

ANALYSIS OF TWO ALUMINUM WELD
ACCEPTANCE PROCEDURES

A Final Report

March, 1986

By

Ricardo T. Barros
Principal Statistical Engineer

New Jersey Department of Transportation
Division of Research and Demonstration

Disclaimer Statement

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the New Jersey Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

1. Report No. FHWA/NJ-86-015-7720		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Analysis of Two Aluminum Weld Acceptance Procedures				5. Report Date March, 1986	
				6. Performing Organization Code N.A.	
7. Author(s) Ricardo T. Barros, Principal Statistical Engineer				8. Performing Organization Report No. 86-015-7720	
9. Performing Organization Name and Address New Jersey Department of Transportation Division of Research and Demonstration 1035 Parkway Avenue Trenton, NJ 08625				10. Work Unit No. (TRAIS) N.A.	
				11. Contract or Grant No. State Study 7720	
12. Sponsoring Agency Name and Address New Jersey Department of Transportation 1035 Parkway Avenue Trenton, NJ 08625				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract Radiographic procedures are used to inspect and accept welds incorporated into aluminum overhead sign support structures. Radiography is expensive, however, so it is obviously desirable to inspect no more frequently than necessary to assure that defective welds are absent from accepted structures. The principles underlying the New Jersey Department of Transportation's present radiographic acceptance procedure are discussed and an alternative procedure is proposed which may save over \$10,000 annually without diminishing the present level of protection.					
17. Key Words Aluminum welds, statistical acceptance procedures, cluster sampling, hypergeometric probabilities			18. Distribution Statement Copies available on request.		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 34	22. Price

TABLE OF CONTENTS

	<u>Page</u>
Introduction	1
The Existing Radiographic Acceptance Procedure	3
Quality Levels and Acceptance Limits	4
Risks and Engineering Design	5
Use of the Hypergeometric Probability Function in an Acceptance Procedure	7
The RQL, Tolerable Risks, and the Average Outgoing Quality	8
Optimum Sampling Strategy.....	13
Cost Considerations	19
Cluster Sampling	20
Conclusions	26
References	27
Appendix: Optimum Acceptance Plans for Radiographic Inspection of Aluminum Weldments	28

LIST OF TABLES AND FIGURES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1	Comparison of selected characteristics of two acceptance procedures for a large lot size	14
2	Comparison of selected characteristics of two acceptance procedures for a small lot size	15
3	Summary of operating characteristics for observed lots, minimum sample size	17
4	Summary of operating characteristics for observed lots, minimum sample size plus two	18
5	NJDOT savings per 1000 radiographs	21
6	Impact of cluster sampling and serial correlation.....	23

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Average outgoing quality concepts	12
2	The effect of serial correlation on the probability of acceptance in clustered samples	25

ANALYSIS OF TWO
ALUMINUM WELD ACCEPTANCE PROCEDURES

INTRODUCTION

Aluminum welds are used by the New Jersey Department of Transportation (NJDOT) in the fabrication of aluminum overhead sign support structures. Every weld is first subjected to a visual inspection and then, additionally, a random sample from each lot of welds is subjected to radiographic inspection. Radiographic inspection is costly, currently \$43.00 per radiograph, so there is an obvious incentive to reduce the number of radiographs taken to the minimum required. Those which are taken must still provide adequate protection against the acceptance of defective welds.

The existing radiographic acceptance procedure appears to provide the required protection. Analysis of the risks involved indicate that, in most cases, lots which contain an excessive number of flawed welds stand a small chance of passing undetected. This inference is based on established theory using the hypergeometric probability distribution.

A discrepancy between statistical theory and practical application of the acceptance procedure introduces a potential flaw into conventional statistical analyses, however, the impact of which was not previously known. As a practical expedient, a cluster sampling technique is used rather than pure random sampling. Risk analyses assuming one sampling procedure may be invalidated if another is used. Consequently, it was necessary to quantify the nature and magnitude of the potential bias introduced. Otherwise, if this step were not taken, it could have been possible that the inferred protection was nonexistent but assumed to be present simply because the quality levels submitted to date have been exceptionally high.

Prerequisite information to any analysis of risk is the concept of acceptable and rejectable weld quality. Knowledge of specific quality levels is necessary to provide reference points at which the risk of not detecting flawed welds can be meaningfully compared. It was found that these specific definitions of quality, as such, had not been explicitly developed within the NJDOT for aluminum welds or the American Welding Society (AWS). Instead, attention was focused on engineering acceptance limits. Lacking explicit quality definitions, it was first necessary to identify reasonable quality levels for which it would be in the agency's interest to consistently accept, and other quality levels which should be consistently rejected. This was done by evaluating historical NJDOT data in the context of operating characteristic (OC) curve analyses.

Given quality levels thus established, it was the objective of this study to critically evaluate the current NJDOT acceptance procedure and to propose an alternative which would afford either of two important benefits -- a reduced exposure to risk and/or a reduced radiographic inspection cost. The alternative acceptance procedure subsequently developed was highly successful in both regards. Considerable cost savings (\$10,000/year, or more) may be realized with risks not only stabilized near but, in some cases, substantially lowered from their present levels.

Initiating a change in an accepted practice is difficult, however, particularly when appreciation of the benefits to be obtained is not reinforced by a dissatisfaction with the procedure already in place. Additionally, the relative merits of competing concerns may not be clear and thus favor that no change be made to the status quo. This report consequently discusses many of the topics relevant to the selection of the best weld inspection strategy, enabling management to make an appropriate, well informed decision.

THE EXISTING RADIOGRAPHIC ACCEPTANCE PROCEDURE

The NJDOT has, for several years, used a minimum sampling rate of 25 percent of the total number of welds in a lot. (Each structure is comprised of several lots.) If more than 10 percent of the radiographed welds are found to be defective, then all of the remaining welds are subsequently radiographed. In any event, all defective welds found are repaired and the lot is eventually accepted.

The NJDOT pays for the cost of all radiographs except for those which reveal a defective weld. These are paid for by the fabricator at the current rate of \$43.00 per radiograph. The total cost to the NJDOT of administering the existing radiographic inspection program ranges from roughly \$40,000 to over \$200,000 per year, depending upon the intensity of the construction activity.

Attempts to determine the origin of this plan have been unsuccessful. Apparently it is not explicitly patterned after any existing standard but simply "evolved" many years ago. NJDOT engineers are under the impression that 100 percent radiographic inspection was generally used originally but later reduced because of (a) the generally satisfactory quality that was being received, (b) the relatively high cost of radiography, and (c) a belief that there is a sufficient amount of structural redundancy to preclude the sudden collapse of a sign support structure.

It is interesting that, in an isolated case, an existing and apparently serviceable aluminum sign support structure was dismantled from its field location and transported to the laboratory where it was subjected to 100 percent radiographic inspection. A subsequent analysis revealed that the tested structure would most likely have failed to pass the initial acceptance criteria. That is, it would have triggered the 100 percent

inspection provision. Implications of this finding are discussed later in this report.

QUALITY LEVELS AND ACCEPTANCE LIMITS

Meaningful risk analyses refer to quality levels, not acceptance limits. The distinction between these two terms is subtle but important. An acceptance limit represents the critical engineering tolerance which precipitates one of two actions -- the acceptance or the rejection of a material -- and hence expresses the policy which is to be followed in dealing with materials which may be submitted with differing levels of quality. Quality levels, on the other hand, are a more fundamental measure and reflect the degree to which a material could be expected to meet specified serviceability requirements if it were to be accepted.

In the present case, acceptable weld quality comprises those quality levels for which weld defects incorporated into a structure do not prevent the structure from providing adequate service over the structure's intended life. Certainly flawless welds meet this criteria, but so do welds which contain flaws not sufficiently large or not sufficiently frequent to diminish the serviceability rendered below some designated threshold. Historical observations strongly indicate that acceptable weld quality levels in a structure can, without a doubt, include some welds which are flawed.

A basic, well-established parameter used to represent the various levels of quality in analyses of this type is percent defective. This parameter simply quantifies the proportion of the welds in a structure which are flawed. (Weld flaws are defined by specific engineering tolerances on porosity, cracking, incomplete penetration, etc.) Structures

with some low value of percent defective are judged to be of acceptable quality while others at higher levels of percent defective are not.

The percent defective parameter is intrinsically keyed to the acceptance limit defining weld flaws by the statistical acceptance procedure. Critical information relevant to the evaluation of an acceptance limit is the frequency with which welds defined to be flawed by this limit are accepted. The net effect of a seemingly stringent limit in a (poorly designed) acceptance procedure prone to accept structures with large percent defective may be that the average quality actually accepted is substantially worse than the stringent limit might suggest.

Acceptance limits must be considered to be primarily the expression of a policy decision, and the adequacy of this policy decision can be evaluated only relative to the assessment of the quality levels it is capable of distinguishing between. This study seeks to identify specific quality levels through analyses of historical data and to assess the relative discriminating power of several alternative acceptance procedures in the recognition of these quality levels. Existing engineering tolerances which characterize welds as defective or not will remain unchanged. In so doing a basis will be established with which to comparatively evaluate the merits of the various acceptance procedures.

RISKS AND ENGINEERING DESIGN

The analyses performed in this study are of an admittedly empirical nature. An abstract parameter, percent defective, is used to gauge quality in structures observed to have provided specific levels of service. Percent defective considerations do not explicitly enter into the original design considerations, however, and the question may be raised as to the relevance of this specific abstraction and whether another, more tangible

procedure might not more meaningfully evaluate risks in a model with physically measurable dimensions. In fact, an alternative analytical procedure does exist. Reliability analyses quantify the risk of specific structural elements failing in prescribed modes. These analyses require comprehensive knowledge of material properties and applied loads, however, effectively placing them beyond the scope of the present investigation. A brief digression may help justify the relevance of the empirical analyses performed and demonstrate why, with historical information available, risks may be addressed in a generalized manner.

The erection of a completed structure may be viewed as the end product of many, distinct engineering analyses. Three of these are the selection of an overall structural configuration as well as individual member dimensions, the specification of engineering limits on desirable material properties, and an analysis of the risks present in (materials) quality assurance. These analyses are obviously interrelated. Stronger material properties permit a more sparse structural configuration. Low confidence in the materials acceptance procedure would require a compensating degree of redundancy in structural support or surplus in material strength.

Given a design load, a structural element, and a specified material limit, the problem becomes one of assuring that the material limit is not exceeded. If this can be accomplished with a reliability comparable to what has historically been achieved, then it can be inferred that the existing (and satisfactory) balance has been preserved. Thus, the presence or absence of defects in a weld becomes the pertinent criteria, and the operating characteristic curve the primary analytical tool.

USE OF THE HYPERGEOMETRIC PROBABILITY FUNCTION IN AN ACCEPTANCE PROCEDURE

Operating characteristic curves for lots which contain a discrete number of defects are calculated with the hypergeometric probability function.⁽¹⁾ Probabilities are determined as a function of the lot size, N , the sample size, n , the total number of defects in the lot, D , and the observed number of defects in the sample, d . A lot is accepted if the sample contains c or fewer defects, where c is the maximum number of allowable defects in a sample. Typically, lots with more than c defects are then subjected to 100 percent inspection and all detected defects are repaired or replaced. Sampled observations are implicitly assumed to meet the requirements of independent, random selection.

Operating characteristic curves developed with the hypergeometric probability function are, in a sense, more limited than curves developed with continuous functions because only discrete integers may be used. It is not possible to have 1.5 defects, for example. It sometimes occurs that an incremental change in one of the foregoing variables (i.e., N , n , D , d , or c) results in a noticeable jump in the incremental probability.

The existing acceptance procedure is especially subject to this type of fluctuation. For example, since the probabilities of acceptance are more sensitive to absolute sample sizes than sampling rates, two lots from which a 25 percent sample is taken will necessarily incur different risks if one contains 60 welds and the other 80 welds. Also, if the acceptance requirement is that 10 percent or less of the sample be defective, then additional imprecision is introduced because c may be set to 1 or 2 defects but never 1.5. And, finally, the existing acceptance procedure randomly selects weld nodes of various sizes until the cumulative number of sampled welds exceeds the minimum number required. (The actual sample size used is the cumulative number rather than the minimum required.) Thus, by chance,

two lots of equal size may be represented by unequal sample sizes and incur different risks.

THE RQL, TOLERABLE RISKS, AND THE AVERAGE OUTGOING QUALITY

Established tolerable risks at specified quality levels have not been universally established in the existing state-of-the-art. The American Welding Society does not recognize statistical risks in the acceptance procedure and favors strictly controlled fabrication conditions. The American Society for Testing and Materials, the American Society for Nondestructive Testing, and the American Society for Quality Control were also contacted but unable to provide further guidance regarding the tolerable risk of accepting marginal quality.

It is fortunate the NJDOT has developed historical information regarding weld quality, and this information gains in authority when other references remain silent. An aluminum sign support structure, scheduled for dismantlement after about 17 years of satisfactory service, was subjected to 100 percent radiographic inspection to provide additional quality - performance data. Scattered porosity was, by far, the most common defect found. A smaller number of cracks and tungsten inclusion were also observed, and even fewer incidences of lack of fusion were detected.

Although a great deal of information was learned about this particular structure, the conspicuous lack of other information necessitates that certain assumptions be made if specific inferences are to be generalized. The structure must be thought of as representative. Or, more specifically, it must be assumed that the relative frequencies of defect types found in the tested sections are not unusual, that the weld defects found at the time of inspection were present at the time of fabrication, and that the

field loading exposure was not atypically light. NJDOT engineers queried on this matter considered this structure to be generally representative of others in use and that these assumptions were reasonably met.

A conservative rejectable quality level (RQL) value can then be derived. The observed quality levels for the five sections were found to range from 17 to 56 percent defective and the weighted average value for all trusses was 33 percent defective. Thus, for the purposes of this analysis, it is assumed that the RQL is no smaller than 33 percent defective.

Setting the RQL at 33 percent defective implies that trusses with no more than this amount of defective welds would serve at least as well as the tested sections. It also implies that trusses with more than RQL defects are not acceptable. Note that this latter implication is fairly conservative since two of the five tested sections were actually in excess of 50 percent defective. Note also that the percent defective parameter applies strictly to the degree of compliance with a specified engineering limit, such as a maximum limit for linear porosity. A change in this engineering limit may necessitate a corresponding change in the definition of the RQL.

The tolerable risk at the RQL is dependent upon several considerations. These include the likelihood of structural failure should an RQL situation occur, the mode of the structural failure, and the potential consequences. (Recall that all welds are subjected to a visual inspection and that the risks discussed below apply exclusively to those defects detectable only through radiographic inspection.)

Based on the above observations, the likelihood of a structural failure exactly at the RQL appears to be extremely small. Should a failure occur, PennDOT sources personally contacted report that individual struts

tend to disengage first and are visually detectable from the roadway. In their experience, this allowed sufficient time for the structure to be dismantled in a timely fashion. (PennDOT failures were generally attributable to incomplete penetration and lack of fusion and were not catastrophic. Also, PennDOT's structures were accepted on the basis of fabricator certification rather than a statistical acceptance procedure.) Thus, the primary consequences of historical weld failures have been engineering costs. Should a catastrophic failure someday occur, it could have a human cost as well. Therefore, the risk of incorporating RQL or worse quality welds into an overhead sign support structure should be kept reasonably small.

Not a single weld defect-related structural failure has occurred in New Jersey during the roughly 20 years in which the Department has installed aluminum sign support structures. Our present statistical acceptance procedure has been in effect for approximately 15 of these years. Therefore, for the purposes of this report, it is assumed that the tolerable risk at the RQL is the risk historically borne over this period. Operating characteristic curve analyses indicate this risk has ranged from virtually 0.0 to over 0.25, depending upon the lot size, and the approximate median value of 0.05 is taken to be the tolerable risk at the RQL.

The corresponding risk of rejecting acceptable quality level (AQL) lots is not a significant concern in the present application because rejected lots are simply submitted to 100 percent inspection. Thus it is not necessary to define an AQL nor to quantify the risk of rejection at the AQL. The cost of unnecessary inspection is a concern, however, and this cost is very much a function of the risk of rejection. The higher the risk of rejection, the greater the overall cost of inspection.

Of the 2833 welds radiographed in 1984, 7 percent were found to be defective. If it can be assumed that 7 percent defective reasonably represents the construction quality of recent years, in which not a single aluminum weld-related structural failure has occurred, then the optimum sampling strategy can be determined.

The reasonableness of 7 percent defective as a representative value is supported by the average outgoing quality limit (AOQL). As illustrated in Figure 1, the average outgoing quality (AOQL) is dependent upon the incoming quality level. When rejected lots are subjected to 100 percent inspection and all defects repaired, an AOQL is established. This is the maximum possible value for the AOQ. The AOQL for the present acceptance procedure is approximately 9 percent defective. This means that the worst the average outgoing quality could have been in the past is 9 percent defective, a value reasonably close to the observed level.

To achieve the average outgoing quality of 7 percent defective observed in 1984, the average incoming quality level could have ranged anywhere from approximately 7 to 20 percent defective. Should the average incoming quality level have been towards the upper part of this range, however, the 100 percent inspection provision would have been triggered more frequently than actually observed. Thus it is reasonable to infer that the average incoming quality level of historical projects was truly in the vicinity of 7 percent defective, that this quality level adequately represents the quality of construction of existing structures in the field and, based on empirical observation, that the existing quality levels in the field have been entirely satisfactory.

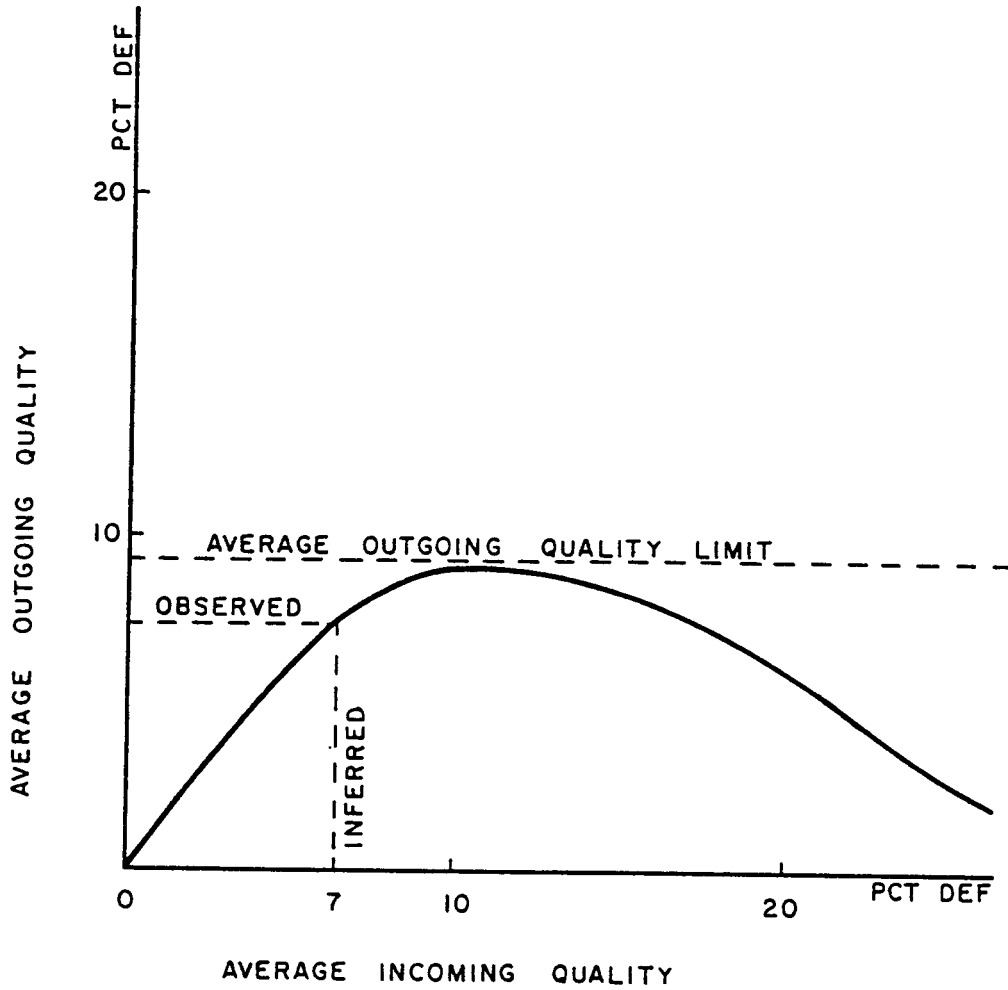


Figure 1. Average outgoing quality concepts.

OPTIMUM SAMPLING STRATEGY

The optimum sampling strategy in the present application is determined by two criteria. First, for any lot size the probability of acceptance at the RQL should not be greater than 0.05. Second, the acceptance procedure should have the minimum average total inspection (ATI) at the 7 percent defective level. (The ATI is computed as the sum of two products: the probability of acceptance times the initial sample size plus the probability of rejection times the lot size. Identification of the optimum plan using these criteria is most conveniently accomplished through an iterative procedure with computer assistance.) If two plans have similar ATI values, then that plan with the smaller initial sample size is generally preferable since it must also have the lesser ATI value for smaller percent defective. Plans which meet the above criteria will effectively provide protection comparable to what has historically been achieved at the minimum cost.

Two examples will illustrate the difference between the optimum sampling strategy and the existing acceptance procedure. Table 1 shows that, for relatively large lots, both the existing and the optimum sampling plans incur suitably small risks of accepting RQL lots. Further, both plans virtually never miss lots which are 40 percent defective or worse. For smaller percent defective values, however, inspection of the ATI columns reveals that the optimum plan requires fewer welds to be radiographed. Thus, while both plans afford comparable protection, the optimum plan is less expensive to operate.

Table 2 shows the analogous information for a case in which the lot size is relatively small. The existing plan is grossly insensitive to the recognition of RQL lots, but the optimum plan maintains virtually the same risk as before. Of course, to achieve this protection the average total

Table 1. Comparison of selected characteristics of two acceptance procedures for a large lot size.

	<u>Plan I, Existing</u>		<u>Plan II, Proposed</u>	
	Lot Size, N = 100		Lot Size, N = 100	
	Sample Size, n = 25		Sample Size, n = 17	
	Acceptance No., c = 3		Acceptance No., c = 2	
<u>Percent Defective</u>	<u>P(Accept)</u>	<u>Avg. Total Inspection</u>	<u>P(Accept)</u>	<u>Avg. Total Inspection</u>
0	1.0	25.0	1.0	17.0
2	1.0	25.0	1.0	17.0
7	0.94	29.8	0.91	24.7
33 (RQL)	0.01	100.0	0.03	97.2
40	0.00	100.0	0.00	100.0

Table 2. Comparison of selected characteristics of two acceptance procedures for a small lot size.

	<u>Plan I, Existing</u>		<u>Plan II, Proposed</u>	
	Lot Size, N = 20		Lot Size, N = 20	
	Sample Size, n = 5		Sample Size, n = 7	
	Acceptance No., c = 1		Acceptance No., c = 0	
<u>Percent Defective</u>	<u>P(Accept)</u>	<u>Avg. Total Inspection</u>	<u>P(Accept)</u>	<u>Avg. Total Inspection</u>
0	1.0	5.0	1.0	7.0
2	1.0	5.0	1.0	7.0
7	1.0	5.0	0.65	11.6
33 (RQL)	0.41	13.9	0.02	19.7
40	0.31	15.4	0.01	19.9
60	0.06	19.1	0.0	20.0

inspection of the optimum plan must be higher, and this is most noticeable when percent defective values are moderately large. Thus, in this case, it is the optimum sampling plan which is more expensive to operate. It is fortunate that the increased inspection is negligible for very small lot sizes, and that such small lot sizes are not very common. In any case, the increased ATI is simply the price to be paid if protection at the RQL is to be assured.

A complete set of optimum acceptance procedures for every lot size from $N = 6$ to $N = 150$ is presented as an appendix to this report. Those lot sizes which were observed in 1984, along with their frequency of occurrence, are shown in Table 3. Also shown are the acceptance criteria for the optimum and existing procedures, as well as selected operating characteristics. Every one of the proposed acceptance procedures allows for that reasonably large acceptance number, c , which still restricts the risk of not detecting an RQL lot to 0.05 or smaller. The risk of not detecting RQL lots with the existing procedure is, of course, variable.

The product of the lot frequency and the ATI for 7 percent defective provides a reasonable estimate of the number of welds radiographed for each lot size, and the sum of these products estimates the number of welds radiographed in one year. Comparison of these two bottom line figures in Table 3 reveals that, on the average, the optimum plans require 334 (11 percent) fewer welds to be inspected per year than the existing acceptance procedure.

It is possible that, due to the sampling technique in which clusters of welds are selected at a time, the actual sample size may be greater than the minimum required. Table 4 shows the same information as Table 3, except here every sample size has been increased by two welds. Under these conditions, and when the average percent defective value is 7 percent, the

Table 3. Summary of operating characteristics for observed lots, minimum sample size.

FREQ	EXISTING PLAN						OPTIMUM PLAN					
	LOT SIZE	SAMPLE SIZE	C	ATI (7%)	WTD ATI	β (33%)	SAMPLE SIZE	C	ATI (7%)	WTD ATI	β (33%)	
1	8	2	1	2.0	2.0	0.89	6	0	7.5	7.5	0.00	
4	12	3	1	3.0	12.0	0.76	6	0	9.0	36.0	0.03	
3	14	4	1	4.0	12.0	0.55	6	0	9.4	28.2	0.03	
2	16	4	1	4.0	8.0	0.63	7	0	10.9	21.8	0.03	
6	20	5	1	5.0	30.0	0.41	6	0	10.2	61.2	0.02	
4	24	6	1	7.0	28.0	0.32	7	0	15.6	62.4	0.03	
1	32	8	1	9.4	9.4	0.14	11	1	13.3	13.3	0.03	
1	34	9	1	10.6	10.6	0.12	12	1	14.6	14.6	0.03	
1	36	9	1	13.0	13.0	0.11	11	1	16.4	16.4	0.04	
1	40	10	1	14.5	14.5	0.08	12	1	17.9	17.9	0.03	
3	48	12	2	12.5	37.5	0.14	12	1	17.4	52.2	0.03	
2	62	16	2	18.3	36.6	0.04	16	2	18.3	36.6	0.04	
3	64	16	2	18.2	54.6	0.04	16	2	18.2	54.6	0.04	
1	66	17	2	22.0	22.0	0.03	16	2	20.4	20.4	0.03	
11	68	17	2	21.9	240.9	0.03	17	2	21.9	240.9	0.03	
2	72	18	2	23.2	46.4	0.02	16	2	19.9	39.8	0.04	
10	80	20	2	29.7	297.0	0.01	17	2	23.7	237.0	0.03	
9	84	21	3	23.0	207.0	0.03	16	2	21.4	192.6	0.04	
7	88	22	3	24.1	168.7	0.02	17	2	22.9	160.3	0.03	
14	96	24	3	28.5	399.0	0.01	16	2	23.0	322.0	0.04	
11	100	25	3	29.8	327.8	0.01	17	2	24.7	271.7	0.03	
12	104	26	3	31.0	372.0	0.01	17	2	24.3	291.6	0.04	
9	112	28	3	36.9	332.1	0.0	21	3	24.6	221.4	0.03	
1	116	29	3	38.2	38.2	0.0	21	3	24.3	24.3	0.04	
4	128	32	4	36.1	144.4	0.0	21	3	25.2	100.8	0.04	
1	140	35	4	42.4	42.4	0.0	21	3	26.2	26.2	0.04	
WEIGHTED TOTAL					2906.1						2571.7	
WEIGHTED AVERAGE											0.10	0.03

Table 4. Summary of operating characteristics for observed lots, minimum sample size plus two.

FREQ	EXISTING PLAN						OPTIMUM PLAN					
	LOT SIZE	SAMPLE SIZE	C	ATI (7%)	WTD ATI	β (33%)	SAMPLE SIZE	C	ATI (7%)	WTD ATI	β (33%)	
1	8	4	1	4.0	4.0	0.50	8	-	8.0	8.0	0.0	
4	12	5	1	5.0	20.0	0.42	8	0	10.7	42.8	0.0	
3	14	6	1	6.0	18.0	0.24	8	0	11.4	34.2	0.0	
2	16	6	1	6.0	12.0	0.35	9	0	12.9	25.8	0.0	
6	20	7	1	7.0	42.0	0.18	8	0	12.8	96.8	0.0	
4	24	8	1	9.6	38.4	0.14	9	0	18.3	73.2	0.01	
1	32	10	1	12.0	12.0	0.06	13	1	16.0	16.0	0.01	
1	34	11	2	11.0	11.0	0.21	14	1	17.2	17.2	0.01	
1	36	11	2	11.6	11.6	0.19	13	1	19.7	19.7	0.02	
1	40	12	2	12.6	12.6	0.15	14	1	21.2	21.2	0.01	
3	48	14	2	14.7	44.1	0.07	14	1	20.8	62.4	0.01	
2	62	18	2	21.1	42.2	0.02	18	2	21.1	42.2	0.02	
3	64	18	2	20.9	62.7	0.02	18	2	20.9	62.7	0.02	
1	66	19	2	25.5	25.5	0.01	18	2	23.8	23.8	0.02	
11	68	19	2	25.3	278.3	0.01	19	2	25.3	278.3	0.01	
2	72	20	2	26.6	53.2	0.01	18	2	23.2	46.4	0.02	
10	80	22	3	24.6	246.0	0.02	19	2	27.7	277.0	0.02	
9	84	23	3	25.8	232.2	0.01	18	2	25.2	226.8	0.02	
7	88	24	3	26.9	188.3	0.01	19	2	26.7	186.9	0.01	
14	96	26	3	31.8	445.2	0.0	18	2	27.3	382.2	0.02	
11	100	27	3	33.1	364.1	0.0	19	2	29.0	319.0	0.02	
12	104	28	3	34.3	411.6	0.0	19	2	28.6	343.2	0.02	
9	112	30	3	40.8	367.2	0.0	23	3	27.8	250.2	0.02	
1	116	31	4	33.6	33.6	0.0	23	3	27.5	27.5	0.02	
4	128	34	4	39.2	156.8	0.0	23	3	28.7	114.8	0.02	
1	140	37	4	46.1	46.1	0.01	23	3	30.0	30.0	0.02	
WEIGHTED TOTAL				3178.7			3008.3					
WEIGHTED AVERAGE							0.05			0.02		

optimum sampling plans require 5 percent fewer welds to be radiographed annually.

As a rule, the optimum sampling plans require more welds to be radiographed than does the existing acceptance procedure when lot sizes are small. Small lot sizes occur less frequently, as inferred from 1984 data, so inspection savings for the larger lot sizes play the dominant role in determining which set of plans is most economical. Note that the net savings is expected to be greater still if percent defective values less than 7 percent are typically submitted for acceptance. In fact, up to 20 percent savings would be realized if quality levels were to consistently approach zero percent defective. And, finally, the optimum acceptance plans achieve this economy with a stabilized risk. Thus, the optimum sampling plans appear to be clearly preferable to those plans currently in use.

COST CONSIDERATIONS

Reduced radiography rates do not translate directly into proportionately reduced costs. Many elements within the radiographic program represent fixed expenses. Travel, equipment and film badge costs, for example, would remain virtually constant while labor and film costs might fluctuate.

In 1984 921 radiographs were shot at a total cost of approximately \$42,000. Knowledgeable NJDOT personnel have indicated this was a relatively light year and that up to five times this many radiographs have been shot annually in the past. Thus the total cost of the aluminum weld inspection program could very well exceed \$200,000 per year. Excluding the share paid by fabricators for defective welds found, the flexible cost associated with the 1984 construction season was approximately \$32,000.

This cost, which could reach the \$150,000 mark in a busier year, is most conveniently evaluated as the cost rate per 1000 radiographs shot.

Table 5 shows the annual flexible cost as a function of the radiographs shot and the anticipated savings resultant from a decrease in the sampling rate. A reasonable number of annual radiographs to consider may be the median value in Table 5, approximately 3000 per year. For this value, an annual savings of nearly \$5,000 to \$20,000 could be realized with the implementation of the alternative sampling plan previously identified. The lower limit of this range would result if it were commonly necessary to inspect more welds than the minimum required, and the upper limit would result if, as a result of the alternative plan's implementation, fabricator quality were to be spurred on to improvement. Perhaps the most reasonable value to expect is an annual savings of approximately \$9,000 to \$10,000. It is thought that most of this savings would result simply from the reduced sample sizes, but a small contribution from increased quality of production is also intuitively expected.

CLUSTER SAMPLING

A discrepancy between the statistical theory assumed appropriate and practical application of weld radiography introduces a flaw into the preceding analysis. Fortunately this discrepancy was found to have a small impact in the present application, but its effects and implications represent a potential concern which could not go unaddressed.

The discrepancy arises from the known violation of a fundamental, underlying assumption. Contrary to theory, the welds inspected are not selected in accordance with standard procedures for obtaining independent,

TABLE 5

NJDOT SAVINGS PER 1000 RADIOGRAPHS

<u>NUMBER OF RADIOGRAPHS SHOT PER YEAR</u>	<u>ANNUAL FLEXIBLE COST, \$</u>	<u>SAVINGS RESULTANT FROM % REDUCTION IN SAMPLING RATE, \$</u>		
		<u>5%</u>	<u>10%</u>	<u>20%</u>
1,000	31,870	1,594	3,187	6,374
2,000	63,740	3,187	6,374	12,748
3,000	95,610	4,781	9,561	19,122
4,000	127,480	6,374	12,748	25,496
5,000	159,350	7,968	15,935	31,870

random samples. They are selected in fixed clusters as they naturally occur. Thus, after the first weld is randomly selected from all possible welds, adjacent welds are automatically inspected and non-adjacent welds may escape inspection altogether. If the weld fabrication environment is such that the defects produced tend to be correlated with one another, then the specter is raised that clusters which are entirely defective may fail to be detected. Conventional risk analyses are insensitive to this and, fooled by the large number of welds inspected, may substantially understate the incurred risk.

A computer simulation model was developed to investigate the nature and degree of bias introduced when the fundamental assumption of independent, random sampling is violated. Lots of varying size were generated in which the total number of defective welds was a controlled variable, and in which the degree of association between two consecutively generated welds could be specified. (Serial correlation was specified within a continuous variable and converted to attribute-type data in the simulated structure. This is believed to realistically represent the manner in which defective welds would tend to be correlated).

Each of the modeled structures was then sampled in two ways, simulating alternative acceptance procedures -- cluster sampling (the current NJDOT practice) and true random sampling. It was possible to tabulate whether the acceptance procedure disposed of each structure properly since the simulated quality levels were known. The long run average frequency with which each procedure correctly rejected defective lots and accepted non-defective lots could then be compared.

The impacts of the sampling technique and the degree of serial correlation (r_s) on the acceptance procedure are shown in Table 6. It can be shown that when $r_s = 0.0$, application of random or cluster sampling

TABLE 6

IMPACT OF CLUSTER SAMPLING AND SERIAL CORRELATION

<u>SAMPLING PROCEDURE</u>	$(r_s = 0)$	$(r_s = \text{LARGE})$
	<u>INDEPENDENT OBSERVATIONS</u>	<u>ASSOCIATED OBSERVATIONS</u>
Random	Reference Datum	Seller's risk, α and buyer's risk β , slightly increased
Cluster	Same as reference datum	Seller's risk, α , and buyer's risk, β , increased to a greater extent

procedures result in equivalent operating characteristics. When the degree of correlation is large, both the producer's risk and the buyer's risk are increased. When the correlation is large and cluster sampling procedures are used, these risks are increased to a still greater extent.

Serial correlation and cluster sampling have a disproportionate and increasingly larger effect on the acceptance procedure as the absolute value of r_s approaches 1.0. This effect is negligible for small percent defective values and increases as the percent defective value grows. This phenomenon is illustrated in Figure 2. Horizontal lines would have been produced if the probabilities of acceptance were independent of the serial correlation. It may be observed that serial correlation introduces greater bias (a steeper slope in Figure 2) when the percent defective values are moderately large. Fortunately, the probability of acceptance (without triggering the 100 percent inspection provision) is relatively small in this region. Extremely large values of serial correlation may also affect the probabilities of acceptance even at small percent defective levels, although such high correlation values are very improbable.

Simulation analyses indicate that the impact of cluster sampling is practically negligible in this application for low levels of serial correlation among weld defects and relatively low levels of percent defective. The degree of serial correlation would have to be rather large (e.g., $r_s = 0.5$) for its effect to be pronounced. At the $r_s = 0.2$ level of serial correlation, a value higher than actually observed in the few lots checked, probabilities of acceptance were increased by approximately 0.03 (or less) in the vicinity of the RQL. Near the 5 percent defective level, the opposite effect was observed with cluster sampling reducing the probability of accepting satisfactory lots by an even smaller amount. AOQL and ATI values were not greatly affected.

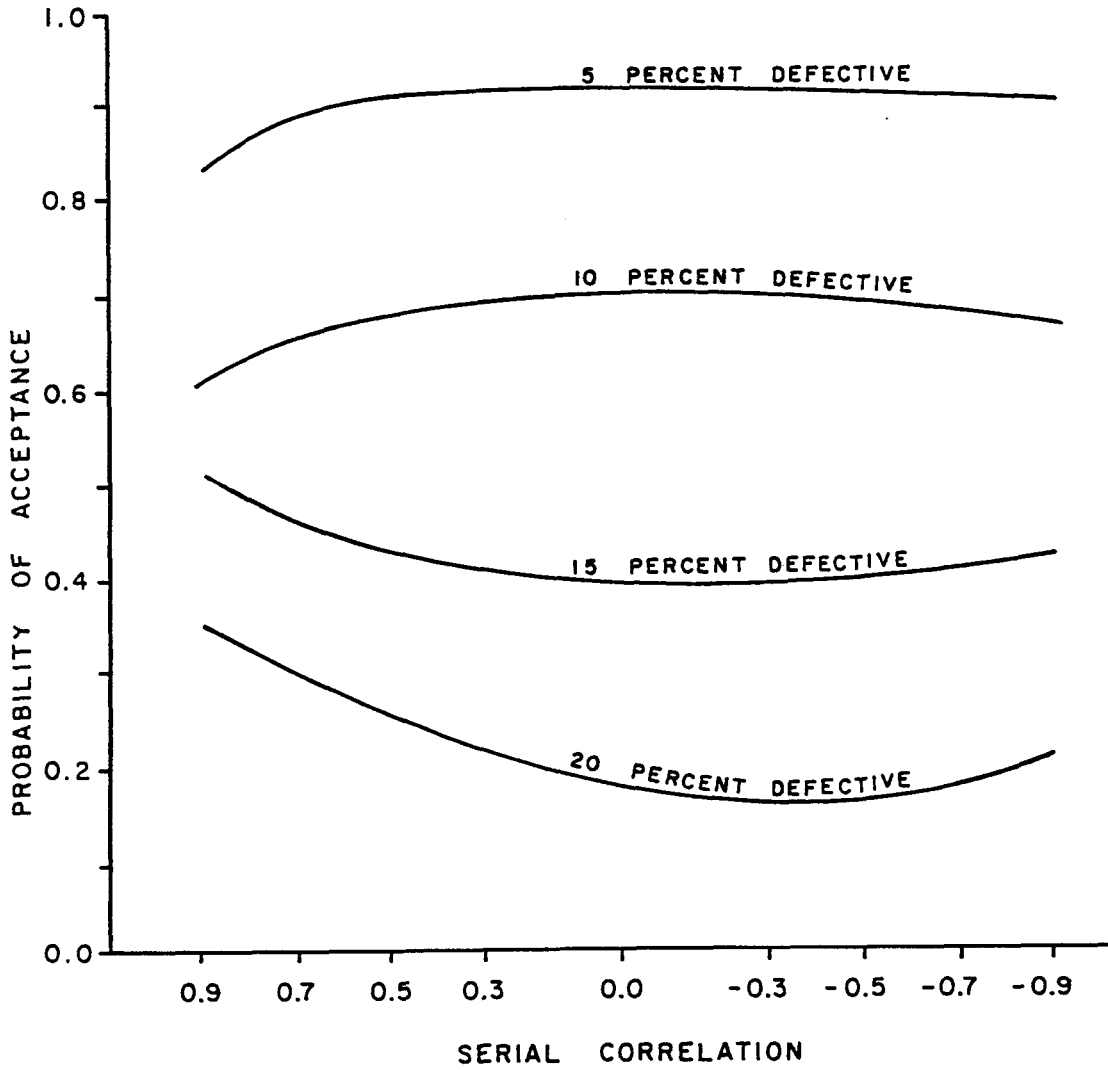


Figure 2. The effect of serial correlation on the probability of acceptance in clustered samples.

Serial correlation itself cannot be controlled, of course, so it is the manner in which it is treated by the acceptance procedure which must be considered. The computer simulation tests strongly suggest that cluster sampling is not a serious problem in the present application.

CONCLUSIONS

The influence of cluster sampling in a procedure where random sampling is assumed has been determined. It is fortuitous that, in the current application, this influence was found to be negligible.

The existing aluminum weld radiographic acceptance procedure appears to provide adequate protection against the acceptance of defective welds, even if this degree of protection is not consistent. Should quality levels worse than 33 percent defective be submitted, these defects will usually be detected provided the lot size is reasonably large. The acceptance procedure becomes increasingly more lenient as the lot sizes are reduced, however, although those increased risks are somewhat offset by the relative scarcity of very small lots. The cost of administering this acceptance procedure is dependent upon the level of construction activity in any given year. Generally, this cost is expected to run between \$40,000 and \$200,000 annually.

An alternative acceptance strategy has been identified which stabilizes the risk of failing to detect defective welds. This risk is kept small regardless of the size of the lot. When compared to the existing sampling strategy, small lots are inspected more thoroughly and large lots are inspected more efficiently. The net result is a reduction in the number of radiographs required to be shot. This reduction may range from 5% to 20% of the number presently required. Translated to dollars, one estimate of the associated savings is \$10,000 per year. Reasonable

lower and upper bounds on this savings might be \$1,000 and \$32,000, respectively, depending upon the quality levels actually submitted, the level of construction activity, and the efficiency with which welds may be included on a radiograph.

Regardless of the acceptance strategy one uses, a risk always exists that defective welds may pass undetected. The proposed acceptance plans stabilize this risk near the existing minimum level, rendering these plans both more effective and more economical. Their implementation by the NJDOT is warranted.

REFERENCES

- 1) Grant, E.L., and Leavenworth, R.S., Statistical Quality Control, 5th Ed., McGraw-Hill Book Company, New York, 1980, pp. 359-386.

APPENDIX

OPTIMUM ACCEPTANCE PLANS FOR RADIOGRAPHIC
INSPECTION OF ALUMINUM WELDMENTS

INSTRUCTIONS

Use the attached tables to determine the minimum required sample size for any given size lot. Randomly select clusters of welds for radiography until their total number equals or exceeds the minimum required sample size. Accept lot without further tests if the number of defects found in the actual sample size is less than or equal to c , the acceptance number listed for that sample size. Otherwise, 100 percent inspection is required.

EXAMPLE

A specific lot is known to contain 88 welds. Scan down the "N" column to determine that the minimum required sample size for this lot is $n = 17$ welds. Randomly radiograph clusters of welds until the cumulative number of welds equals or exceeds 17. If the cumulative number were to be 18, then refer to the "c" column corresponding to $N = 88$ and $n = 18$ to find the maximum number of permissible defective welds is $c = 2$. If more than c defects are found, then 100 percent inspection is required. Otherwise, accept the lot without further tests.

ALUMINUM WELDMENT RADIOGRAPHIC ACCEPTANCE PROCEDURE

N = Lot Size, n = Sample Size, and c = Acceptance Number.
(Accept lot if c or fewer defects found, otherwise 100% inspect.)

N	n	c	N	n	c	N	n	c	N	n	c	N	n	c
6	5	0	16	14	2	21	10	1	24	18	3	27	17	3
7	6	0	16	15	3	21	11	1	24	19	4	27	18	3
8	5	0	17	6	0	21	12	1	24	20	4	27	19	3
8	6	0	17	7	0	21	13	2	24	21	5	27	20	4
8	7	1	17	8	0	21	14	2	24	22	5	27	21	4
9	6	0	17	9	1	21	15	2	24	23	5	27	22	5
9	7	0	17	10	1	21	16	3	25	7	0	27	23	5
9	8	1	17	11	1	21	17	3	25	8	0	27	24	5
10	6	0	17	12	2	21	18	4	25	9	0	27	25	5
10	7	0	17	13	2	21	19	4	25	10	0	28	11	1
10	8	0	17	14	3	21	20	5	25	11	1	28	12	1
10	9	1	17	15	3	22	7	0	25	12	1	28	13	1
11	6	0	17	16	4	22	8	0	25	13	1	28	14	1
11	7	0	18	7	0	22	9	0	25	14	2	28	15	2
11	8	1	18	8	0	22	10	0	25	15	2	28	16	2
11	9	1	18	9	0	22	11	1	25	16	2	28	17	2
11	10	2	18	10	1	22	12	1	25	17	3	28	18	3
12	6	0	18	11	1	22	13	1	25	18	3	28	19	3
12	7	0	18	12	1	22	14	2	25	19	3	28	20	4
12	8	0	18	13	2	22	15	2	25	20	4	28	21	4
12	9	1	18	14	2	22	16	2	25	21	4	28	22	4
12	10	1	18	15	3	22	17	3	25	22	5	28	23	5
12	11	2	18	16	3	22	18	3	25	23	5	28	24	5
13	7	0	18	17	4	22	19	4	25	24	5	28	25	5
13	8	0	19	7	0	22	20	4	26	7	0	29	11	1
13	9	0	19	8	0	22	21	5	26	8	0	29	12	1
13	10	1	19	9	0	23	7	0	26	9	0	29	13	1
13	11	1	19	10	0	23	8	0	26	10	1	29	14	2
13	12	2	19	11	1	23	9	0	26	11	1	29	15	2
14	6	0	19	12	1	23	10	1	26	12	1	29	16	2
14	7	0	19	13	1	23	11	1	26	13	1	29	17	3
14	8	0	19	14	2	23	12	1	26	14	2	29	18	3
14	9	1	19	15	2	23	13	2	26	15	2	29	19	3
14	10	1	19	16	3	23	14	2	26	16	3	29	20	4
14	11	2	19	17	3	23	15	2	26	17	3	29	21	4
14	12	2	19	18	4	23	16	3	26	18	3	29	22	5
14	13	3	20	6	0	23	17	3	26	19	4	29	23	5
15	6	0	20	7	0	23	18	4	26	20	4	29	24	5
15	7	0	20	8	0	23	19	4	26	21	5	29	25	5
15	8	0	20	9	0	23	20	5	26	22	5	30	11	1
15	9	0	20	10	1	23	21	5	26	23	5	30	12	1
15	10	1	20	11	1	23	22	5	26	24	5	30	13	1
15	11	1	20	12	1	24	7	0	26	25	5	30	14	2
15	12	2	20	13	2	24	8	0	27	7	0	30	15	2
15	13	2	20	14	2	24	9	0	27	8	0	30	16	2
15	14	3	20	15	3	24	10	0	27	9	0	30	17	2
16	7	0	20	16	3	24	11	1	27	10	0	30	18	3
16	8	0	20	17	4	24	12	1	27	11	1	30	19	3
16	9	0	20	18	4	24	13	1	27	12	1	30	20	4
16	10	1	20	19	5	24	14	2	27	13	1	30	21	4
16	11	1	21	7	0	24	15	2	27	14	2	30	22	4
16	12	1	21	8	0	24	16	2	27	15	2	30	23	5
16	13	2	21	9	0	24	17	3	27	16	2	30	24	5

ALUMINUM WELDMENT RADIOGRAPHIC ACCEPTANCE PROCEDURE

N = Lot Size, n = Sample Size, and c = Acceptance Number.
(Accept lot if c or fewer defects found, otherwise 100% inspect.)

N	n	c	N	n	c	N	n	c	N	n	c	N	n	c
30	25	5	34	20	3	38	14	1	41	24	5	45	20	3
31	12	1	34	21	4	38	15	2	41	25	5	45	21	3
31	13	1	34	22	4	38	16	2	42	12	1	45	22	4
31	14	1	34	23	4	38	17	2	42	13	1	45	23	4
31	15	2	34	24	5	38	18	3	42	14	1	45	24	4
31	16	2	34	25	5	38	19	3	42	15	2	45	25	5
31	17	2	35	11	1	38	20	3	42	16	2	46	12	1
31	18	3	35	12	1	38	21	4	42	17	2	46	13	1
31	19	3	35	13	1	38	22	4	42	18	2	46	14	1
31	20	3	35	14	2	38	23	4	42	19	3	46	15	1
31	21	4	35	15	2	38	24	5	42	20	3	46	16	2
31	22	4	35	16	2	38	25	5	42	21	3	46	17	2
31	23	4	35	17	2	39	12	1	42	22	4	46	18	2
31	24	5	35	18	3	39	13	1	42	23	4	46	19	3
31	25	5	35	19	3	39	14	1	42	24	4	46	20	3
32	11	1	35	20	4	39	15	2	42	25	5	46	21	3
32	12	1	35	21	4	39	16	2	43	12	1	46	22	3
32	13	1	35	22	4	39	17	2	43	13	1	46	23	4
32	14	2	35	23	5	39	18	3	43	14	1	46	24	4
32	15	2	35	24	5	39	19	3	43	15	1	46	25	4
32	16	2	35	25	5	39	20	3	43	16	2	47	12	1
32	17	3	36	11	1	39	21	4	43	17	2	47	13	1
32	18	3	36	12	1	39	22	4	43	18	2	47	14	1
32	19	3	36	13	1	39	23	4	43	19	3	47	15	2
32	20	4	36	14	1	39	24	5	43	20	3	47	16	2
32	21	4	36	15	2	39	25	5	43	21	3	47	17	2
32	22	4	36	16	2	40	12	1	43	22	4	47	18	2
32	23	5	36	17	2	40	13	1	43	23	4	47	19	3
32	24	5	36	18	3	40	14	1	43	24	4	47	20	3
32	25	5	36	19	3	40	15	1	43	25	5	47	21	3
33	11	1	36	20	3	40	16	2	44	11	1	47	22	4
33	12	1	36	21	4	40	17	2	44	12	1	47	23	4
33	13	1	36	22	4	40	18	2	44	13	1	47	24	4
33	14	1	36	23	4	40	19	3	44	14	1	47	25	5
33	15	2	36	24	5	40	20	3	44	15	2	48	12	1
33	16	2	36	25	5	40	21	3	44	16	2	48	13	1
33	17	2	37	12	1	40	22	4	44	17	2	48	14	1
33	18	3	37	13	1	40	23	4	44	18	3	48	15	1
33	19	3	37	14	1	40	24	4	44	19	3	48	16	2
33	20	3	37	15	2	40	25	5	44	20	3	48	17	2
33	21	4	37	16	2	41	11	1	44	21	4	48	18	2
33	22	4	37	17	2	41	12	1	44	22	4	48	19	3
33	23	5	37	18	2	41	13	1	44	23	4	48	20	3
33	24	5	37	19	3	41	14	1	44	24	5	48	21	3
33	25	5	37	20	3	41	15	2	44	25	5	48	22	4
34	12	1	37	21	3	41	16	2	45	12	1	48	23	4
34	13	1	37	22	4	41	17	2	45	13	1	48	24	4
34	14	1	37	23	4	41	18	3	45	14	1	48	25	5
34	15	2	37	24	4	41	19	3	45	15	2	49	12	1
34	16	2	37	25	5	41	20	3	45	16	2	49	13	1
34	17	2	38	11	1	41	21	4	45	17	2	49	14	1
34	18	3	38	12	1	41	22	4	45	18	2	49	15	1
34	19	3	38	13	1	41	23	4	45	19	3	49	16	2

ALUMINUM WELDMENT RADIOGRAPHIC ACCEPTANCE PROCEDURE

N = Lot Size, n = Sample Size, and c = Acceptance Number.
 (Accept lot if c or fewer defects found, otherwise 100% inspect.)

N	n	c	N	n	c	N	n	c	N	n	c	N	n	c
49	17	2	53	14	1	56	25	4	60	22	3	64	19	2
49	18	2	53	15	1	57	12	1	60	23	4	64	20	3
49	19	3	53	16	2	57	13	1	60	24	4	64	21	3
49	20	3	53	17	2	57	14	1	60	25	4	64	22	3
49	21	3	53	18	2	57	15	1	61	12	1	64	23	4
49	22	3	53	19	2	57	16	2	61	13	1	64	24	4
49	23	4	53	20	3	57	17	2	61	14	1	64	25	4
49	24	4	53	21	3	57	18	2	61	15	1	65	13	1
49	25	4	53	22	3	57	19	3	61	16	2	65	14	1
50	12	1	53	23	4	57	20	3	61	17	2	65	15	1
50	13	1	53	24	4	57	21	3	61	18	2	65	16	1
50	14	1	53	25	4	57	22	3	61	19	2	65	17	2
50	15	1	54	12	1	57	23	4	61	20	3	65	18	2
50	16	2	54	13	1	57	24	4	61	21	3	65	19	2
50	17	2	54	14	1	57	25	4	61	22	3	65	20	3
50	18	2	54	15	1	58	12	1	61	23	4	65	21	3
50	19	2	54	16	2	58	13	1	61	24	4	65	22	3
50	20	3	54	17	2	58	14	1	61	25	4	65	23	3
50	21	3	54	18	2	58	15	1	62	12	1	65	24	4
50	22	3	54	19	3	58	16	2	62	13	1	65	25	4
50	23	4	54	20	3	58	17	2	62	14	1	66	16	2
50	24	4	54	21	3	58	18	2	62	15	1	66	17	2
50	25	4	54	22	3	58	19	2	62	16	2	66	18	2
51	12	1	54	23	4	58	20	3	62	17	2	66	19	2
51	13	1	54	24	4	58	21	3	62	18	2	66	20	3
51	14	1	54	25	4	58	22	3	62	19	2	66	21	3
51	15	1	55	12	1	58	23	4	62	20	3	66	22	3
51	16	2	55	13	1	58	24	4	62	21	3	66	23	4
51	17	2	55	14	1	58	25	4	62	22	3	66	24	4
51	18	2	55	15	1	59	12	1	62	23	3	66	25	4
51	19	3	55	16	2	59	13	1	62	24	4	67	16	2
51	20	3	55	17	2	59	14	1	62	25	4	67	17	2
51	21	3	55	18	2	59	15	1	63	12	1	67	18	2
51	22	4	55	19	2	59	16	2	63	13	1	67	19	2
51	23	4	55	20	3	59	17	2	63	14	1	67	20	3
51	24	4	55	21	3	59	18	2	63	15	1	67	21	3
51	25	4	55	22	3	59	19	2	63	16	2	67	22	3
52	12	1	55	23	4	59	20	3	63	17	2	67	23	4
52	13	1	55	24	4	59	21	3	63	18	2	67	24	4
52	14	1	55	25	4	59	22	3	63	19	2	67	25	4
52	15	1	56	12	1	59	23	3	63	20	3	68	17	2
52	16	2	56	13	1	59	24	4	63	21	3	68	18	2
52	17	2	56	14	1	59	25	4	63	22	3	68	19	2
52	18	2	56	15	1	60	12	1	63	23	4	68	20	3
52	19	2	56	16	2	60	13	1	63	24	4	68	21	3
52	20	3	56	17	2	60	14	1	63	25	4	68	22	3
52	21	3	56	18	2	60	15	1	64	12	1	68	23	3
52	22	3	56	19	2	60	16	2	64	13	1	68	24	4
52	23	4	56	20	3	60	17	2	64	14	1	68	25	4
52	24	4	56	21	3	60	18	2	64	15	1	69	16	2
52	25	4	56	22	3	60	19	3	64	16	2	69	17	2
53	12	1	56	23	4	60	20	3	64	17	2	69	18	2
53	13	1	56	24	4	60	21	3	64	18	2	69	19	2

ALUMINUM WELDMENT RADIOGRAPHIC ACCEPTANCE PROCEDURE

N = Lot Size, n = Sample Size, and c = Acceptance Number.
 (Accept lot if c or fewer defects found, otherwise 100% inspect.)

N	n	c	N	n	c	N	n	c	N	n	c	N	n	c
69	20	3	74	25	4	80	20	2	86	17	2	91	23	3
69	21	3	75	16	2	80	21	3	86	18	2	91	24	4
69	22	3	75	17	2	80	22	3	86	19	2	91	25	4
69	23	4	75	18	2	80	23	3	86	20	2	92	17	2
69	24	4	75	19	2	80	24	4	86	21	3	92	18	2
69	25	4	75	20	3	80	25	4	86	22	3	92	19	2
70	16	2	75	21	3	81	16	2	86	23	3	92	20	2
70	17	2	75	22	3	81	17	2	86	24	4	92	21	3
70	18	2	75	23	4	81	18	2	86	25	4	92	22	3
70	19	2	75	24	4	81	19	2	87	16	2	92	23	3
70	20	3	75	25	4	81	20	3	87	17	2	92	24	4
70	21	3	76	16	2	81	21	3	87	18	2	92	25	4
70	22	3	76	17	2	81	22	3	87	19	2	93	16	2
70	23	3	76	18	2	81	23	3	87	20	3	93	17	2
70	24	4	76	19	2	81	24	4	87	21	3	93	18	2
70	25	4	76	20	3	81	25	4	87	22	3	93	19	2
71	17	2	76	21	3	82	17	2	87	23	3	93	20	3
71	18	2	76	22	3	82	18	2	87	24	4	93	21	3
71	19	2	76	23	3	82	19	2	87	25	4	93	22	3
71	20	3	76	24	4	82	20	3	88	17	2	93	23	3
71	21	3	76	25	4	82	21	3	88	18	2	93	24	4
71	22	3	77	17	2	82	22	3	88	19	2	93	25	4
71	23	3	77	18	2	82	23	3	88	20	3	94	17	2
71	24	4	77	19	2	82	24	4	88	21	3	94	18	2
71	25	4	77	20	3	82	25	4	88	22	3	94	19	2
72	16	2	77	21	3	83	17	2	88	23	3	94	20	3
72	17	2	77	22	3	83	18	2	88	24	4	94	21	3
72	18	2	77	23	3	83	19	2	88	25	4	94	22	3
72	19	2	77	24	4	83	20	2	89	17	2	94	23	3
72	20	3	77	25	4	83	21	3	89	18	2	94	24	4
72	21	3	78	16	2	83	22	3	89	19	2	94	25	4
72	22	3	78	17	2	83	23	3	89	20	2	95	17	2
72	23	4	78	18	2	83	24	4	89	21	3	95	18	2
72	24	4	78	19	2	83	25	4	89	22	3	95	19	2
72	25	4	78	20	3	84	16	2	89	23	3	95	20	2
73	16	2	78	21	3	84	17	2	89	24	4	95	21	3
73	17	2	78	22	3	84	18	2	89	25	4	95	22	3
73	18	2	78	23	4	84	19	2	90	16	2	95	23	3
73	19	2	78	24	4	84	20	3	90	17	2	95	24	4
73	20	3	78	25	4	84	21	3	90	18	2	95	25	4
73	21	3	79	16	2	84	22	3	90	19	2	96	16	2
73	22	3	79	17	2	84	23	3	90	20	3	96	17	2
73	23	3	79	18	2	84	24	4	90	21	3	96	18	2
73	24	4	79	19	2	84	25	4	90	22	3	96	19	2
73	25	4	79	20	3	85	17	2	90	23	3	96	20	3
74	17	2	79	21	3	85	18	2	90	24	4	96	21	3
74	18	2	79	22	3	85	19	2	90	25	4	96	22	3
74	19	2	79	23	3	85	20	3	91	17	2	96	23	3
74	20	3	79	24	4	85	21	3	91	18	2	96	24	4
74	21	3	79	25	4	85	22	3	91	19	2	96	25	4
74	22	3	80	17	2	85	23	3	91	20	3	97	17	2
74	23	3	80	18	2	85	24	4	91	21	3	97	18	2
74	24	4	80	19	2	85	25	4	91	22	3	97	19	2

ALUMINUM WELDMENT RADIOGRAPHIC ACCEPTANCE PROCEDURE

N = Lot Size, n = Sample Size, and c = Acceptance Number.
 (Accept lot if c or fewer defects found, otherwise 100% inspect.)

N	n	c	N	n	c	N	n	c	N	n	c	N	n	c
97	20	3	103	18	2	108	29	5	114	20	3	119	22	3
97	21	3	103	19	2	108	30	5	114	21	3	119	23	3
97	22	3	103	20	2	109	21	3	114	22	3	119	24	3
97	23	3	103	21	3	109	22	3	114	23	3	119	25	4
97	24	4	103	22	3	109	23	3	114	24	4	119	26	4
97	25	4	103	23	3	109	24	4	114	25	4	119	27	4
98	17	2	103	24	4	109	25	4	114	26	4	119	28	5
98	18	2	103	25	4	109	26	4	114	27	4	119	29	5
98	19	2	104	17	2	109	27	4	114	28	5	119	30	5
98	20	2	104	18	2	109	28	5	114	29	5	120	21	3
98	21	3	104	19	2	109	29	5	114	30	5	120	22	3
98	22	3	104	20	2	109	30	5	115	21	3	120	23	3
98	23	3	104	21	3	110	21	3	115	22	3	120	24	4
98	24	4	104	22	3	110	22	3	115	23	3	120	25	4
98	25	4	104	23	3	110	23	3	115	24	4	120	26	4
99	16	2	104	24	4	110	24	3	115	25	4	120	27	4
99	17	2	104	25	4	110	25	4	115	26	4	120	28	5
99	18	2	105	17	2	110	26	4	115	27	4	120	29	5
99	19	2	105	18	2	110	27	4	115	28	5	120	30	5
99	20	3	105	19	2	110	28	5	115	29	5	121	21	3
99	21	3	105	20	3	110	29	5	115	30	5	121	22	3
99	22	3	105	21	3	110	30	5	116	21	3	121	23	3
99	23	3	105	22	3	111	20	3	116	22	3	121	24	4
99	24	4	105	23	3	111	21	3	116	23	3	121	25	4
99	25	4	105	24	4	111	22	3	116	24	3	121	26	4
100	17	2	105	25	4	111	23	3	116	25	4	121	27	4
100	18	2	106	17	2	111	24	4	116	26	4	121	28	5
100	19	2	106	18	2	111	25	4	116	27	4	121	29	5
100	20	2	106	19	2	111	26	4	116	28	5	121	30	5
100	21	3	106	20	2	111	27	4	116	29	5	122	21	3
100	22	3	106	21	3	111	28	5	116	30	5	122	22	3
100	23	3	106	22	3	111	29	5	117	20	3	122	23	3
100	24	4	106	23	3	111	30	5	117	21	3	122	24	3
100	25	4	106	24	4	112	21	3	117	22	3	122	25	4
101	17	2	106	25	4	112	22	3	117	23	3	122	26	4
101	18	2	107	17	2	112	23	3	117	24	4	122	27	4
101	19	2	107	18	2	112	24	4	117	25	4	122	28	5
101	20	2	107	19	2	112	25	4	117	26	4	122	29	5
101	21	3	107	20	2	112	26	4	117	27	4	122	30	5
101	22	3	107	21	3	112	27	4	117	28	5	123	21	3
101	23	3	107	22	3	112	28	5	117	29	5	123	22	3
101	24	4	107	23	3	112	29	5	117	30	5	123	23	3
101	25	4	107	24	3	112	30	5	118	21	3	123	24	4
102	17	2	107	25	4	113	21	3	118	22	3	123	25	4
102	18	2	108	20	3	113	22	3	118	23	3	123	26	4
102	19	2	108	21	3	113	23	3	118	24	4	123	27	4
102	20	3	108	22	3	113	24	3	118	25	4	123	28	5
102	21	3	108	23	3	113	25	4	118	26	4	123	29	5
102	22	3	108	24	4	113	26	4	118	27	4	123	30	5
102	23	3	108	25	4	113	27	4	118	28	5	124	21	3
102	24	4	108	26	4	113	28	5	118	29	5	124	22	3
102	25	4	108	27	4	113	29	5	118	30	5	124	23	3
103	17	2	108	28	5	113	30	5	119	21	3	124	24	4

ALUMINUM WELDMENT RADIOGRAPHIC ACCEPTANCE PROCEDURE

N = Lot Size, n = Sample Size, and c = Acceptance Number.
(Accept lot if c or fewer defects found, otherwise 100% inspect.)

N	n	c	N	n	c	N	n	c	N	n	c	N	n	c
124	25	4	129	28	5	135	21	3	140	24	3	145	27	4
124	26	4	129	29	5	135	22	3	140	25	4	145	28	5
124	27	4	129	30	5	135	23	3	140	26	4	145	29	5
124	28	5	130	21	3	135	24	4	140	27	4	145	30	5
124	29	5	130	22	3	135	25	4	140	28	5	146	21	3
124	30	5	130	23	3	135	26	4	140	29	5	146	22	3
125	21	3	130	24	3	135	27	4	140	30	5	146	23	3
125	22	3	130	25	4	135	28	5	141	21	3	146	24	3
125	23	3	130	26	4	135	29	5	141	22	3	146	25	4
125	24	3	130	27	4	135	30	5	141	23	3	146	26	4
125	25	4	130	28	5	136	21	3	141	24	4	146	27	4
125	26	4	130	29	5	136	22	3	141	25	4	146	28	5
125	27	4	130	30	5	136	23	3	141	26	4	146	29	5
125	28	5	131	21	3	136	24	3	141	27	4	146	30	5
125	29	5	131	22	3	136	25	4	141	28	5	147	21	3
125	30	5	131	23	3	136	26	4	141	29	5	147	22	3
126	21	3	131	24	3	136	27	4	141	30	5	147	23	3
126	22	3	131	25	4	136	28	5	142	21	3	147	24	4
126	23	3	131	26	4	136	29	5	142	22	3	147	25	4
126	24	4	131	27	4	136	30	5	142	23	3	147	26	4
126	25	4	131	28	5	137	21	3	142	24	3	147	27	4
126	26	4	131	29	5	137	22	3	142	25	4	147	28	5
126	27	4	131	30	5	137	23	3	142	26	4	147	29	5
126	28	5	132	21	3	137	24	3	142	27	4	147	30	5
126	29	5	132	22	3	137	25	4	142	28	5	148	21	3
126	30	5	132	23	3	137	26	4	142	29	5	148	22	3
127	21	3	132	24	4	137	27	4	142	30	5	148	23	3
127	22	3	132	25	4	137	28	5	143	21	3	148	24	3
127	23	3	132	26	4	137	29	5	143	22	3	148	25	4
127	24	4	132	27	4	137	30	5	143	23	3	148	26	4
127	25	4	132	28	5	138	21	3	143	24	3	148	27	4
127	26	4	132	29	5	138	22	3	143	25	4	148	28	5
127	27	4	132	30	5	138	23	3	143	26	4	148	29	5
127	28	5	133	21	3	138	24	4	143	27	4	148	30	5
127	29	5	133	22	3	138	25	4	143	28	5	149	21	3
127	30	5	133	23	3	138	26	4	143	29	5	149	22	3
128	21	3	133	24	3	138	27	4	143	30	5	149	23	3
128	22	3	133	25	4	138	28	5	144	21	3	149	24	3
128	23	3	133	26	4	138	29	5	144	22	3	149	25	4
128	24	3	133	27	4	138	30	5	144	23	3	149	26	4
128	25	4	133	28	5	139	21	3	144	24	4	149	27	4
128	26	4	133	29	5	139	22	3	144	25	4	149	28	4
128	27	4	133	30	5	139	23	3	144	26	4	149	29	5
128	28	5	134	21	3	139	24	3	144	27	4	149	30	5
128	29	5	134	22	3	139	25	4	144	28	5	150	21	3
128	30	5	134	23	3	139	26	4	144	29	5	150	22	3
129	21	3	134	24	3	139	27	4	144	30	5	150	23	3
129	22	3	134	25	4	139	28	5	145	21	3	150	24	3
129	23	3	134	26	4	139	29	5	145	22	3	150	25	4
129	24	4	134	27	4	139	30	5	145	23	3	150	26	4
129	25	4	134	28	5	140	21	3	145	24	3	150	27	4
129	26	4	134	29	5	140	22	3	145	25	4	150	28	4
129	27	4	134	30	5	140	23	3	145	26	4	150	29	5