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EVALUATION OF RADIOGRAPHIC FLAW DETECTION IN 2219 ALUMINUM TIG WELDS

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ABSTRACT

This report describes the project conducted by the Methods and Research Section, R-QUAL-AMR, to evaluate radiographic weld flaw detection in S-IC 2219 aluminum TIG welds.

Destructive test specimens were incrementally milled and evaluated. Flaws were plotted in three dimensions with respect to size and location. Radiographic and metallographic data were compared and evaluated. It was concluded that radiography has a good level of reliability for porosity detection in the subject weld material, but can be readily improved by attaining film sensitivity levels in the order of 1 percent.

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APPLIED TECHNOLOGY BRANCH
ANALYTICAL OPERATIONS DIVISION

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SUMMARY

This report describes the project conducted by the Methods and Research Section, R-QUAL-AMR, to evaluate radiographic weld flaw (porosity) detection in S-IC 2219 aluminum TIG welds.

Porosity and porosity-related flaws were predominant in the test specimens, so the data and conclusions were based upon these types. Destructive test specimens were incrementally milled and evaluated. Flaws were plotted in three dimensions with respect to size and location. Radiographic and metallographic data were compared and evaluated, and are presented in chart form. Film sensitivity and allowable flaws by specification were correlated with results and are discussed herein. It was concluded that radiography has a good level of reliability for porosity detection in the subject weld material, but can be readily improved by attaining film sensitivity levels in the order of 1 percent. X-ray film of test specimens used in this project reflected a sensitivity level of 2 percent, which correlated with the minimum porosity size detected by film interpretation and confirmed by metallographic dissection.

SECTION I. INTRODUCTION

This evaluation was performed to establish the level of reliability relative to radiographic weld flaw detection for 2219 aluminum TIG welds. During the evaluation, the level of reliability was specifically related to the minimum flaw size detectable. Since film sensitivity is closely related to level of reliability, it was given emphasis in this respect. Defect types considered were porosity, inclusions, cracks, lack of fusion, lack of penetration, and backside concavity. In addition to minimum flaw size detectable, the accuracy of identifying flaws according to size and type was an objective of this evaluation. Radiographs were provided by the Manufacturing Analysis Section, R-QUAL-AMS. Metallographic specimen selection, incremental dissection, interpretation, and evaluation were performed by the Methods and Research Section, R-QUAL-AMR.

SECTION II. DESCRIPTION

A. SPECIMEN SELECTION

Old radiographs were used to select seven on-hand test panels in thicknesses of 0.25, 0.50, and 0.75 inch for the greatest extent and variety of flaws. New radiographs were obtained and the panels were cut perpendicular to the weld into 4-inch segments. Nine of 39 segments thus obtained were selected for incremental milling on the basis of greatest flaw extent and variety.

B. METALLOGRAPHIC SEQUENCE

Prior to metallographic dissection, each 4-inch segment was milled parallel to the weld centerline to approximately 0.125 inch of the heat affected zone. Each segment was then milled in 0.010-inch progressive increments parallel to the weld centerline. After each progressive milling step, segments were chemically etched and polished in a Molectrics, Inc. Summa Processor. Each segment was then examined with a 7X magnifier. Flaws were numbered, identified by type, sized, and located by XYZ coordinates. Each flaw area was photographed with a special Polaroid camera 5X magnifier. A typical data sheet used during the metallographic sequence and flaw area photographs are shown in figures 1 and 2.

DATA SHEET - RADIOGRAPHIC ANALYSIS PROJECT - ETD A-2-7-10

By Goldsberry Date 1-9-67

SEGMENT NO. C5 MILLING CUT NO. 31 CUT DEPTH .010 in. ACC. CUT DEPTH .310 in.

PHOTOGRAPHIC DATA

Photographs Taken					Not Photographed Because	
Left	Left Ctr.	Right Ctr.	Right	None	No Flaws	No Flaw Pattern Change
✓		✓	✓			

FLAW DATA

No.	Type	Location and Size "X" Coordinate	"Y" Coordinate	"Z" Coordinate
1	.030 PORE	-1.531	-.344	+.480
2	.015 PORE	-1.468	-.219	+.480
3	.030 PORE	-1.218	-.375	+.480
4	.020 PORE	+.781	-.391	+.480
5	.020 PORE	+1.312	-.235	+.480

NO FLAWS NOTED THRU CUT NO. 30

By Goldsberry Date 1-9-67

SEGMENT NO. C5 MILLING CUT NO. 32 CUT DEPTH .010 in. ACC. CUT DEPTH .320 in.

PHOTOGRAPHIC DATA

Photographs Taken					Not Photographed Because	
Left	Left Ctr.	Right Ctr.	Right	None	No Flaws	No Flaw Pattern Change
✓	✓					

FLAW DATA

No.	Type	Location and Size "X" Coordinate	"Y" Coordinate	"Z" Coordinate
1	.020 PORE	-1.531	-.344	+.470
3	.025 PORE	-1.218	-.375	+.470
6	.010 PORE	-.890	-.475	+.470

NOTE: Flaws 2 and 4 were removed by cut no. 32.

Figure 1. Typical Metallographic Data Sheet

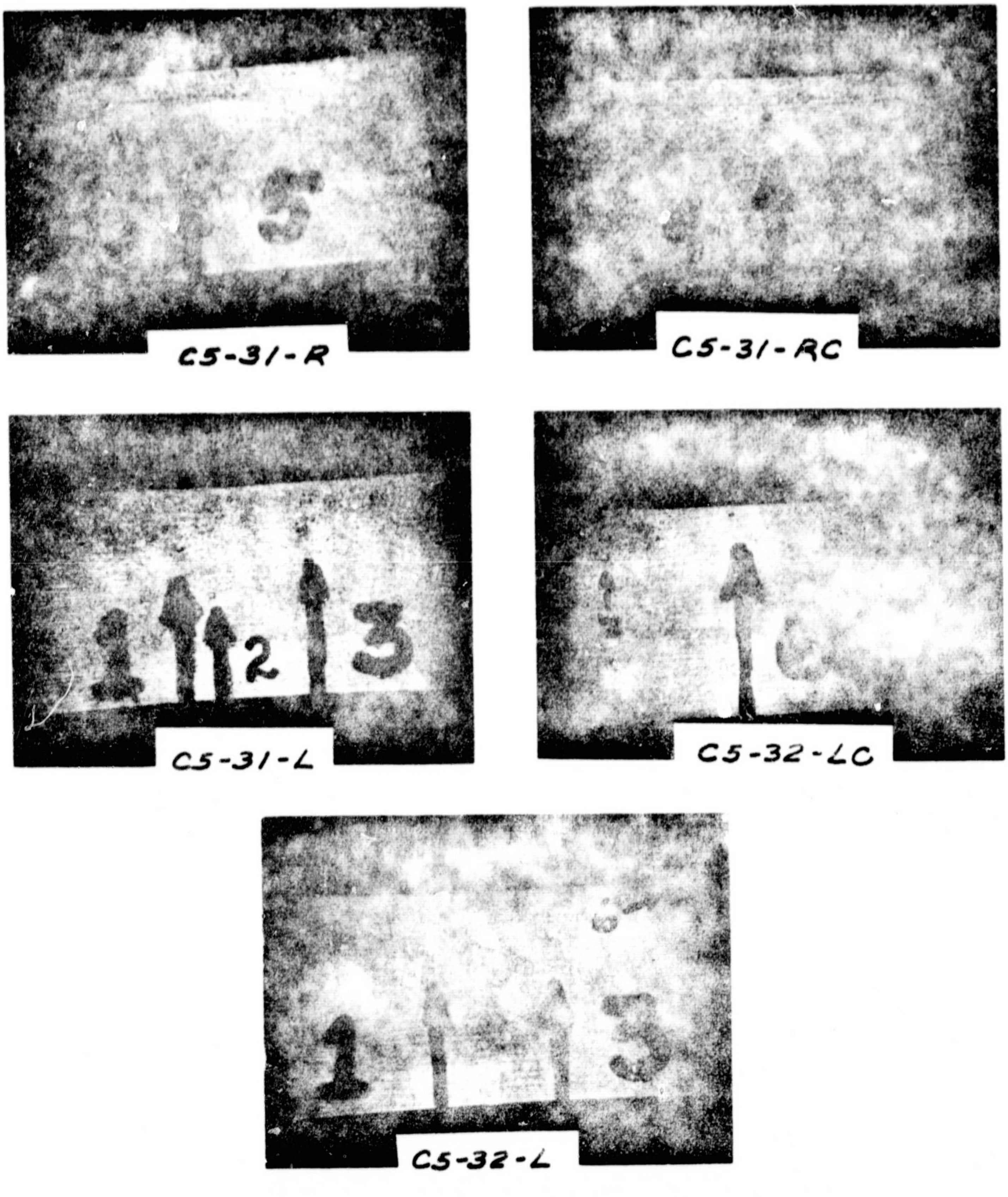

Figure 2. Typical Flaw Area 5X Photographs

C. FLAW PLOTTING

Metallographic and radiographic flaw locations were both recorded in X, Y, and Z coordinates. (See figure 3.) The reference point was a punch mark on a strip of lead identification tape located in the center of each 4-inch segment. A scale graduated to 1/64 inch was used in conjunction with the 7X magnifier scales for flaw measurements. A milk light viewer with a film density range to 3.0 was used for radiographic interpretation and flaw plotting. Radiographic flaw depth locations (Y-coordinate) were calculated by using flaw shift data derived from the 45 and 90 degree shots.

The X-dimension was parallel to the weld centerline; the Y-dimension reflected flaw depths; the Z-dimension was transverse to the weld centerline.

D. RADIOGRAPHS

Radiographs were taken by the Manufacturing Analysis Section, R-QUAL-AMS. Specific X-ray parameters used are shown in table 1. Both 90 and 45 degree angle shots were taken. The 45 degree shots were less effective than desired due to X-ray tube positioner limitations. The 45 degree angle was approximate because the positioner did not have a protractor feature and the focal film distance (FFD) was limited by the positioner's height capability.

Table 1. X-ray Parameters

X-Ray Parameter	Specimen Thickness (in.)	
	0.500	0.250
Kilovoltage	75.0	85.0
Milliamperes	15.0	10.0
Exposure Time (sec)	75.0	45.0
Focal Spot Size (mm)	2.5	2.5
Focal Film Distance (in.)	36.0	36.0
Film	Extra fine grain, Kodak Type M	Extra fine grain, Kodak Type M

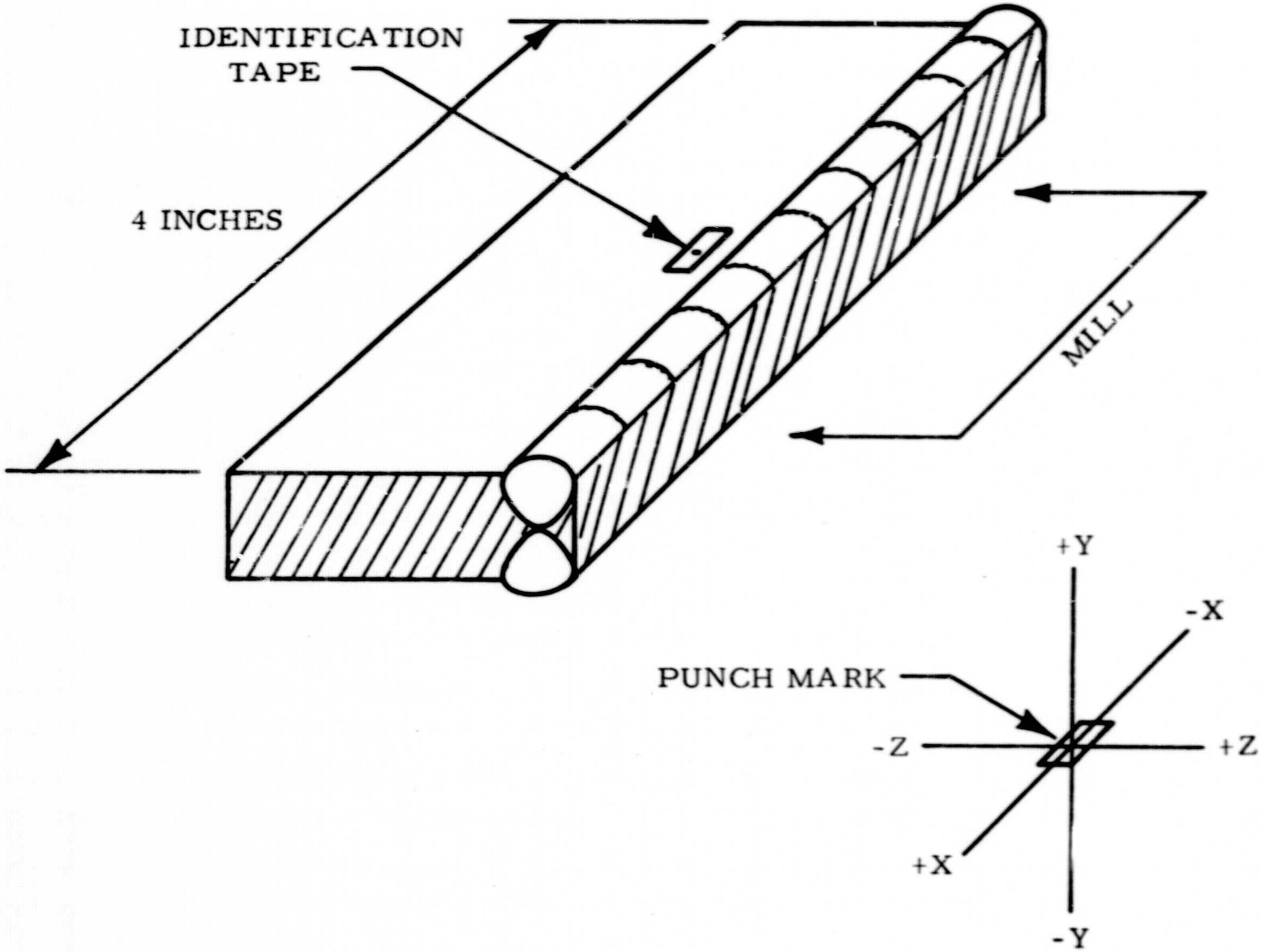

Figure 3. Typical Test Specimen

SECTION III. EVALUATION

A. FILM SENSITIVITY

For many years specifications and standards have imposed a radiographic quality level in terms of percent film sensitivity. This sensitivity, or contrast sensitivity, may be defined as the degree of sharpness evidenced by the detail of the outline of the penetrameter. It is also defined as the ratio between the thickness of the smallest detectable defect and the thickness of the specimen, expressed as percent of contrast. Most specifications, including those applicable at MSFC, usually require 2 percent or 2T. See table 2 for relationships between percent and T designations. Some specifications state "2 percent or better" which is no more expressive and binding than a requirement of 2 percent. An absolute minimum limit of 0.5 percent has been achieved in the industry.

Table 2. Radiographic Quality Levels

Radiographic Quality Level	Minimum Perceptible Penetrameter Hole	Equivalent Sensitivity (Percent)
1	1T	1.4
2	2T	2.0
2	4T	2.8

Radiographs of the specimens used in this evaluation did show both the 1T and 2T penetrameter holes; however, the image outlines were fuzzy or unsharp. Therefore, the film sensitivity would range between 1.4 and 2.0 percent, with 2.0 percent being a more reasonable level. This value correlates with the minimum flaw size data discussed in a subsequent paragraph.

B. SPECIFICATION REQUIREMENTS

Radiographic operations were performed in accordance with QRAL Acceptance Procedure 6-QHSIC-AMS-1005, except for the 45 degree angle shots and location of the lead marker tapes on each 4-inch specimen. Allowable flaw sizes by specification were obtained from MSFC-SPEC-259A dated April 9, 1965, which was referenced by 6-QHSIC-AMS-1005. Weld soundness requirements from 259A are as follows:

1. Cracks are unacceptable.

2. Incomplete fusion is unacceptable.

3. Incomplete penetration is unacceptable unless otherwise specified by drawing.

4. Porosity:

	Material Thickness	
	0.250 in.	0.500 in.
Class I, Rule 1	0.047	0.075
Class I, Rule 2	0.067	0.100
Class II, Rule 1	0.067	0.100
Class II, Rule 2	0.095	0.145

5. Inclusions shall be considered porosity.

C. DATA ANALYSIS

1. General. The majority of flaws in the test specimens were gross and were of two types, porosity and voids, with gas piping tying them together or emanating in random directions. For specification/ rejection purposes, both types are categorized under porosity. The total number of flaws located in the nine specimens by radiography and metallographic dissection are as stated in Table 3. All rejectable porosity flaws per specification requirements were detected by radiography.

Inasmuch as porosity and porosity-related flaws were predominant, all data displayed herein are based upon these types. The extent of cracks, lack of fusion, lack of penetration, and inclusions were not sufficient to warrant significant conclusions.

2. Flaw Distribution by Type. Table 3 presents a summary of flaws detected and identified by type. As can be seen, the majority were porosity.

Table 3. Flaw Identification

Flaw Type	Flaws Identified By	
	Radiography	Metallography
Porosity	39	42
Inclusions	1	3*
Cracks	1	4*
Total	41	49

*Some of these were in combination with porosity.

3. Minimum Flaw Size Detected. The minimum size pore detected was 0.010 inch. The average minimum size pore detected was 0.015 inch for both the 0.250 and 0.500 inch thick specimens. Table 4 presents these data plus film sensitivity values for each specimen.

4. Flaw Size Accuracy. The accuracy of radiography in flaw size detection was determined for porosity. Computed values are:

Coordinate	X	Y	Z
Accuracy (%)	90	77	89
Average Flaw Size (in.)	0.096	0.079	0.047

Guidelines used to establish these values were:

a. Percent Accuracy =

$$100\left[1-\left(\frac{\text{Metallographic Size - Radiographic Size}}{\text{Metallographic Size}}\right)\right]$$

b. The overall dimensional limits of clustered porosity and pores were used.

c. When flaw orientation affected accuracy calculations, the data were not used. Due to the orientation and shape of some defects, a 0.010 inch mill cut will remove more than 0.010 inch of the flaw in a particular plane.

Table 4. Minimum Flaw Sizes

Specimen No.	Thickness (in.)	Penetrameter Hole Resolved	Equivalent Sensitivity	Theoretical Min. Flaw per Sensitivity	Minimum** Size Flaw Detected	Minimum Size Flaw Existing
B4	0.250	2T	2.0%	.005	0.010	0.005
C2	0.500	1T*	1.4 - 2.0%	.007 - .010	0.020	0.020
C4	0.500	1T*	1.4 - 2.0%	.007 - .010	0.020	0.020
C5	0.500	1T*	1.4 - 2.0%	.007 - .010	0.010	0.010
C6	0.500	1T*	1.4 - 2.0%	.007 - .010	0.010	0.010
D4	0.250	1T*	1.4 - 2.0%	.0035 - .005	0.025	0.025
F3	0.250	1T*	1.4 - 2.0%	.0035 - .005	0.015	0.015
F4	0.250	1T*	1.4 - 2.0%	.0035 - .005	0.050***	0.050
F5	0.250	1T*	1.4 - 2.0%	.0035 - .005	0.010	0.010

*Visible, but not sharply defined.

**Smallest of X and Z dimensions as detected by X-ray.

***Clustered porosity, not used to compute average minimum flaw size.

d. Two clustered porosity flaws were exceptionally large in the X dimension. These were not used for the average size determination.

It will be noted that an accuracy of 90 percent, for example, denotes a 10 percent error in size determination. By applying this value to the average X dimension flaw size (10% x 0.096 = 0.0096), the quantity error obtained very closely approximates the 2 percent film sensitivity value of 0.010 inch.

The Y dimension accuracy was, as expected, less than X or Z due to the inability of the tube positioning equipment to provide accurate 45 degree shots.

SECTION IV. CONCLUSIONS

Radiography has a good level of reliability in weld porosity detection for 2219 aluminum TIG welds. Radiographic quality in this evaluation did meet specification requirements and was consistent with that achieved in other Saturn programs. As an NDT technique, radiography is better than would be concluded from the data due to equipment and other limitations discussed below.

A 2 percent film sensitivity, in accordance with specification requirements, was achieved. The minimum detected porosity size of 0.010 inch corresponds to the 2 percent sensitivity level for 0.500 inch thick material. Few occurrences of porosity smaller than 0.010 inch were located by the metallographic process. This indicates the absence of such flaws and/or supports the statistical probability of cutting out smaller flaws by the 0.010 inch mill cuts.

Improved tube positioning equipment would permit more accurate angle shots with a resulting increase in Y-dimension (flaw depth) accuracy. However, since the depth location is usually required only for determining which side of the weld to grind for rework purposes, present equipment is satisfactory if all factors of the radiographic process are properly observed.

Radiography, as reflected by the test specimens, can be significantly improved by use of longer focal spot-to-film distances (FFD), which provides sharper flaw contrast, higher sensitivity, and less fringe area distortion. These factors affected flaw location and size accuracy in the test specimens. Restrictions upon FFD are also a function of tube positioning equipment limitations.

SECTION V. RECOMMENDATIONS

A. GENERAL

1. On angle shots, markers should be placed on the bottom as well as on the top of the material. This will assist flaw shift measurements when calculating flaw depths in the weld. Care should be exercised to avoid placing the top marker too close to the weld causing it to be shifted over the weld area on angle shots.

2. Shims should be used under the pentrameters to assure that the desired film sensitivity is in the weld rather than in the parent material only.

3. On angle shots, the X-ray tube should be consistently angled either toward or away from the marker.

4. An 8000 candlepower viewer in an area with low background illumination is recommended for film interpretation.

5. For a metallographic project such as that described herein, test specimens with naturally occurring flaws are recommended.

B. TECHNIQUES FOR MAXIMUM FILM SENSITIVITY

When highly developed radiographic techniques are used, 1.0 percent film sensitivity can be routinely obtained and 0.5 percent has been attained. For precise flaw identification and resolution, the following points are mandatory:

1. Overhead tube suspension and positioning equipment for precise angulations and distances

2. Double fractional focal spot size to minimize flaw magnification and/or minification

3. Very fine or ultra-fine grain film

4. Precisely developed radiation exposure charts (curves) combining:

   a. Low KVP

   b. Maximum time

   c. Highest milliamperage

   d. Maximum distance

   e. Processing conditions

   f. Film density

   g. Film type

5. Use of double parallax exposure methods

6. Scatter reduction techniques

7. Precise processing procedures

8. Precision film image measuring devices