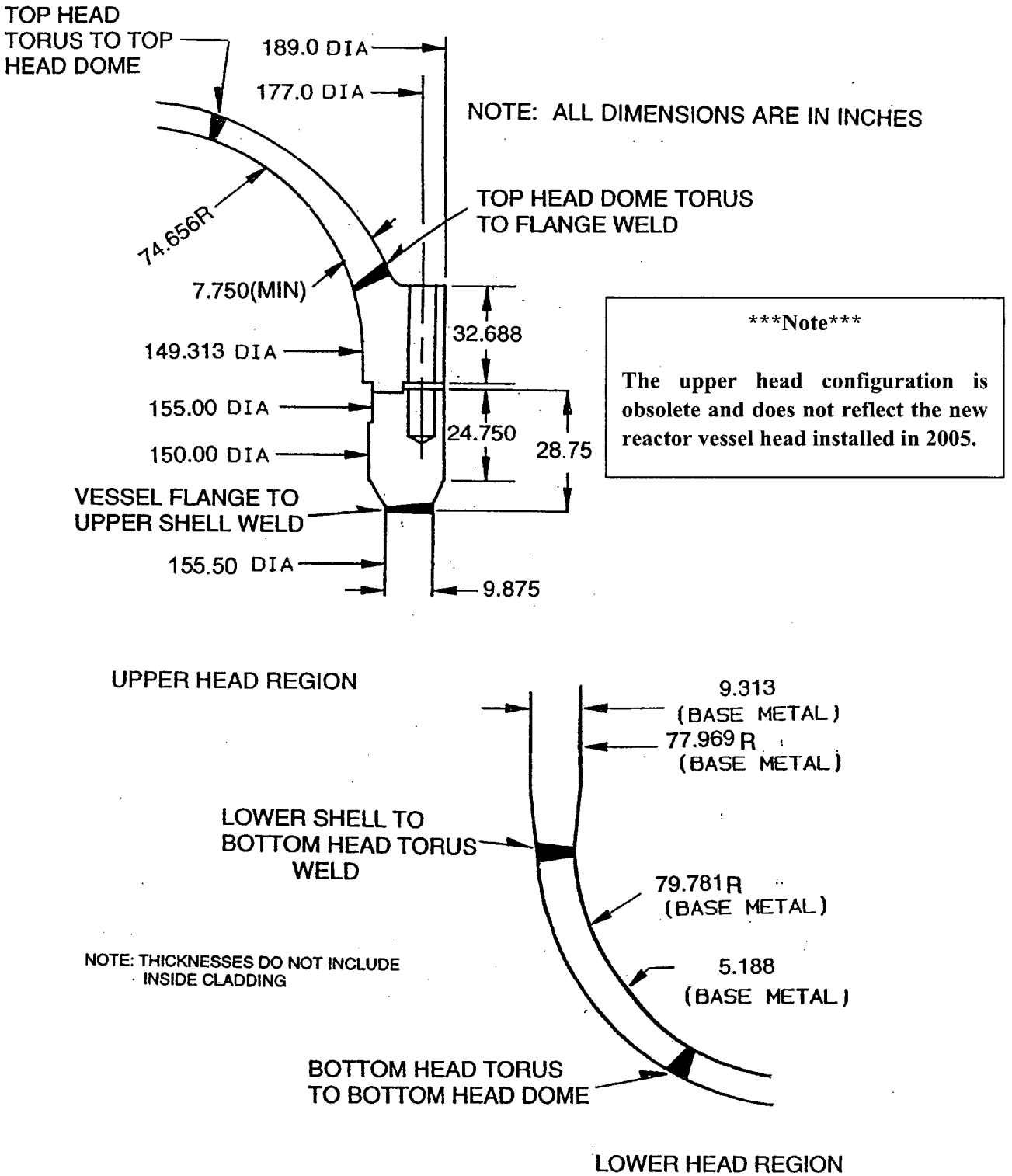


Figure 1-2 Reactor Vessel Welds and Geometry: H. B. Robinson Nuclear Power Plant



Note

The upper head configuration is obsolete and does not reflect the new reactor vessel head installed in 2005.

Figure 1-3 Upper Head and Lower Head Regions: H. B. Robinson Nuclear Power Plant

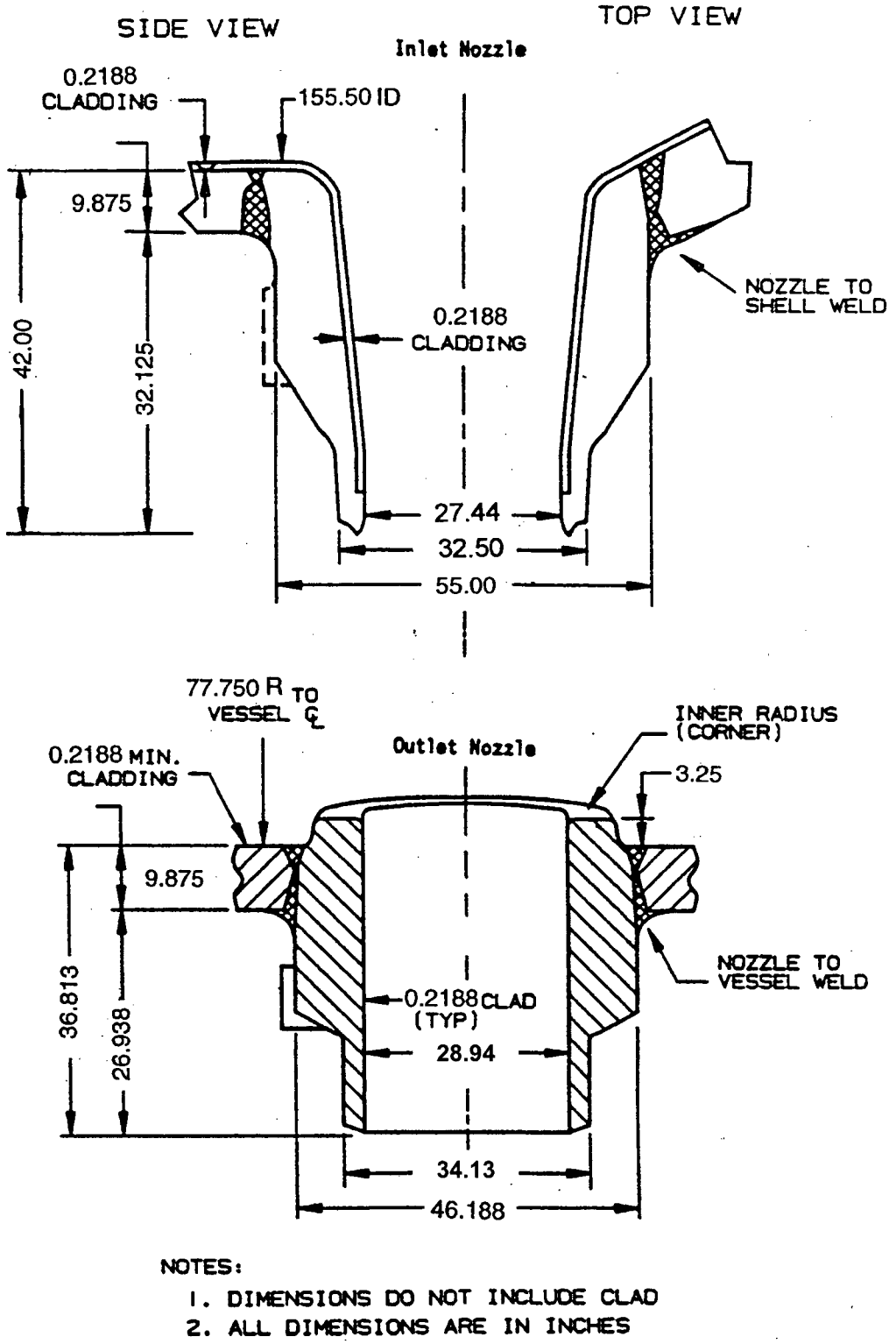


Figure 1-4 Geometry of Reactor Vessel Inlet and Outlet Nozzles: H. B. Robinson Nuclear Power Plant

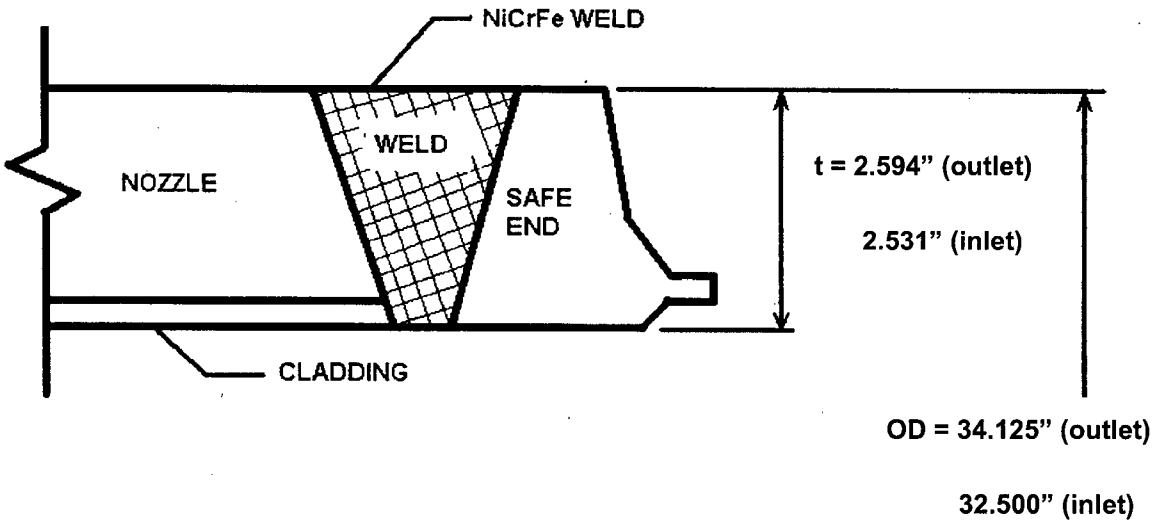


Figure 1-5 Geometry of Reactor Vessel Inlet and Outlet Nozzles Safe-end Regions

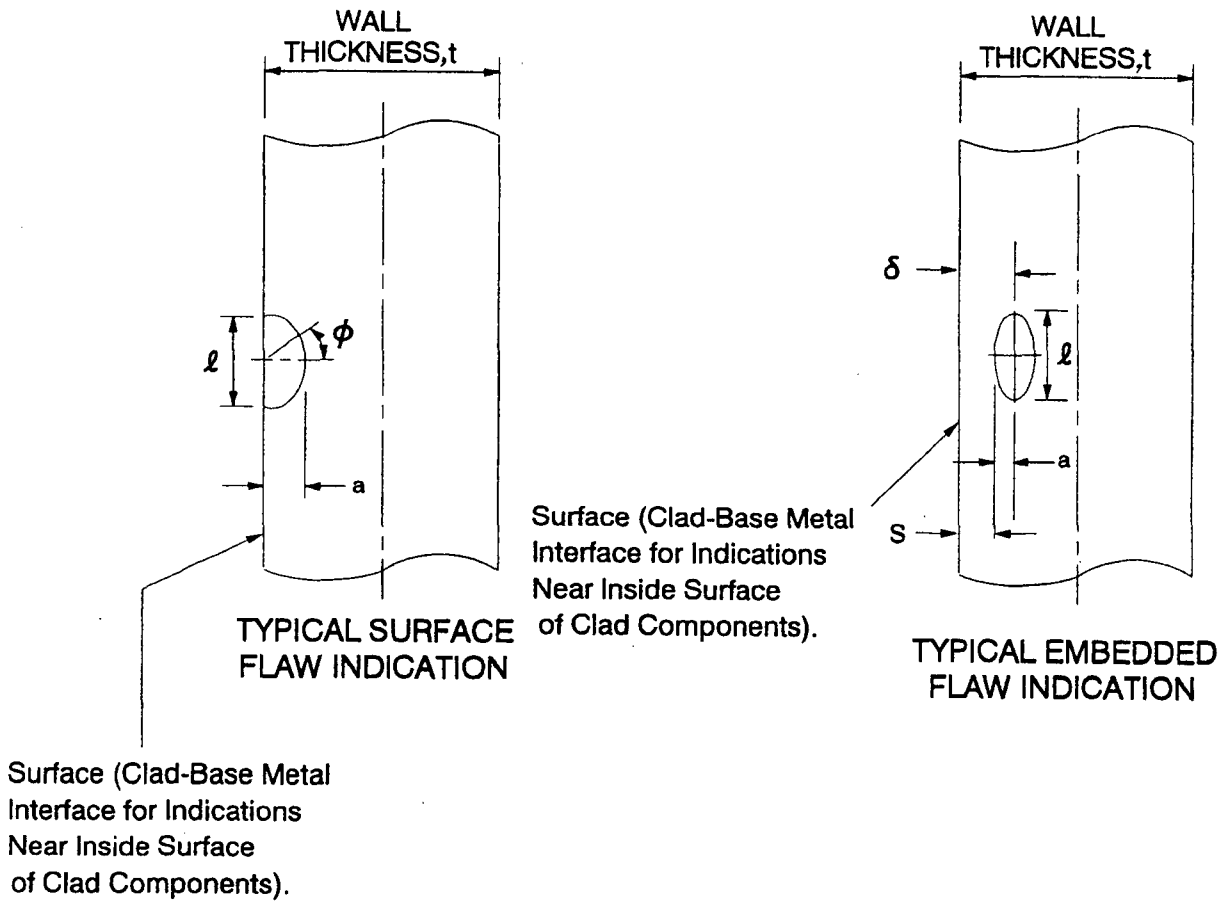


Figure 1-6 Typical Notation for Surface and Embedded Flaw Indications

2 LOAD CONDITIONS

2.1 TRANSIENTS FOR THE REACTOR VESSEL

The H. B. Robinson Unit 2 reactor vessel design transients are listed in Table 2-1. Both the minimum critical flaw sizes, such as a_c under normal operating conditions, or a_i under faulted conditions for criteria (1) of IWB-3611, and the stress intensity factors, K_I, for criteria (2) of IWB-3612 are a function of the stresses at the cross-section where the flaw of interest is located, along with the material properties. Therefore, the first step for the evaluation of a flaw indication is to determine the appropriate limiting load conditions for the location of interest.

The selection of the most limiting transient for normal/upset/test conditions was straightforward. The transient that produced the highest surface stress in the area where the flaw was postulated was chosen as the worst case. Note that this can result in a different limiting transient for an inside flaw as opposed to an outside flaw, as may be seen in the detailed treatments of the individual locations. The transients listed in these tables are the governing ones for the region involved, regardless of the criteria used to construct the flaw evaluation charts, either the criteria on flaw size (Section 1.1.1) or on applied K_I (Section 1.1.2). The selection of the most limiting emergency and faulted condition transient is discussed in Section 4 of the technical basis document [1].

For flaws near the outside surface of the vessel, separate considerations are required, since most of the thermal transients which occur affect the inside surface, and not the outside surface, which is insulated. Therefore, allowable flaw indications at the inside surface are generally smaller than those on the outside surface, as may be seen in the individual charts in Appendix A.

For flaws in the nozzle safe-end weld regions, the piping loads for H. B. Robinson Unit 2 have been included. It should be noted that only the nozzle to safe-end butter weld was stress relieved during vessel fabrication. Since the nozzle to safe-end and safe-end to pipe weld has not been stress relieved, reference residual stresses were also applied. These loads and stresses are detailed in the technical basis document [1].

Table 2-1 Summary of Reactor Vessel Transients

Number	Typical Transient Identification	Number of Cycles
1	TURBINE ROLL	20
2	COLD HYDRO	10
3	HEATUP/COOLDOWN	200
4	LOADING AND UNLOADING	14500
5	REDUCED TEMPERATURE RETURN TO POWER	2000
6	STEP LOAD DECREASE/INCREASE	2000
7	LARGE STEP LOAD DECREASE WITH STEAM DUMP	200
8	INITIAL STEADY STATE FLUCTUATION	150000
9	RANDOM STEADY STATE FLUCTUATION	3000000
10	FEEDWATER CYCLING	2000
11	LOOP OUT OF SERVICE SHUTDOWN & STARTUP	80
12	LOSS OF LOAD	80
13	LOSS OF POWER	40
14	PARTIAL LOSS OF FLOW	80
15	REACTOR TRIP WITH NO COOLDOWN	230
16	REACTOR TRIP WITH COOLDOWN NO SI	160
17	REACTOR TRIP WITH COOLDOWN AND SI	10
18	INADVERTANT DEPRESSURIZATION	60
19	INADVERTANT STARTUP OF AN INACTIVE LOOP	60
20	INADVERTANT SAFETY INJECTION ACTUATION	80
21	CONTROL ROD DROP	80
22	EXCESSIVE FEEDWATER FLOW	30
23	BORON CONCENTRATION	26400
24	REFUELING	80
25	HOT HYDRO	280

3 SUBCRITICAL CRACK GROWTH

3.1 FATIGUE CRACK GROWTH

In applying code acceptance criteria of Section 1, the final flaw size a_f used in criteria (1) is defined as the minimum flaw size to which the detected flaw is calculated to grow at the end of a specified period, or until the next inspection time. In this handbook, a range of inspection periods are assumed.

Crack growth calculations have been carried out for all key regions in the H. B. Robinson Nuclear Power Plant reactor vessel. This section will examine the calculations, and provide the methodology used as well as the assumptions. A more detailed discussion is contained in the technical basis document [1].

The analysis procedure involves postulating an initial flaw at specific regions and predicting the growth of that flaw due to an imposed series of loading transients. The input required for a fatigue crack growth analysis is basically the information necessary to calculate the parameter ΔK_I, which depends on crack and structure geometry and the range of applied stresses in the area where the crack exists. Once ΔK_I is calculated, the growth due to that particular stress cycle can be calculated. This increment of growth is then added to the original crack size, and the analysis proceeds to the next transient. The procedure is continued in this manner until all of the transients expected to occur in the period of evaluation have been analyzed.

The transients considered in the analysis are all of the design transients contained in the vessel equipment specification, as shown in Section 2. These transients are distributed equally over the design lifetime of the vessel, with the exception that the preoperational tests are considered first. Faulted conditions are not considered because their frequency of occurrence is too low to affect fatigue crack growth.

Crack growth calculations were carried out for three basic flaw types over a range of flaw depths. The first type was a finite surface flaw with length equal to a certain amount (e.g. 2, 3, 6, 10) times the depth. Next was a continuous surface flaw, which represents a worst case for surface flaws. The third flaw type was an embedded flaw, with a range of shapes and locations. For all cases the flaw was assumed to maintain a constant shape as it grew. The expressions used for calculating stress intensity factors for the various flaw types are documented in the technical basis document [1].

The crack growth rate curves used in the analyses of all the regions were taken directly from Appendix A of Section XI of the ASME Code with the exception of Alloy 82/182 weld material at the nozzle to safe-end weld regions. Water environment curves were used for all inside surface flaws, and the air environment curve was used for embedded flaws and outside surface flaws.

Growth rate is a function of both the applied stress intensity factor range, and the R ratio (K_{min}/K_{max}) for the transient. The crack growth rate reference curve for air environments is a single curve, with growth rate being only a function of applied ΔK. The fatigue crack growth curve for stainless steel was taken from Section XI Appendix C, and a factor of 2 was applied to account for the PWR environment [1]. The fatigue crack growth curve for Alloy 82/182 weld metal was obtained from NUREG/CR-6907 and NUREG/CR-6721 [4, 5], and is fully described in the technical basis document [1].

3.2 STRESS CORROSION CRACK GROWTH

The most significant potential mechanism of subcritical crack growth is stress corrosion cracking in the Alloy 82/182 nozzle to safe-end welds. Such cracking has recently been observed in several operating plants, and several experimental programs have been completed to characterize the growth rates of Alloy 82/182 materials in PWR environments.

There is presently no reference curve in the ASME Code for this mechanism of cracking; however, Alloy 82/182 stress corrosion crack growth reference curve is available in EPRI MRP-115 [6], and a full discussion for this reference curve is provided in the technical basis document [1].

4 CRITICAL FLAW SIZE CALCULATIONS

4.1 INTRODUCTION

The key parameters used in the evaluation of any indication discovered during inservice inspection are the critical flaw depths (a_c and a_i) required for the evaluation of the indication (critical flaw depth a_c is for the governing normal upset and test conditions and critical flaw depth a_i is for the governing emergency and faulted conditions).

The governing transient for normal, upset, and test conditions is easily selected based on the highest surface stress in the area of interest. For emergency and faulted conditions, this choice is not as straightforward due to recent developments on the pressurized thermal shock issue, which must be considered. After careful consideration of this issue, the governing transients for both normal and faulted conditions were chosen. The details of this procedure are provided in Reference [1].

4.2 STRESS INTENSITY FACTOR CALCULATIONS

One of the key elements of the critical flaw size calculations is the determination of the crack driving force or stress intensity factor. This was done for each of the regions, using expressions available from the literature. In all cases the stress intensity factor for the critical flaw size calculations utilized a representation of the actual stress profile rather than a linearization. This was necessary to provide the most accurate determination possible of the critical flaw size, and is particularly important for consideration of emergency and faulted conditions, where the stress profile is generally nonlinear and often very steep. The details of these calculation procedures are provided in Reference [1].

4.3 FRACTURE TOUGHNESS

The other key element in the determination of critical flaw sizes is the fracture toughness of the material. The fracture toughness has been taken directly from the reference curves of Appendix A, Section XI. In the transition temperature region, these curves can be represented by the following equations:

$$K_{Ic} = 33.2 + 2.806 \exp[0.02\ (T\text{-}RT_{NDT} + 100°F)]$$

$$K_{Ia} = 26.8 + 1.233 \exp[0.0145\ (T\text{-}RT_{NDT} + 160°F)]$$

where K_{IC} and K_{Ia} are in ksi$\sqrt{}$ in.

The upper shelf temperature regime requires utilization of a shelf toughness which is not specified in the ASME Code. The upper shelf fracture toughness of the nozzle inner radius was set at 250 ksi$\sqrt{}$in because of the high quality of the forging, and the beneficial effects of the geometry. A value of 200 ksi$\sqrt{}$in has been used here for all other unirradiated regions, which covers all but the beltline region. This value is consistent with general practice in such evaluations, as shown for example in [3] which provides the background and technical basis of Appendix A of Section XI. The value of RT_{NDT} used in these toughness equations was taken from the limiting (worst) properties of materials in the vessel, along with irradiation damage trend curves used to predict end-of-life values. These determinations are discussed in [1].

4.4 CRITICAL FLAW SIZE BASED ON LIMIT LOAD

Although rapid, nonductile failure is possible for ferritic material at low temperatures, it is not applicable to ductile material such as austenitic steel. For the austenitic steel material at the inlet/outlet nozzle safe end weld region, the flaw evaluation procedures and acceptance criteria are contained in paragraph IWB-3640 of ASME Section XI code [2], These procedures and criteria are used to determine the critical flaw sizes and are discussed further in the technical document [1].

4.5 RESULTS

The results of the critical flaw size calculations were used along with the subcritical crack growth results to determine the flaw size which is acceptable based on the criteria of Section XI. These allowable flaw sizes are shown graphically for each region in the charts of Appendix A, with separate figures for surface and embedded flaws in each region.

5 REFERENCES

1. Westinghouse Document, "Background and Technical Basis: Handbook on Flaw Evaluation for the H. B. Robinson Unit 2 Reactor Vessel," Westinghouse Electric Corporation, WCAP-15620-P Revision 1, August 2008.

2. ASME Code Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 1983 edition, Winter 1985 Addendum; 1995 edition with 1996 Addendum.

3. Marston, T. U. editor, "Flaw Evaluation Procedures, ASME Boiler and Pressure Vessel Code, Section XI," Electric Power Research Institute report EPRI-NP719SR, August 1978.

4. NUREG/CR-6907, ANL-04/3, "Crack Growth Rates of Nickel Alloy Welds in a PWR Environment," May 2006.

5. NUREG/CR-6721, ANL-01/07, "Effects of Alloy Chemistry, Cold Work, and Water Chemistry on Corrosion Fatigue and Stress Corrosion Cracking of Nickel Alloys and Welds," April 2001.

6. Material Reliability Program: Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182 and 132 Welds (MRP-115), EPRI. Palo Alto, CA: 2004, 1006696. (EPRI Proprietary Document).

APPENDIX A
FLAW EVALUATION

INTRODUCTION TO EVALUATION PROCEDURE

The evaluation procedures contained in ASME Section XI are clearly specified in paragraph IWB-3600. Use of the evaluation charts herein follows these procedures directly, but the steps are greatly simplified.

Once the indication is discovered, it must be characterized as to its location, length (ℓ) and depth dimension (a) for surface flaws, (2a) for embedded flaws, including its distance from the clad-base metal interface (S) for embedded indications. This characterization is discussed in further detail in paragraph IWA-3000 of Section XI.

The following parameters must be calculated from the above dimensions to use the charts (see Figure 1-6 in Section 1):

- Flaw shape parameter, $\frac{a}{\ell}$
- Flaw depth parameter, $\frac{a}{t}$
- Surface proximity parameter (for embedded flaws only), $\frac{\delta}{t}$

where

t	=	wall thickness of region where indication is located (not including clad thickness)
ℓ	=	length of indication
a	=	depth of surface flaw; or half depth of embedded flaw in the crack width direction
δ	=	distance from flaw centerline to surface (for embedded flaws crack only, $\delta = S + a$)
S	=	smallest distance from edge of embedded flaw to surface

Once the above parameters have been determined and a decision made as to whether the indication is embedded or surface, then the two parameters may be plotted directly on the appropriate evaluation chart. The location of these points on the charts determines whether or not the indication is acceptable.

Important Observations on the Handbook Charts

Although the use of the handbook charts is conceptually straightforward, experience in their development and use has led to a number of observations which will be helpful.

Flaws accepted by the analyses contained herein, however, require future monitoring per IWB-2420 of Section XI. The analysis used to develop these charts is documented in the main body of this report as well as the technical basis document [1]. If this report is used to justify a flaw, approval by the NRC is necessary prior to restart.

Surface Flaws

An example handbook chart for surface flaws is shown in Figure A-1. The flaw indication parameters (whose calculation is described above) may be plotted directly on the chart to determine acceptability. The lower two curves shown (labeled "...Code Allowable...") are simply the acceptance standards from IWB-3500, which are tabulated in Section XI. If the plotted point falls below these lines, the indication is acceptable without further analytical justification. If the plotted point falls between the Code Allowable Limit Lines, and the lines labeled "...acceptable flaw limits" it is acceptable by meeting the requirements of IWB-3600, which allow acceptance by fracture analysis. There are three lines shown in the chart, labeled 10, 20 and 30 years. The number of years indicates the length of time the acceptance limit applies, from the date that a flaw indication is discovered. They are based on fatigue crack growth calculations.

As may be seen in Figure A-1, the chart gives results for surface flaw shapes up to a semi-circular flaw ($a/\ell = 0.5$). For the unlikely occurrence of flaws for which the value of a/ℓ exceeds 0.5, the limits on acceptance for $a/\ell = 0.5$ should be used, according to ASME Code requirements.

Embedded Flaws

An example chart for embedded flaws is shown in Figure A-2. The heavy diagonal line, labeled as "Surface/Embedded Flaw Demarcation Line" in the figure can be used directly to determine whether the indication should be characterized as an embedded flaw, or whether it is sufficiently close to the surface that it must be considered as a surface flaw (by the rules of Section XI). If the flaw parameters produce a plotted point below the heavy diagonal line, it is acceptable by analysis if the point is below the appropriate a/ℓ limit line. If it is above the line, it cannot be justified by analysis, and is, therefore, not acceptable.

The flaw evaluation charts for embedded flaws are presented in a form which does not allow direct comparison to the Section XI, IWB-3500 standards. For comparison purposes, these standards have been presented graphically in Figures A-3 and A-4. Figure A-3 covers section thicknesses greater than 4 inches, while Figure A-4 covers section thicknesses less than 4 inches. If an indication is below the appropriate standards limit of these figures, it is acceptable without analytical evaluation.

For cases where there are no branching limit lines below the heavy diagonal line, then all flaws classified as embedded are acceptable. The only limitation is

$$\frac{2a}{t} < 0.250$$

Note that the embedded flaw evaluation charts are applicable for flaws near either the inner or outer vessel surface, and the parameters "S" and "δ" are defined from the nearest surface.

Another important observation is the procedure to be used for an embedded flaw whose plotted point falls above the heavy diagonal line, and must therefore be considered a surface flaw. An example of this is provided in "Embedded Flaw Example 1" below, but it is important to note that when this must be done, the depth of the flaw is redefined. The new depth is $a^* = 2a + S$, as shown in the example. It is this effective crack depth a^*, which is used for the surface flaw chart.

Surface Flaw Example 1 (Figure A-1)

Suppose an indication has been discovered which is a surface flaw, and has the following characterized dimensions:

$a = 0.428$ in.

$\ell = 2.14$ in.

$t = 9.31$ in.

The flaw parameters for the use of the charts are

$$\frac{a}{t} = 0.046$$

$$\frac{a}{\ell} = 0.20$$

By plotting these parameters on Figure A-1, it is quickly seen that the indication is acceptable by analysis. To justify operation without repair it is necessary to submit this plot along with the technical basis document to the regulatory authorities.

Embedded Flaw Example 1

A longitudinal* embedded flaw of 2.21" x 5.00", located within 0.16" from the surface, was detected. Determine whether this flaw should be considered as an embedded flaw.

$2a = 2.21"$

$S = 0.16"$

$\delta = S + a = 0.16 + 1/2\ (2.21) = 1.27$

$t = 9.31"$

$\ell = 5.0"$

*Note: longitudinal herein means relative to the vessel or nozzle centerline, <u>not</u> the weld length. For the nozzle inner radius, and other regions of a nozzle, longitudinal is relative to the nozzle centerline.

and,

$a = ½\ (2.21")$

$= 1.11"$

Using Figure A-2:

$$\frac{a}{t} = \frac{1.11}{9.31} = 0.119$$

$$\frac{\delta}{t} = \frac{1.27}{9.31} = 0.136$$

Since the plotted point (X) is above the diagonal line, the flaw must be considered a surface flaw.

Since the flaw must be considered as a surface flaw, the depth must be redefined as the distance from the surface to the deepest point of the flaw. This is equivalent to circumscribing the embedded flaw with a semi-elliptical surface flaw. Operationally, the parameters are recalculated as follows. Defining a* as the corrected crack depth for the surface flaw,

$a^* = 2a + S = 2.37"$

$\ell = 5.0"$

$$\frac{a^*}{t} = 0.254$$

$$\frac{a^*}{\ell} = 0.474$$

Referring to Figure A-1 for the surface flaw, it is quickly seen that this flaw is much too large to be acceptable, and must be repaired.

Embedded Flaw Example 2 (Point A, Figure A-2)

Suppose an indication has been discovered which is embedded, and has the following characterized dimensions:

$2a = 1.15$ in.

$\ell = 1.72$ in.

$t = 10.53$ in.

$S = 0.86$ in.

Calculating the flaw parameters, we have:

$$\frac{a}{t} = 0.0546$$

$$\frac{a}{\ell} = 0.334$$

$$\delta = S + a = 1.43 \text{ in.}$$

$$\frac{\delta}{t} = 0.136$$

By plotting these parameters on the embedded flaw evaluation chart, Figure A-2, it may be quickly seen that the indication is embedded, and is acceptable by analysis (point A), since it lies below the $a/\ell = 0.333$ limit case.

Embedded Flaw Example 3 (Point B, Figure A-2)

Suppose an indication has been discovered which is embedded, and has the following characterized dimensions:

$2a = 1.68 \qquad a = 0.84$

$\ell = 2.55$

$t = 10.53$

$S = 1.52$

Calculating the flaw parameters, we have:

$$\frac{a}{t} = 0.08$$

$$\frac{a}{\ell} = 0.33$$

$$\delta = S + a = 2.36 \text{ in.}$$

$$\frac{\delta}{t} = 0.224$$

By plotting these parameters on Figure A-2 (point B), we see that the indication is acceptable, since it falls <u>below</u> the line which is applicable to $a/\ell = 0.333$. (Note that if $a/\ell = 0.167$, for example, the indication would not be acceptable, since point B would lie above that line, as may be seen in the figure.)

Embedded Flaw Example 4 (Point C, Figure A-2)

A longitudinal embedded flaw of 1.318" x 6.52" was detected at a distance S = 1.140 in. from the surface. Evaluate the flaw for code acceptance for continued service without repair.

The flaw geometry parameters are determined as follows:

$$a = 1/2 \times 1.318''$$

$$= 0.659''$$

$$t = 7.75''$$

$$S = 1.14''$$

$$\delta = S + a = 1.8''$$

$$\ell = 6.52''$$

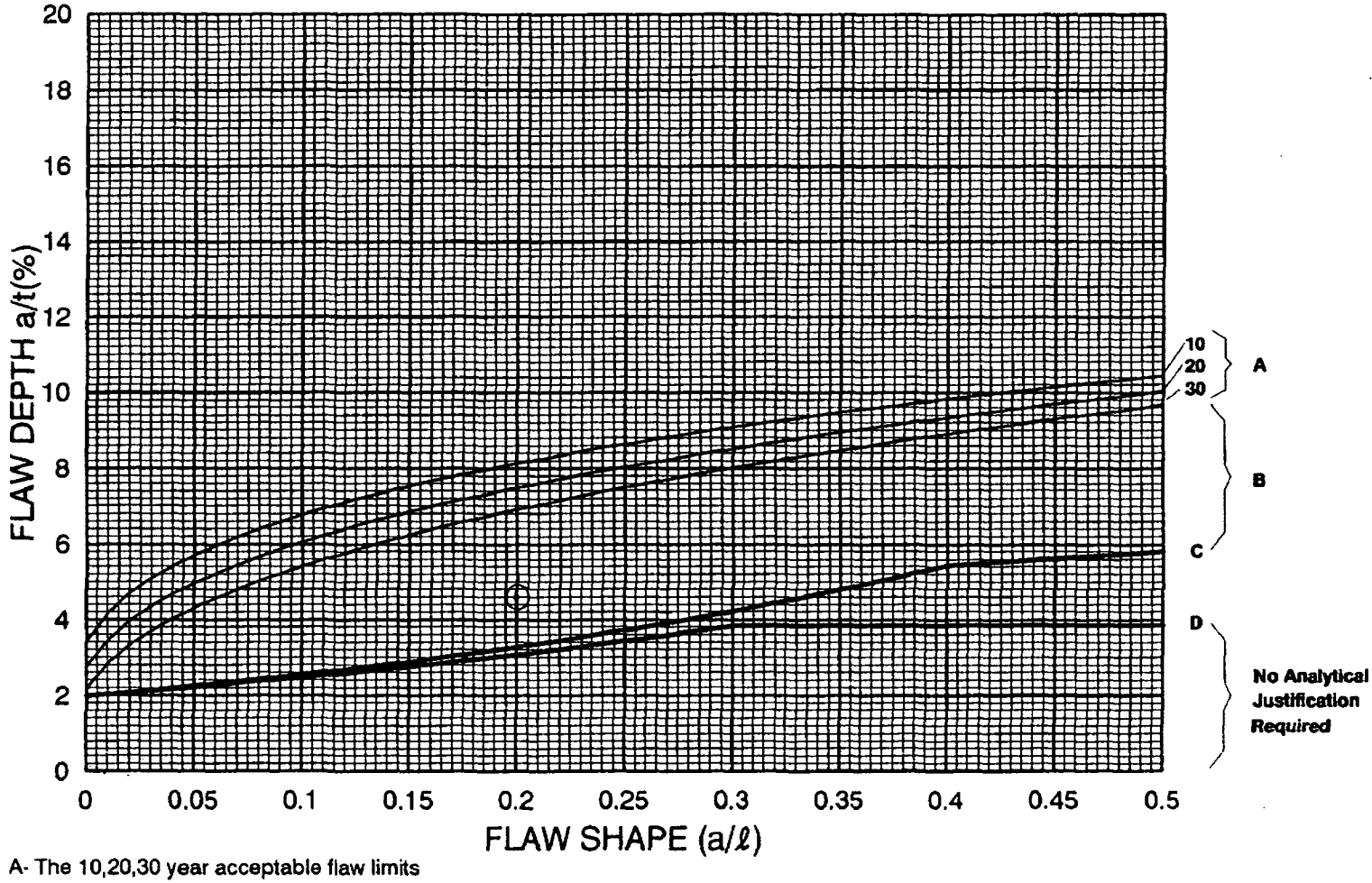
and

$$\frac{\delta}{t} = \left(\frac{1.8}{7.75}\right) = 0.232$$

$$\frac{a}{\ell} = \left(\frac{.659}{6.52}\right) = 0.101$$

$$\frac{a}{t} = \left(\frac{0.659}{7.75}\right) = 0.085$$

Evaluate the flaw by referring to Fig. A-2 and plotting the point (as point C). This point is above the code acceptance limit line for $a/\ell = 0.167$. Therefore, the flaw is not acceptable, and must be repaired.



A- The 10,20,30 year acceptable flaw limits
B- Surface flaw acceptable per IWB-3600 criteria
C- ASME Code allowable since 1983 Winter Addendum (IWB 3500)
D- ASME Code allowable prior to 1983 Winter Addendum (IWB 3500)

Figure A-1 Example of Surface Flaw Evaluation

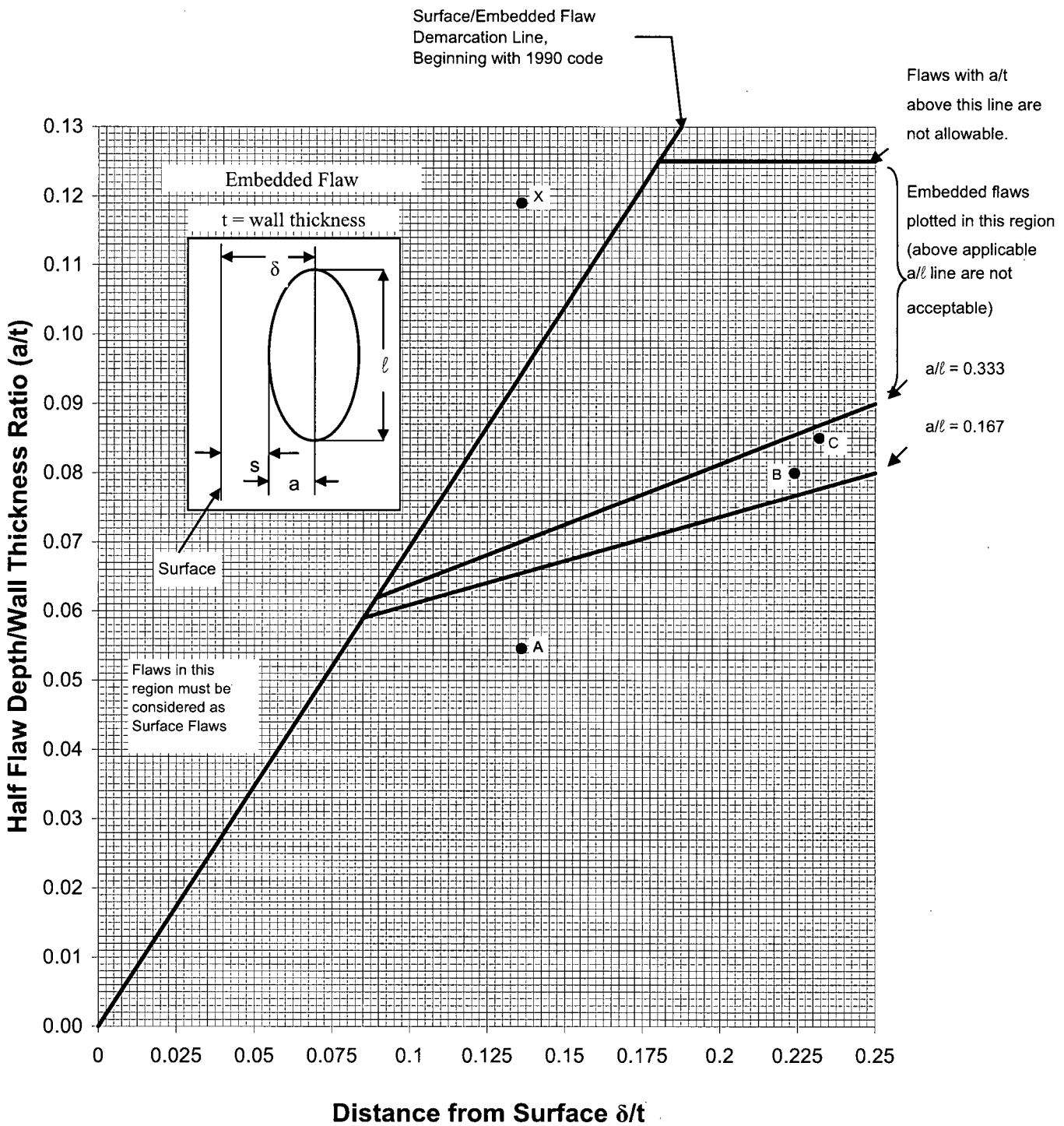


Figure A-2 Example of Embedded Flaw Evaluation

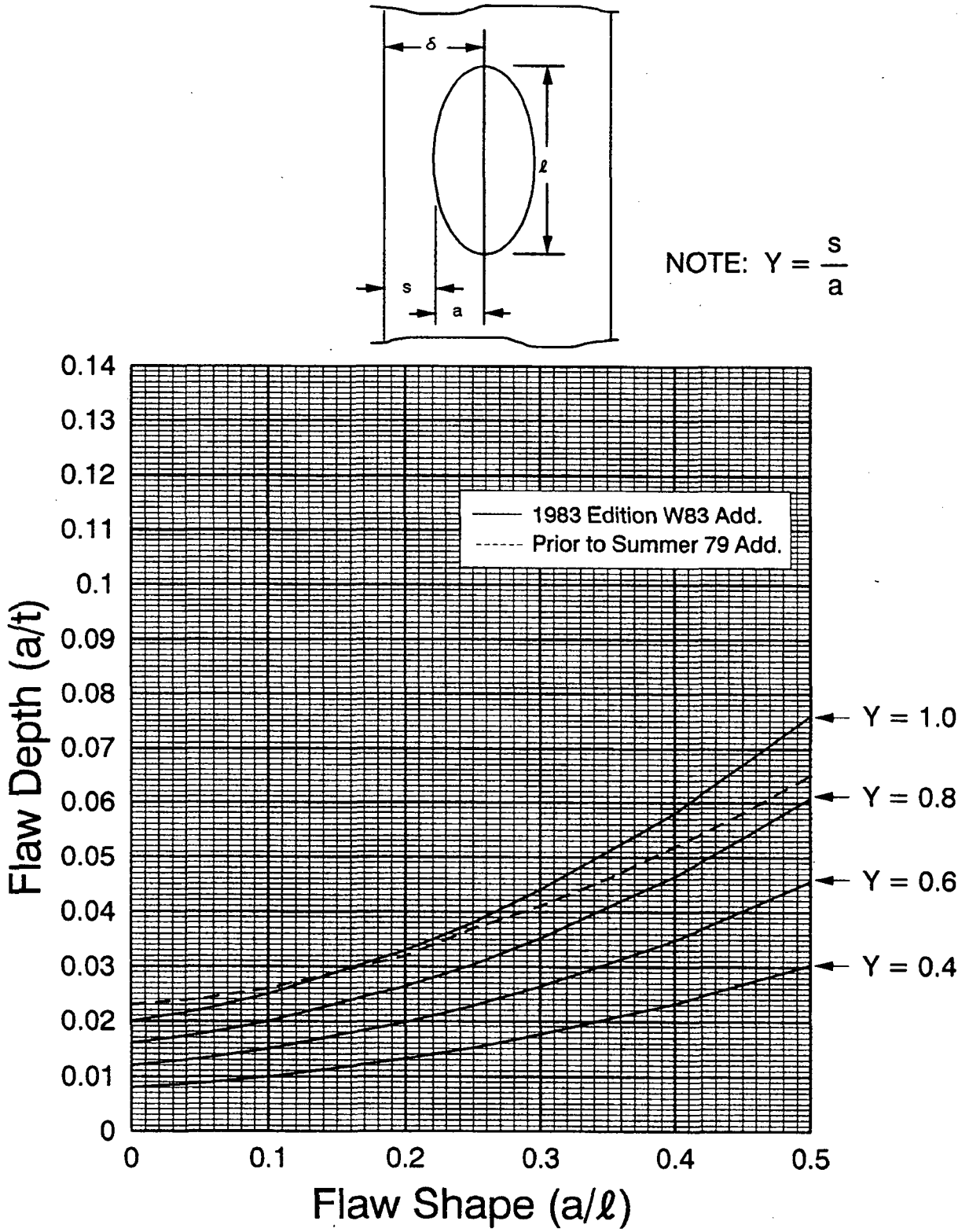


Figure A-3 Acceptance Standards for Embedded Flaws, for Section Thickness 4 Inches and Greater (From Tables IWB-3510 and IWB-3512)

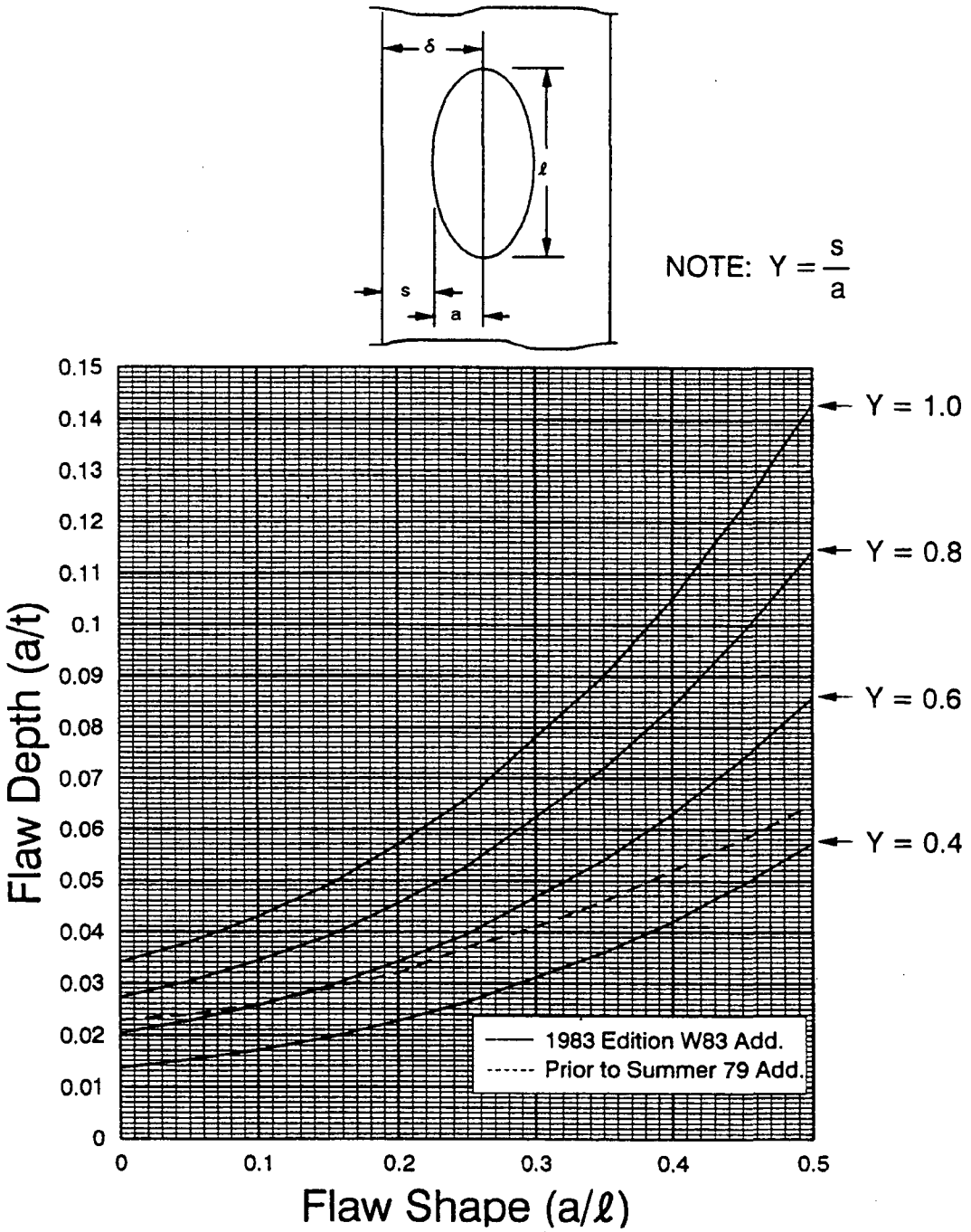


Figure A-4 Acceptance Standards for Embedded Flaws, for Section Thicknesses Less than 4 Inches (From Tables IWB-3510 and IWB-3512)

Note: Prior to the Summer 79 Addendum, no specific standards were available for these section thicknesses, but the standards for thicknesses of 4 inches and greater were generally used.

A-1 BELTLINE (INCLUDING CIRCUMFERENTIAL AND LONGITUDINAL SEAM WELDS)

A-1.1 Surface Flaws

The geometry and terminology used for flaws in the beltline region is depicted in Figure A-1.1. The following parameters must be determined for surface flaw evaluation with the charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where a - the surface flaw depth detected, (in.)

ℓ - the surface flaw length detected, (in.)

t - wall thickness at the beltline (t = 9.313")

The surface flaw evaluation charts for the beltline are listed below:

- Figure A-1.2 Evaluation Chart for Reactor Vessel Beltline

X	Inside Surface	X	Surface Flaw	X	Longitudinal Flaw
__	Outside Surface	__	Embedded Flaw	__	Circumferential Flaw

- Figure A-1.3 Evaluation Chart for Reactor Vessel Beltline

X	Inside Surface	X	Surface Flaw	__	Longitudinal Flaw
__	Outside Surface	__	Embedded Flaw	X	Circumferential Flaw

- Figure A-1.4 Evaluation Chart for Reactor Vessel Beltline

__	Inside Surface	X	Surface Flaw	X	Longitudinal Flaw
X	Outside Surface	__	Embedded Flaw	__	Circumferential Flaw

- Figure A-1.5 Evaluation Chart for Reactor Vessel Beltline

__	Inside Surface	X	Surface Flaw	__	Longitudinal Flaw
X	Outside Surface	__	Embedded Flaw	X	Circumferential Flaw

A-1.2 Embedded Flaws

The geometry and terminology used for embedded flaws at the beltline is depicted in Figure A-1.1.

Basic Data:

t = 9.313 in.

δ = Distance of the centerline of the embedded flaw to the surface (in.)

a = Flaw depth (Defined as one half of the minor diameter) (in.)

ℓ = Flaw length (Major diameter) (in.)

a_o = Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization criteria.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter, $\frac{a}{\ell}$
- Flaw depth parameter, $\frac{a}{t}$
- Surface proximity parameter $\frac{\delta}{t}$

The evaluation chart for embedded flaws in the beltline is shown in Figure A-1.6. Any embedded flaw in this region will be acceptable regardless of its size, shape and location (as long as $a/t < 0.125$) as shown in Figure A-1.6 and discussed in [1] and in the introduction to this Appendix. This determination can be easily made by plotting the indication parameters on the figure, to check whether it lies below the appropriate demarcation line (embedded not surface).

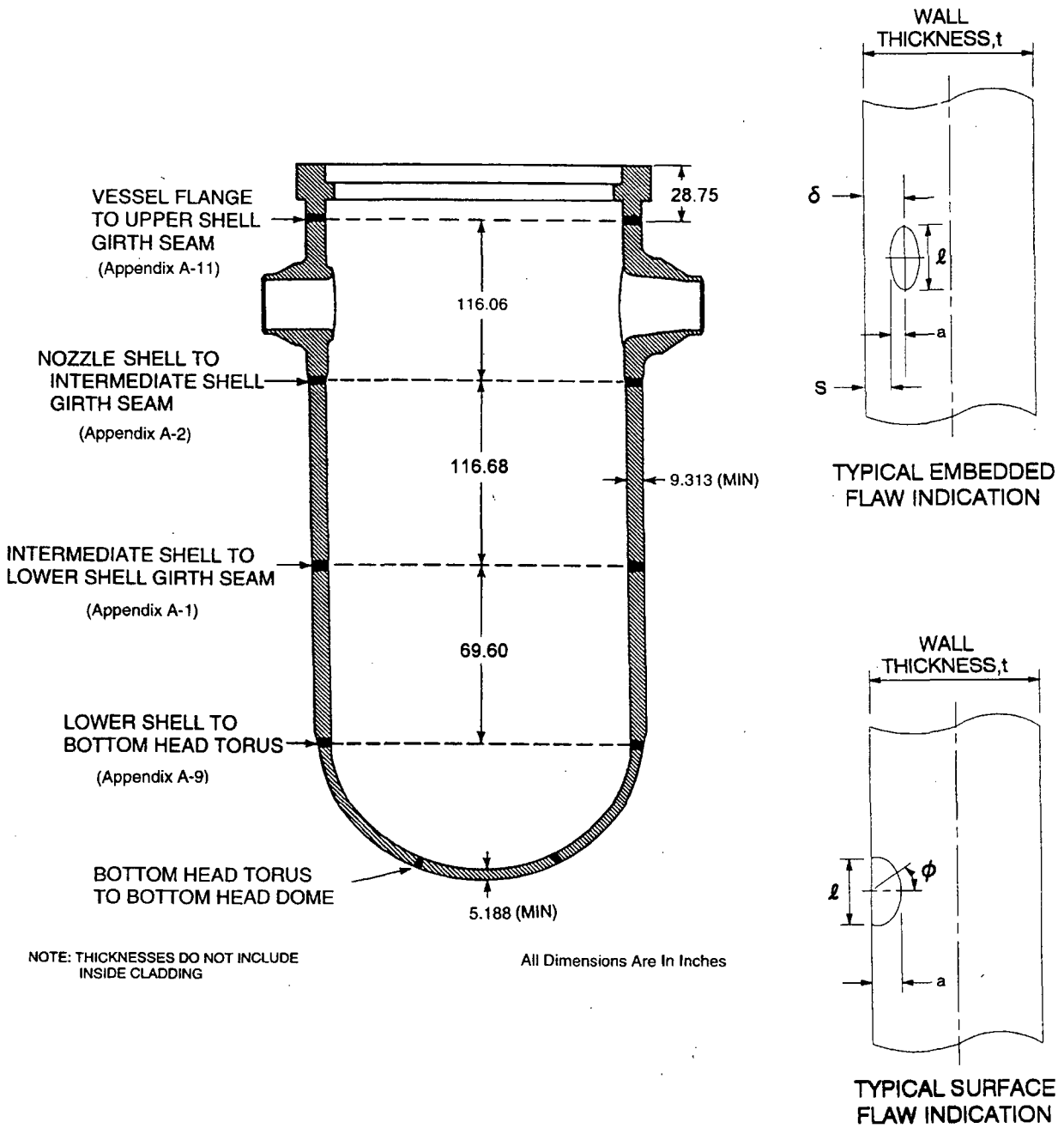


Figure A-1.1 Geometry and Terminology for Flaws in the Beltline

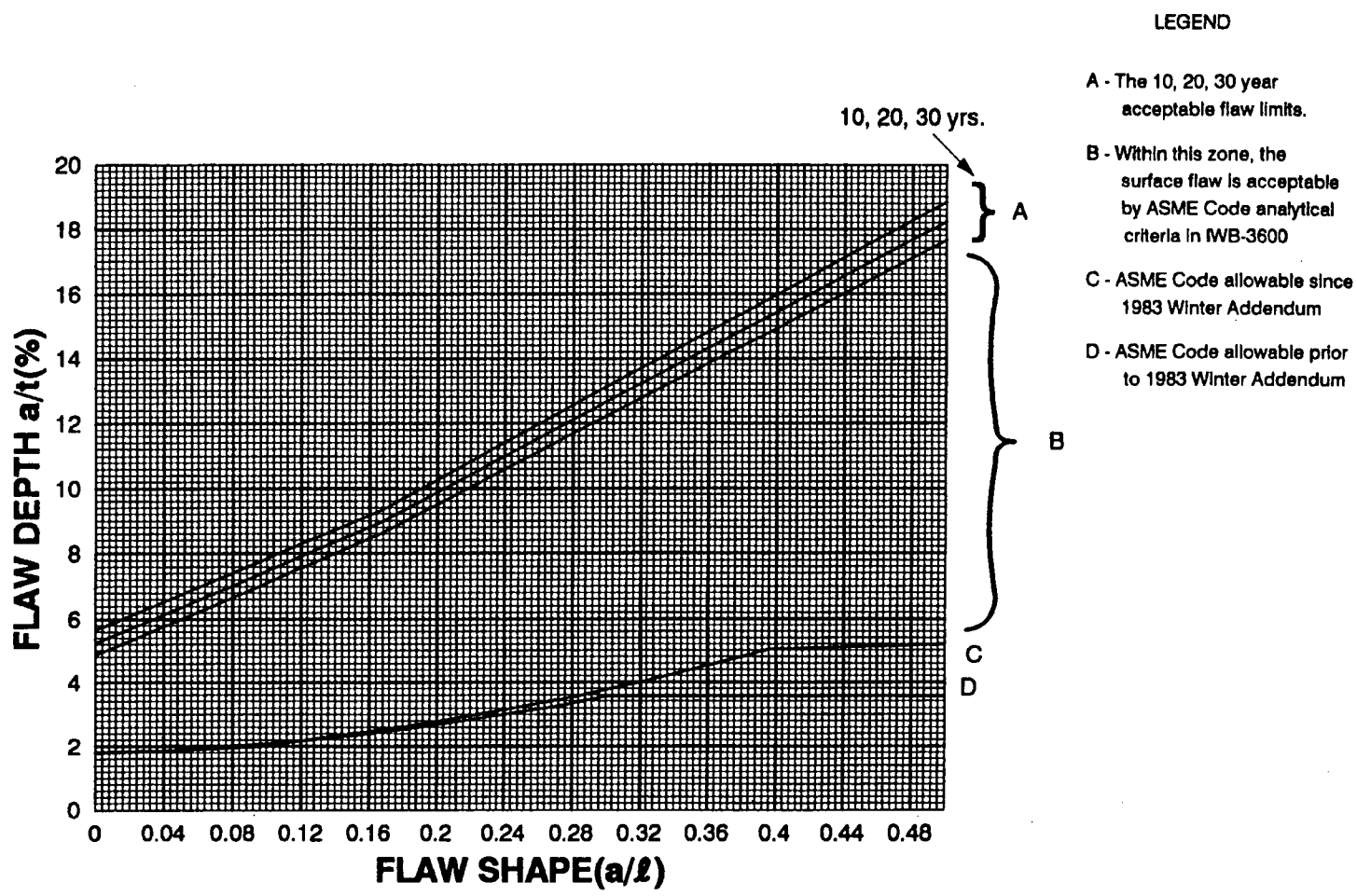


Figure A-1.2 Evaluation Chart for Reactor Vessel Beltline

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

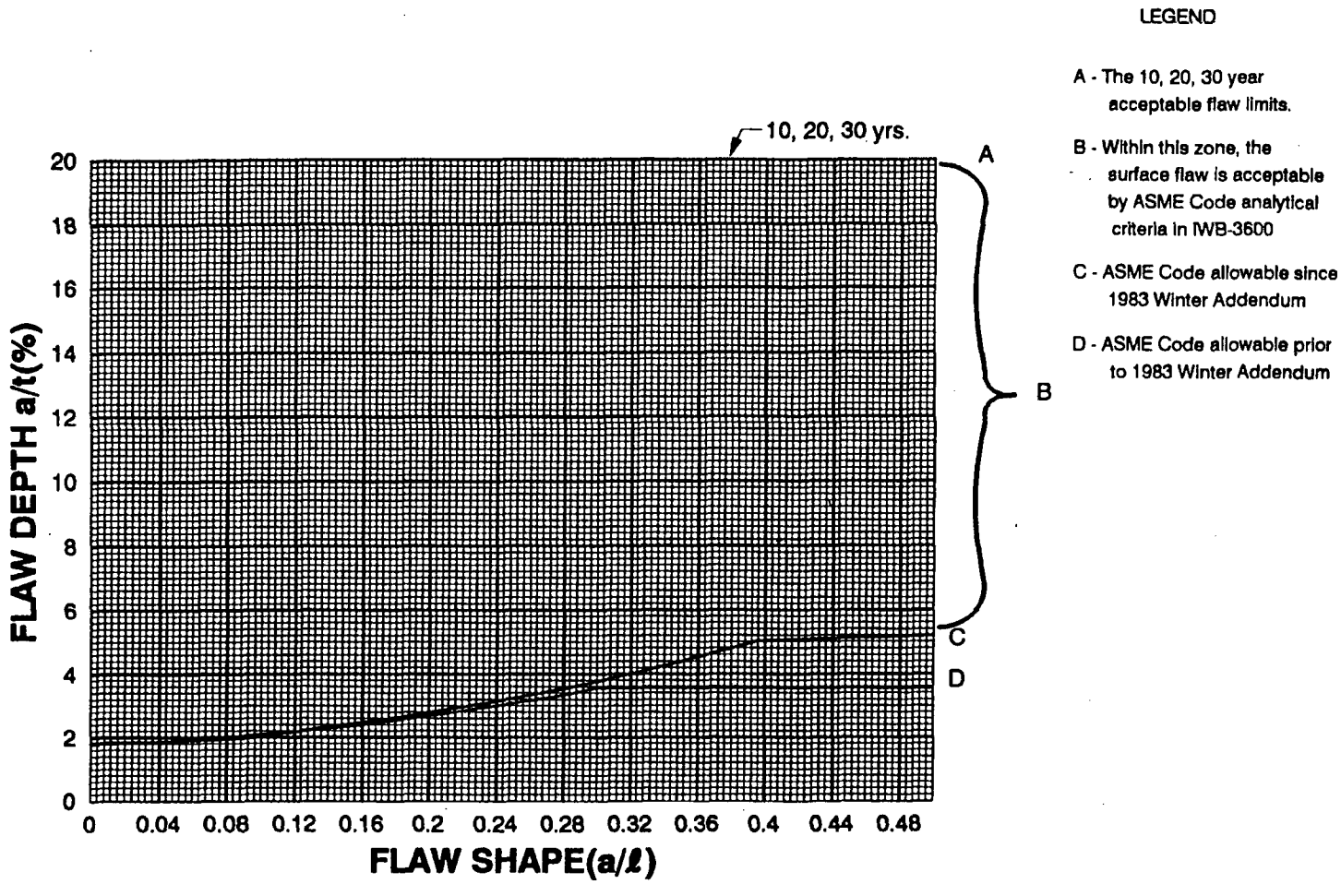


Figure A-1.3 Evaluation Chart for Reactor Vessel Beltline (RT_{NDT} < 245°F)

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

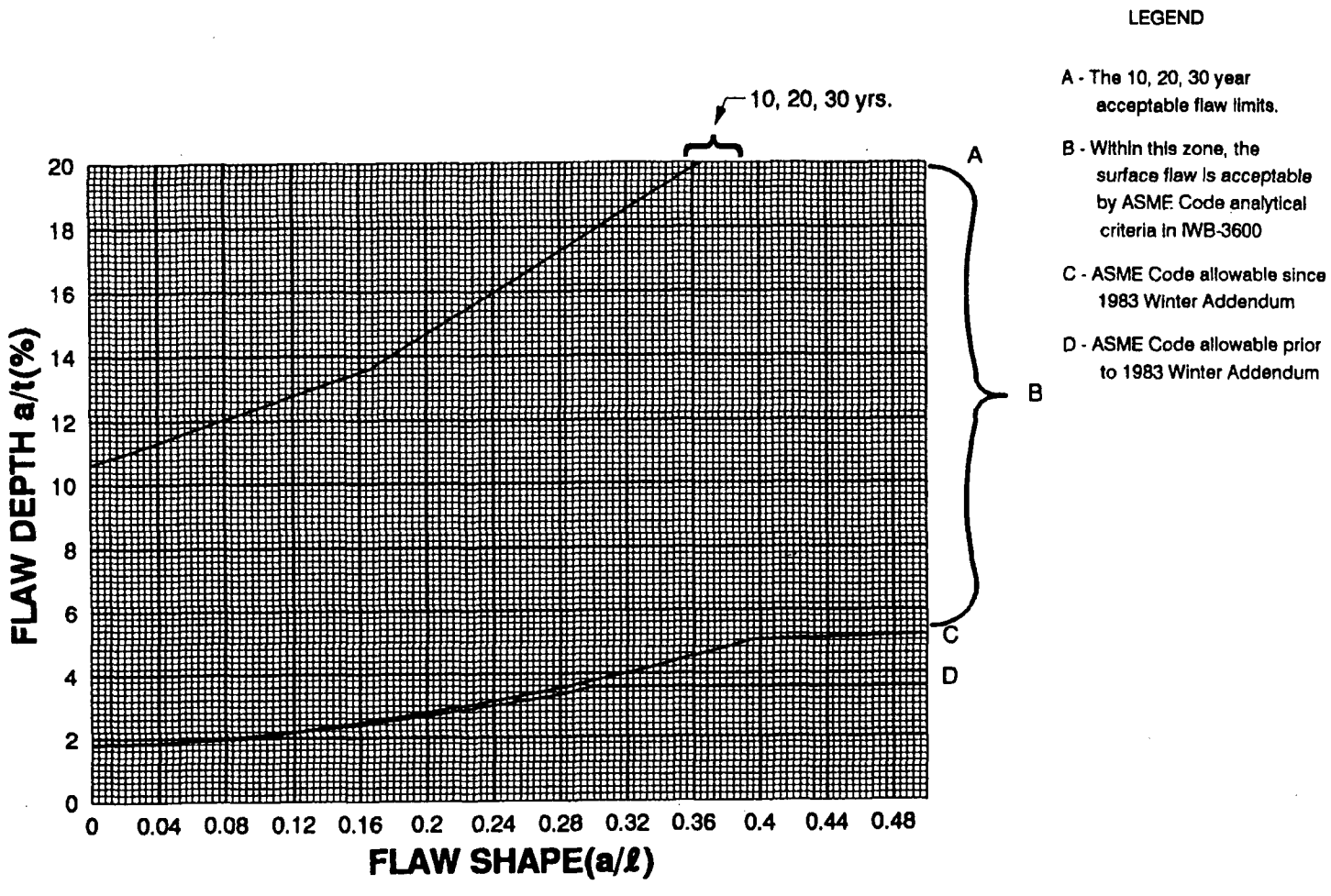


Figure A-1.4 Evaluation Chart for Reactor Vessel Beltline (RT_{NDT} < 260°F)

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

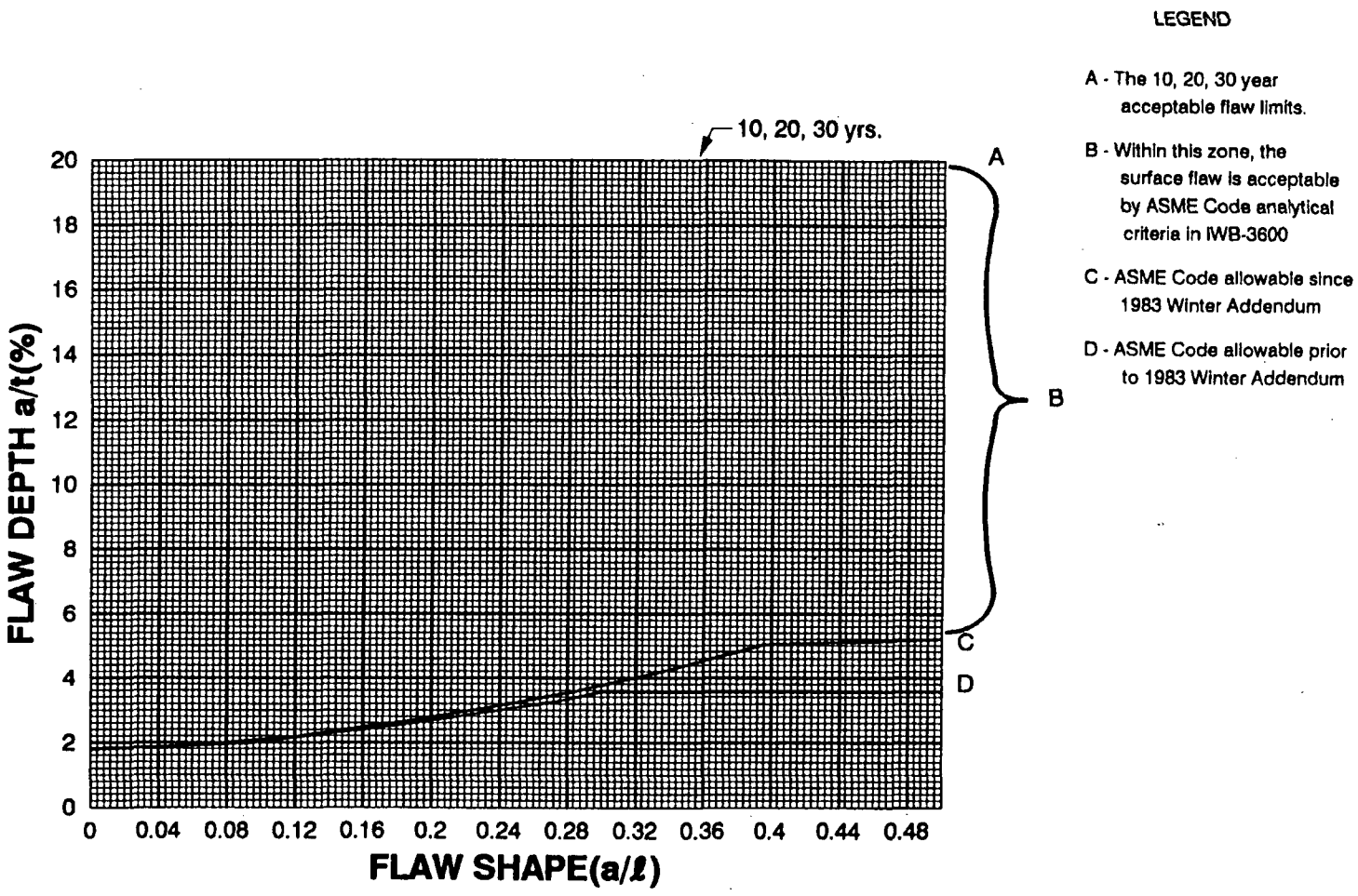


Figure A-1.5 Evaluation Chart for Reactor Vessel Beltline

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

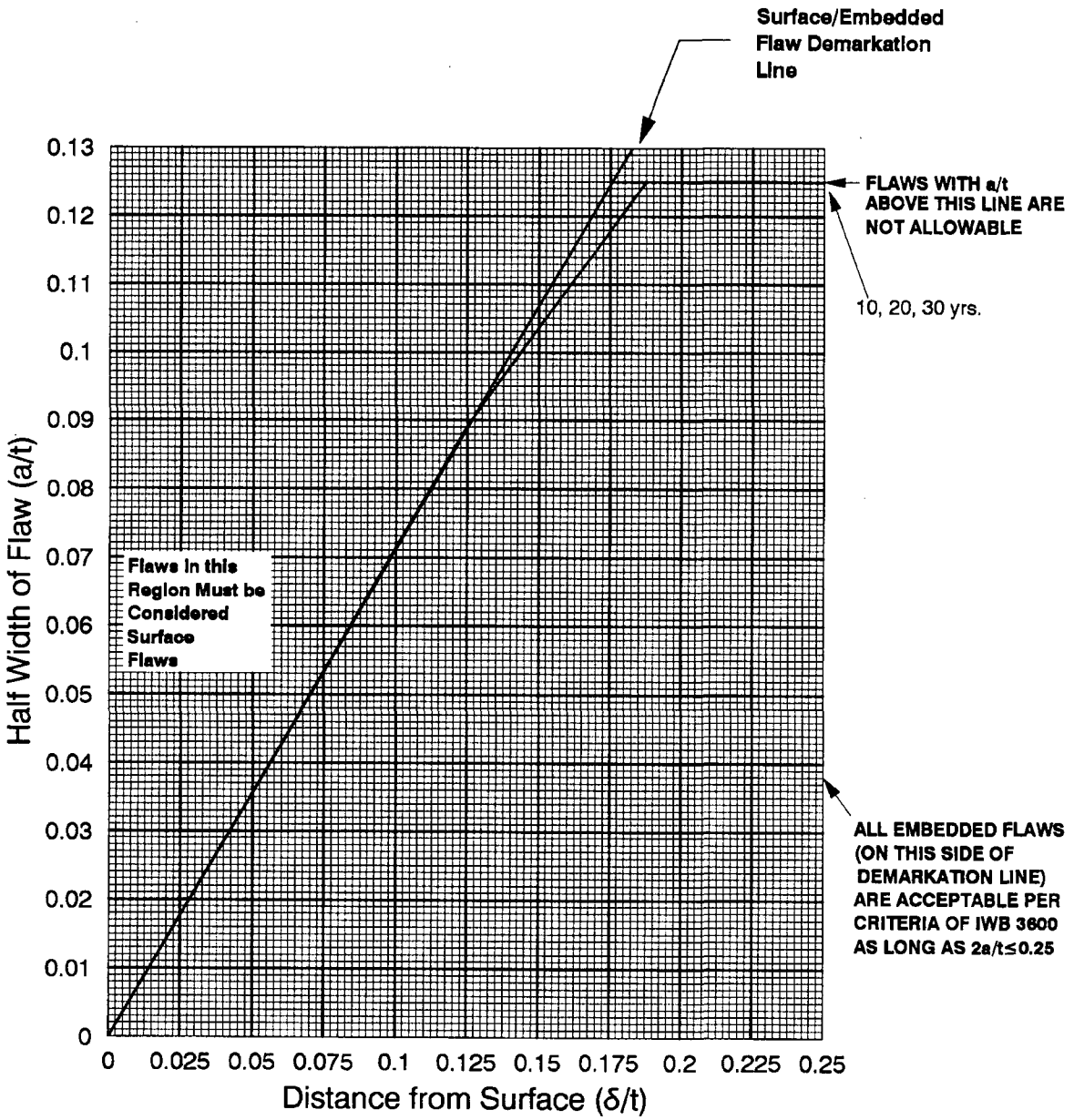


Figure A-1.6 Evaluation Chart for the Reactor Vessel Beltline

_X_ Inside Surface	___ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

A-2 NOZZLE SHELL TO INTERMEDIATE SHELL WELD

A-2.1 Surface Flaws

The geometry and terminology for surface flaws at the nozzle shell to intermediate shell weld is depicted in Figure A-2.1. The following parameters must be determined for surface flaw evaluation with the charts

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness at the inlet nozzle to vessel weld (t = 9.313")

The surface flaw evaluation charts for the nozzle shell to intermediate shell weld are listed below:

- Figure A-2.2 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-2.3 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

- Figure A-2.4 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-2.5 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

A-2.2 Embedded Flaws

The geometrical description of an embedded flaw at the nozzle shell to intermediate shell weld is depicted in Figure A-2.6.

Basic Data:

t	=	9.313 in.
δ	=	Distance of the centerline of the embedded flaw to the surface (in.)
a	=	Flaw depth (defined as one half of the minor diameter) (in.)
ℓ	=	Flaw length (major diameter) (in.)
a_o	=	Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$
- Surface proximity parameter, $\frac{\delta}{t}$

The evaluation chart for embedded flaws is as follows:

- Figure A-2.6 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

- Figure A-2.7 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

X Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
X Outside Surface	X Embedded Flaw	X Circumferential Flaw

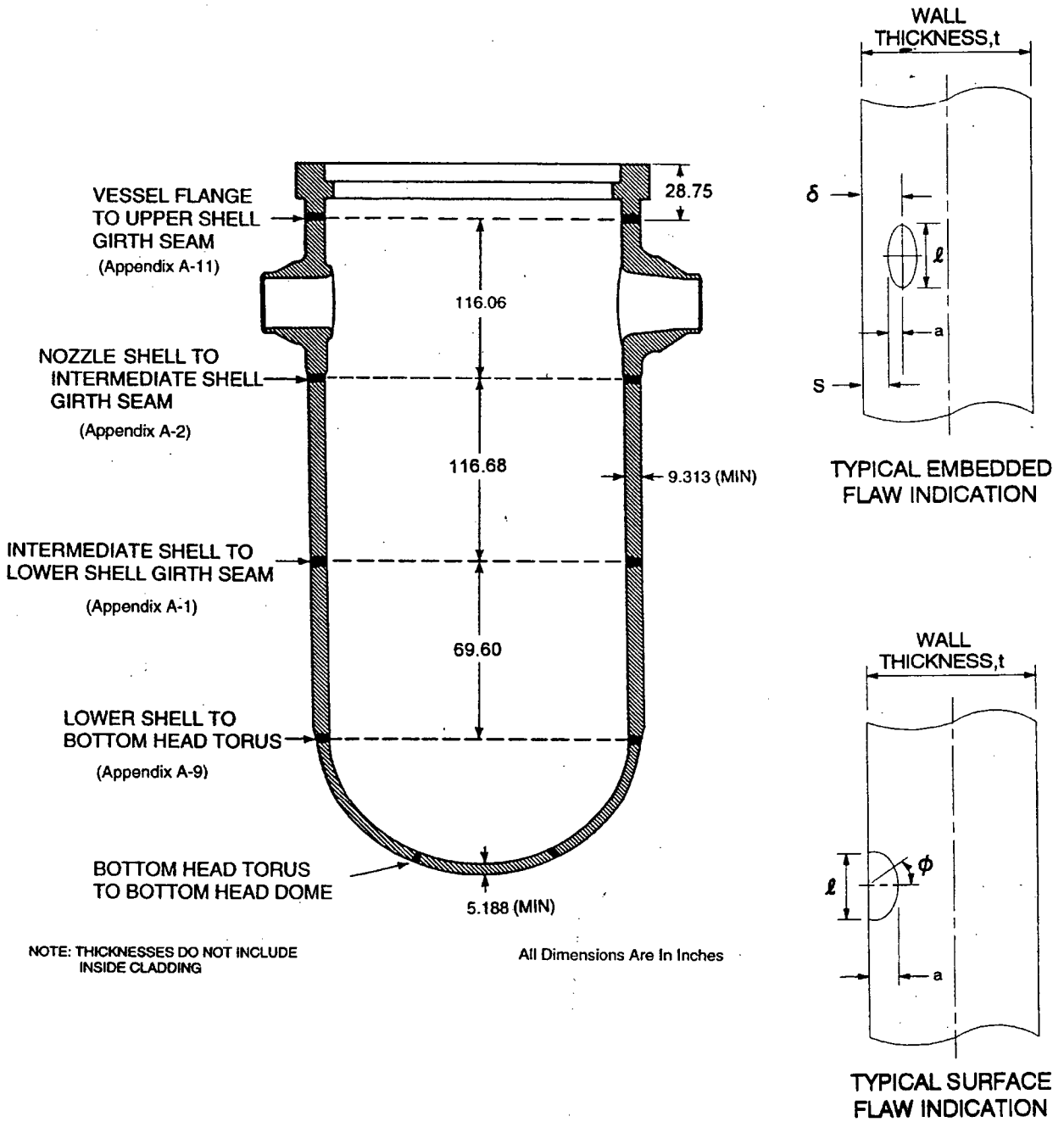


Figure A-2.1 Geometry and Terminology for Flaws at the Nozzle Shell to Intermediate Shell Weld

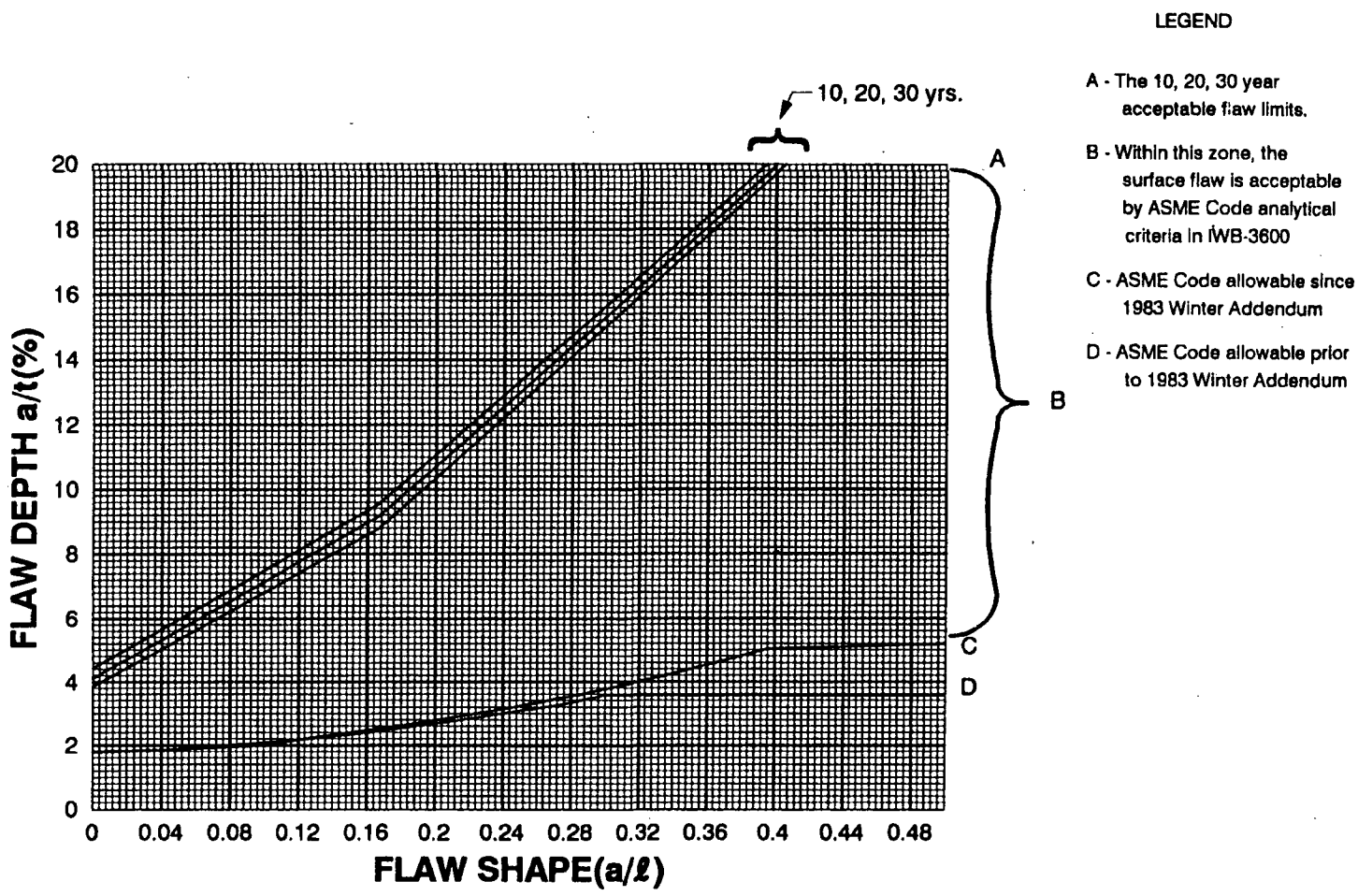


Figure A-2.2 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

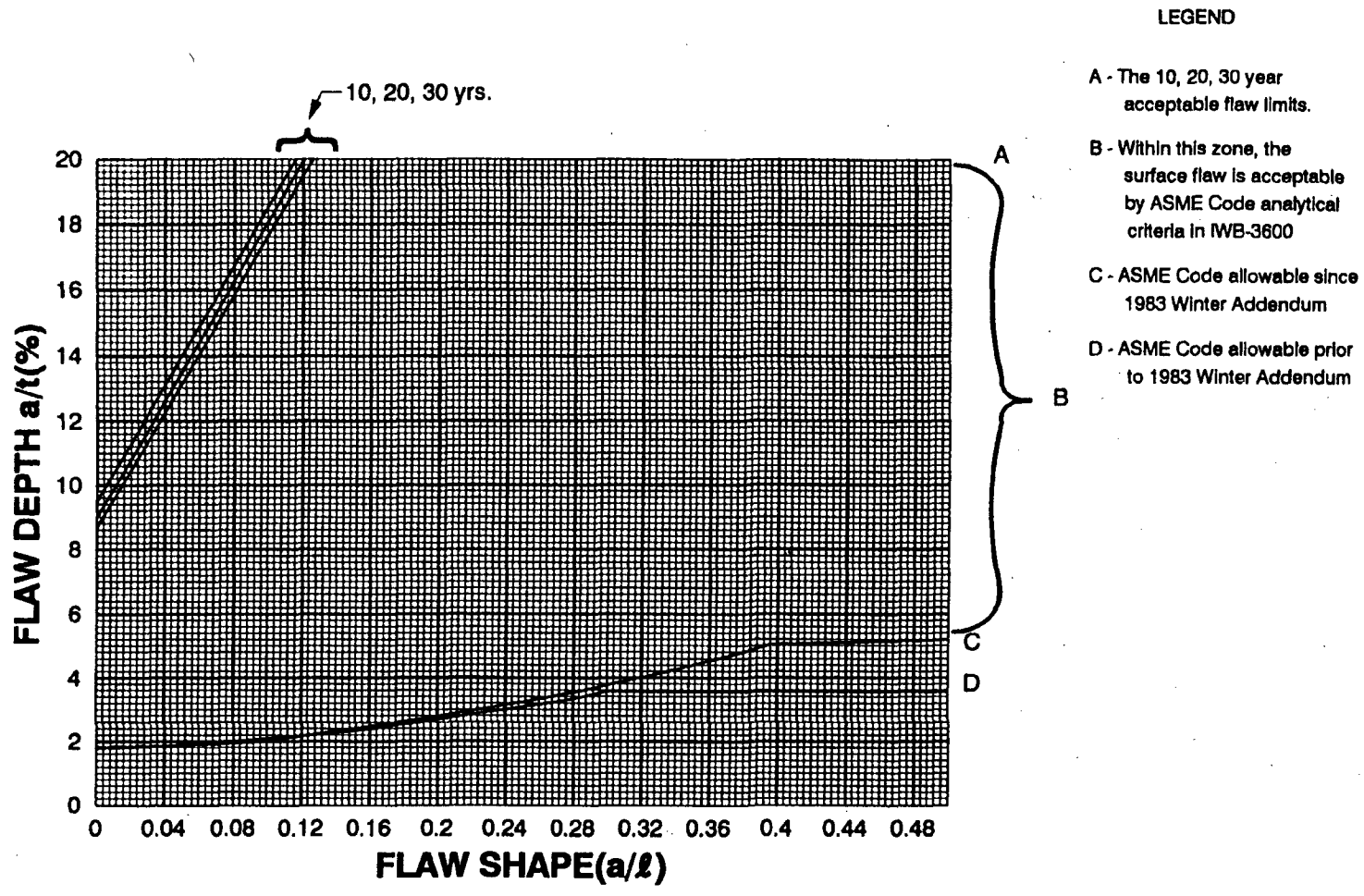


Figure A-2.3 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

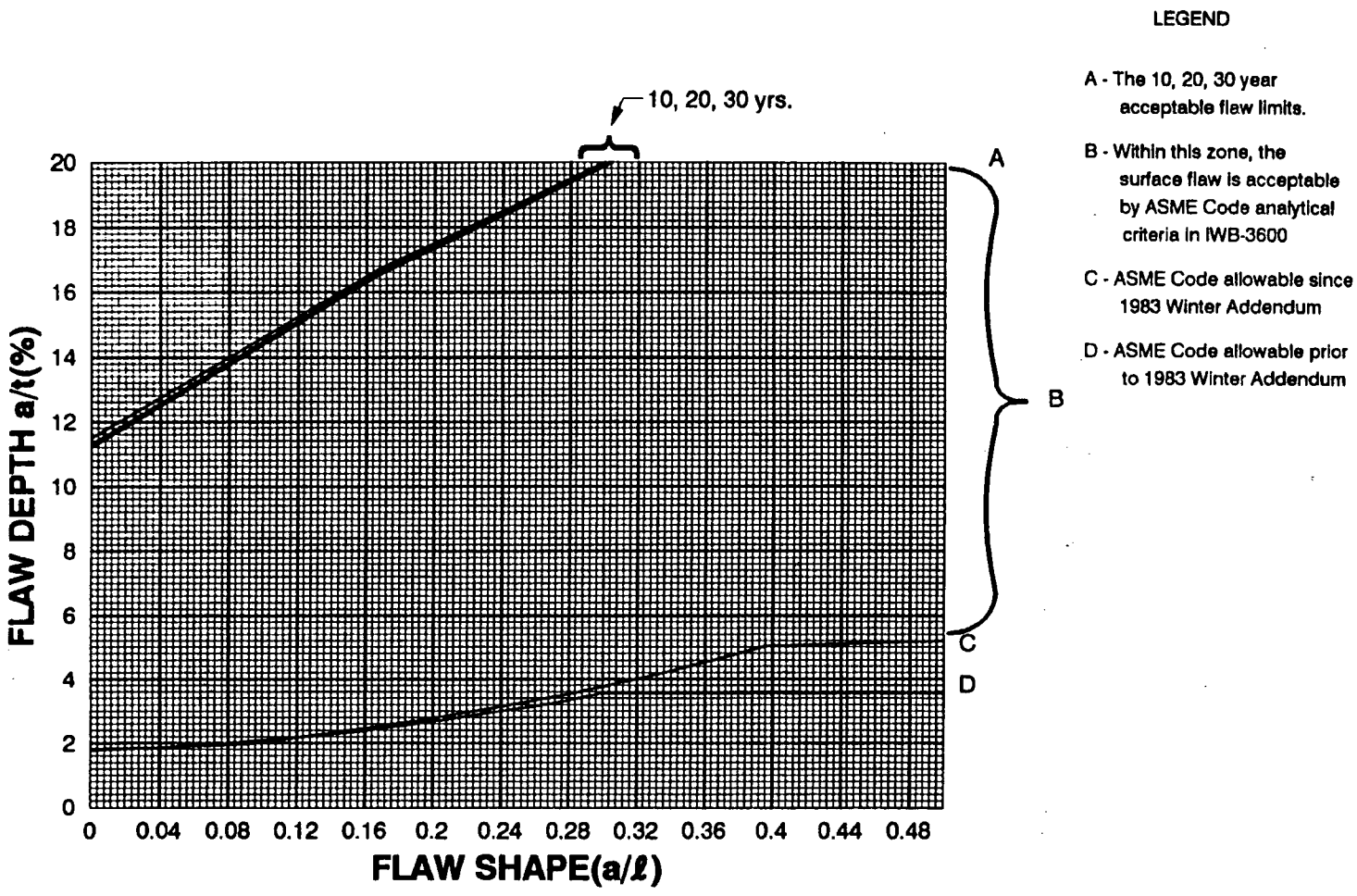
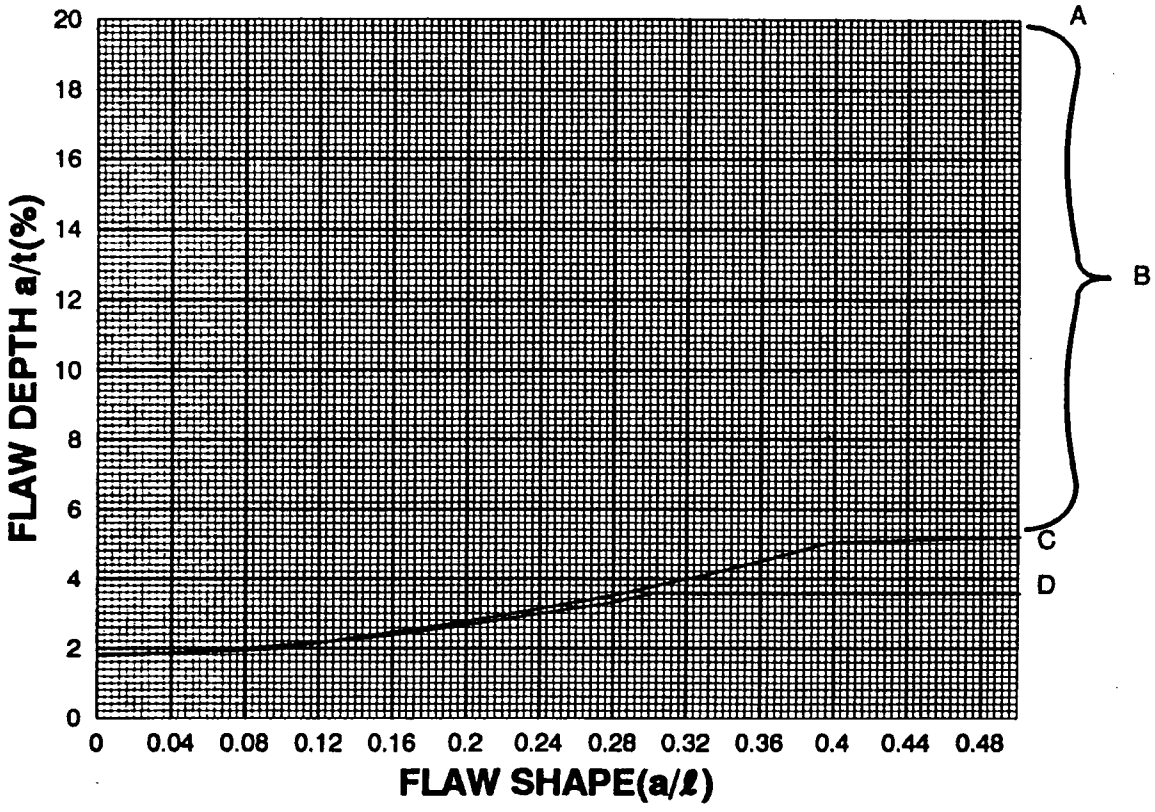


Figure A-2.4 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw



LEGEND

A - The 10, 20, 30 year acceptable flaw limits.

B - Within this zone, the surface flaw is acceptable by ASME Code analytical criteria in IWB-3600

C - ASME Code allowable since 1983 Winter Addendum

D - ASME Code allowable prior to 1983 Winter Addendum

Figure A-2.5 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

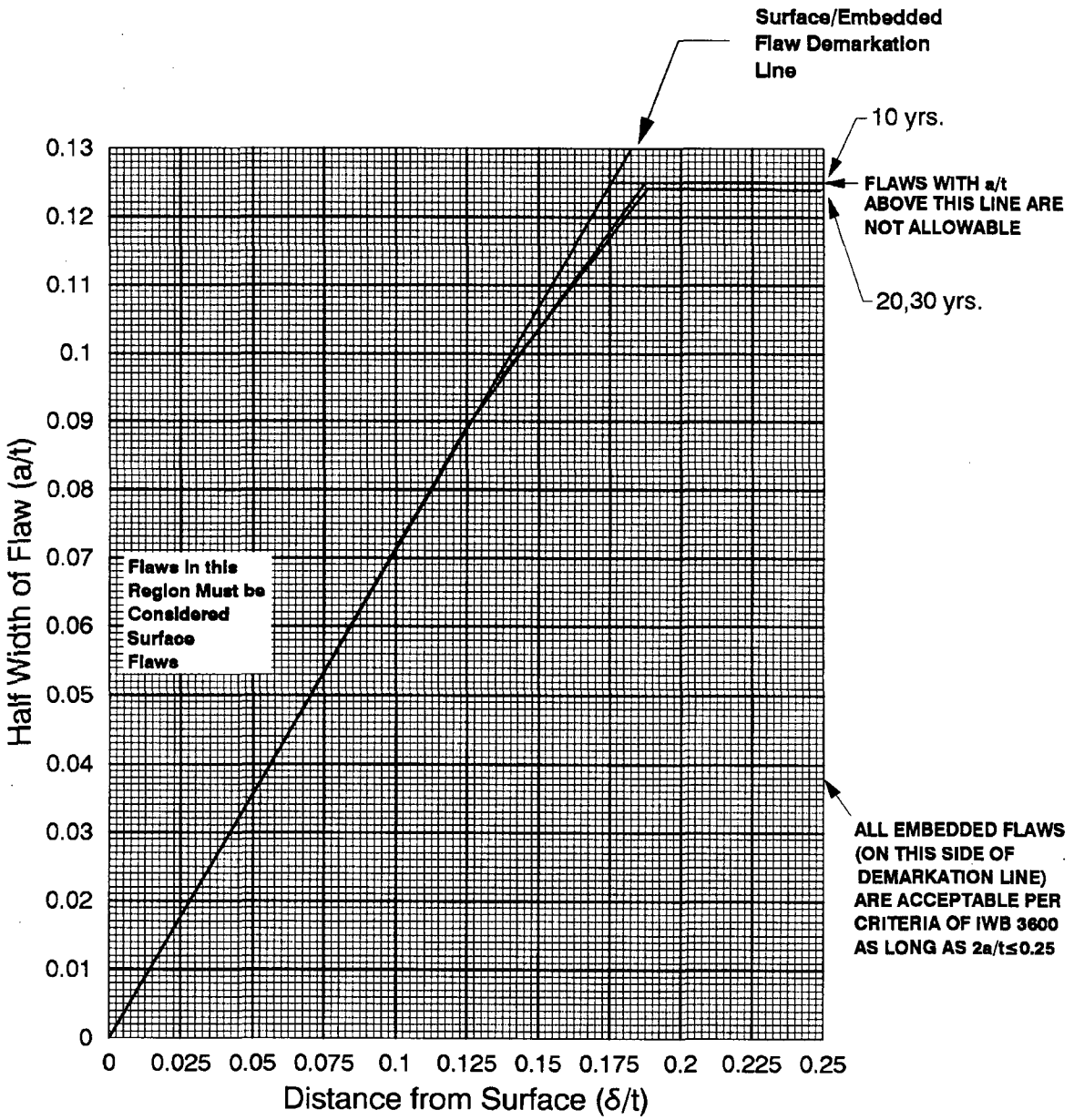


Figure A-2.6 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

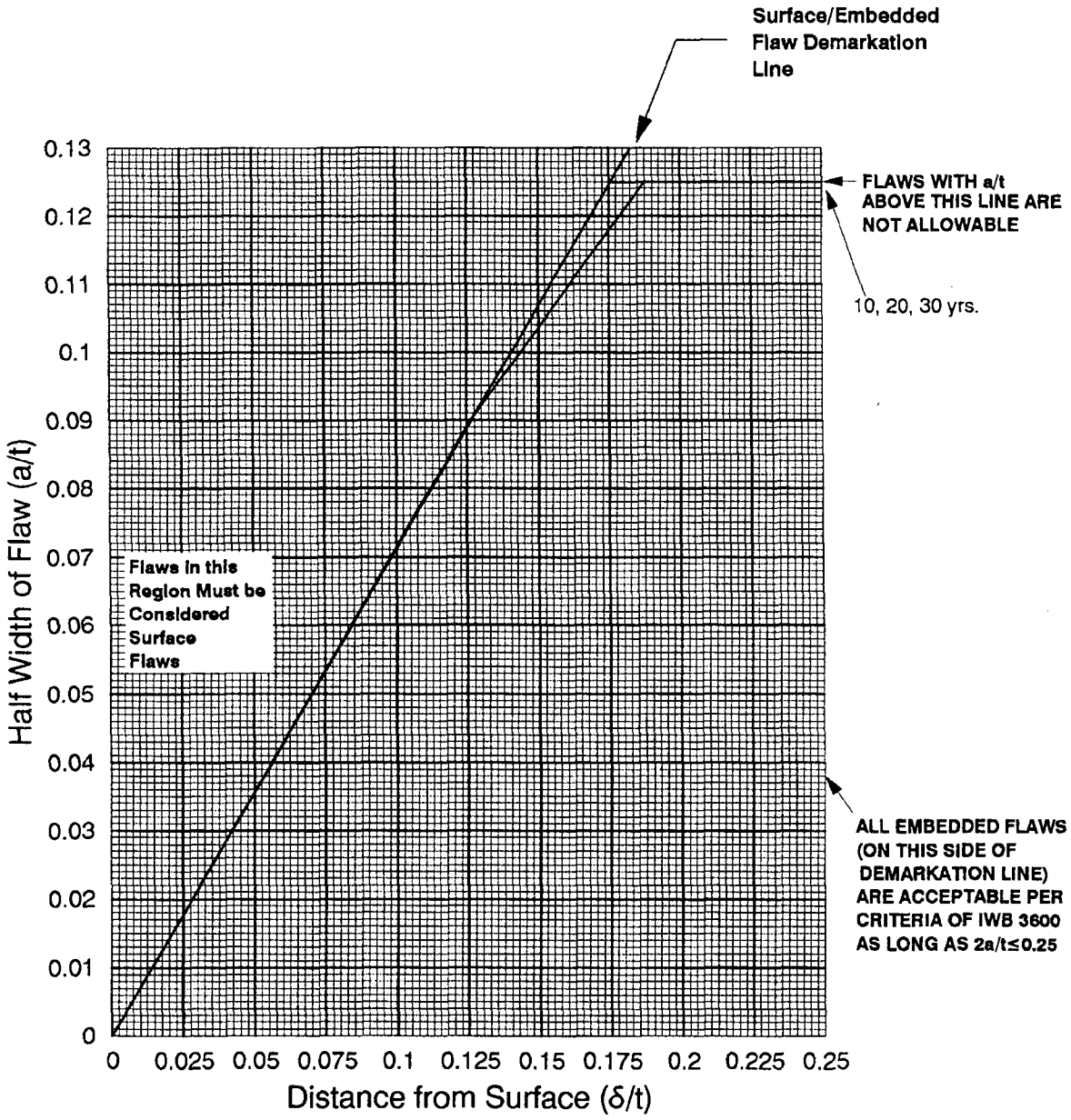


Figure A-2.7 Evaluation Chart for Nozzle Shell to Intermediate Shell Weld

X Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
X Outside Surface	X Embedded Flaw	X Circumferential Flaw

A-3 INLET NOZZLE TO SHELL WELD

A-3.1 Surface Flaws

The geometry and terminology for surface flaws at the inlet nozzle to shell weld is depicted in Figure A-3.1. The following parameters must be determined for surface flaw evaluation with the charts

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness at the inlet nozzle to vessel weld (t = 9.875")

The surface flaw evaluation charts for the inlet nozzle to vessel shell weld are listed below:

- Figure A-3.2 Evaluation Chart for Inlet Nozzle to Shell Weld

X	Inside Surface	X	Surface Flaw	X	Longitudinal Flaw
___	Outside Surface	___	Embedded Flaw	___	Circumferential Flaw

- Figure A-3.3 Evaluation Chart for Inlet Nozzle to Shell Weld

X	Inside Surface	X	Surface Flaw	___	Longitudinal Flaw
___	Outside Surface	___	Embedded Flaw	X	Circumferential Flaw

- Figure A-3.4 Evaluation Chart for Inlet Nozzle to Shell Weld

___	Inside Surface	X	Surface Flaw	X	Longitudinal Flaw
X	Outside Surface	___	Embedded Flaw	___	Circumferential Flaw

- Figure A-3.5 Evaluation Chart for Inlet Nozzle to Shell Weld

___	Inside Surface	X	Surface Flaw	___	Longitudinal Flaw
X	Outside Surface	___	Embedded Flaw	X	Circumferential Flaw

A-3.2 Embedded Flaws

The geometrical description of an embedded flaw at the inlet nozzle to vessel shell weld is depicted in Figure A-3.1.

Basic Data:

t	=	9.875 in.
δ	=	Distance of the centerline of the embedded flaw to the surface (in.)
a	=	Flaw depth (defined as one half of the minor diameter) (in.)
ℓ	=	Flaw length (major diameter) (in.)
a_o	=	Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$
- Surface proximity parameter, $\frac{\delta}{t}$

The evaluation charts for embedded flaws are as follows:

- Figure A-3.6 Evaluation Chart for Inlet Nozzle to Shell Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

- Figure A-3.7 Evaluation Chart for Inlet Nozzle to Shell Weld

X Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
X Outside Surface	X Embedded Flaw	X Circumferential Flaw

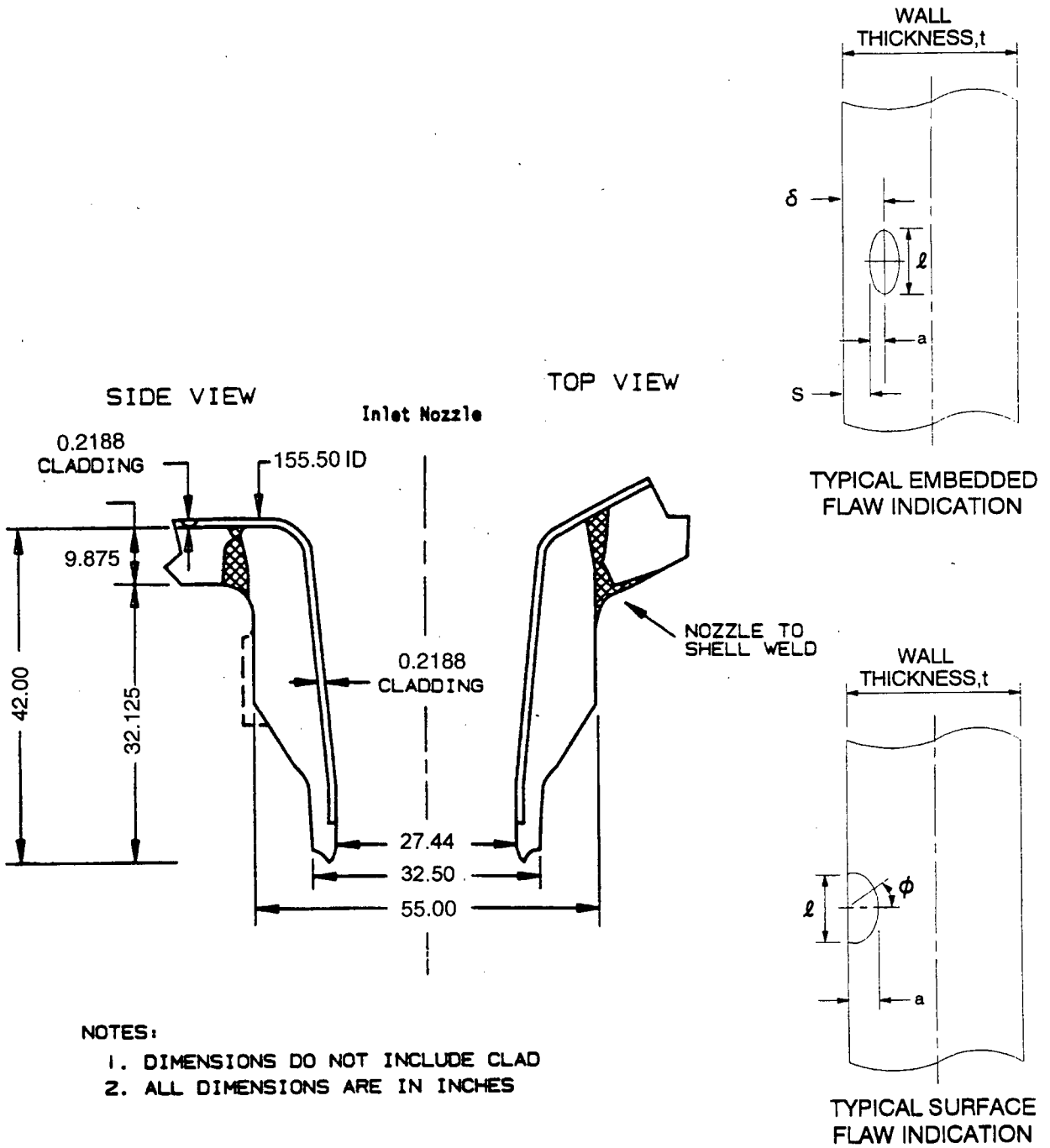


Figure A-3.1 Geometry and Terminology for Flaws at the Inlet Nozzle to Shell Weld

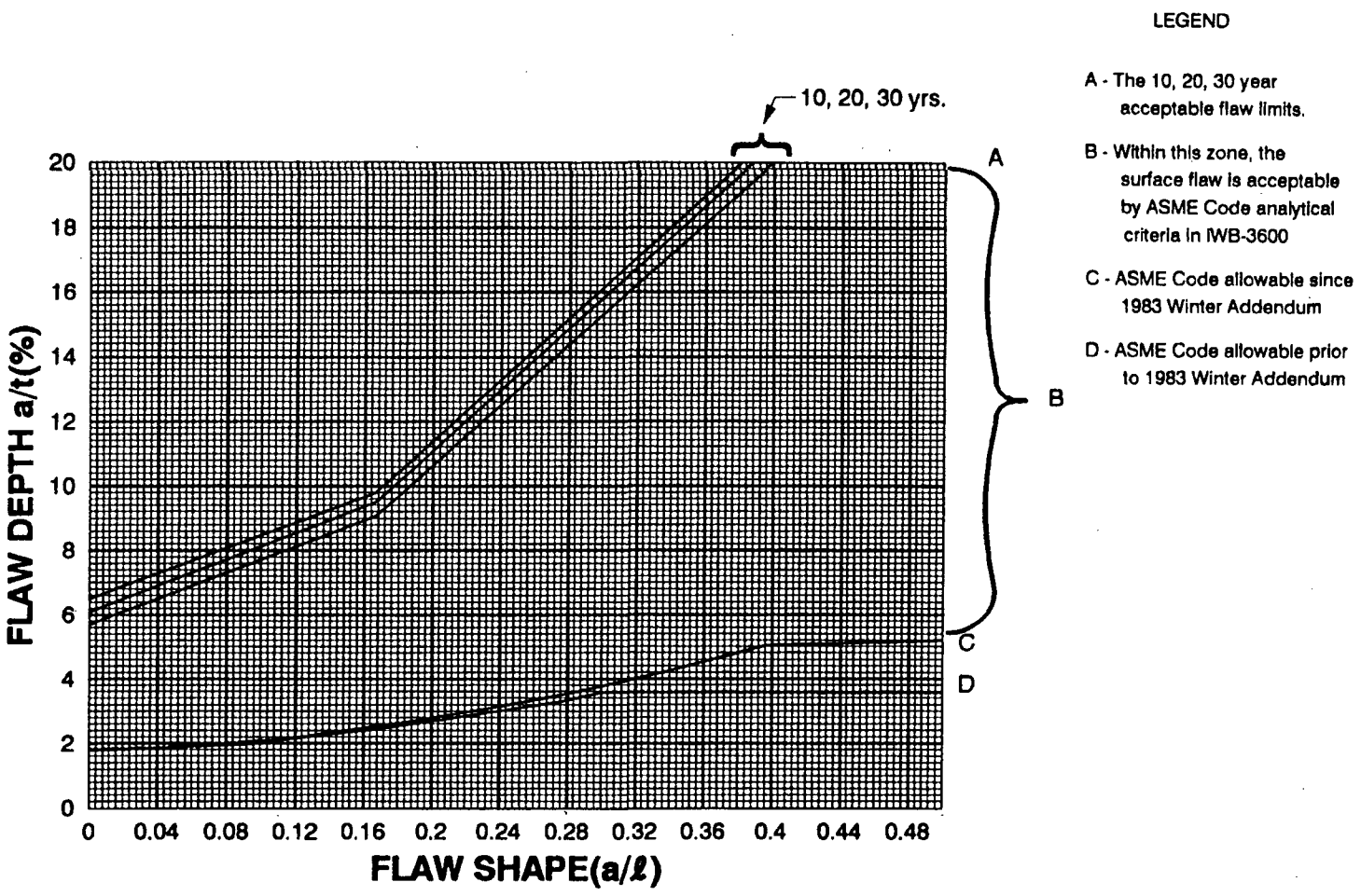


Figure A-3.2 Evaluation Chart for Inlet Nozzle to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

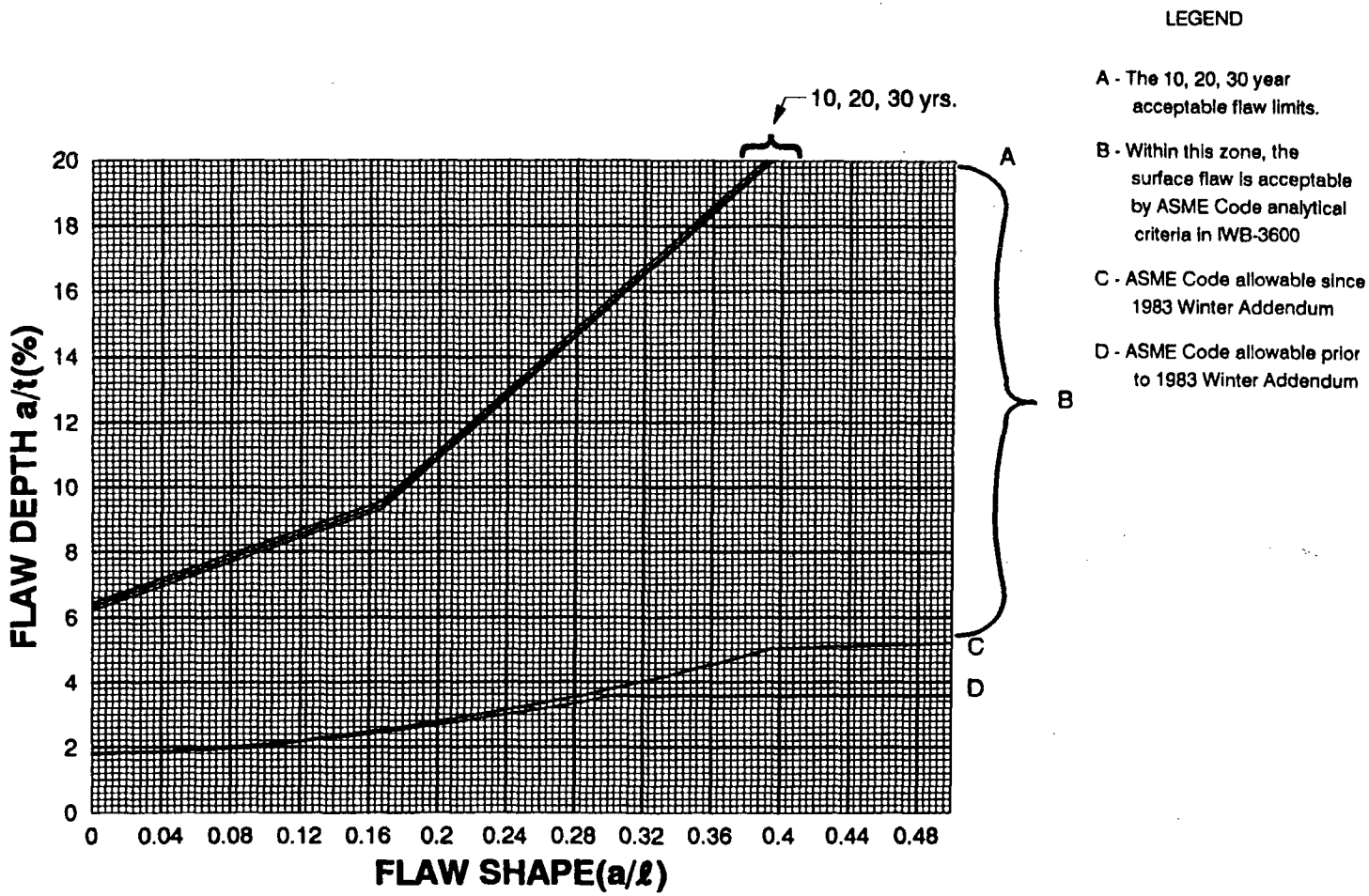
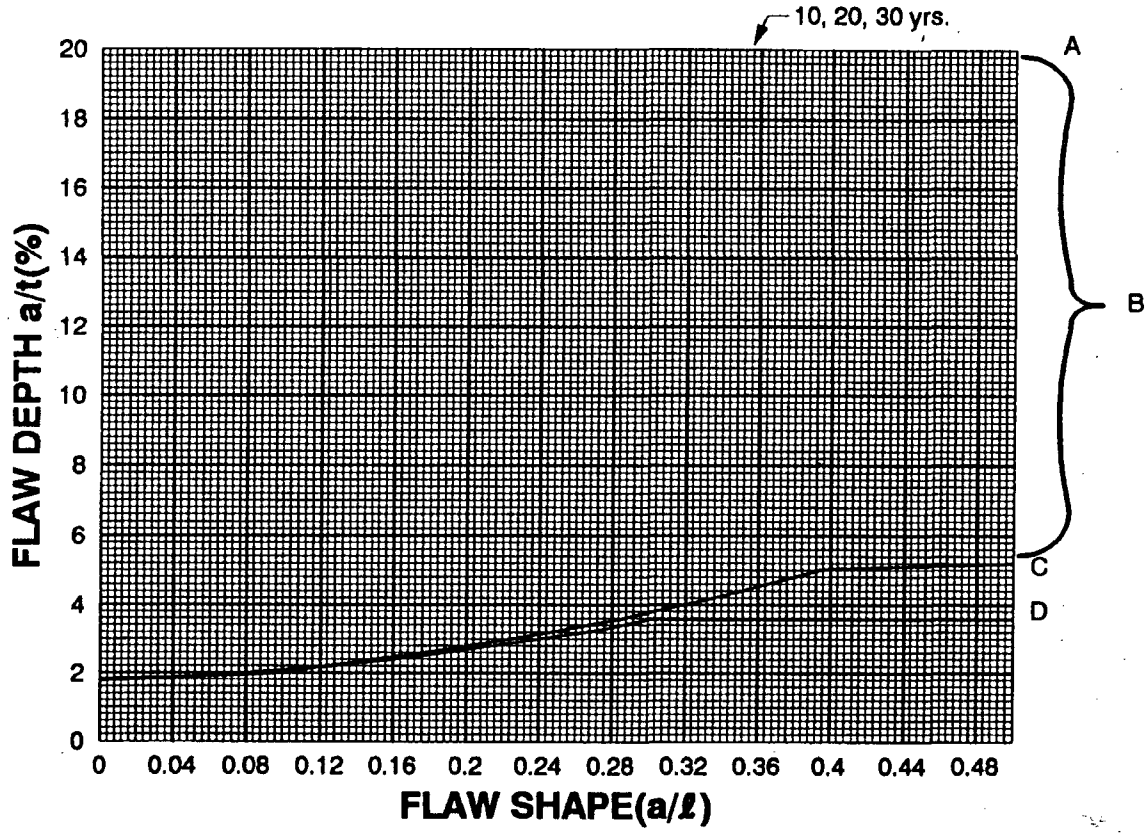


Figure A-3.3 Evaluation Chart for Inlet Nozzle to Shell Weld

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw



LEGEND

A - The 10, 20, 30 year acceptable flaw limits.

B - Within this zone, the surface flaw is acceptable by ASME Code analytical criteria in IWB-3600

C - ASME Code allowable since 1983 Winter Addendum

D - ASME Code allowable prior to 1983 Winter Addendum

Figure A-3.4 Evaluation Chart for Inlet Nozzle to Shell Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

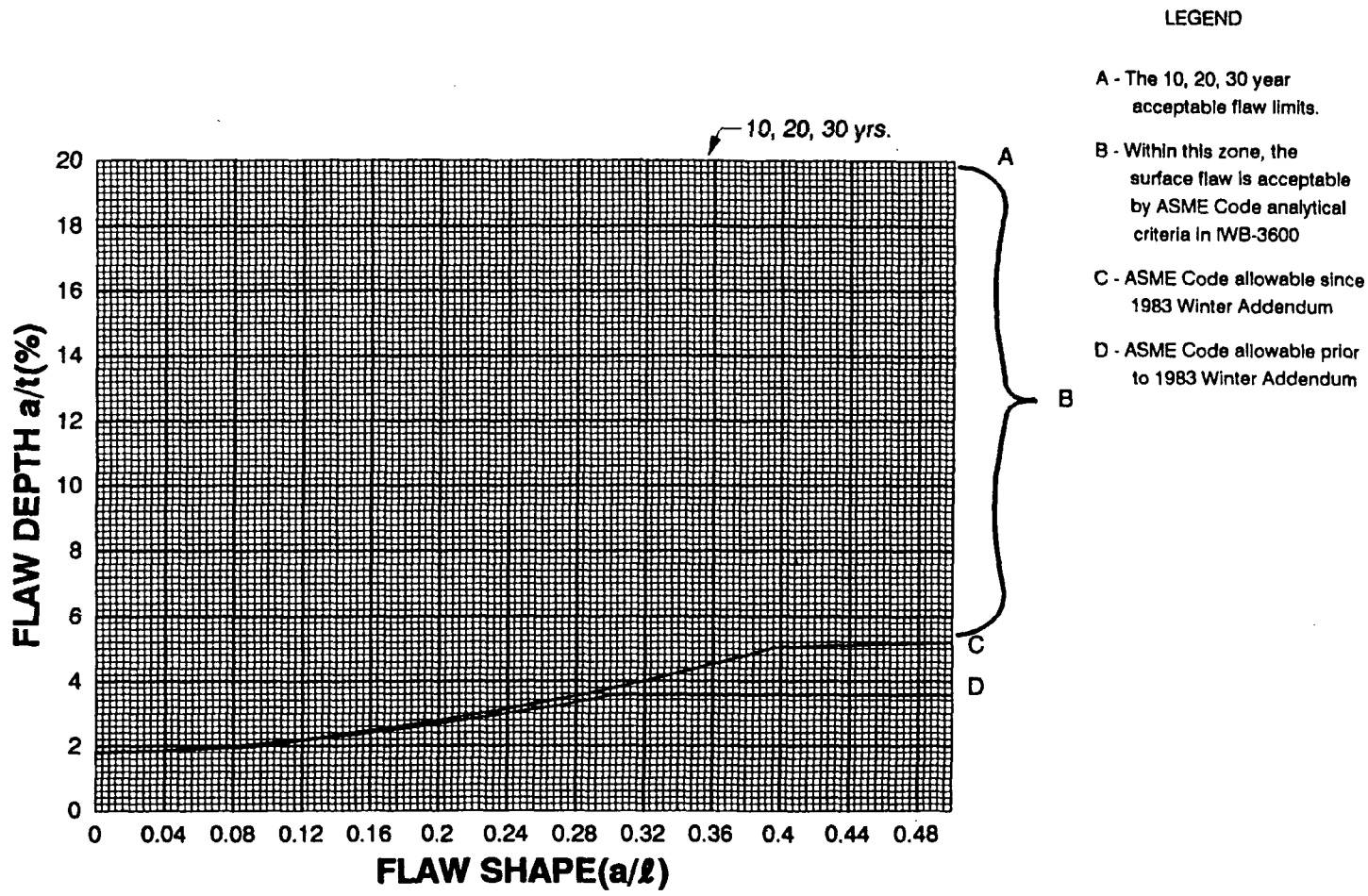


Figure A-3.5 Evaluation Chart for Inlet Nozzle to Shell Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

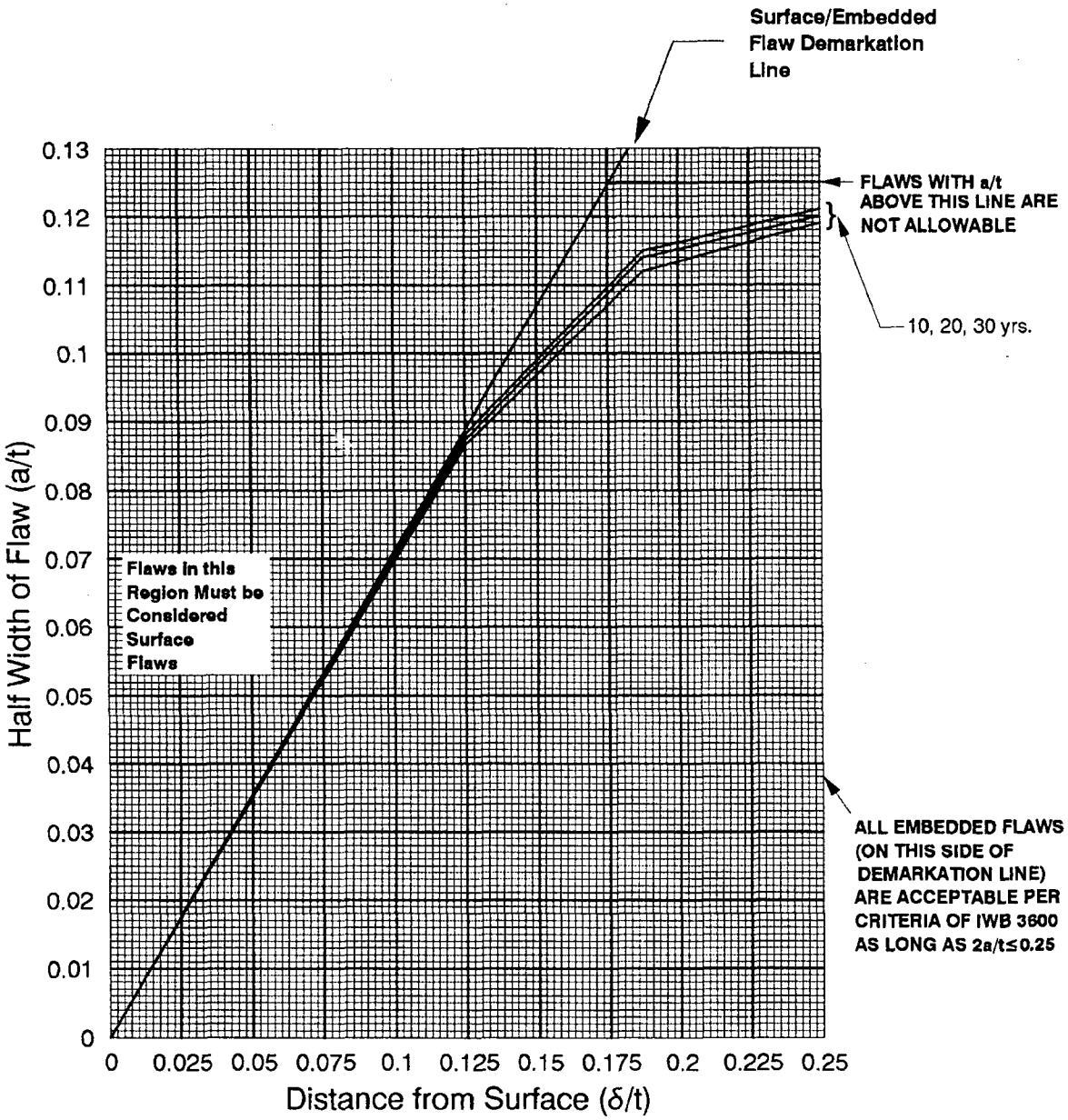


Figure A-3.6 Evaluation Chart for Inlet Nozzle to Shell Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

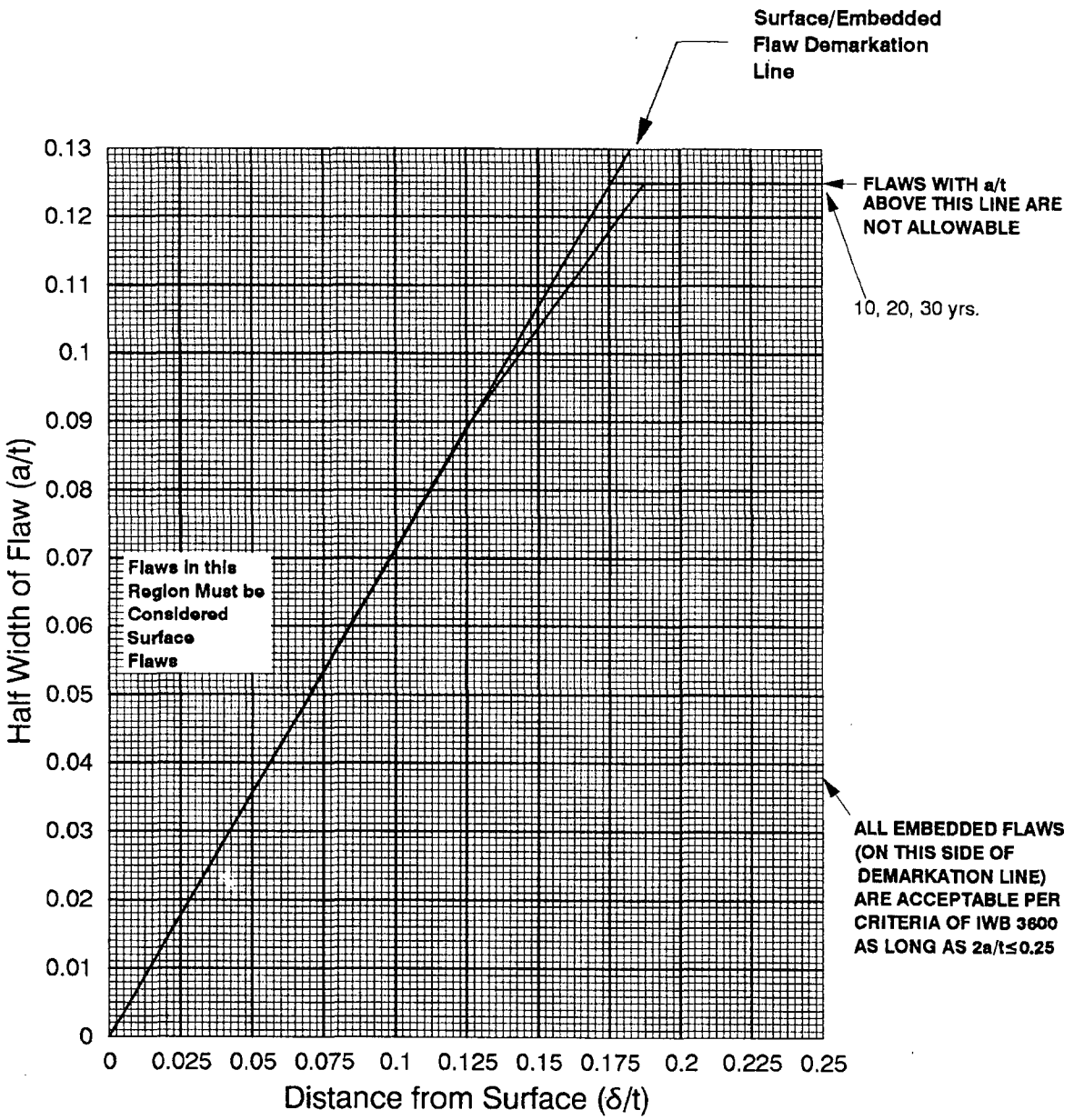


Figure A-3.7 Evaluation Chart for Inlet Nozzle to Shell Weld

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

A-4 INLET NOZZLE INNER RADIUS (CORNER)

A-4.1 Surface Flaws

The geometry of surface flaws at the inlet nozzle corner is depicted in Figure A-4.1.

The following parameters must be prepared for surface flaw evaluation charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness at the inlet nozzle inner radius (t = 13.3")

The surface flaw evaluation charts for the inlet nozzle inner corner radius are listed below:

- Figure A-4.2 Evaluation Chart for Inlet Nozzle Inner Radius (Corner)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

Embedded flaws are not considered in the nozzle corner region.

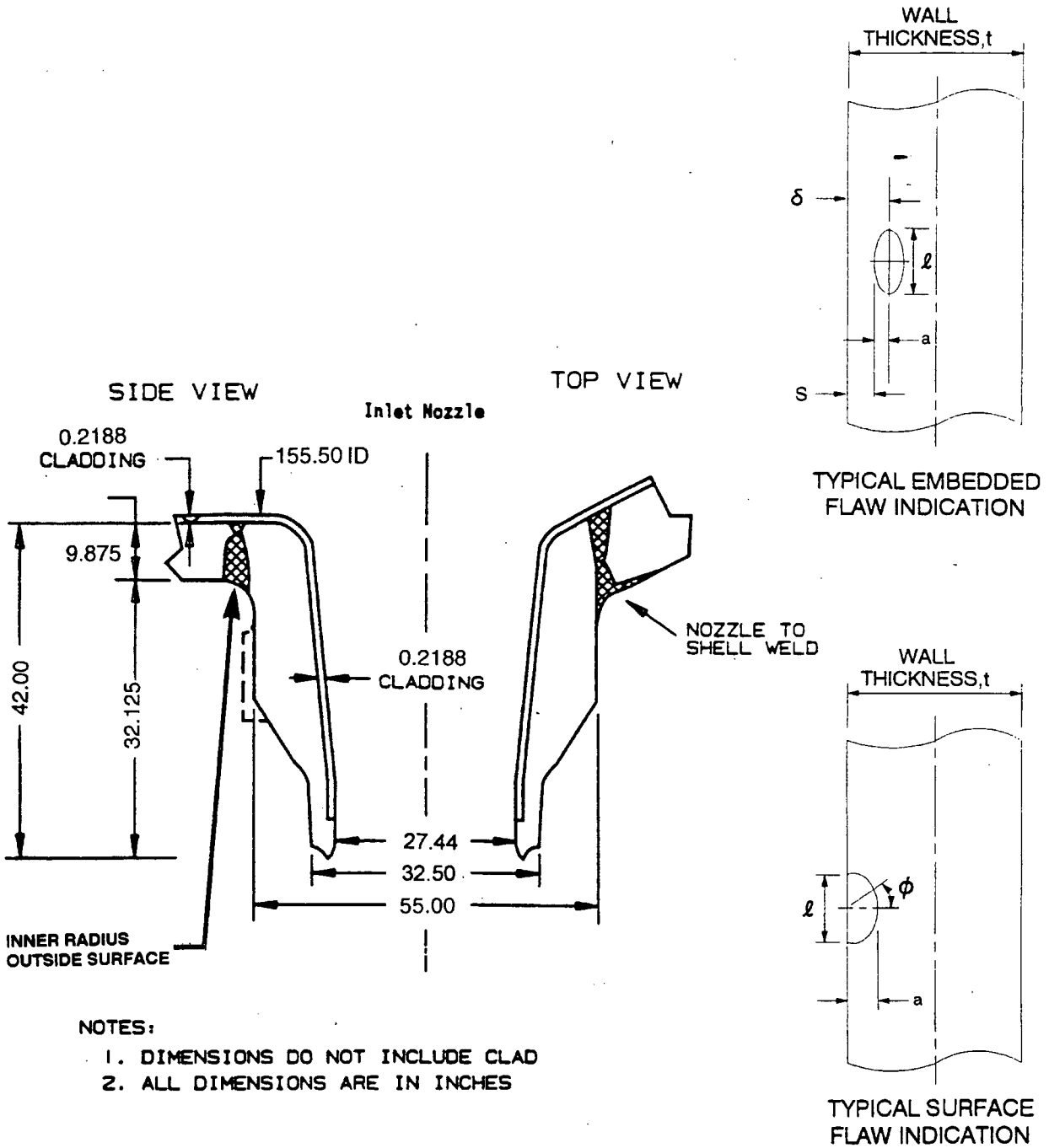


Figure A-4.1 Geometry and Terminology for Flaws at the Inlet Nozzle Inner Radius (Corner)

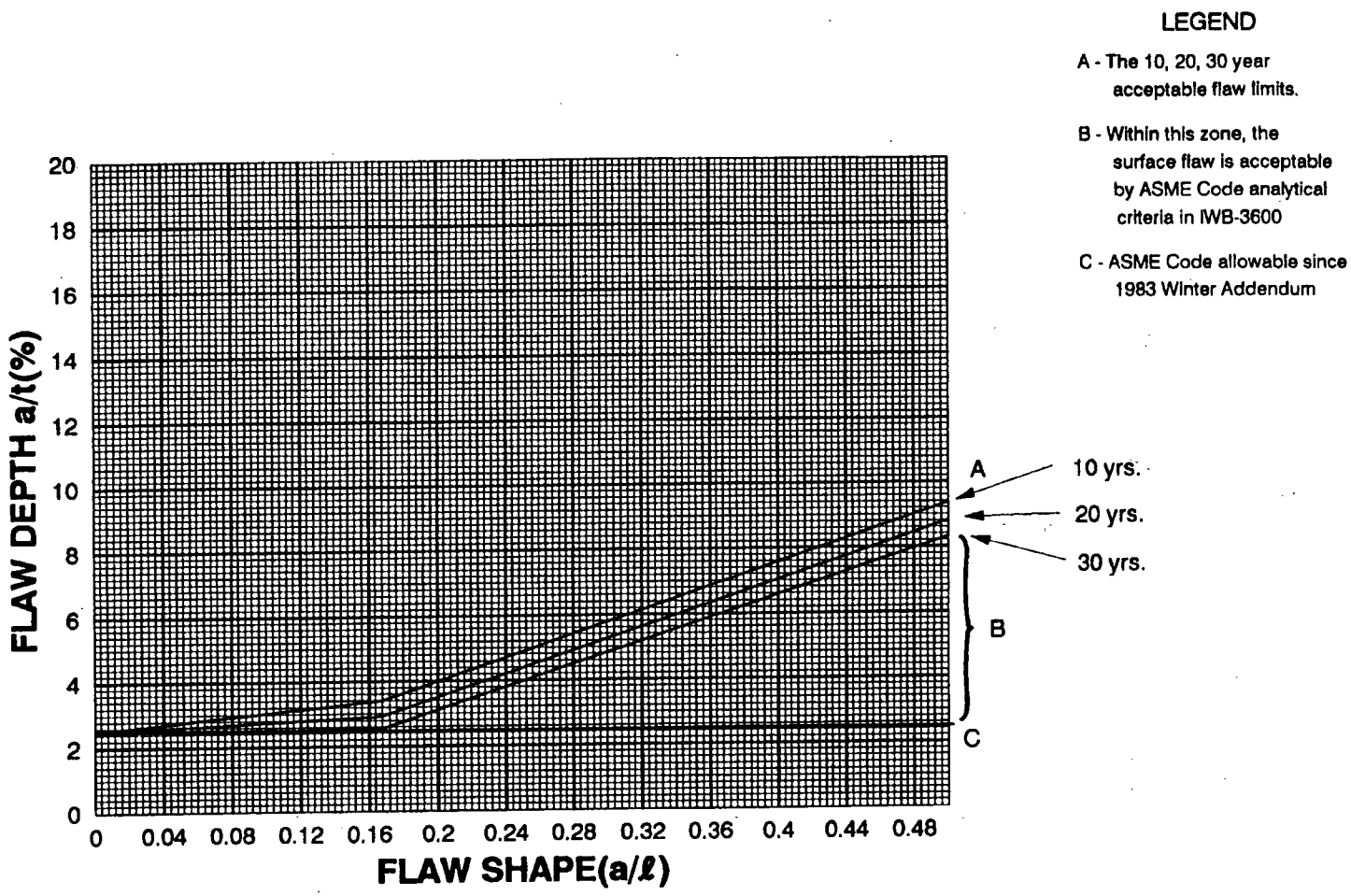


Figure A-4.2 Evaluation Chart for Inlet Nozzle Inner Radius (Corner)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

A-5 INLET NOZZLE SAFE-END WELD REGIONS

A-5.1 Surface Flaws

The geometry of surface flaws at the inlet nozzle safe-end weld region is depicted in Figure A-5.1. The following parameters must be prepared for surface flaw evaluation with charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness at the inlet nozzle safe end (t = 2.531")

The surface flaw evaluation charts for inlet nozzle safe-end weld regions are listed below:

- Figure A-5.2 Evaluation Chart for Inlet Nozzle Safe-end to Pipe Weld (Stainless Steel)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-5.3 Evaluation Chart for Inlet Nozzle Safe-end to Pipe Weld (Stainless Steel)

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

- Figure A-5.4 Evaluation Chart for Inlet Nozzle Safe-end to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-5.5 Evaluation Chart for Inlet Nozzle Safe-end to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

A-5.2 Embedded Flaws

The geometry of embedded flaws at the inlet nozzle safe-end weld region is depicted in Figure A-5.1.

Basic Data:

t	=	2.531"
δ	=	Distance of the centerline of the embedded flaw to the surface (in.)
a	=	Flaw depth (defined as one half of the minor diameter) (in.)
ℓ	=	Flaw length (major diameter) (in.)
a_o	=	Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$
- Surface proximity parameter, $\frac{\delta}{t}$

The evaluation charts for embedded flaws are as follows:

- Figure A-5.6 Evaluation Chart for Inlet Nozzle Safe-end to Pipe Weld (Stainless Steel)

  _X_ Inside Surface ___ Surface Flaw _X_ Longitudinal Flaw
  _X_ Outside Surface _X_ Embedded Flaw ___ Circumferential Flaw

- Figure A-5.7 Evaluation Chart for Inlet Nozzle Safe-end to Pipe Weld (Stainless Steel)

  _X_ Inside Surface ___ Surface Flaw ___ Longitudinal Flaw
  _X_ Outside Surface _X_ Embedded Flaw _X_ Circumferential Flaw

- Figure A-5.8 Evaluation Chart for Inlet Nozzle Safe-end to Nozzle Weld (Alloy 82/182)

  _X_ Inside Surface ___ Surface Flaw _X_ Longitudinal Flaw
  _X_ Outside Surface _X_ Embedded Flaw ___ Circumferential Flaw

- Figure A-5.9 Evaluation Chart for Inlet Nozzle Safe-end to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

The flaw shape or the aspect ratio for this chart is restricted to flaws with $\frac{a}{\ell} \geq 0.1$.

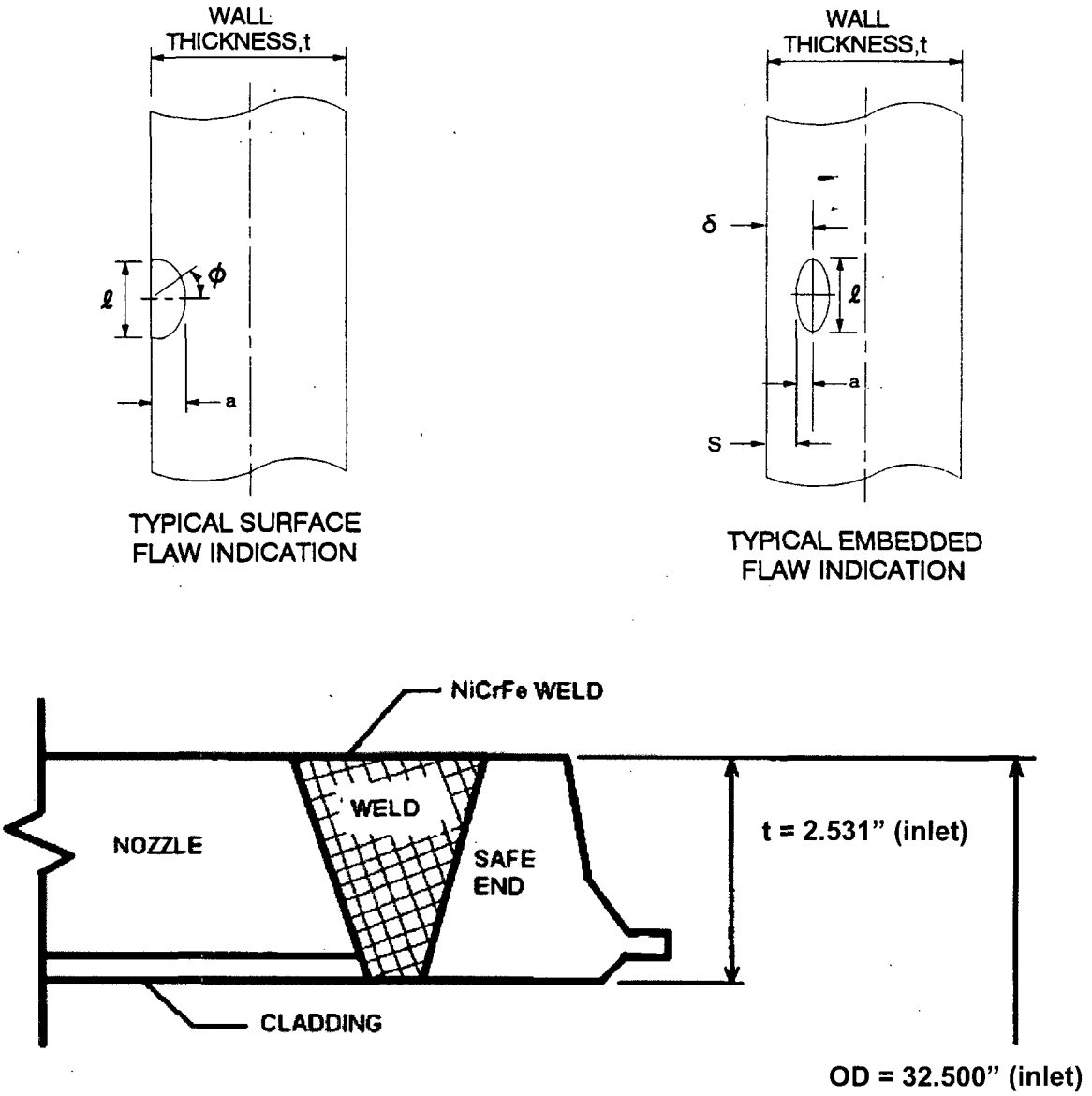


Figure A-5.1 Geometry and Terminology for Flaws at the Inlet Nozzle Safe-End Weld Region

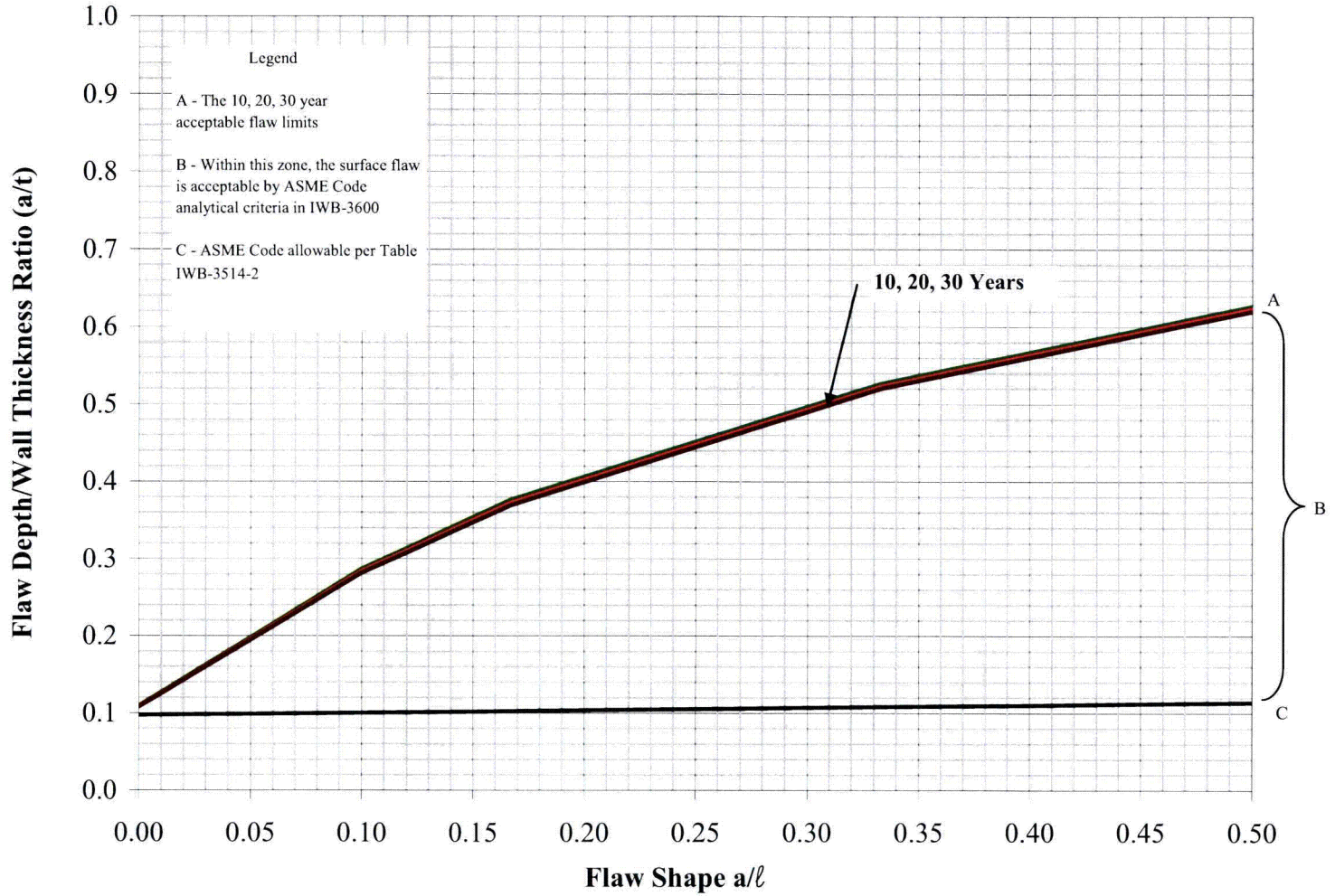


Figure A-5.2 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

X Inside Surface	X Surface Flaw	X Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

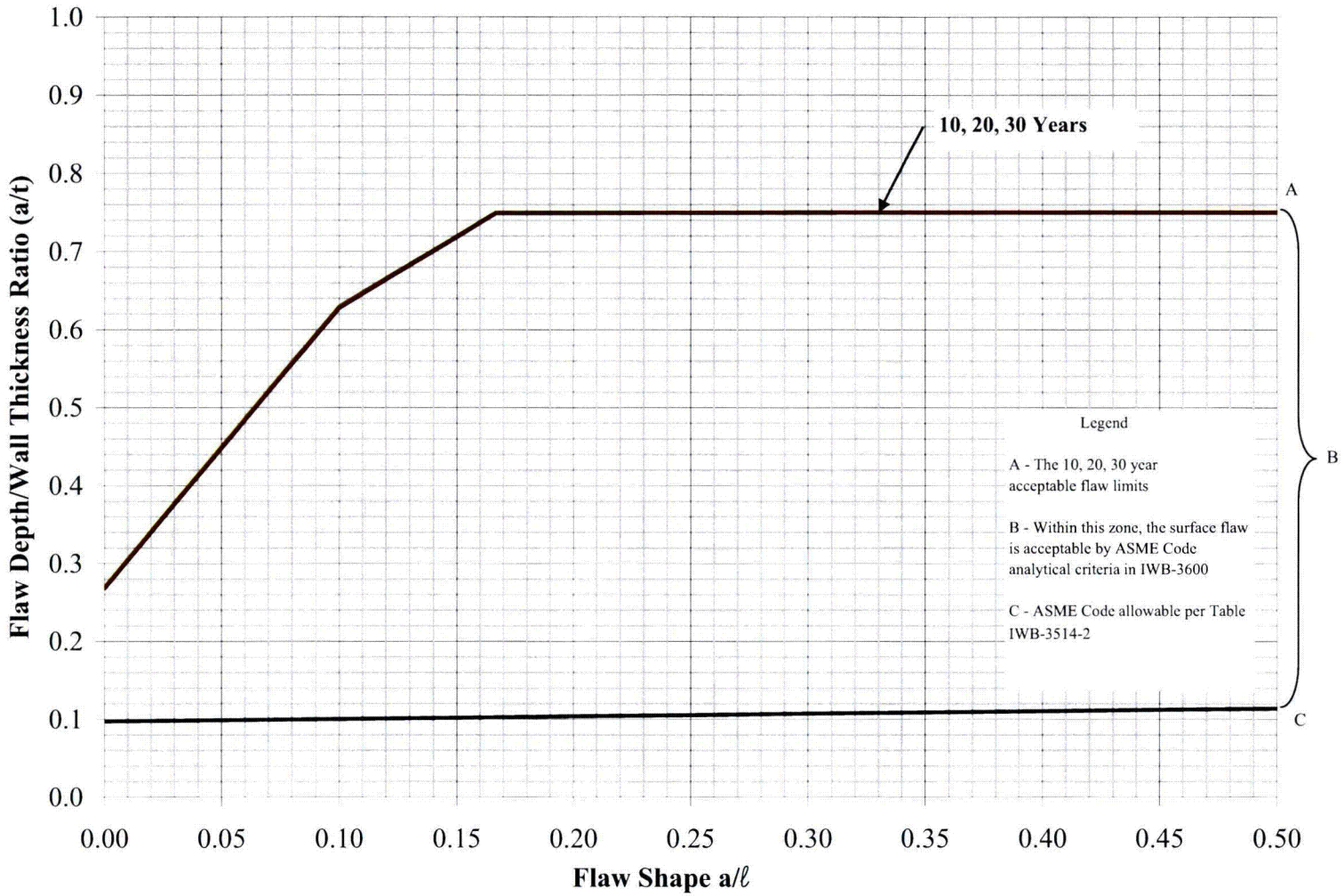


Figure A-5.3 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

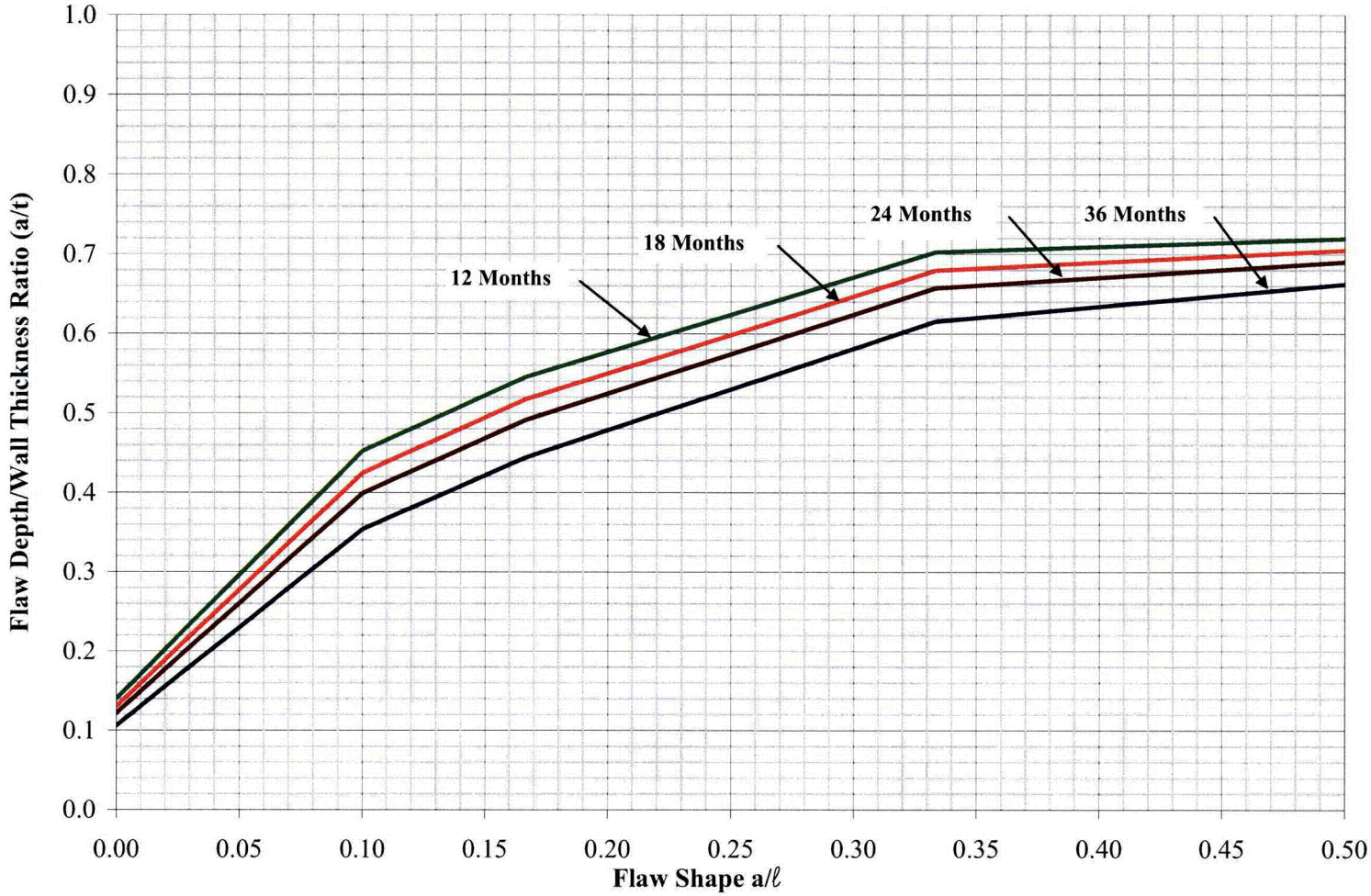


Figure A-5.4 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

X Inside Surface	X Surface Flaw	X Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

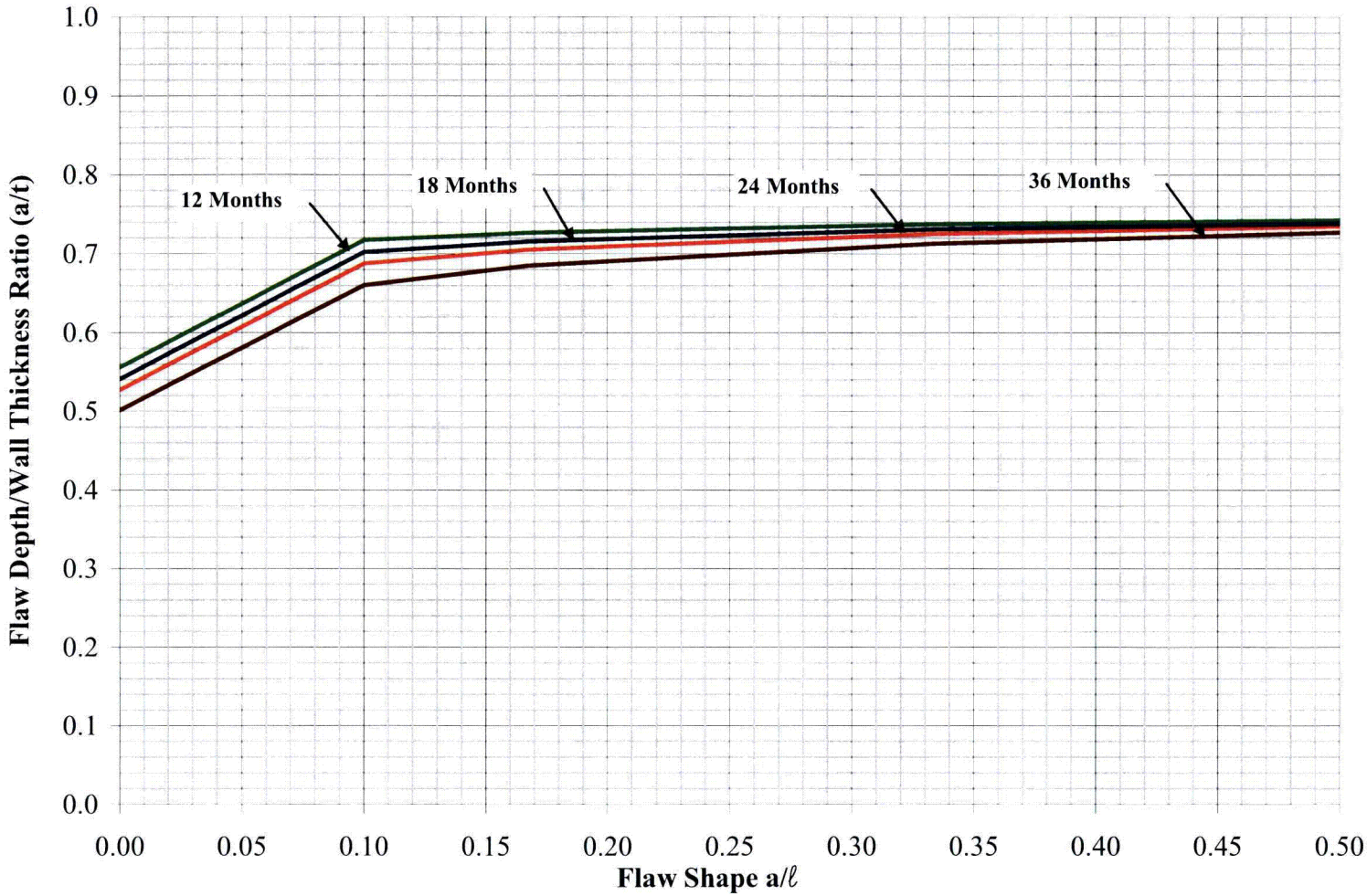


Figure A-5.5 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

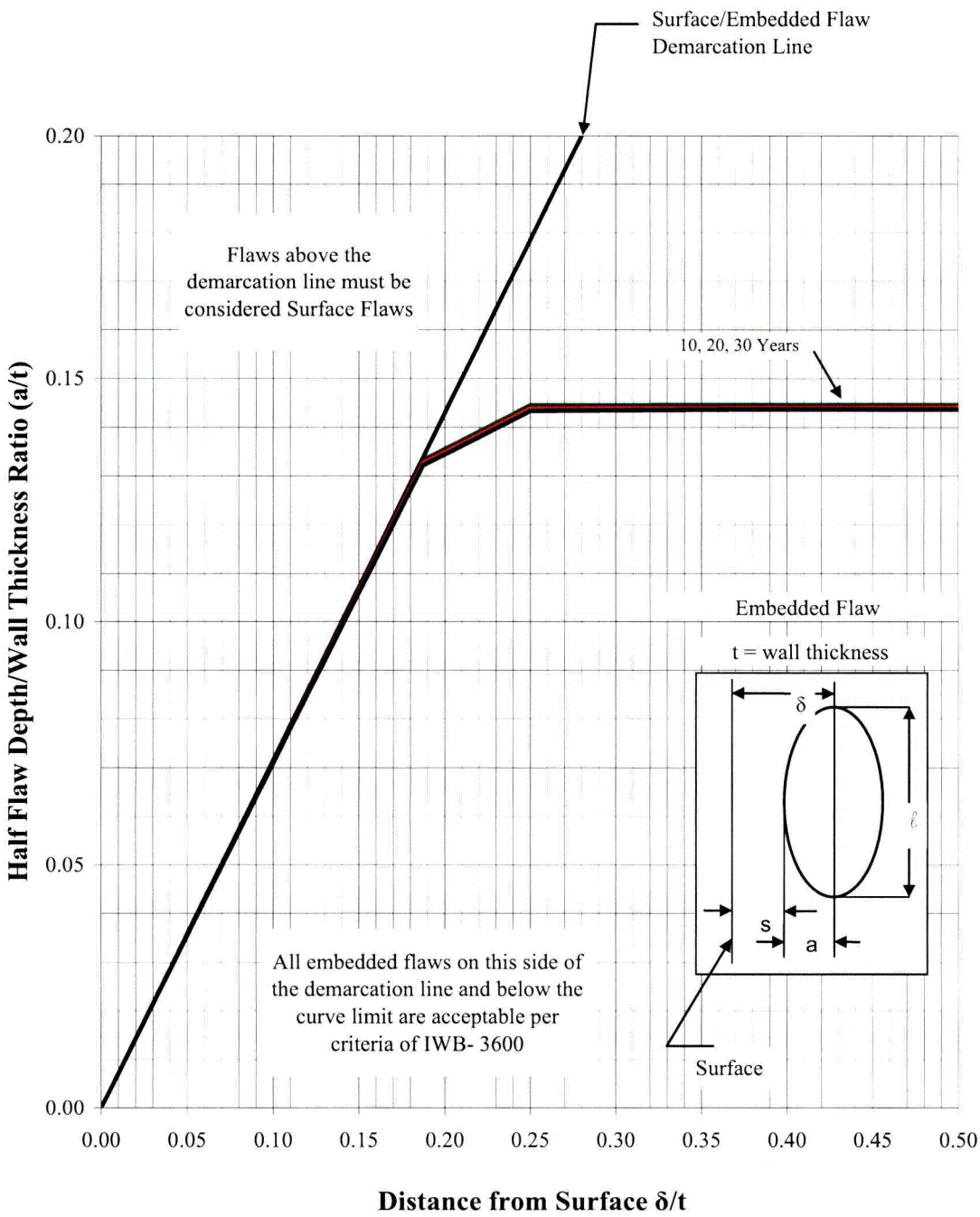


Figure A-5.6 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

_X_ Inside Surface	___ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	___ Circumferential Flaw

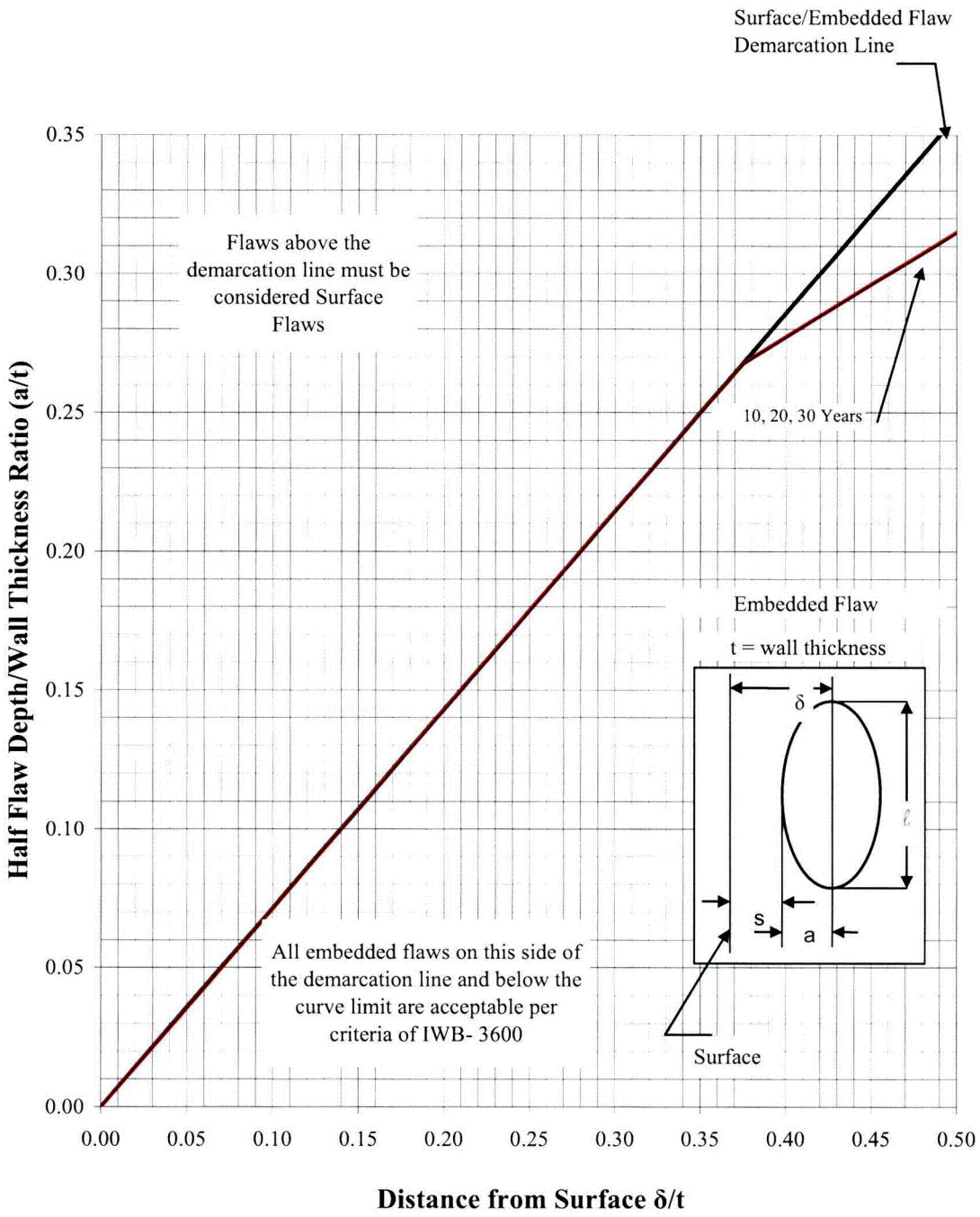


Figure A-5.7 Evaluation Chart for Inlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

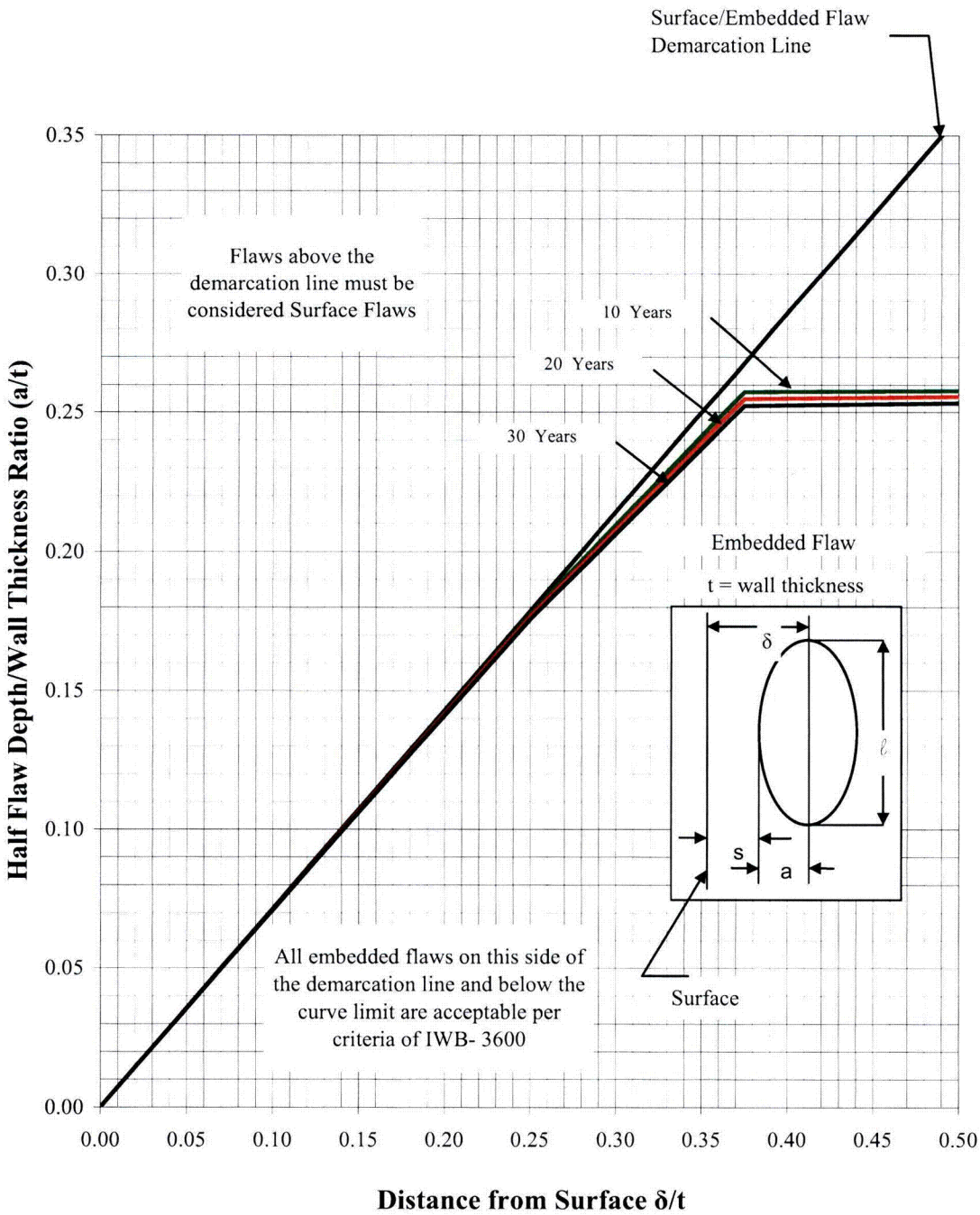


Figure A-5.8 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

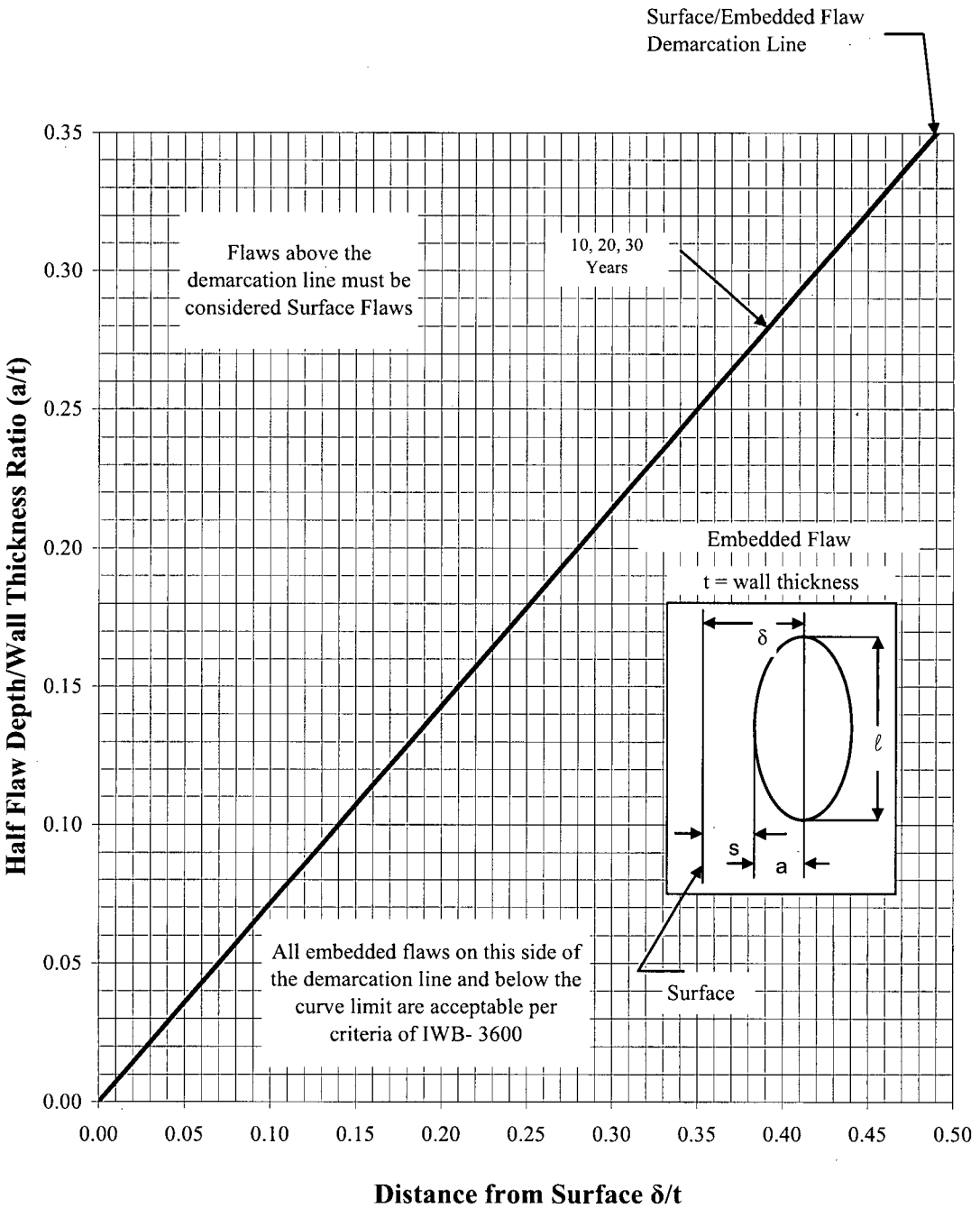


Figure A-5.9 Evaluation Chart for Inlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	___ Surface Flaw	____ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

A-6 OUTLET NOZZLE TO SHELL WELD

A-6.1 Surface Flaws

The geometry and terminology for surface flaws at the outlet nozzle to shell weld is depicted in Figure A-6.1. The following parameters must be prepared for surface flaw evaluation with charts.

- Flaw shape parameter $\frac{a}{\ell}$

- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness at the inlet nozzle safe end (t = 9.875")

The surface flaw evaluation charts for outlet nozzle to shell weld are listed below:

- Figure A-6.2 Evaluation Chart for Outlet Nozzle to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
____ Outside Surface	____ Embedded Flaw	____ Circumferential Flaw

- Figure A-6.3 Evaluation Chart for Outlet Nozzle to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	____ Longitudinal Flaw
____ Outside Surface	____ Embedded Flaw	_X_ Circumferential Flaw

- Figure A-6.4 Evaluation Chart for Outlet Nozzle to Shell Weld

____ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	____ Embedded Flaw	____ Circumferential Flaw

- Figure A-6.5 Evaluation Chart for Outlet Nozzle to Shell Weld

____ Inside Surface	_X_ Surface Flaw	____ Longitudinal Flaw
_X_ Outside Surface	____ Embedded Flaw	_X_ Circumferential Flaw

A-6.2 Embedded Flaws

The geometry of embedded flaws at the outlet nozzle to shell weld is depicted in Figure A-6.1.

Basic Data:

t	=	9.875"
δ	=	Distance of the centerline of the embedded flaw to the surface (in.)
a	=	Flaw depth (defined as one half of the minor diameter) (in.)
ℓ	=	Flaw length (major diameter) (in.)
δ	=	Distance of the centerline of the flaw to surface (in.)
a_o	=	Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$
- Surface proximity parameter, $\frac{\delta}{t}$

The evaluation charts are given in Figure A-6.6 and A-6.7.

- Figure A-6.6 Evaluation Chart for Outlet Nozzle to Shell Weld

_X_ Inside Surface	___ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	___ Circumferential Flaw

- Figure A-6.7 Evaluation Chart for Outlet Nozzle to Shell Weld

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

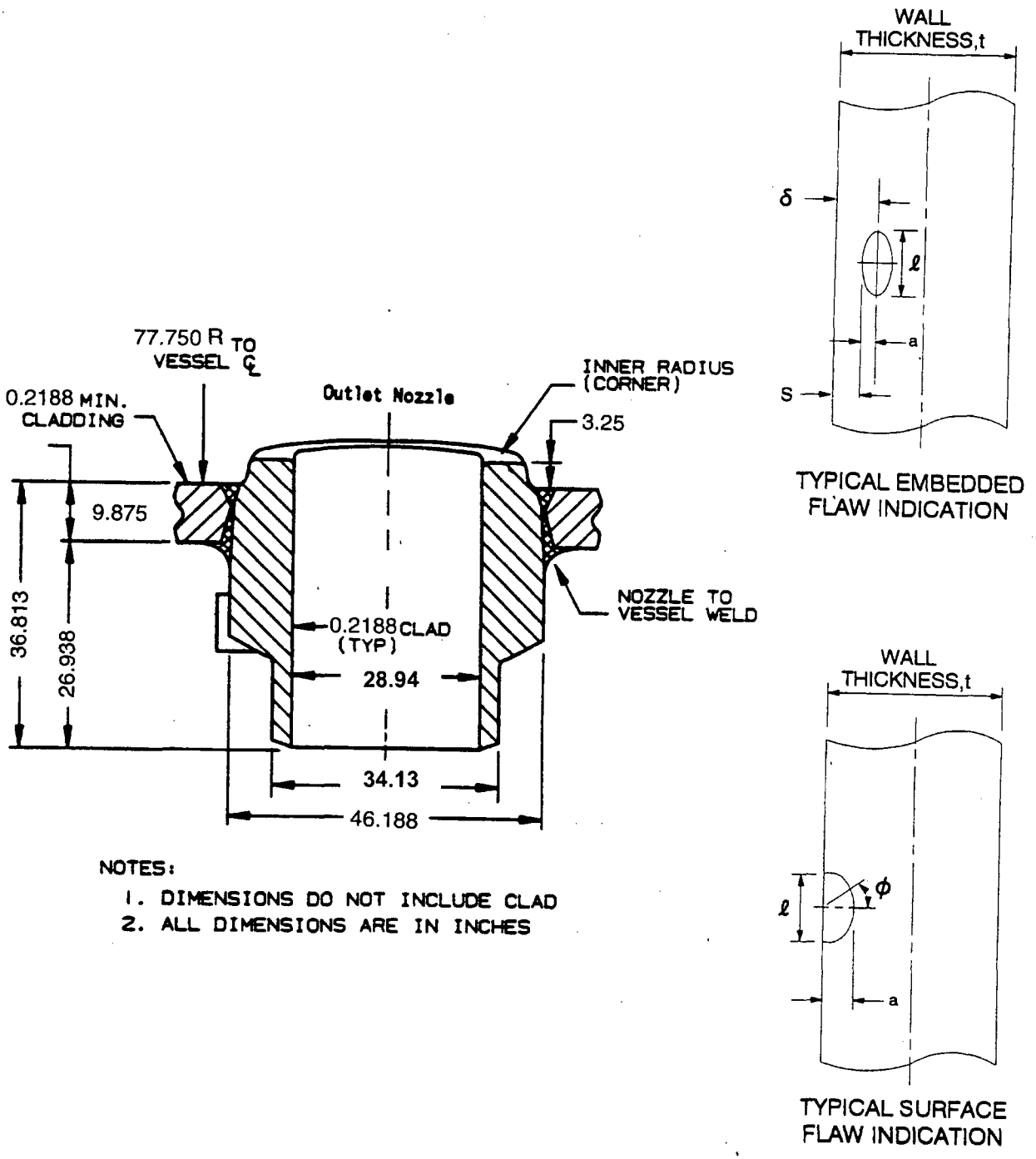


Figure A-6.1 Geometry and Terminology for Flaws at the Outlet Nozzle to Shell Weld

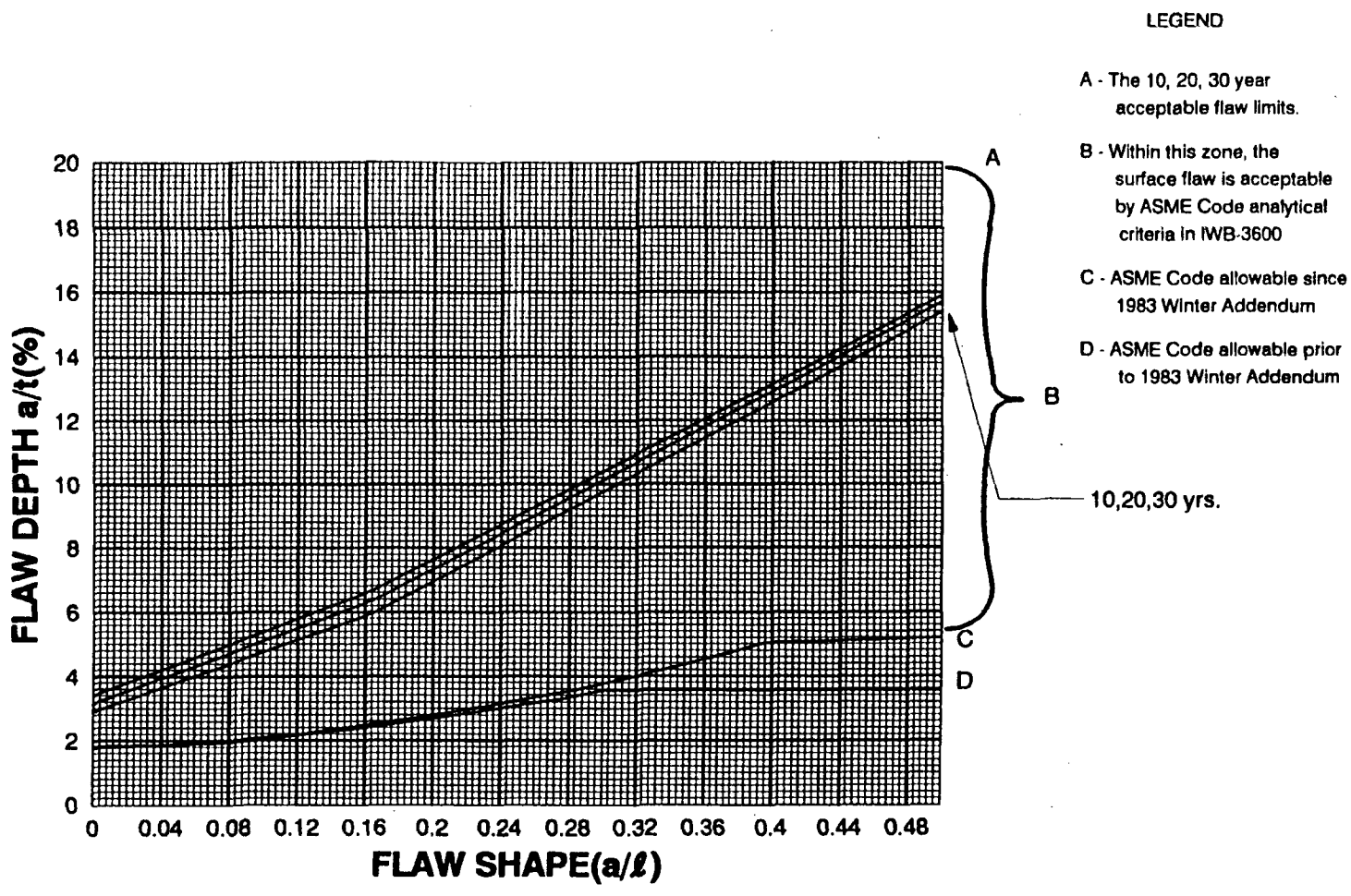


Figure A-6.2 Evaluation Chart for Outlet Nozzle to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

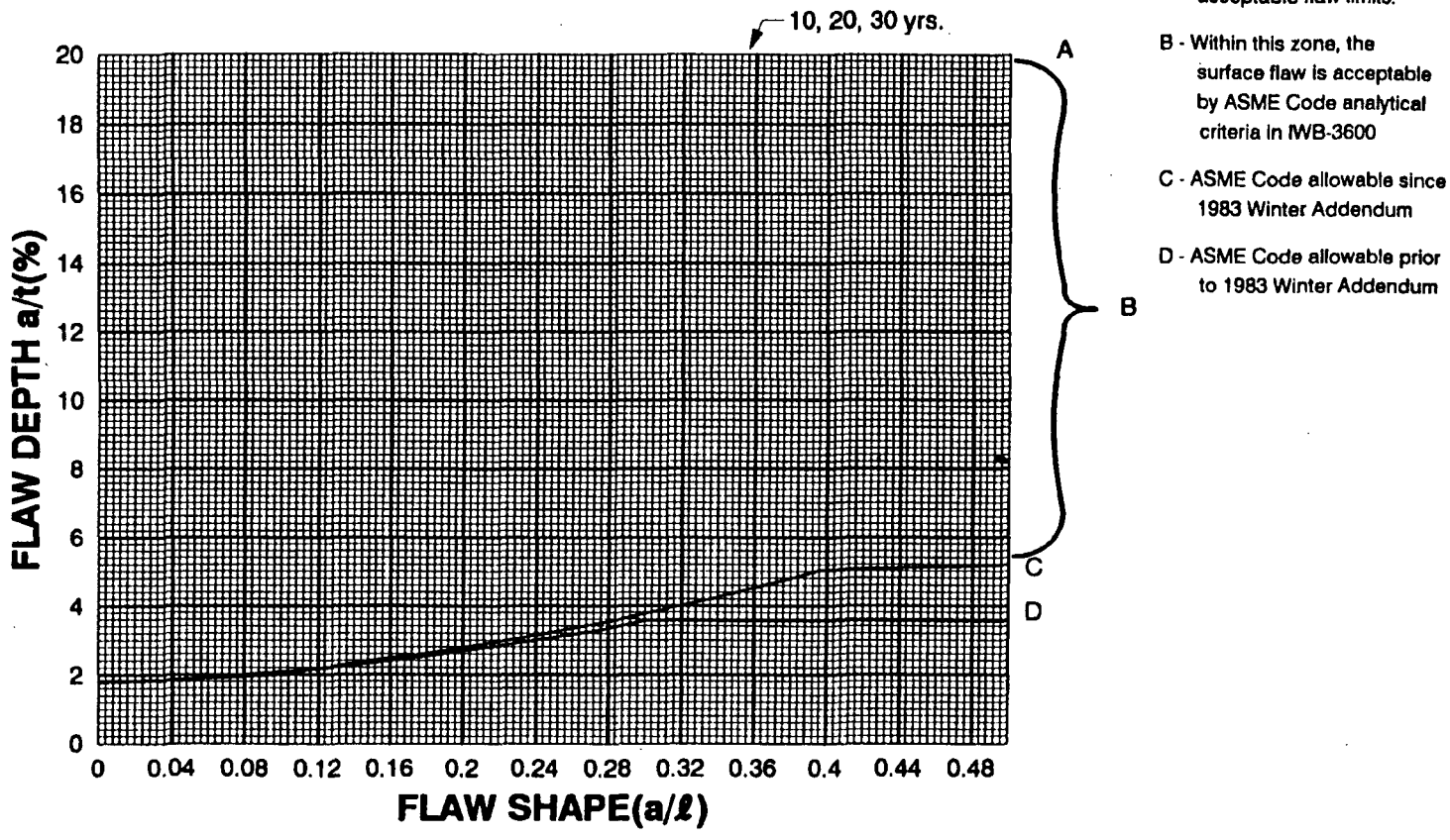


Figure A-6.3 Evaluation Chart for Outlet Nozzle to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

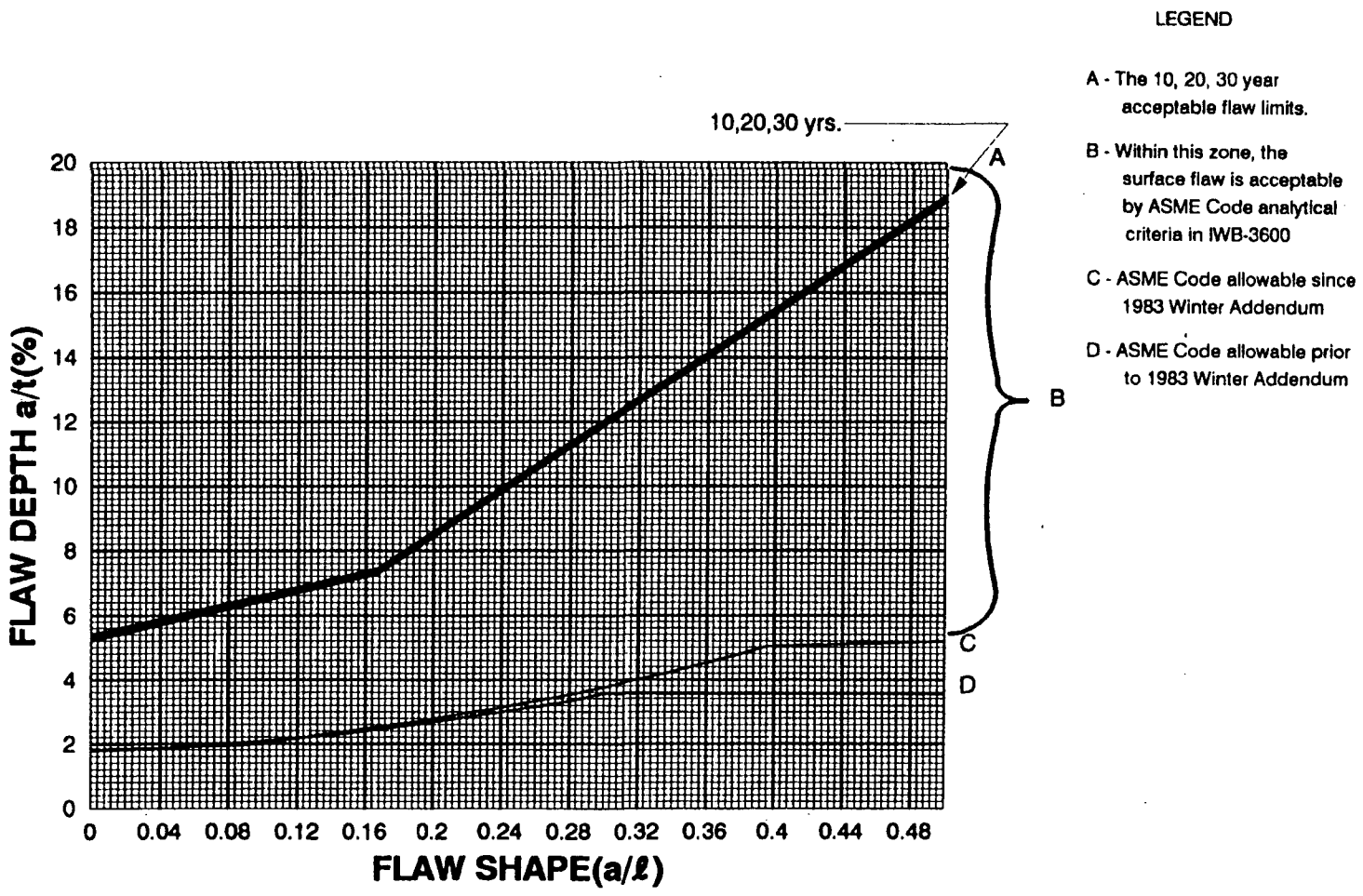


Figure A-6.4 Evaluation Chart for Outlet Nozzle to Shell Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

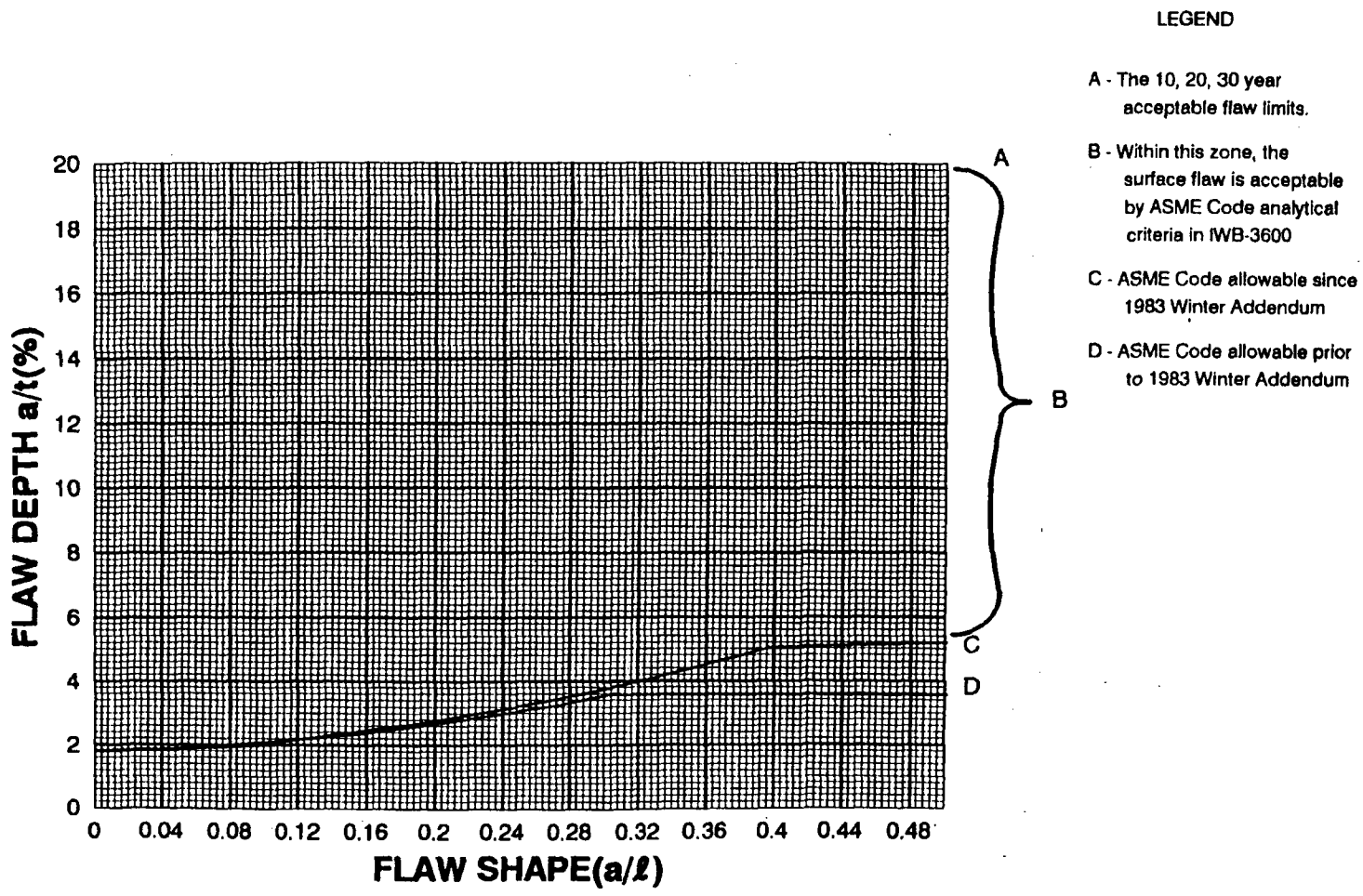


Figure A-6.5 Evaluation Chart for Outlet Nozzle to Shell Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

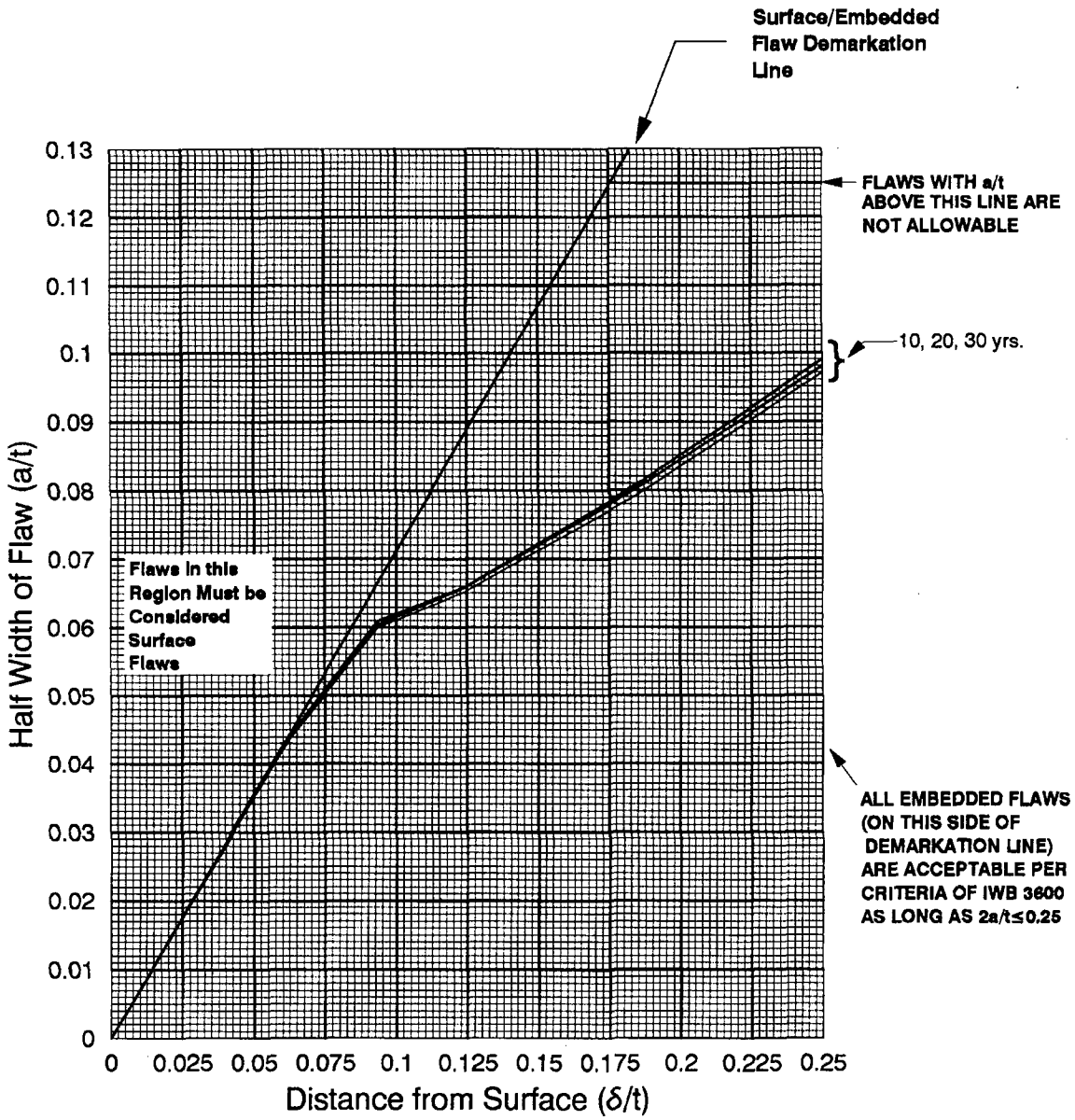


Figure A-6.6 Evaluation Chart for Outlet Nozzle to Shell Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

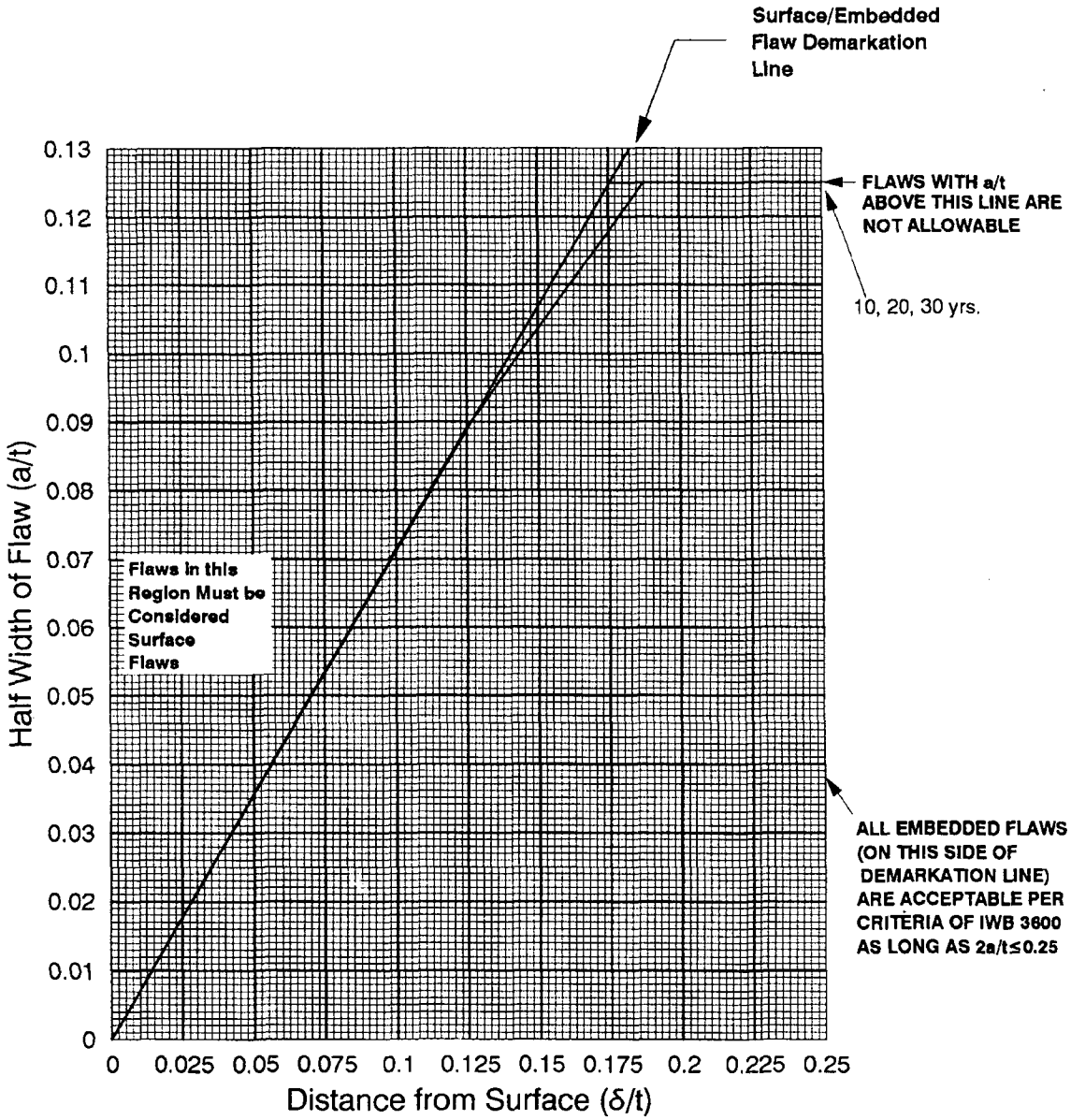


Figure A-6.7 Evaluation Chart for Outlet Nozzle to Shell Weld

X Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
X Outside Surface	X Embedded Flaw	X Circumferential Flaw

A-7 OUTLET NOZZLE INNER RADIUS (CORNER)

A-7.1 Surface Flaws

The location of surface flaws at outlet nozzle corner is depicted in Figure A-7.1. The following parameters must be prepared for surface flaw evaluation with charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness (t = 14.9")

The surface flaw evaluation charts for outside nozzle inner corner radius are listed below:

- Figure A-7.2 Evaluation Chart for Outlet Nozzle Inner Radius (Corner)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

Embedded flaws are not considered in the nozzle corner region.

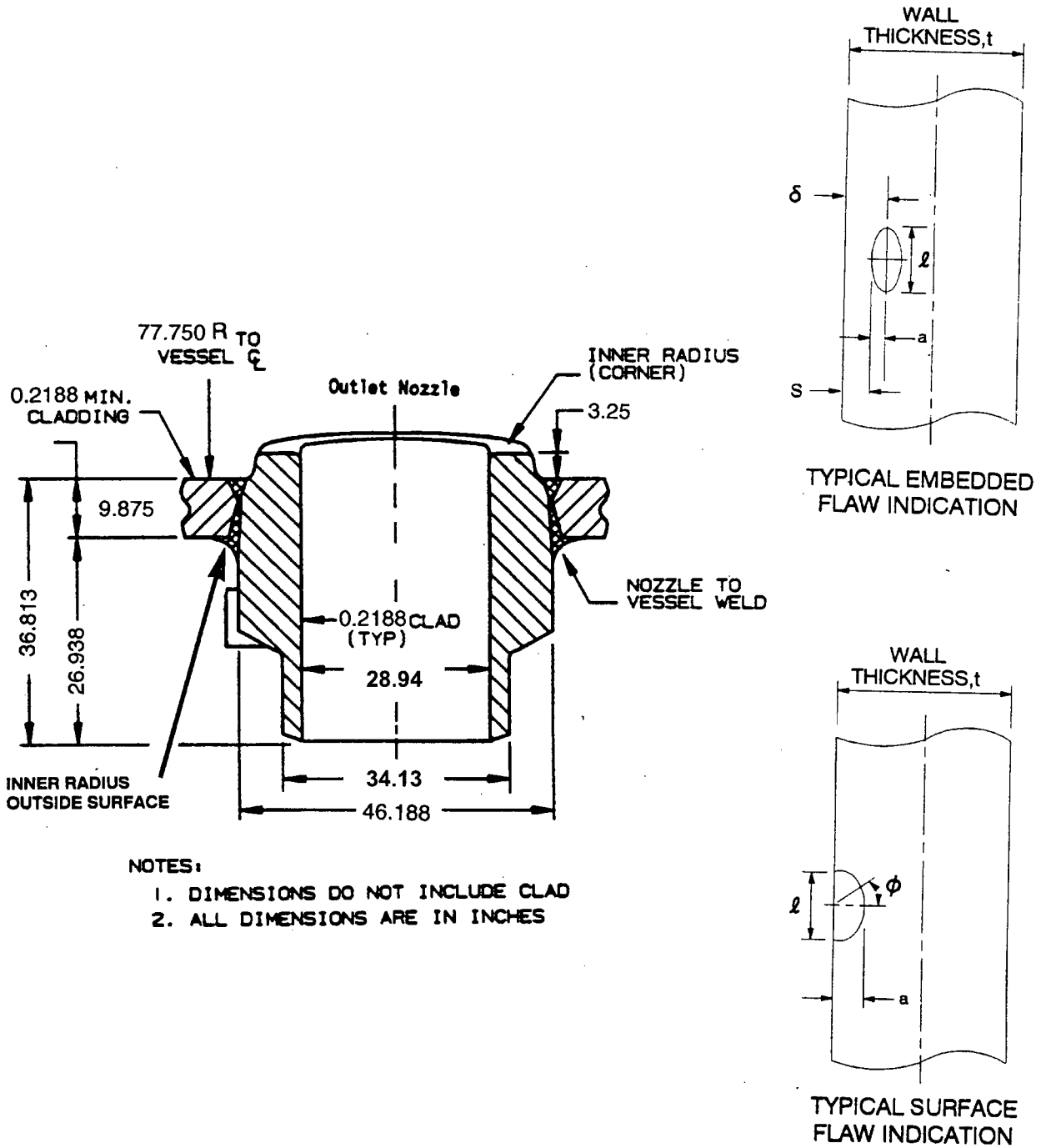


Figure A-7.1 Geometry and Terminology for Flaws at the Outlet Nozzle Inner Radius (Corner)

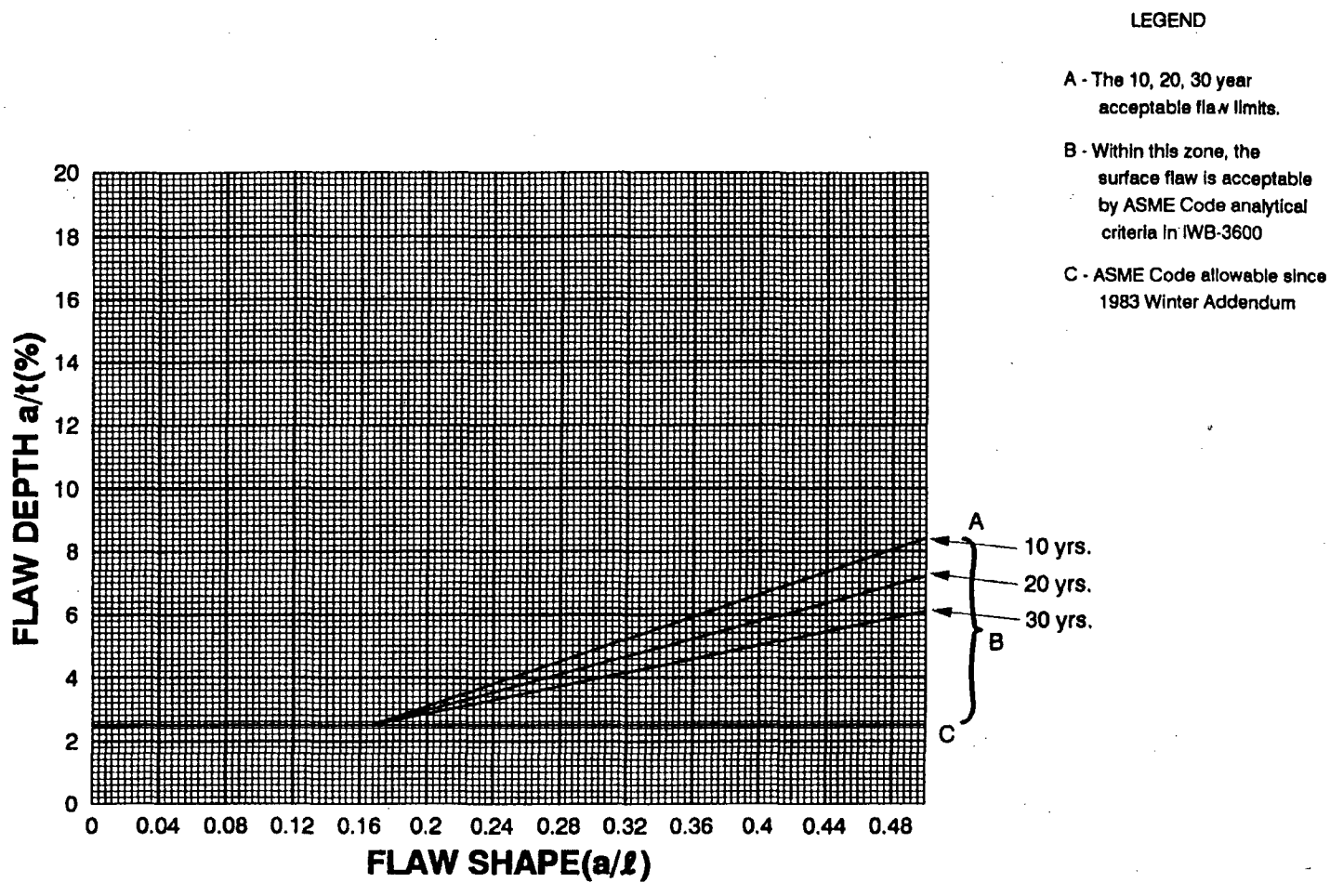


Figure A-7.2 Evaluation Chart for Outlet Nozzle Inner Radius (Corner)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

A-8 OUTLET NOZZLE SAFE-END WELD REGIONS

A-8.1 Surface Flaws

The geometry and terminology for surface flaws at the outlet nozzle safe-end weld region is depicted in Figure A-8.1. The following parameters must be prepared for surface flaw evaluation with charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness (t = 2.594")

The surface flaw evaluation charts for outlet nozzle safe-end weld regions are listed below:

- Figure A-8.2 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-8.3 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

- Figure A-8.4 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-8.5 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

A-8.2 Embedded Flaws

The geometry of embedded flaws at the outlet nozzle safe-end weld region is depicted in Figure A-8.1.

Basic Data:

t	=	2.594"
δ	=	Distance of the centerline of the embedded flaw to the surface (in.)
a	=	Flaw depth (defined as one half of the minor diameter) (in.)
ℓ	=	Flaw length (major diameter) (in.)
a_o	=	Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$
- Surface proximity parameter, $\frac{\delta}{t}$

The evaluation charts for embedded flaws are as follows:

- Figure A-8.6 Evaluation Chart for Outlet Nozzle Safe-end to Pipe Weld (Stainless Steel)

  _X_ Inside Surface ___ Surface Flaw _X_ Longitudinal Flaw
  _X_ Outside Surface _X_ Embedded Flaw ___ Circumferential Flaw

- Figure A-8.7 Evaluation Chart for Outlet Nozzle Safe-end to Pipe Weld (Stainless Steel)

  _X_ Inside Surface ___ Surface Flaw ___ Longitudinal Flaw
  _X_ Outside Surface _X_ Embedded Flaw _X_ Circumferential Flaw

- Figure A-8.8 Evaluation Chart for Outlet Nozzle Safe-end to Nozzle Weld (Alloy 82/182)

  _X_ Inside Surface ___ Surface Flaw _X_ Longitudinal Flaw
  _X_ Outside Surface _X_ Embedded Flaw ___ Circumferential Flaw

- Figure A-8.9 Evaluation Chart for Outlet Nozzle Safe-end to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

The flaw shape or the aspect ratio for this chart is restricted to flaws with $\frac{a}{\ell} \geq 0.1$.

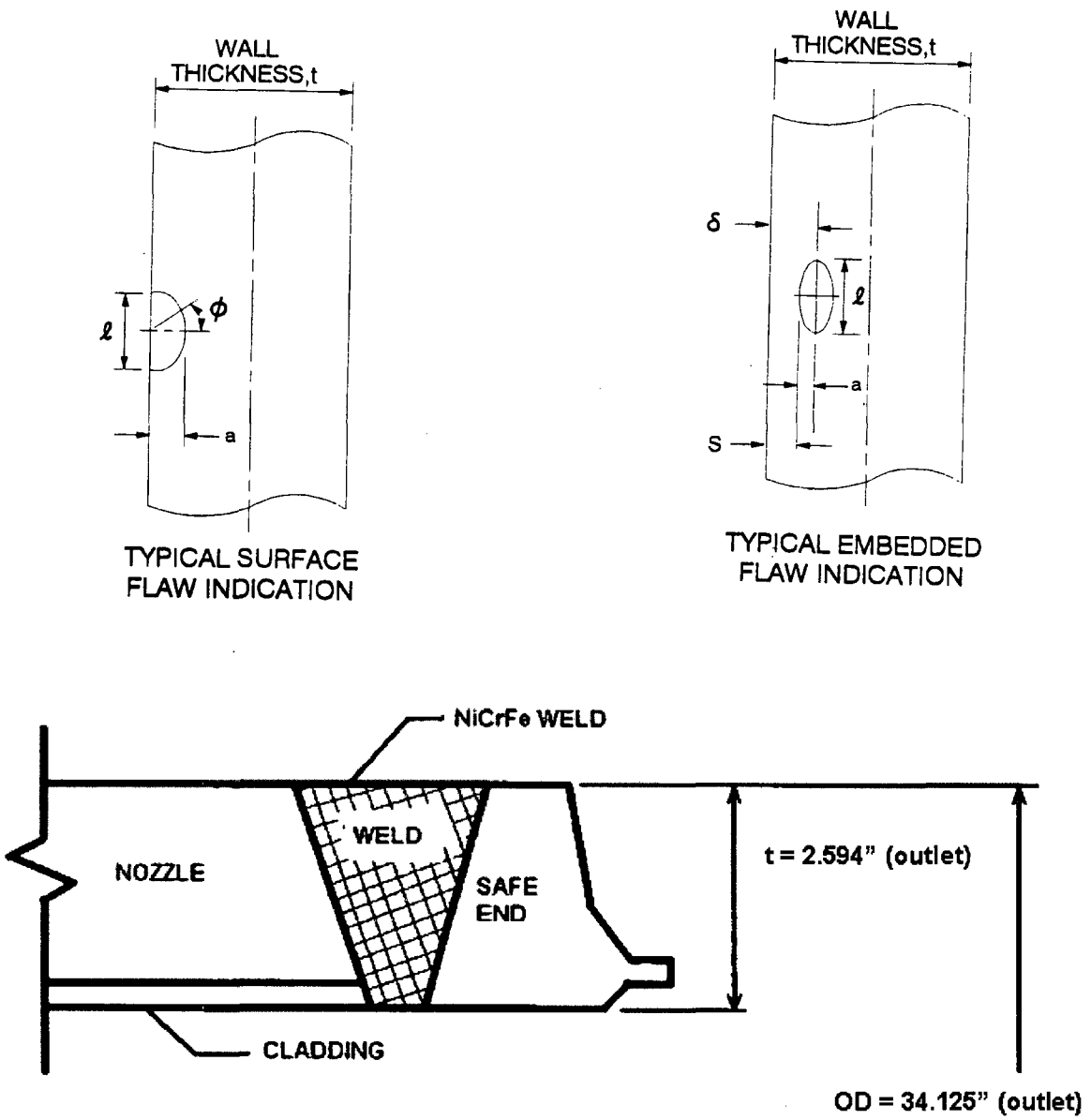


Figure A-8.1 Geometry and Terminology for Flaws at the Outlet Nozzle Safe-End Nozzle Weld

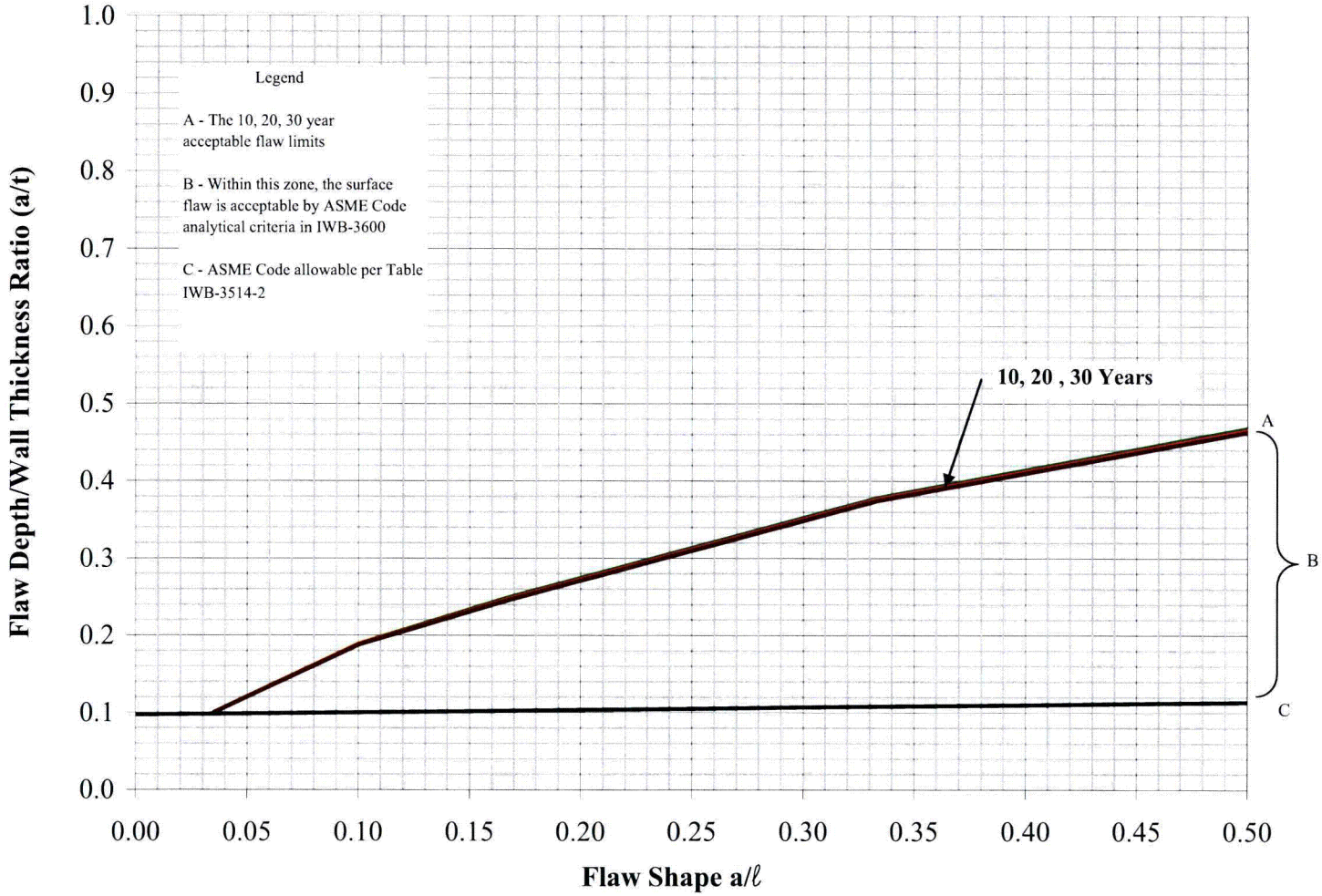


Figure A-8.2 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

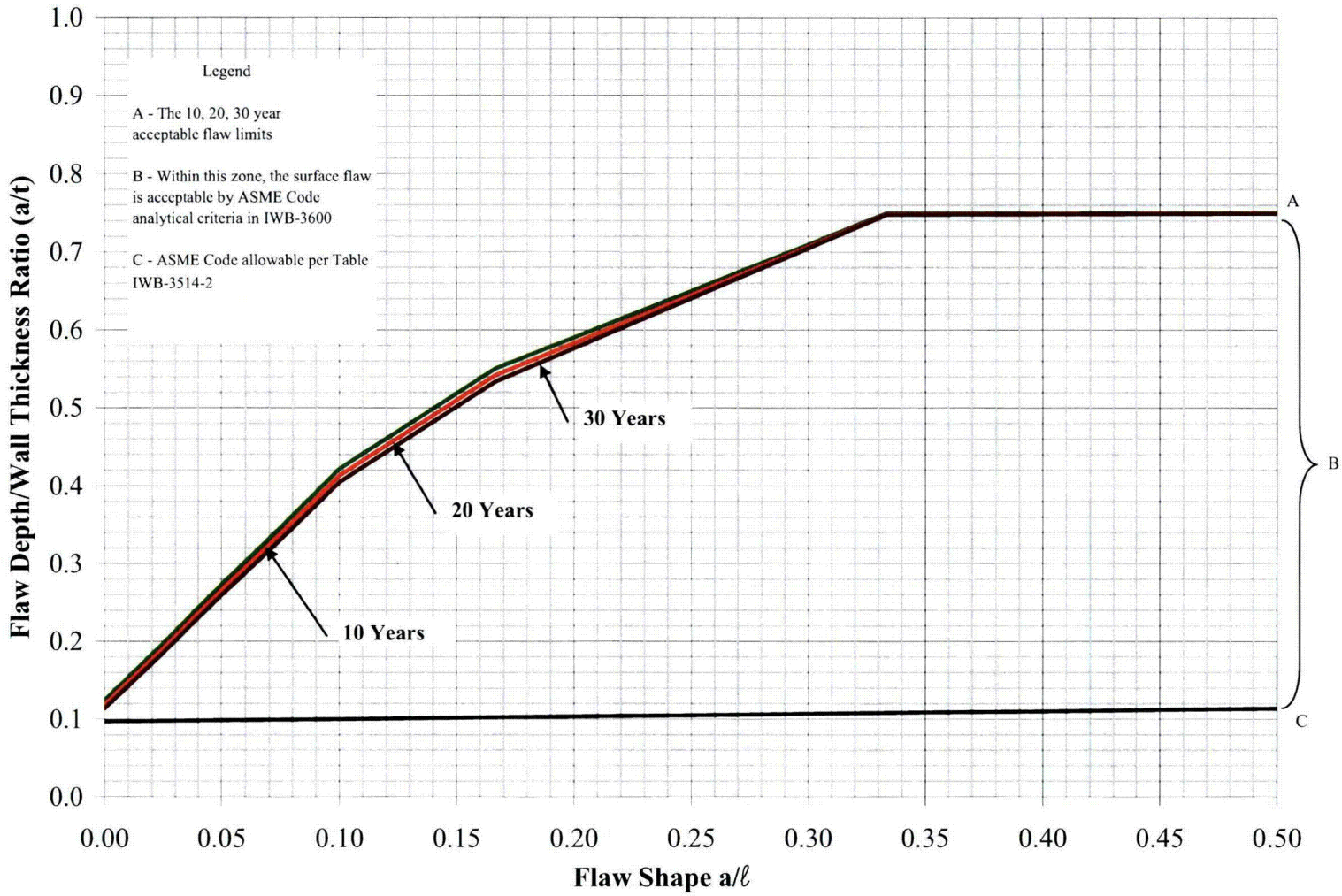


Figure A-8.3 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

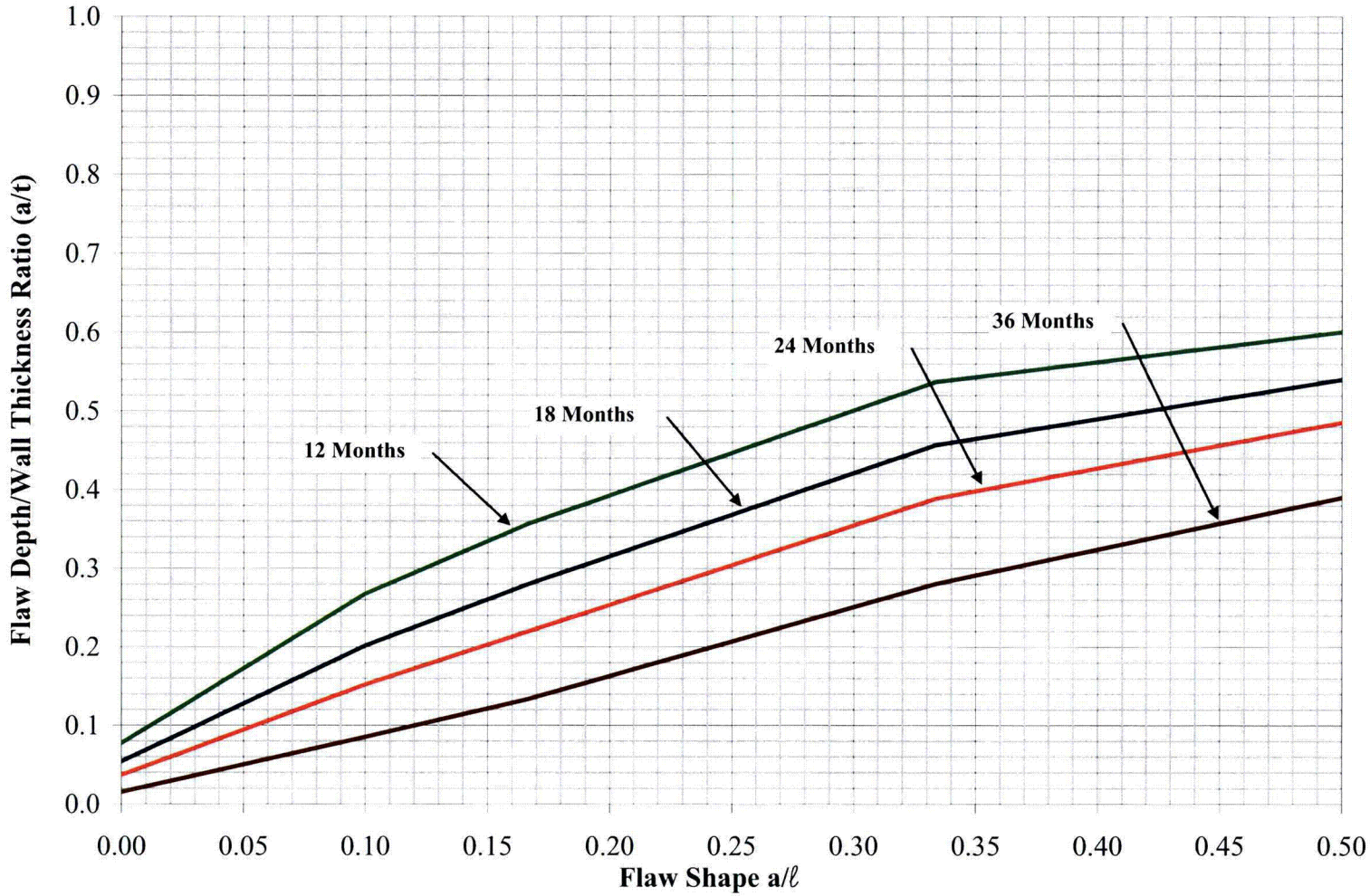


Figure A-8.4 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

X Inside Surface	X Surface Flaw	X Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

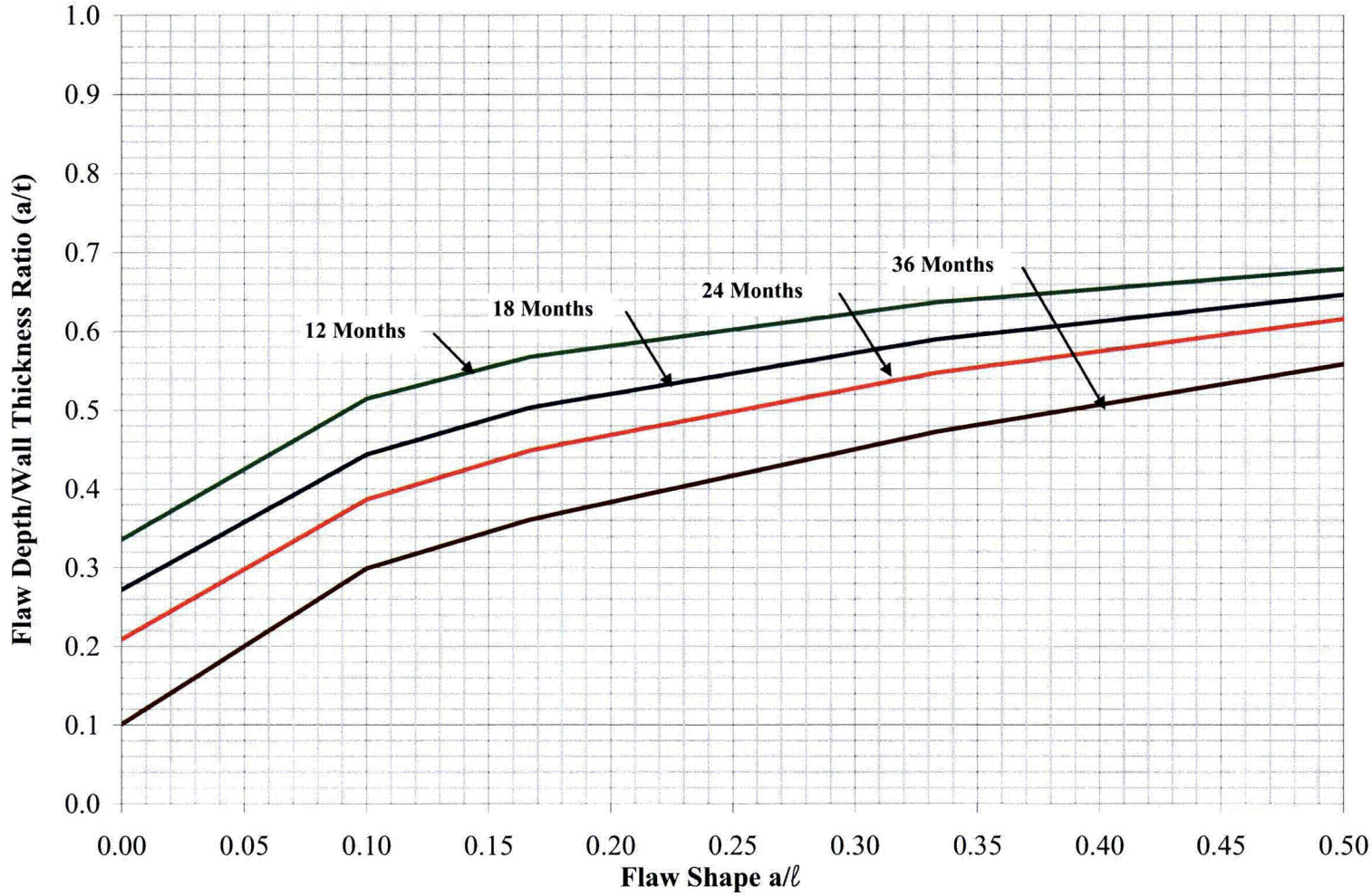


Figure A-8.5 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

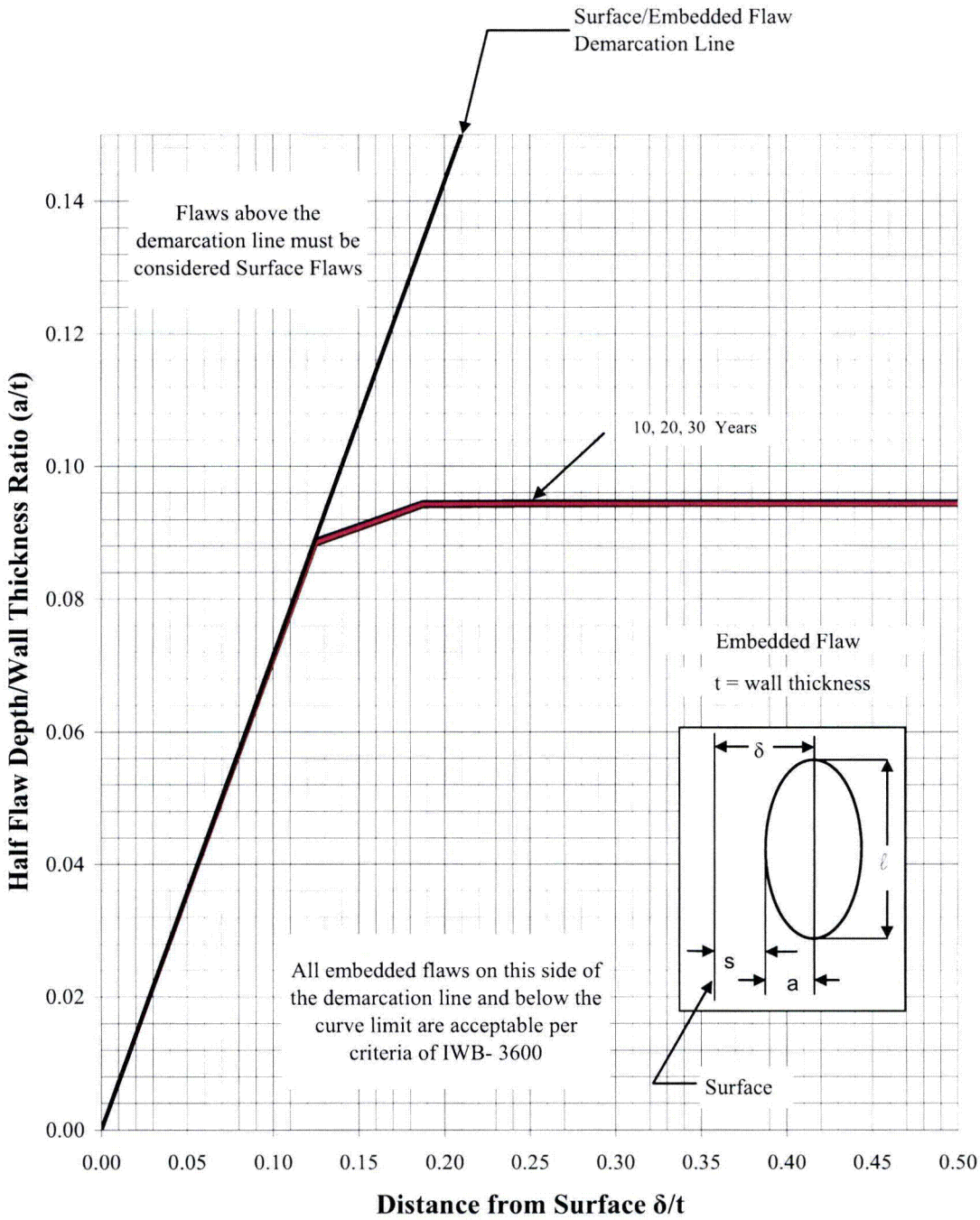


Figure A-8.6 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

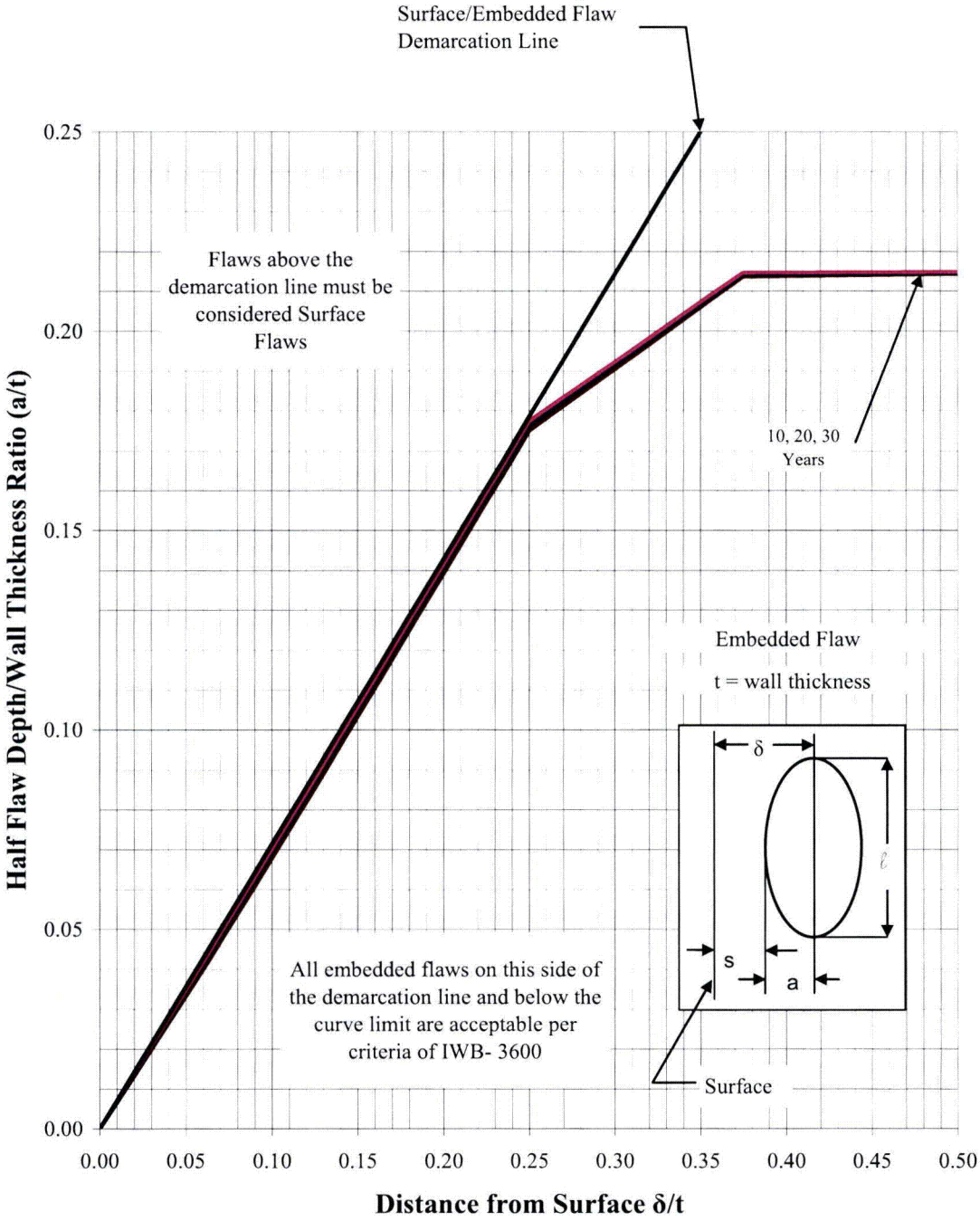


Figure A-8.7 Evaluation Chart for Outlet Nozzle Safe-End to Pipe Weld (Stainless Steel)

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

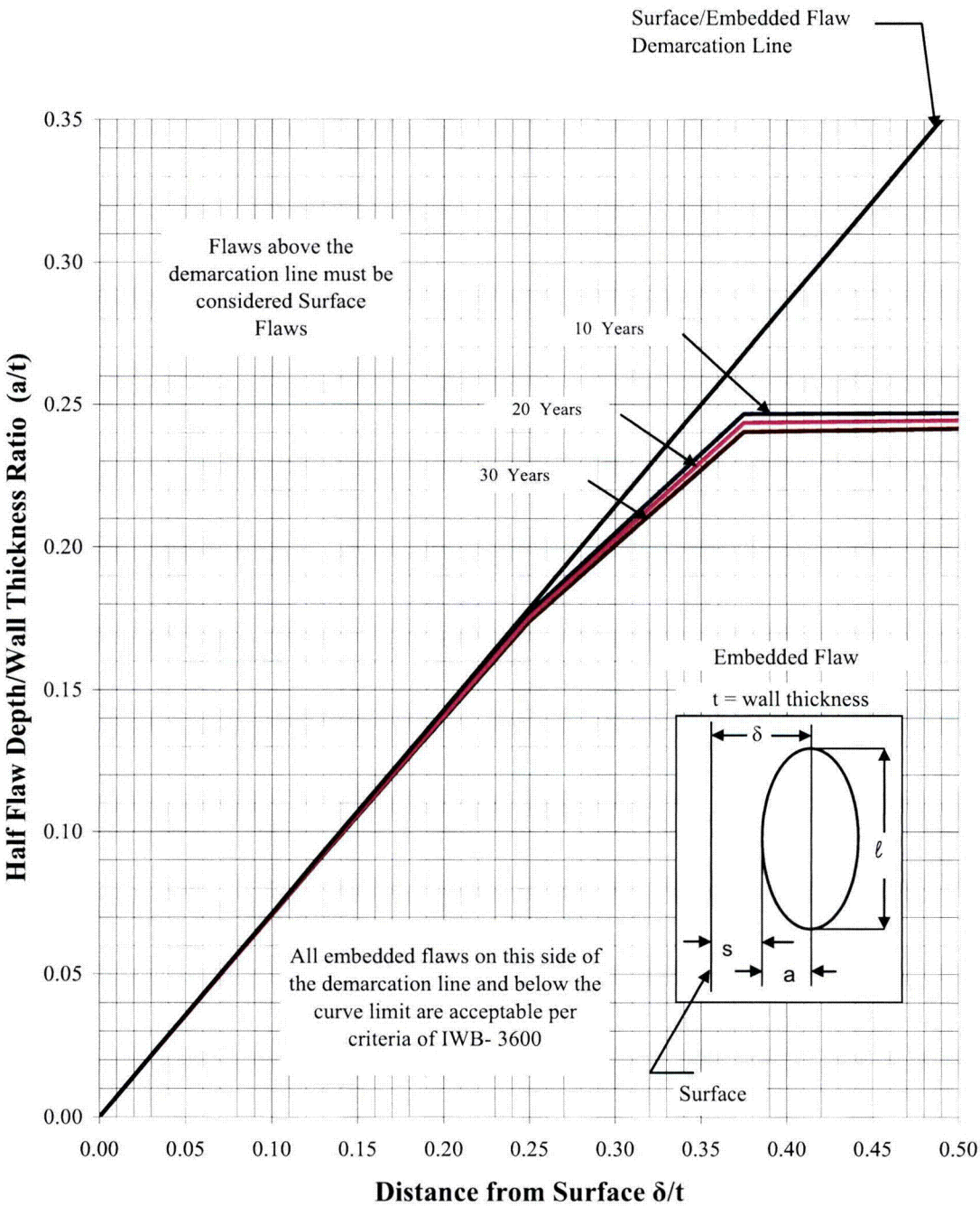


Figure A-8.8 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	___ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	___ Circumferential Flaw

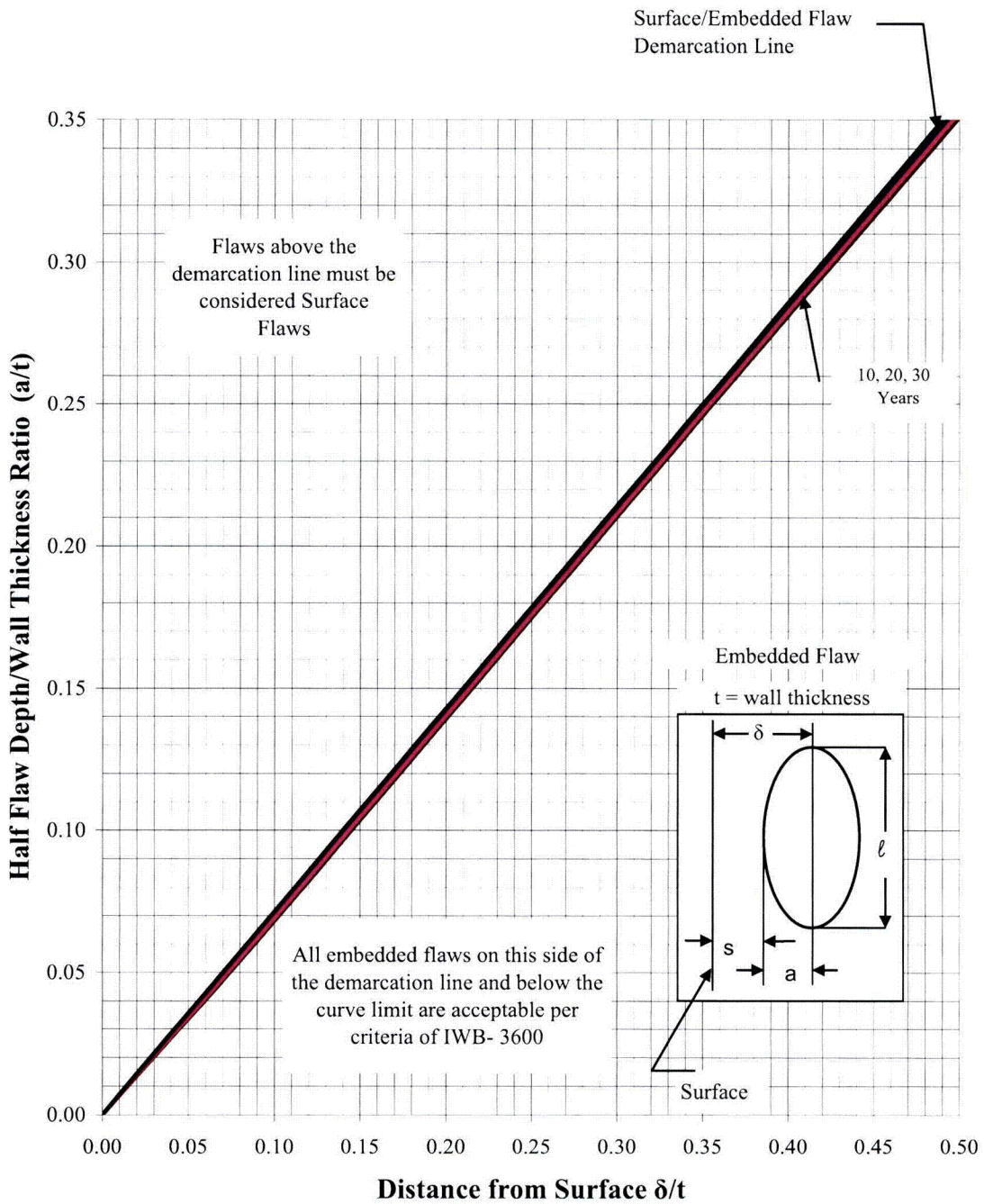


Figure A-8.9 Evaluation Chart for Outlet Nozzle Safe-End to Nozzle Weld (Alloy 82/182)

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

A-9 LOWER HEAD TO SHELL WELDS (INCLUDES DOLLAR WELD)

A.9-1 Surface Flaws

The geometry and terminology for surface flaws at the lower head to shell welds is depicted in Figure A-9.1. The charts of this section also apply to the dollar weld, or lower head ring to dome weld. Indications in the dollar weld in the bottom head would be evaluated using the circumferential flaw charts of this section. The following parameters must be prepared for surface flaw evaluation with charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness (t = 5.22")

The surface flaw evaluation charts for the lower head to lower head shell weld are listed below:

- Figure A-9.2 Evaluation Chart for Lower Head to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-9.3 Evaluation Chart for Lower Head to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

- Figure A-9.4 Evaluation Chart for Lower Head to Shell Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-9.5 Evaluation Chart for Lower Head to Shell Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

A-9.2 Embedded Flaws

The geometry of embedded flaws at the lower head to shell weld is depicted in Figure A-9.1.

Basic Data:

t	=	5.22"
δ	=	Distance from the centerline of the embedded flaw to the surface (in.)
a	=	Flaw depth (defined as one half of the minor diameter) (in.)
ℓ	=	Flaw length (major diameter) (in.)
a_o	=	Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$
- Surface proximity parameter, $\frac{\delta}{t}$

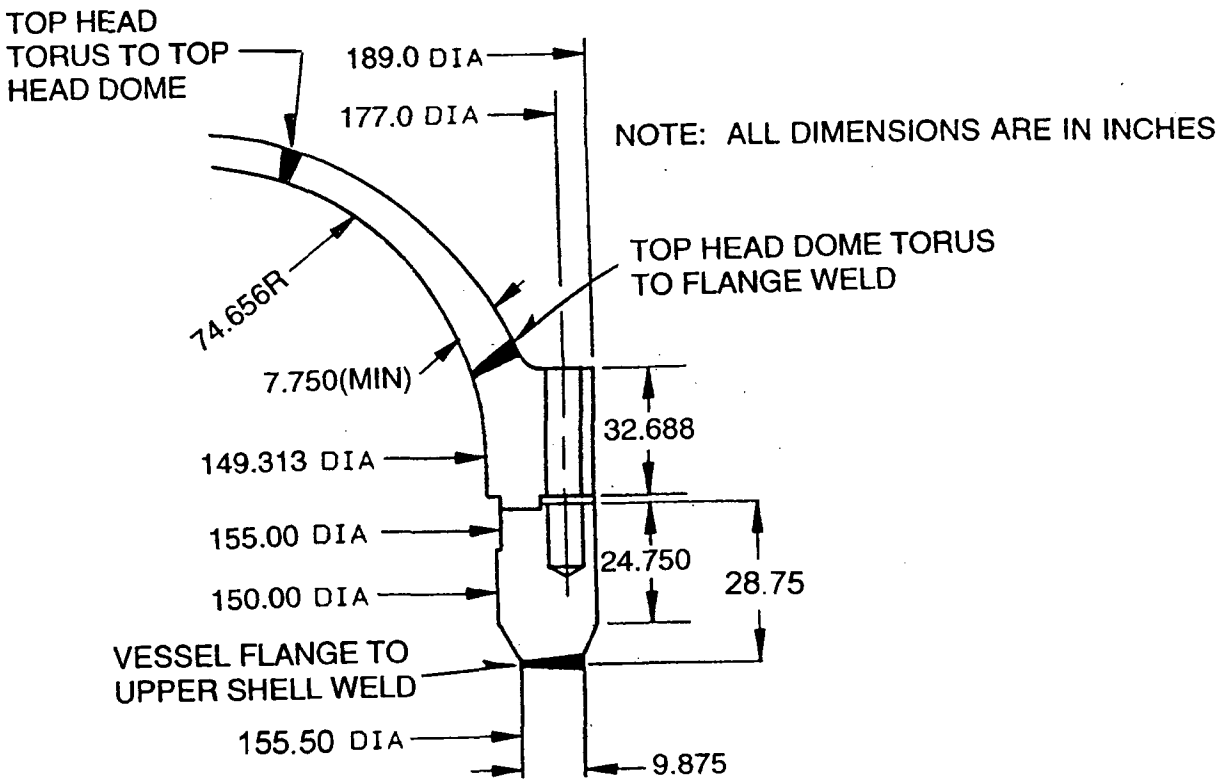
The evaluation chart for embedded flaws are shown in Figure A-9.6 and A-9.7.

- Figure A-9.6 Evaluation Chart for Lower Head to Shell Weld

_X_ Inside Surface	___ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	___ Circumferential Flaw

- Figure A-9.7 Evaluation Chart for Lower Head to Shell Weld

_X_ Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw



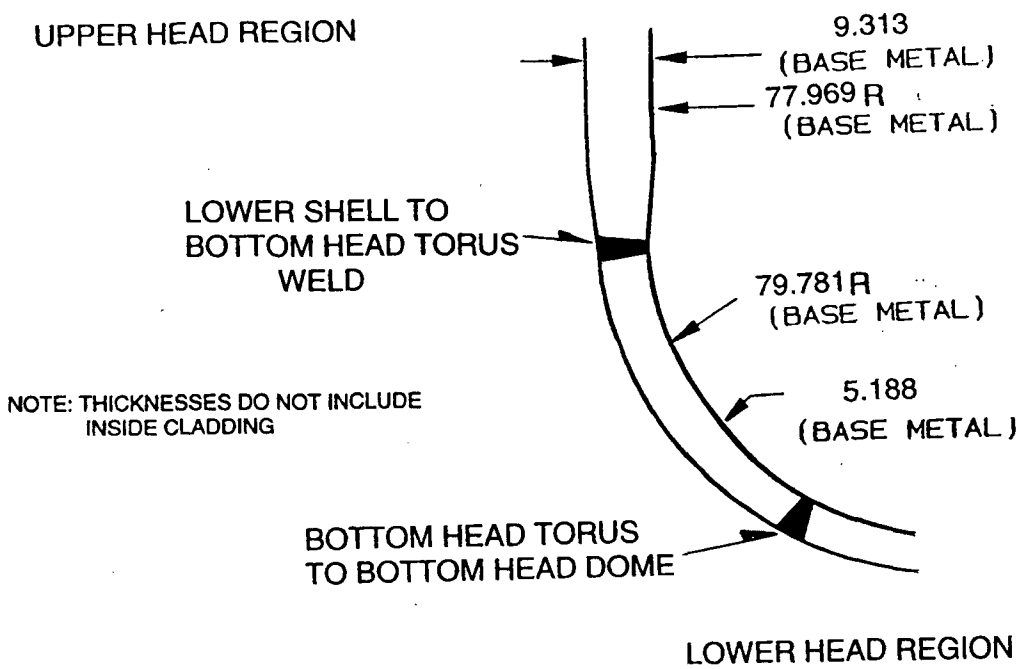


Figure A-9.1 Geometry and Terminology for Flaws at the Lower Head to Shell Weld

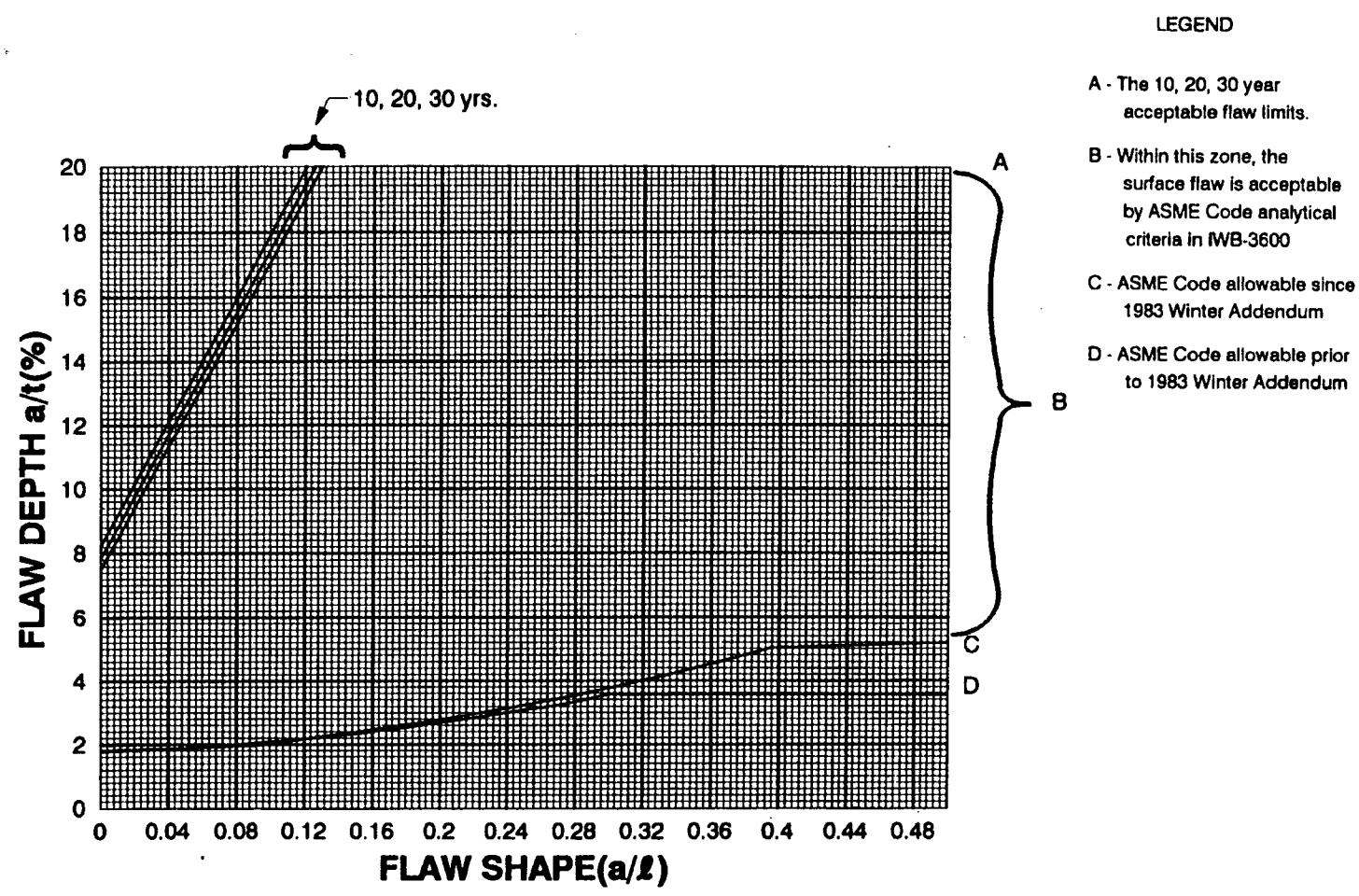


Figure A-9.2 Evaluation Chart for Lower Head to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

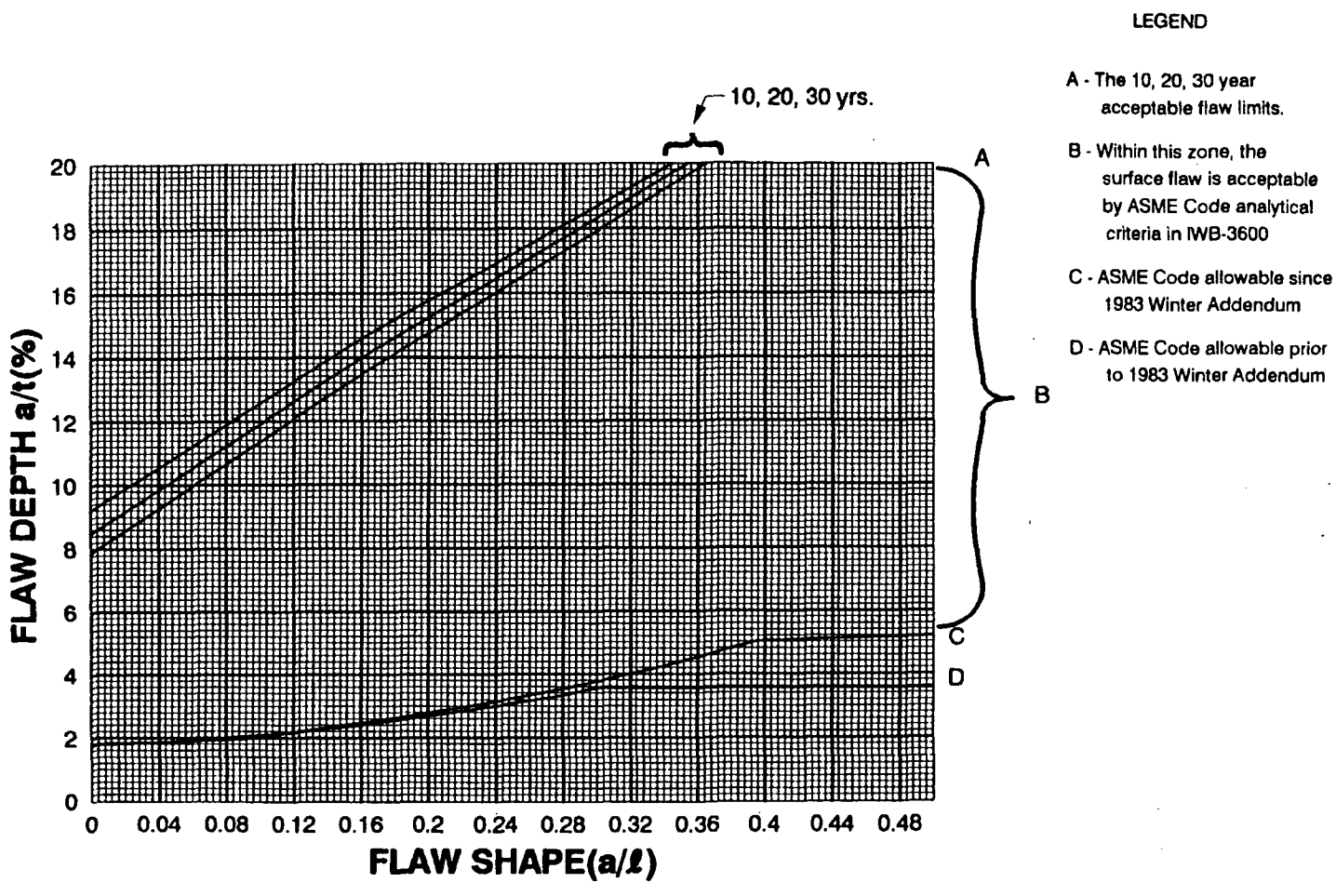


Figure A-9.3 Evaluation Chart for Lower Head to Shell Weld

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

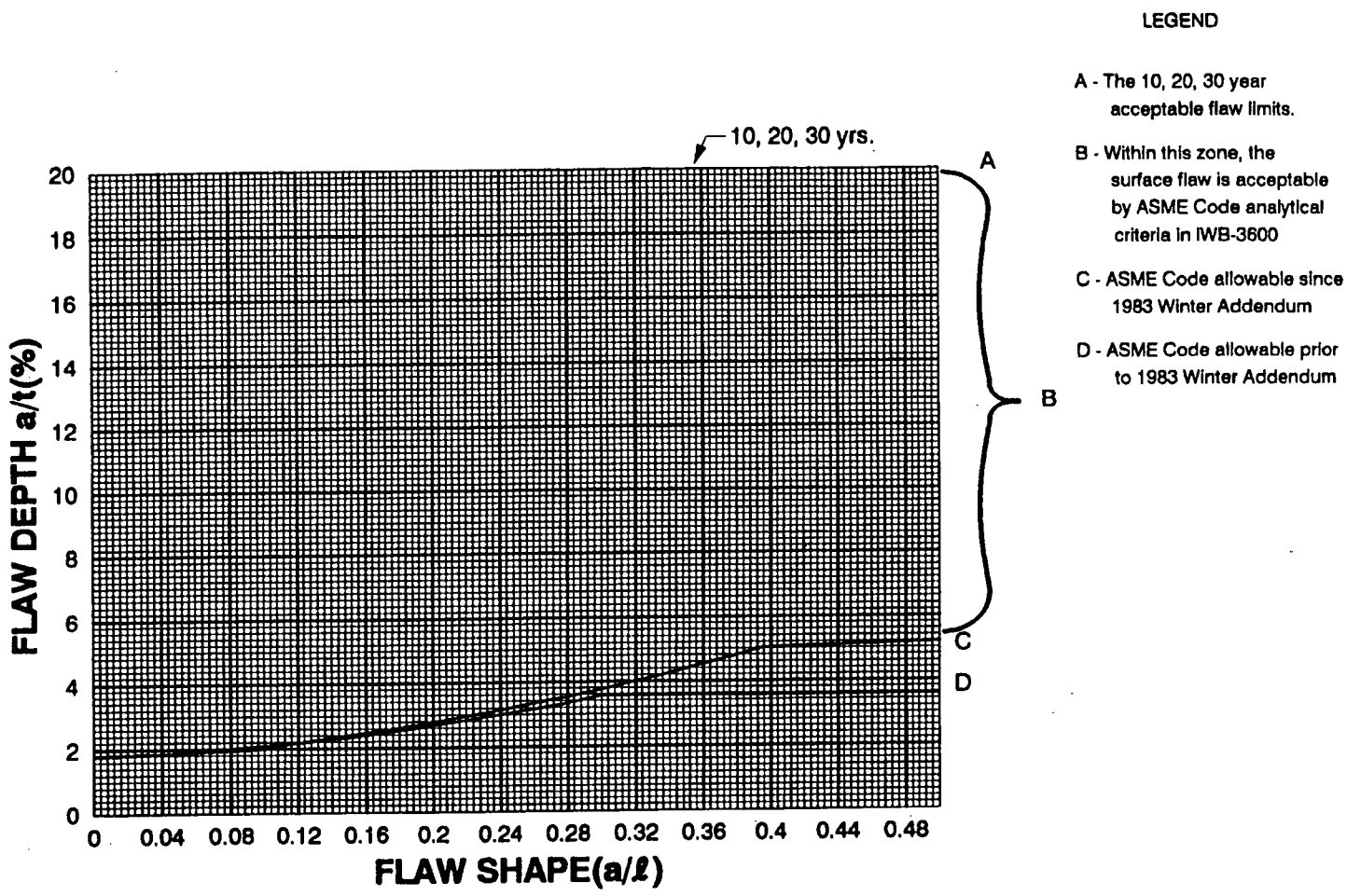


Figure A-9.4 Evaluation Chart for Lower Head to Shell Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

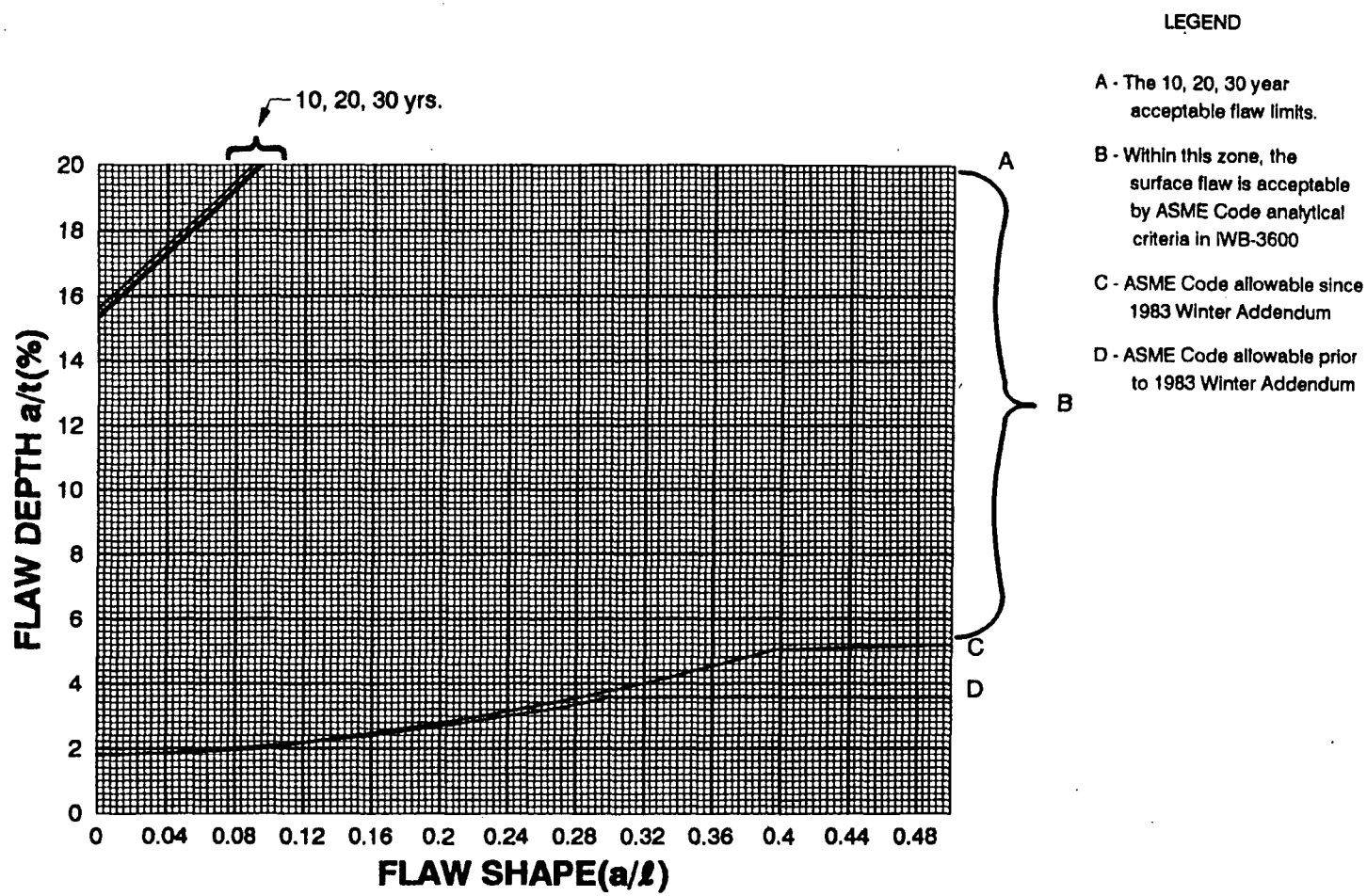


Figure A-9.5 Evaluation Chart for Lower Head to Shell Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

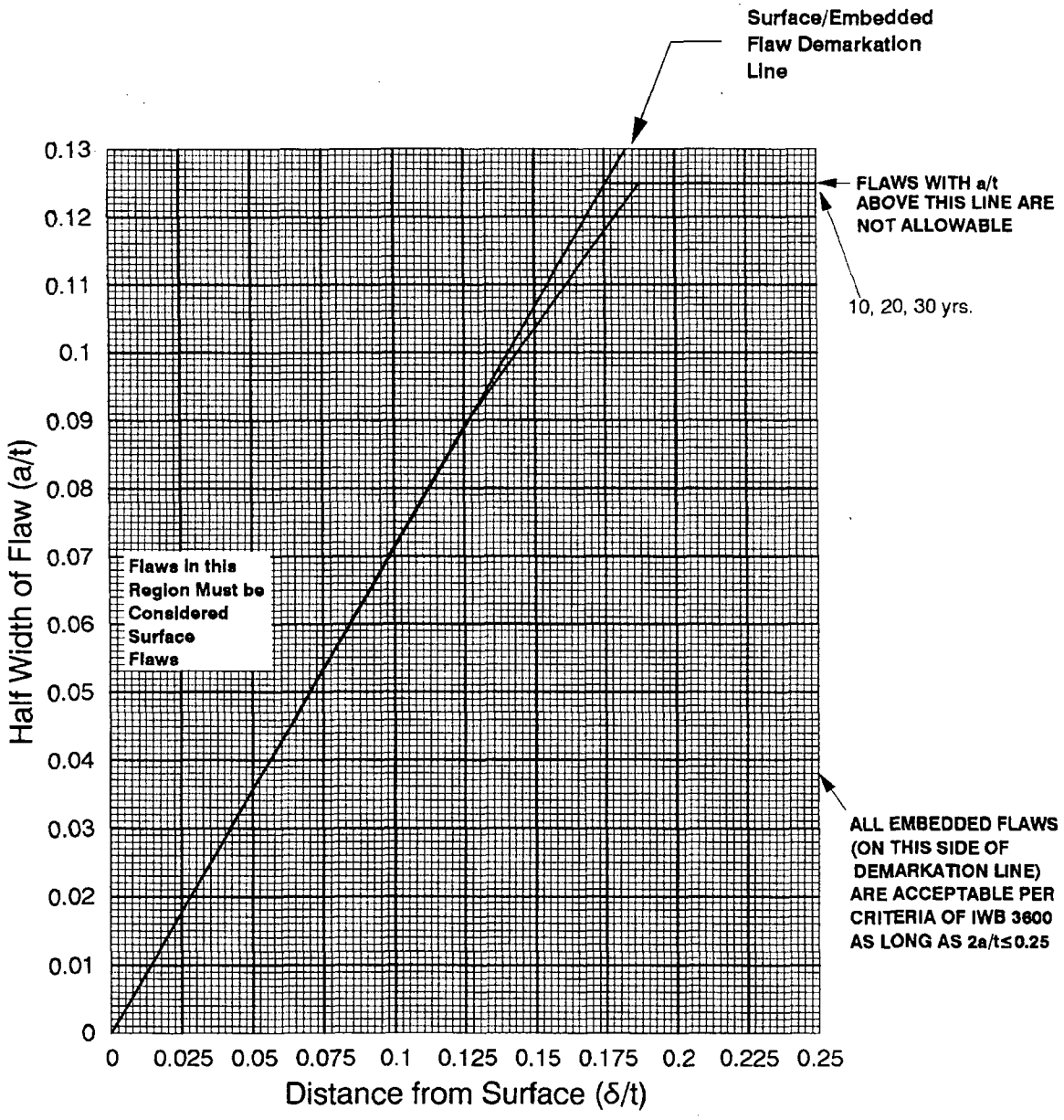


Figure A-9.6 Evaluation Chart for Lower Head to Shell Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	___ Circumferential Flaw

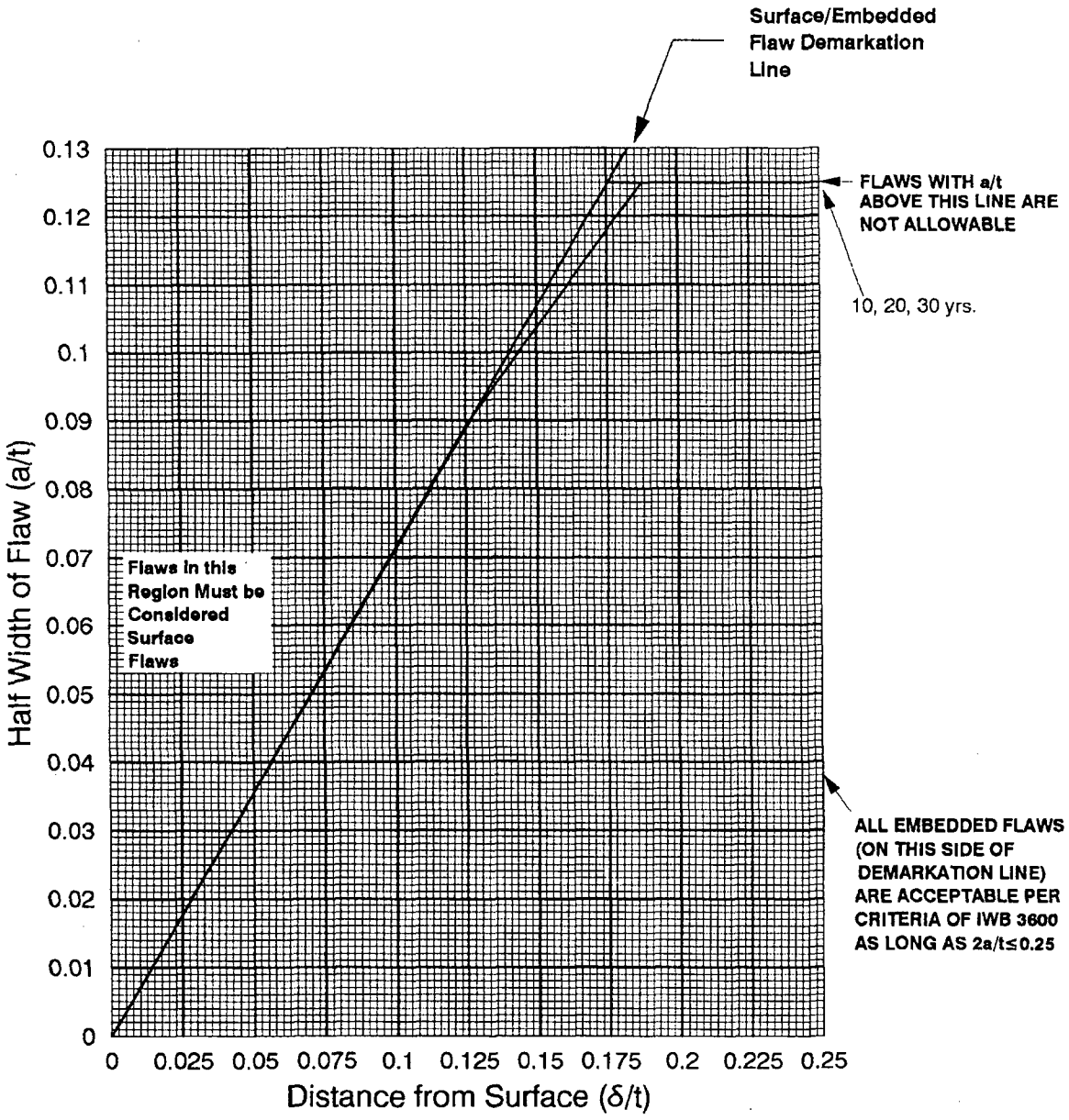


Figure A-9.7 Evaluation Chart for Lower Head to Shell Weld

X Inside Surface	___ Surface Flaw	___ Longitudinal Flaw
X Outside Surface	X Embedded Flaw	X Circumferential Flaw

A-10 TOP HEAD TO FLANGE WELD (INCLUDES TORUS TO DOME WELD)

**** NOTE ****

The information contained in this section pertaining to the reactor vessel closure head is obsolete because it does not reflect the configuration of the current reactor vessel head that was installed in 2005. Additional evaluation and/or reconciliation are necessary to update this section to reflect the new reactor vessel head configuration.

The stress distribution at the top flange junction is unique since high boltup stresses are applied in this region in addition to the regular pressure and thermal stresses. Moreover, the governing transient which creates the worst stresses at the inside surface is different from that for the outside surface. The orientations of the maximum stresses at both the inside and the outside surfaces are also different, not to mention in different environments. As a consequence, fracture mechanics investigation on both surfaces becomes necessary.

A-10.1 Surface Flaws

The geometry and terminology for surface flaws at the top head to flange weld is depicted in Figure A-10.1. The following parameters must be determined for surface flaw evaluation with the charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where: a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness at the top head ring to flange weld (t = 7.75")

The surface flaw evaluation charts for the top head to flange weld are listed below:

- Figure A-10.2 Evaluation Chart for Top Head to Flange Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
____ Outside Surface	____ Embedded Flaw	____ Circumferential Flaw

- Figure A-10.3 Evaluation Chart for Top Head to Flange Weld

_X_ Inside Surface	_X_ Surface Flaw	____ Longitudinal Flaw
____ Outside Surface	____ Embedded Flaw	_X_ Circumferential Flaw

- Figure A-10.4 Evaluation Chart for Top Head to Flange Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-10.5 Evaluation Chart for Top Head to Flange Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

A-10.2 Embedded Flaws

The geometrical description of an embedded flaw at the top head to flange is depicted in Figure A-10.1 also.

Basic Data:

t = 7.75"

δ = Distance of the centerline of the embedded flaw to the surface (in.)

a = Flaw depth (defined as one half of the minor diameter) (in.)

ℓ = Flaw length (major diameter) (in.)

a_o = Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$

- Flaw depth parameter $\frac{a}{t}$

- Surface proximity parameter, $\frac{\delta}{t}$

The evaluation chart for embedded flaws:

- Figure A-10.6 Evaluation Chart for Top Head to Flange Weld

_X_ Inside Surface	___ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

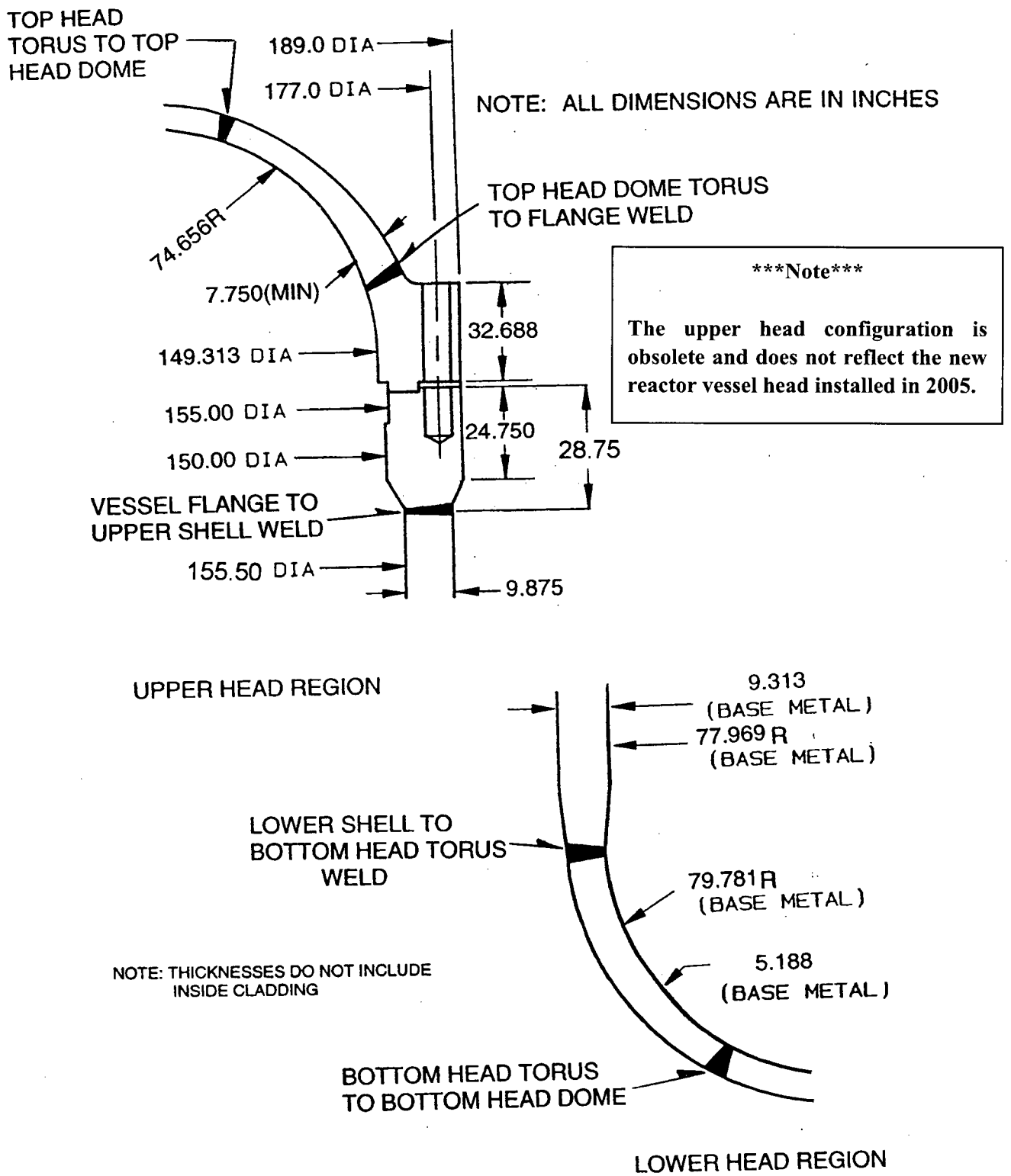


Figure A-10.1 Geometry and Terminology for Flaws at the Top Head to Flange Weld

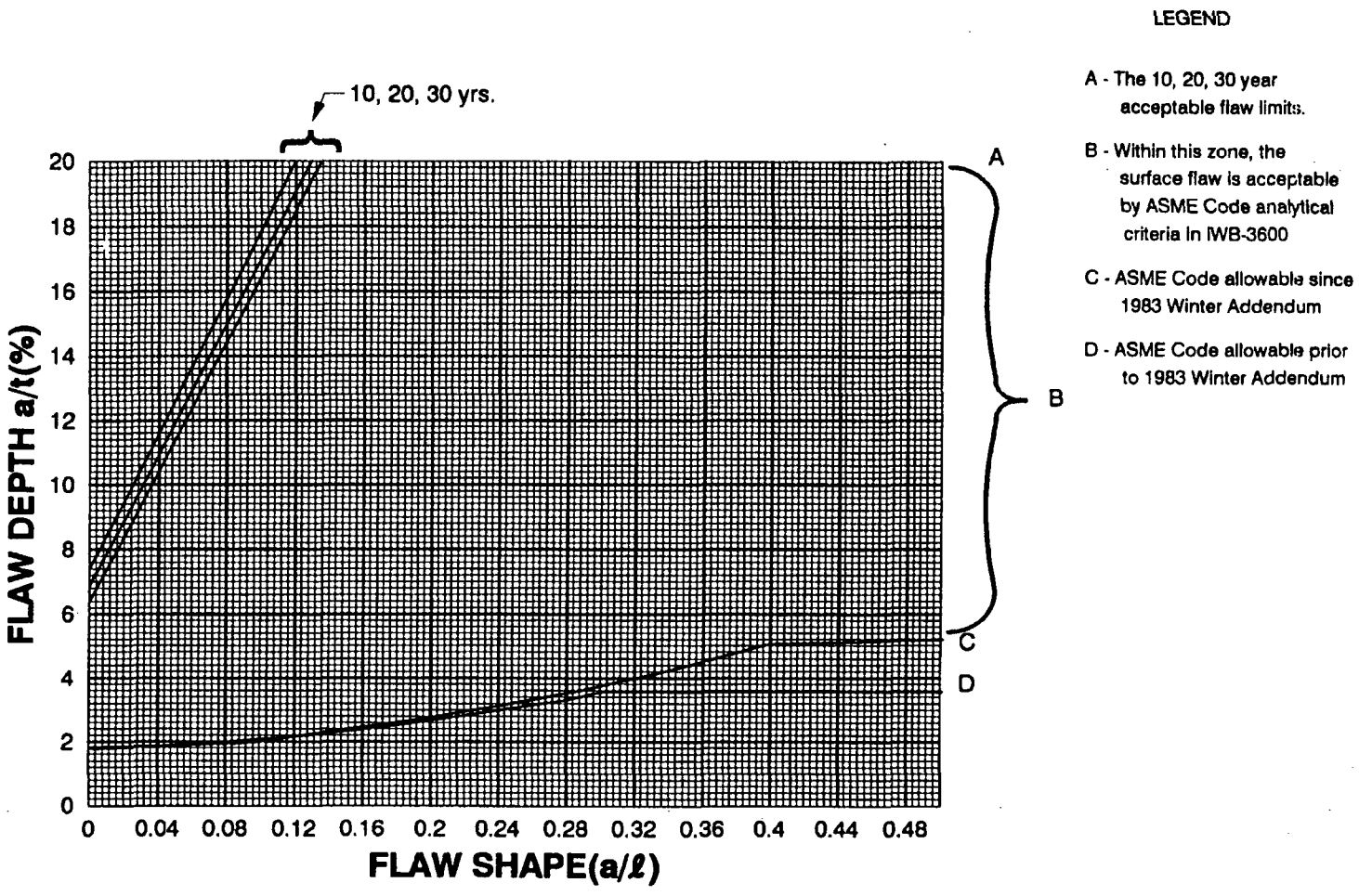


Figure A-10.2 Evaluation Chart for Top Head to Flange Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

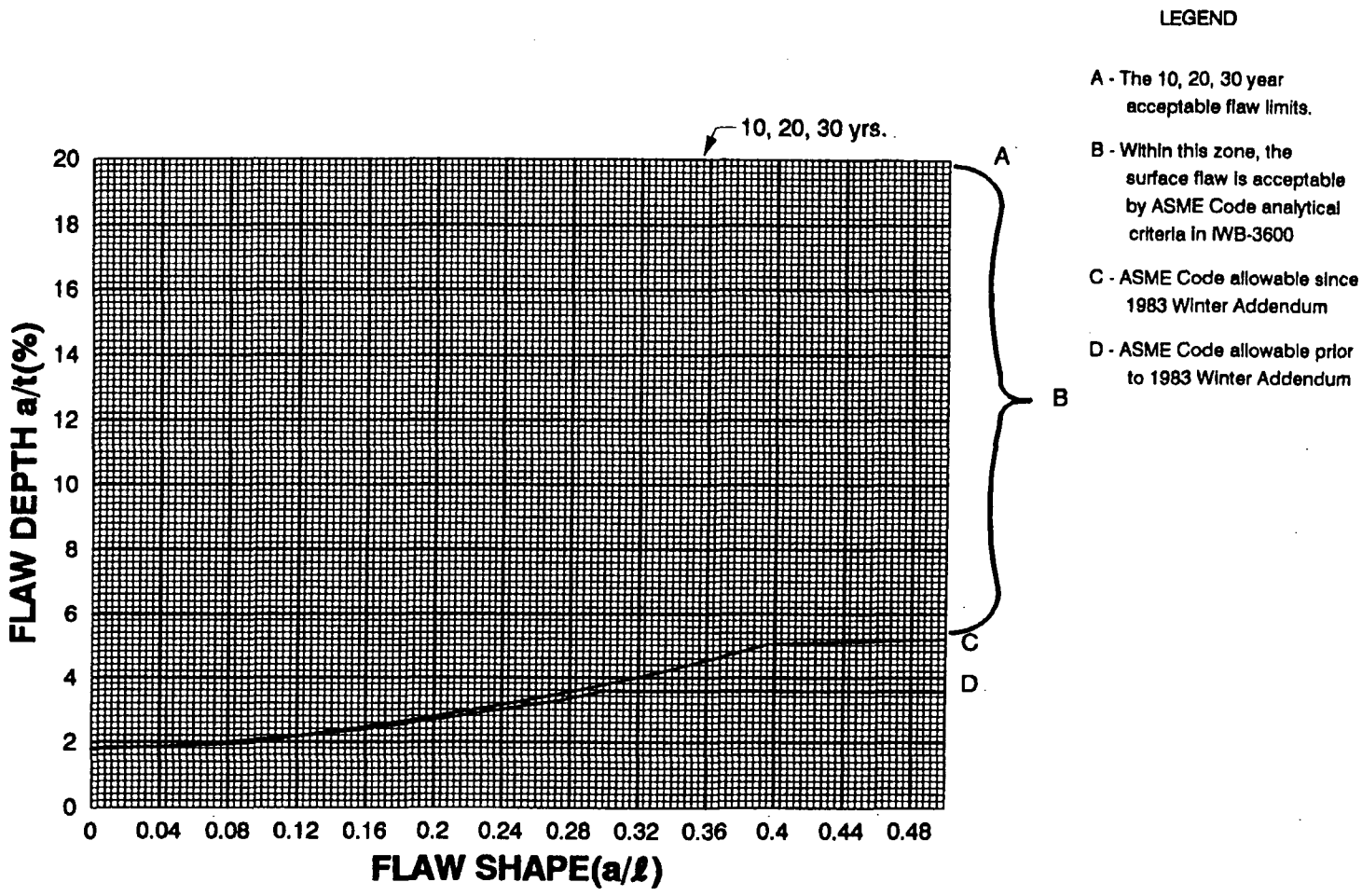
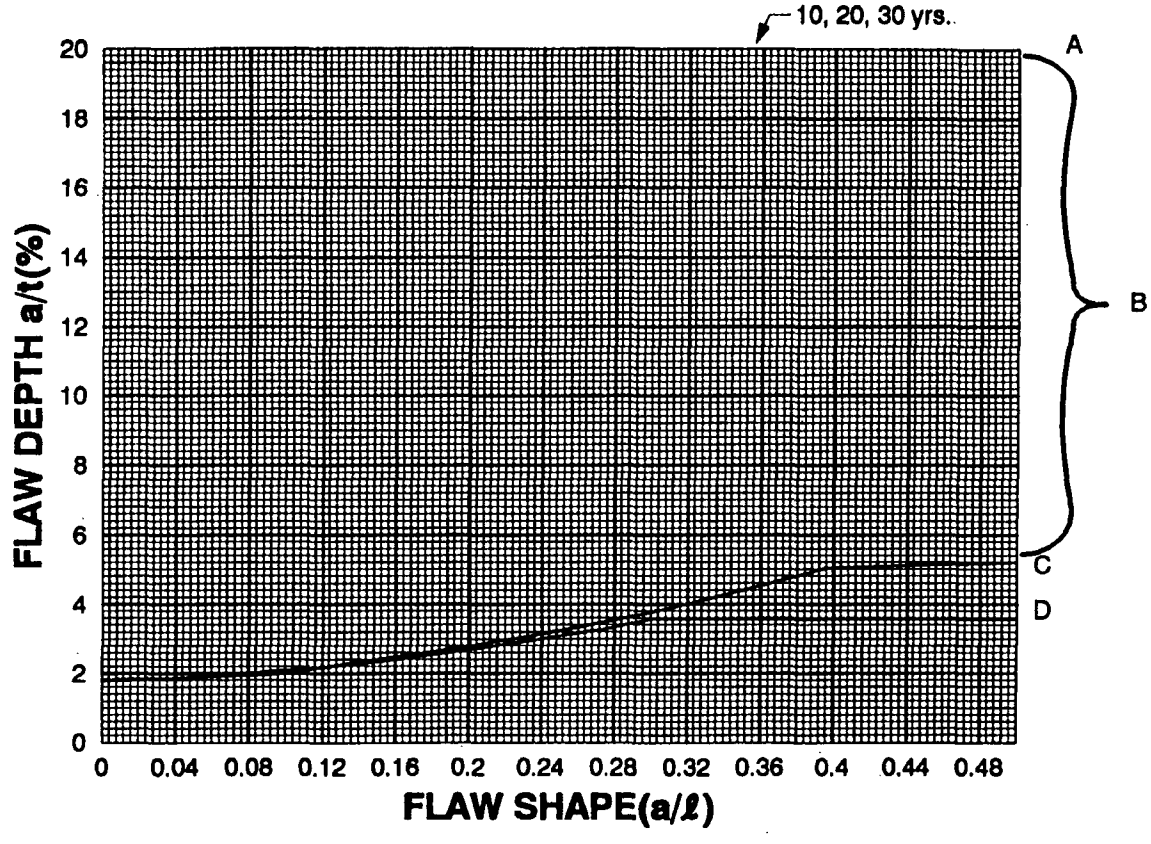


Figure A-10.3 Evaluation Chart for Top Head to Flange Weld

_X_ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw



LEGEND

A - The 10, 20, 30 year acceptable flaw limits.

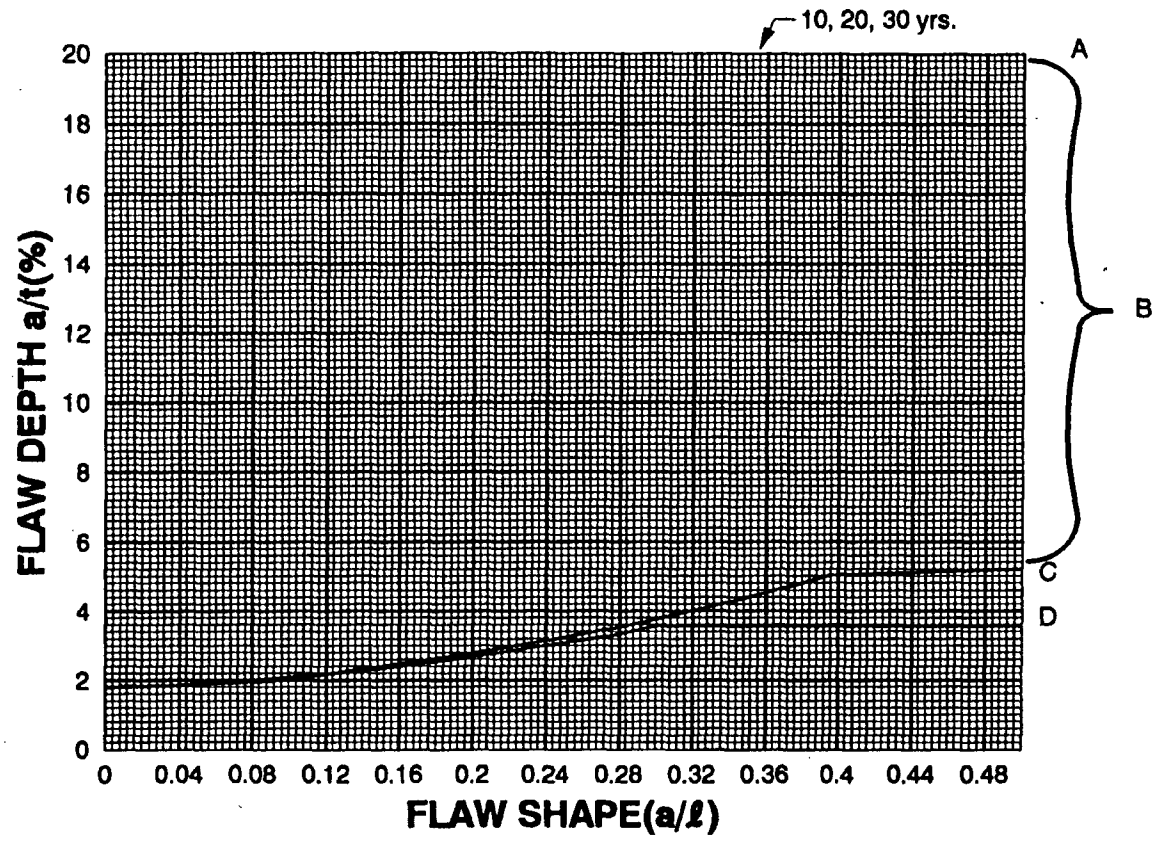
B - Within this zone, the surface flaw is acceptable by ASME Code analytical criteria in IWB-3600

C - ASME Code allowable since 1983 Winter Addendum

D - ASME Code allowable prior to 1983 Winter Addendum

Figure A-10.4 Evaluation Chart for Top Head to Flange Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw



LEGEND

A - The 10, 20, 30 year acceptable flaw limits.

B - Within this zone, the surface flaw is acceptable by ASME Code analytical criteria in IWB-3600

C - ASME Code allowable since 1983 Winter Addendum

D - ASME Code allowable prior to 1983 Winter Addendum

Figure A-10.5 Evaluation Chart for Top Head to Flange Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

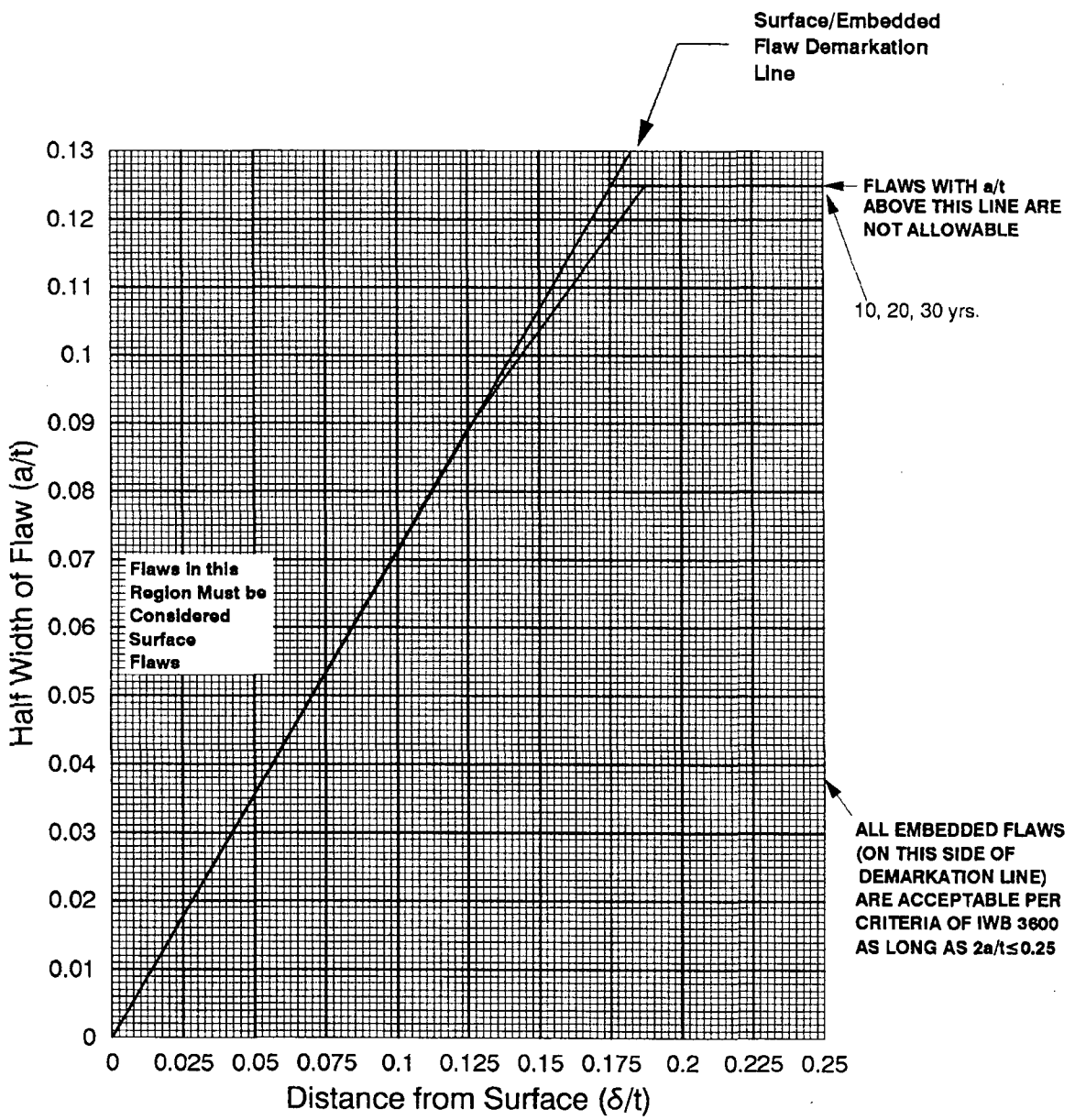


Figure A-10.6 Evaluation Chart for Top Head to Flange Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	X Circumferential Flaw

A-11 LOWER FLANGE TO SHELL WELD (INCLUDES DOLLAR WELD)

As found for the top head dome to flange weld, the stress analysis and fracture evaluation for this region are rather complex. The stresses for some transients are highest at the outer surface, so in some cases the outer surface flaw charts are more limiting.

The governing normal and upset transient at the inside surface was found to be cooldown, whereas that at the outside surface is heat-up.

A-11.1 Surface Flaws

The following parameters must be determined for the surface flaw evaluation at both inside and outside surfaces with charts.

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$

where:

a = The surface flaw depth detected (in.)

ℓ = The surface flaw length detected (in.)

t = Wall thickness at the lower head ring to flange junction (t = 9.875")

The surface flaw evaluation charts for the lower flange to shell weld are listed below:

- Figure A-11.2 Evaluation Chart for Lower Flange to Shell Weld

X Inside Surface	X Surface Flaw	X Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-11.3 Evaluation Chart for Lower Flange to Shell Weld

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

- Figure A-11.4 Evaluation Chart for Lower Flange to Shell Weld

___ Inside Surface	X Surface Flaw	X Longitudinal Flaw
X Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

- Figure A-11.5 Evaluation Chart for Lower Flange to Shell Weld

___ Inside Surface	_X_ Surface Flaw	___ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	_X_ Circumferential Flaw

A-11.2 Embedded Flaws

The geometry of the embedded flaws for both inside and outside surfaces of the lower flange junction are depicted as shown in Figure A-11.1.

The basic data used for the evaluation of the embedded flaws for either side of the lower flange to shell weld are summarized as follows:

t = 9.875"

δ = Distance of the centerline of the embedded flaw to the surface concerned (in.)

a = Flaw depth (defined as one half of the minor diameter) (in.)

ℓ = Flaw length (major diameter) (in.)

a_o = Maximum embedded flaw size in depth direction, beyond which it must be considered a surface flaw, per Section XI characterization rules.

The following parameters must be calculated from the above dimensions to use the charts for evaluating the acceptability of an embedded flaw

- Flaw shape parameter $\frac{a}{\ell}$
- Flaw depth parameter $\frac{a}{t}$
- Surface proximity parameter, $\frac{\delta}{t}$

The evaluation chart for the embedded flaws in the lower flange to shell weld is found in Figure A-11.6.

- Figure A-11.6 Evaluation Chart for Lower Flange to Shell Weld

_X_ Inside Surface	___ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	_X_ Embedded Flaw	_X_ Circumferential Flaw

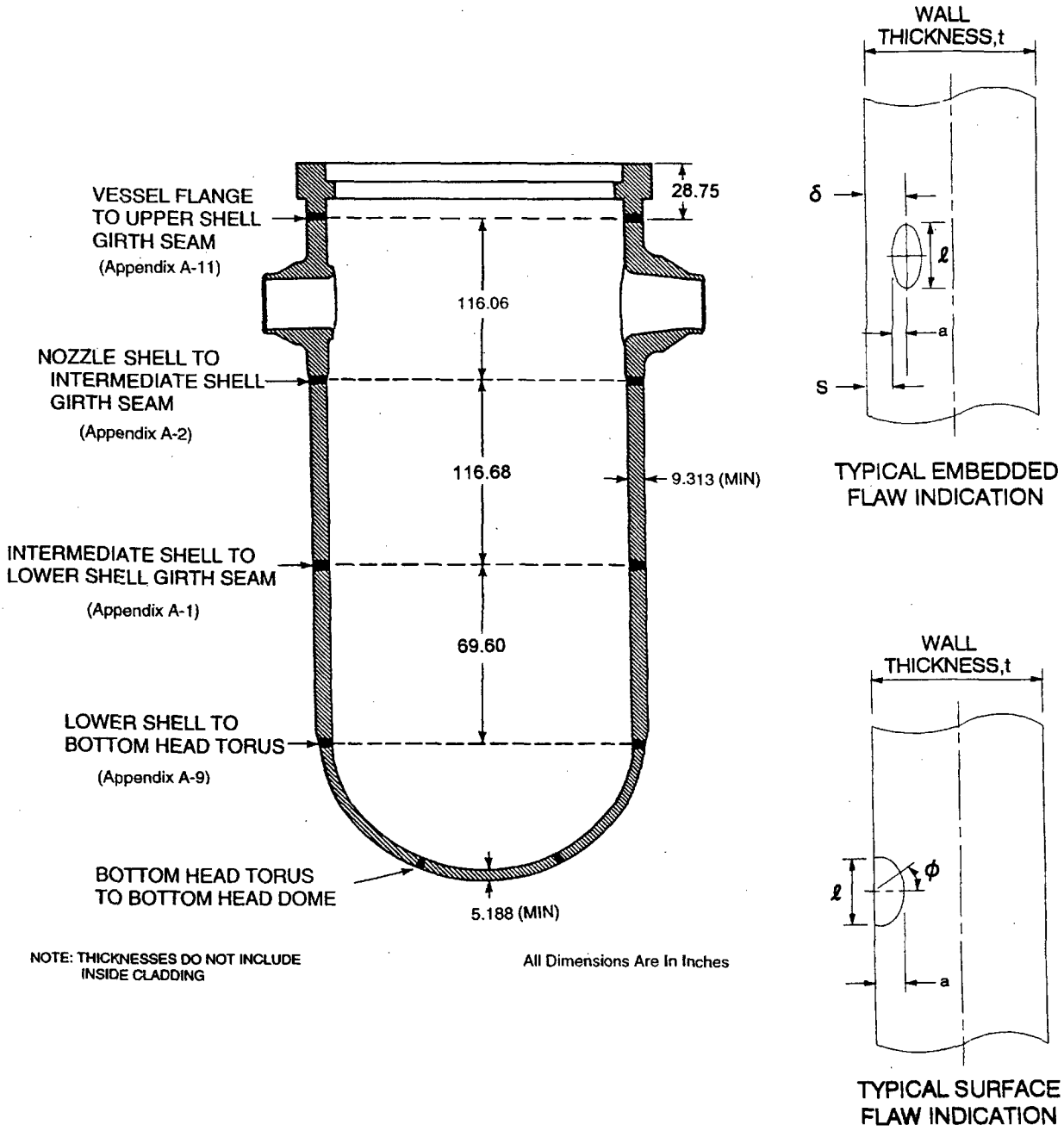


Figure A-11.1 Surface and Embedded Flaw Indications at the Lower Flange to Shell Weld

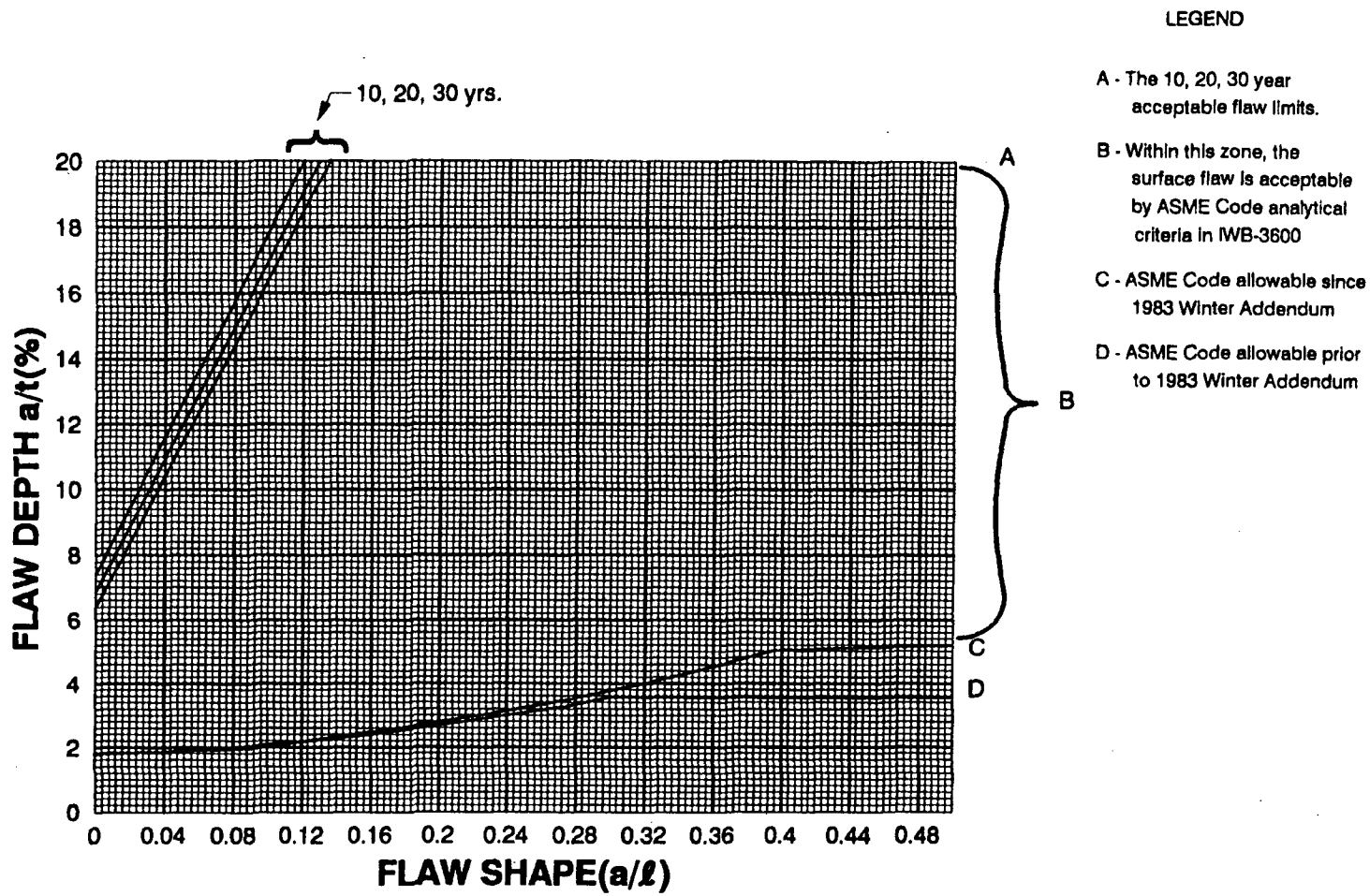


Figure A-11.2 Evaluation Chart for Lower Flange to Shell Weld

_X_ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

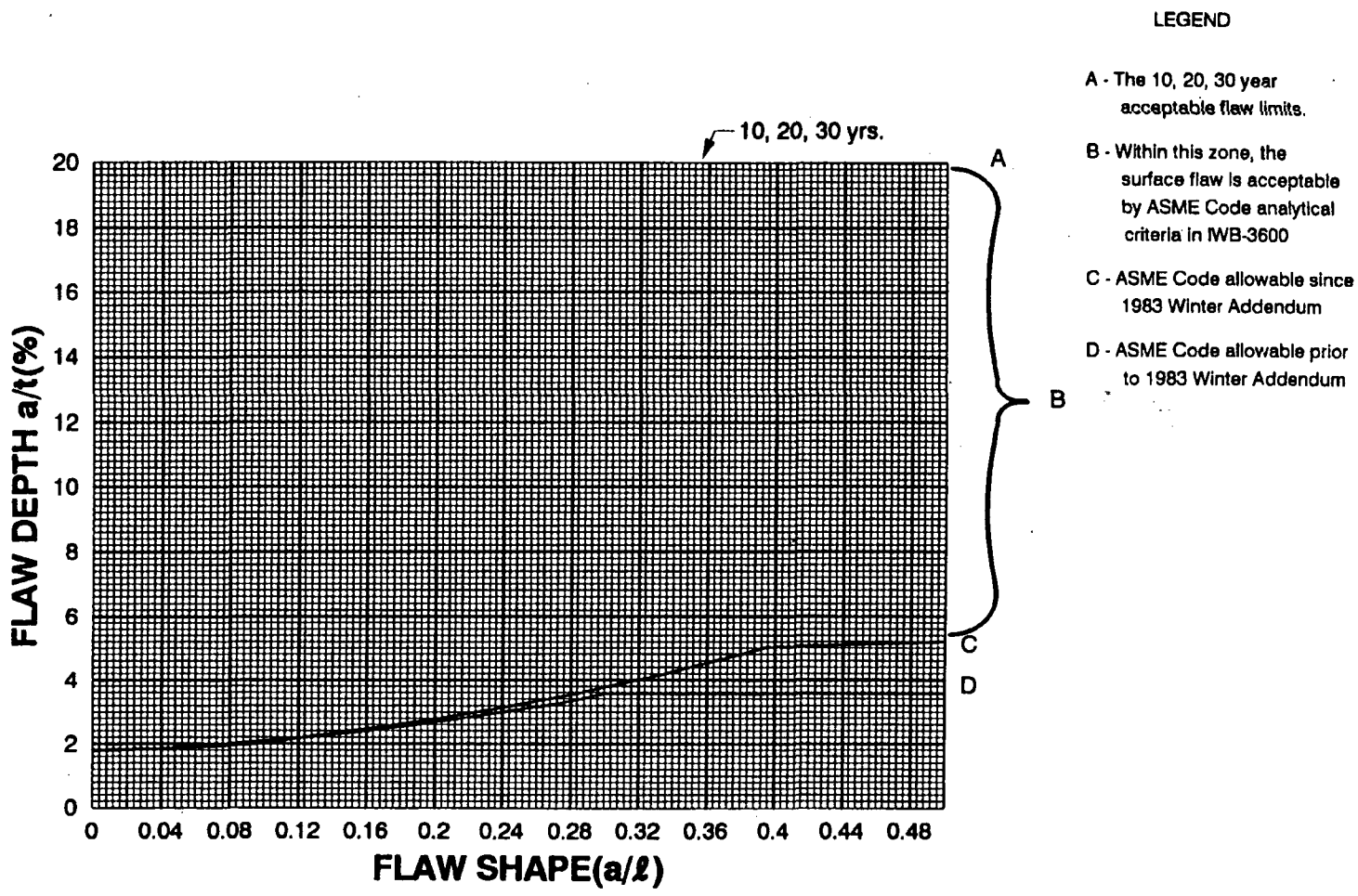


Figure A-11.3 Evaluation Chart for Lower Flange to Shell Weld

X Inside Surface	X Surface Flaw	___ Longitudinal Flaw
___ Outside Surface	___ Embedded Flaw	X Circumferential Flaw

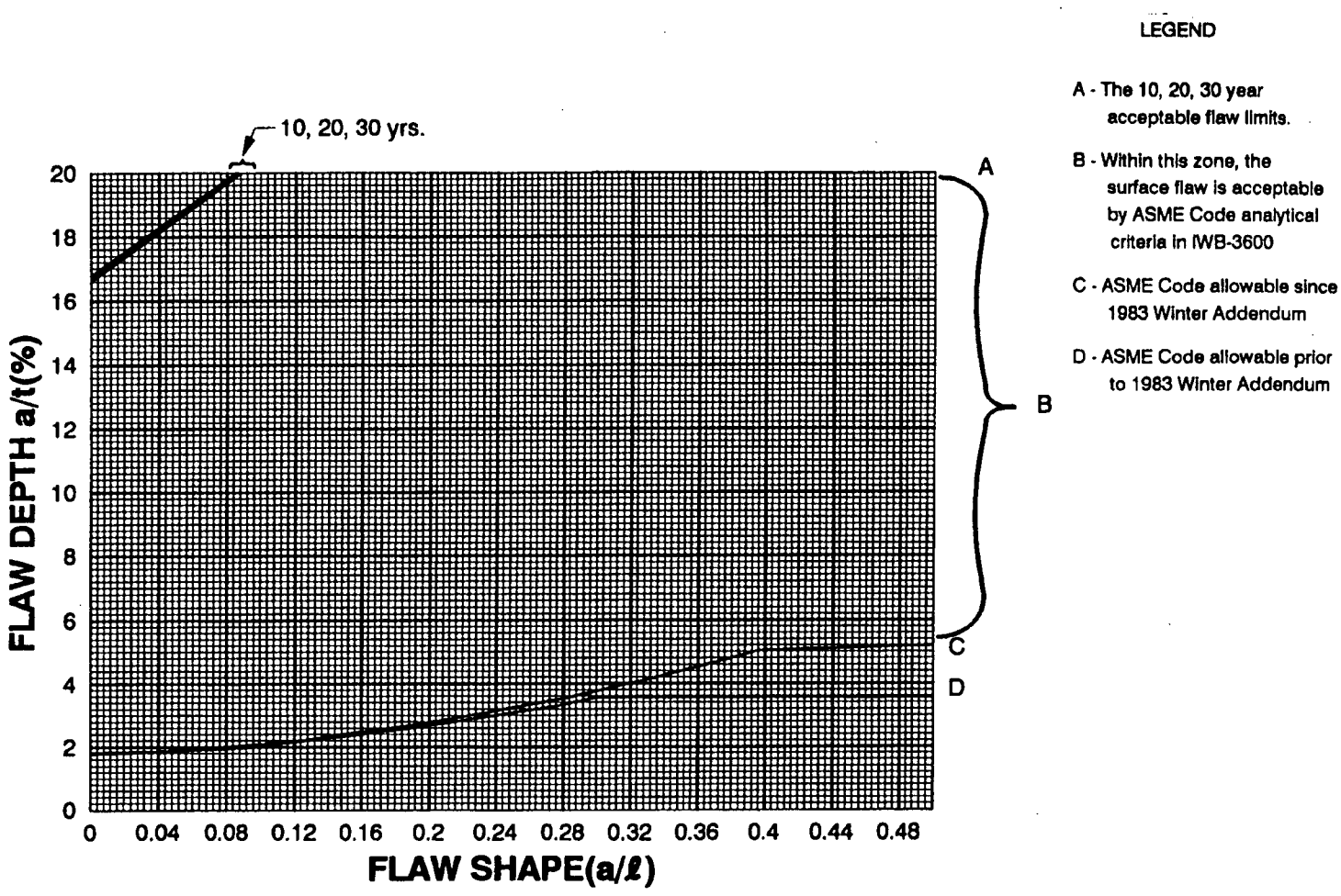


Figure A-11.4 Evaluation Chart for Lower Flange to Shell Weld

___ Inside Surface	_X_ Surface Flaw	_X_ Longitudinal Flaw
_X_ Outside Surface	___ Embedded Flaw	___ Circumferential Flaw

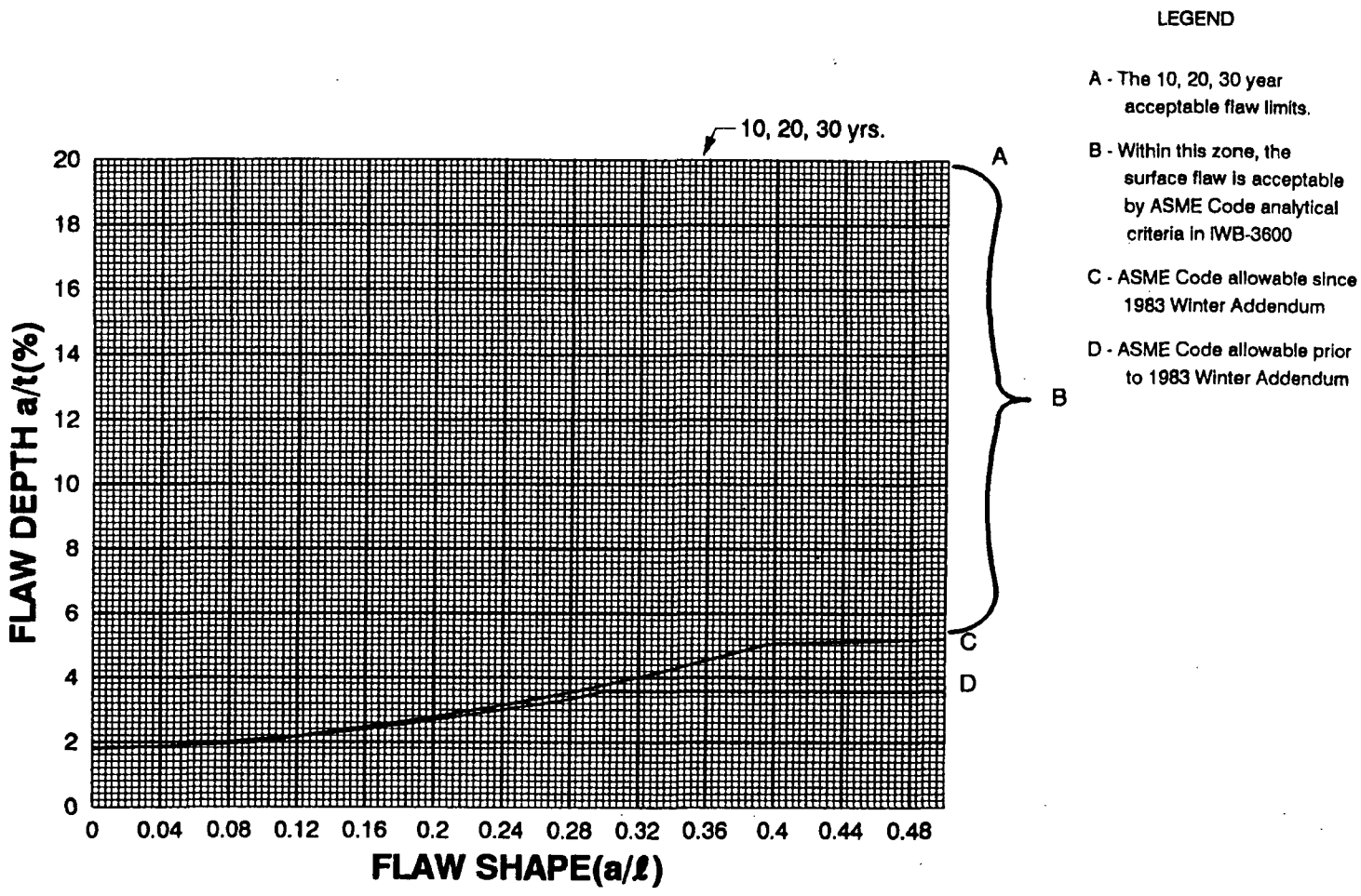


Figure A-11.5 Evaluation Chart for Lower Flange to Junction Shell Weld

___ Inside Surface	X Surface Flaw	___ Longitudinal Flaw
X Outside Surface	___ Embedded Flaw	X Circumferential Flaw

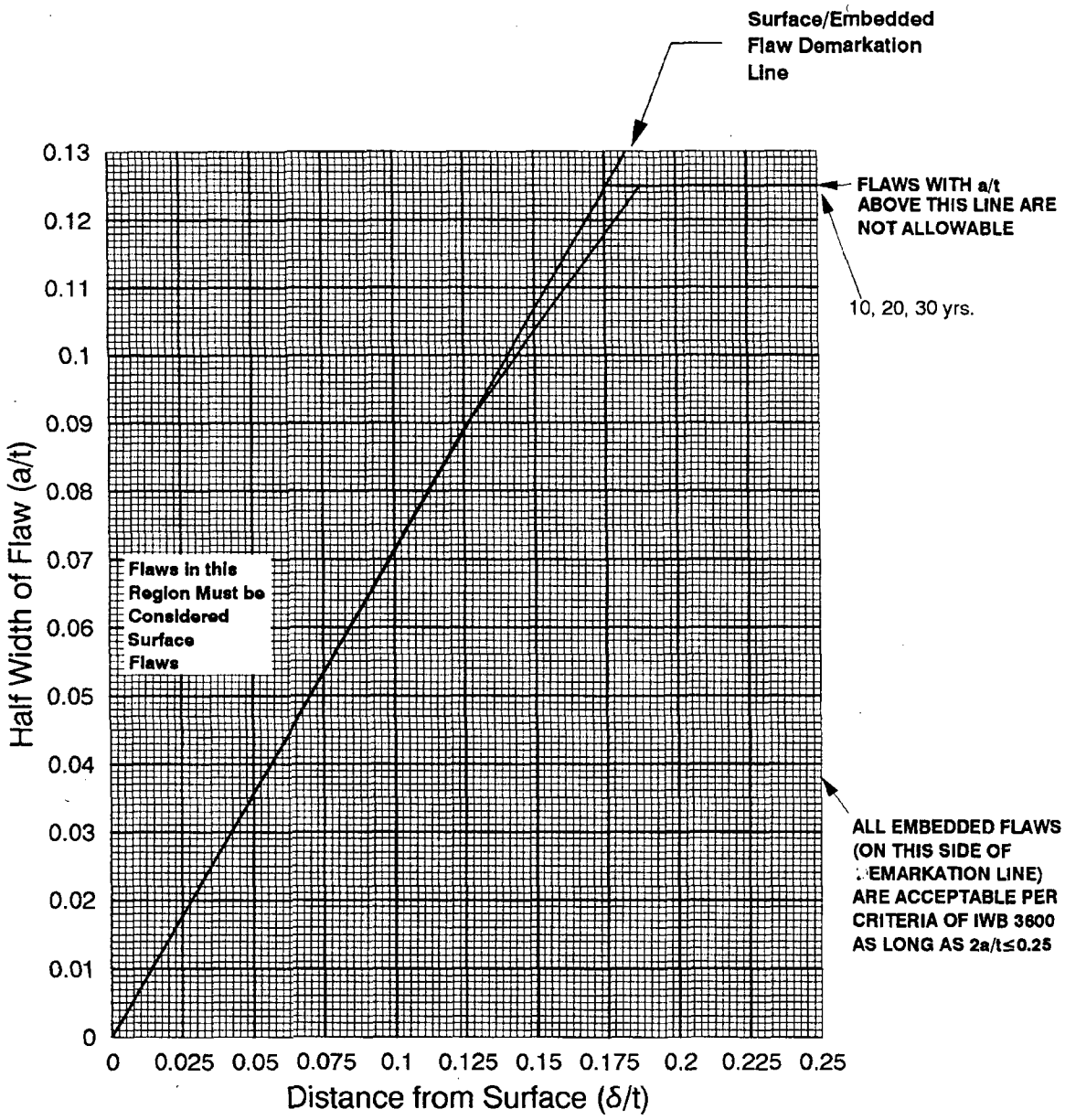


Figure A-11.6 Evaluation Chart for Lower Flange to Shell Weld

X Inside Surface	___ Surface Flaw	X Longitudinal Flaw
X Outside Surface	X Embedded Flaw	X Circumferential Flaw