M I D L A N D N U C L E A R P L A N T

LOW ALLOY QUENCHED AND TEMPERED STEEL BOLTING/COMPONENT SUPPORT MATERIALS REVIEW

CONSUMERS POWER COMPANY

DESIGN PRODUCTION DEPARTMENT

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Prepared by:
James A Pastor

mi1082-2825a102

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ATTACHMENTS

1.0 INTRODUCTION

Failures of high strength bolting used in Class I component supports have been reported by several plants since as early as 1970. In most cases these failures have been attributed to intergranular stress corrosion cracking (SCC). A common feature of these reported incidents is that overly hard bolts fabricated from Low Alloy Quenched and Tempered Steels (LAQTS) under sustained high tensile stresses were utilized in a moist environment. The key observation of the field failures was that they involved materials that were above the specified maximum hardness. It is known that the SCC susceptibility of LAQTS materials increases with increased strength (hardness).

A number of materials problems with threaded fasteners fabricated from LAQT steels, have been experienced at the Midland Plant. These problems include failure of Unit 1 reactor anchor studs due to SCC. In addition to SCC concerns, an incident involving the substitution of a plain carbon steel for LAQTS bolting for use in pipe whip restraints, has occurred. This incident, involving a single heat of fasteners, raised further concerns since the supplied documentation erroneously certified the material to be LAQTS. In a further incident it was found that excessive tempering had been applied to such an extent as to produce strength levels below those required by the relevant specification. Also, during hardness testing of installed bolting material it was found that the actual range of hardness values exceeded those specified in referenced specifications.

As a result of these problems, Consumers Power Company (CP Co) made a commitment to the Nuclear Regulatory Commission (NRC) Region III office

as described in the August 18, 1980 letter from the NRC's Mr J G Keppler to CP Co's Mr S H Howell. The commitment was to undertake a review to confirm that safety related low alloy steel bolting and/or component support materials which have been quenched and tempered and are 7/8" or greater in diameter have been procured in accordance with proper codes and standards. Consumers Power Company is leading the investigation required by this commitment.

This report provides a summary and the details of the Low Alloy Quenched and Tempered Steel (LAQTS) bolting and component support evaluation being conducted as a result of the CP Co commitment.

The commitment is defined and clarified as follows:

Low Alloy Steel - The definition assumed is the definition presented in ASTM-354 for alloy steel with the following addition "The total content of alloying elements when summed shall not exceed 5% with the exclusion of carbon and commonly encountered amounts of manganese (0.65%) silicon (0.15%), and copper (0.10%).

Bolting Material - Includes Bechtel Engineering or Construction purchases for 7/8" or greater in diameter bolts, studs (threaded fasteners), rod or bar stock (from which threaded fasteners are fabricated). Examples are purchase orders for steel grouted anchor bolts, embedded anchor bolts or flange bolts.

Component Support Material - Includes Bechtel Engineering or Construction purchases for component support materials, 7/8" or greater in diameter or thickness. The material may be round, flat, etc. Examples are shear pins, support plate, pipe hanger components.

Quenched and Tempered - A low alloy steel is consider to be quenched and tempered if it has experienced the following heat treatment:

- Heating to a temperature of 1550°F or greater followed by rapid cooling in a fluid medium.

- Subsequent heating to a temperature in the range of 650 to 1250°F for a period of 1 to 3 hours, or for thick sections, approximately 1 hour per inch of thickness, usually followed by slow cooling.

Procured in Accordance with Proper Codes and Standards - This phrase is interpreted as meaning that confirmation will be provided that the materials are in accordance with the installation design requirements.

2.0 EVALUATION SUMMARY

To ensure that execution of the commitment will mitigate future materials problems, the underlying reasons for the problems already experienced must be considered. The specific concerns are:

1. Material susceptibility to the SCC failure mode due to a combination of:

   a. lack of a specified upper limit on strength,

   b. high sustained tensile stresses,

   c. a corrosive environment.

2. Material susceptibility to a non-ductile failure mode (low fracture toughness) due to the excess strength properties that contribute to SCC.

3. Wrong materials or improperly heat treated materials being supplied which result in situations where the actual components are too weak for the intended application.

The following paragraphs summarize the LAQTS evaluation. CP Co has the overall responsibility for conducting and is directly managing the evaluation with assistance from others as identified. For details of each activity refer to Section 3.0.

1. Commonwealth Associates Inc (CAI) was responsible for reviewing purchase order and quality records and for providing the quantity of safety-related LAQTS bolting and component support materials which have been purchased. In addition CAI provided data from these orders which is necessary for the evaluation.

2. APTECH Engineering Services (APTECH) is responsible for reviewing the safety-related LAQTS Bolting and component support materials which have been purchased and identifing the material type/grades and/or applications that require further evaluation.

3. Science Applications Inc (SAI) developed the statistically based sampling plan that determined the quantity of items to be tested.

4. CAI was also retained by CP Co to implement the SAI sampling plan by locating and hardness testing the quantities and items recommended for test by SAI. Some hardness testing is also being accomplished by CP Co personnel.

5. SAI was also retained by CP Co to process the raw hardness data collected and produce statistical data to be utilized in the evaluation.

6. APTECH will provide an evaluation method utilizing the statistical data (hardness testing results). Bechtel will provide design calculation results to be used in the evaluation.

7. Quality Control receipt inspection hardness testing has been established to evaluate recent and future purchases of safety-related LAQTS bolting and component support materials per the CP Co commitment.

3.0 EVALUATION DESCRIPTION

3.1 Quantification and Data Collection of Safety-related Bolting and Component Support Materials Purchased.

Commonwealth Associates Inc (CAI) completed this activity in a two phased approach.

Phase I

The first phase consisted of searching safety-related field purchase records and listing all bolting and steel material types purchased. This listing was then evaluated as described in Section 3.2 and reduced to a listing of safety-related LAQTS bolting and component support purchases that required testing and/or further evaluation.

CAI then searched quality records and provided quantities and data to be utilized in the evaluation. This preliminary listing covered field purchase orders placed through the end of June 1981.

Phase II

The second phase of this activity was identical to the first except that it covered:

1. Safety-related field purchase orders placed from July 1981 to June 1982. Site Quality Control receipt inspection hardness testing of LAQTS materials (described in Section 3.7) began in May 1982.

2. Bechtel Engineering purchase orders for LAQTS bolting and component support materials.

3. Field purchase orders for LAQTS materials not previously identified as LAQTS.

The second phase is completed. Preliminary information provided by CAI indicates that approximately 60,000 bolts, studs and approximately 6,000 linear feet of rod wi' require evaluation (Table 3.1-1 provides a summary of material types and quantities identified).

3.2 Identification of Safety-Related Bolting and Component Support Materials Purchased Requiring Evaluation.

APTECH Engineering Services reviewed the CAI listing of bolting and steel material types which were purchased and identified the specifications which could possibly include materials that were LAQTS (Tables 3.2-1). CAI utilized this information in the data collection activity.

The listing of potential LAQTS materials included some non-bolting material specifications. These non-bolting specifications were reviewed by Bechtel to identify the LAQTS materials which were used as component supports.

The combined listing of LAQTS bolting and component support material specifications forms the complete listing of LAQTS materials to be evaluated.

A detailed evaluation of each of these specifications was performed by APTECH to determine which materials or applications could be exempted from further review without violating the intent of the commitment (refer to Appendix 3.2-1 for exemption details).

APTECH then provided the information that resulted in a listing (Table 3.2-2) of LAQTS material specifications/applications to CP Co with the following recommendations for further evaluation:

1. Due to the large quantities of items purchased a reliable statisically based sampling plan should be developed.

2. Hardness measurements of the samples should be utilized to demonstrate compliance with the requirements of the commitment.

   From hardness measurements estimation of tensile strength is possible and, from a knowledge of the behavior of individual materials in tensile tests, yield strength levels may be implied. From such considerations it can reliably be established that proper strength and toughness levels have been achieved and susceptibility to stress corrosion cracking can be evaluated.

3. It may be necessary in some cases to supplement hardness measurements with some destructive testing.

3.3 Sampling Plan

The activities described in Section 3.1 resulted in a listing of approximately 65,000 LAQTS bolts/studs/component support items requiring further evaluation or hardness testing. If 100% testing of that quantity was conducted it would not significantly improve the knowledge of expected performance over the knowledge gained from a sample. Therefore, a statistical sampling plan was utilized. Science Applications Inc (SAI) was retained by CP Co to assist in developing a statistical based sampling plan. The primary objective is to obtain sufficient data to characterize the distribution of hardness values within each of several applications:

1. SAI was provided with the preliminary listing (Phase I quantities, approximately 50,000, and data) of LAQTS bolting and component support materials. SAI developed a preliminary sampling plan based on this information.

   SAI then developed a final sampling plan which incorporated the second phase data and additional materials as discussed in Section 3.1.

2. The major aspects of the sampling plan are as follows:

   a. The total population of material to be evaluated is partitioned into primary strata based on:

      . material specification, type or grade

      . diameter/width

. length category

. application (Table 3.3-1)

b. For small strata size (ie, 50 or less) sample all bolts.

c. Construct histograms.

d. Sample enough to construct (90%-95%) two-sided tolerance intervals for each stratum. These two-sided tolerance intervals will contain 90% of the population with 95% confidence.

e. Construct (90%-95%) one-sided tolerance intervals for each stratum. These one-sided tolerance intervals will be used to support evaluations of stratum that exhibit hardness values outside the range of hardness values allowed.

The criteria discussed in this item and Item d (90%-95%) was taken from the APTECH "Assessment of Stud Integrity for the Reactor Coolant Pump Snubber Anchor Bolting" report transmitted to Mr J G Keppler by Mr J W Cook with CP Co letter dated May 17, 1982.

f. For large stratum (which may contain several subsets such as heat lots) sample enough to be reasonably sure that at least one item will be chosen from each subset. Specifically, the plan was designed so that there is a 95% probability that at least one item from a subset of size 50 will be selected.

g. CP Co is to identify, locate and test the items within each stratum. Within a given stratum diversify the sample as much as possible. Attempt to partition the primary stratum proportionally into secondary strata based on:

- installed location
- vendor
- exact length
- heat lot

3.4 Implementation of Hardness Testing.

A. CAI is assisting in implementing the sampling plan. CAI personnel assisted in developing the method by which LAQTS materials were located and selected for hardness testing. They also were utilized to locate and select the specific bolting and component support materials to be tested. The major aspects of the implementation program are as follows:

1. For civil applications it is generally possible to locate bolts for a primary and/or secondary stratum by comparison of the sampling plan to civil drawings and physical inspection for bolt specific identification markings.

2. For mechanical applications the use of drawings to locate materials is not generally possible. In these cases materials are located by a general walkdown of plant areas utilizing specific size information and material identification markings (ie, material type, vendor, heat lot identification markings). This information is then compared to the sampling plan to identify a primary and/or secondary stratum.

3. The person locating and marking an item for hardness testing enters the following information on a bolt test data sheet (Appendix 3.4-1).

a) application

b) material

c) diameter and length

d) bolt markings

e) detailed description of location.

f) reference drawing (if applicable)

g) purchase order sequence number (if available)- This number identifies the item as part of a specific purchase order delivery and in some cases the material heat lot number.

4. The preliminary test data sheet is provided to the hardness testing personnel for completion of the testing.

CAI is also performing the majority of the hardness testing with the remainder being accomplished by CP Co personnel. The key points of the hardness testing are as follows:

1. Hardness testing is performed according to a procedure developed by CP Co laboratory services department.

2. All on site testing is being accomplished with an Equotip Hardness tester.

3. A portion of the materials have been and/or may be tested at the CP Co laboratory utilizing a Rockwell bench tester.

4. Completed hardness test data sheets are reviewed by CAI personnel for data accurracy prior to submittal to CP Co.

5. CAI has developed and is maintaining a test status log which identifies materials tested and provides a status of the overall program.

3.5 Processing of Hardness Test Data

SAI is processing hardness test data and producing statistical data to be utilized in the evaluation. SAI is also providing computerized tracking of the sampling plan to assure completion. The major aspects of the data processing are as follows:

1. After correction for test impact direction and equipment calibration, raw test data are converted from Equotip LEEB values to Rockwell C averaged data points.

2. Test data are separated into proper strata.

3. The following statistical information is provided by stratum (refer to Appendix 3.5-1 for example).

    a) mean hardness

    b) standard deviation

    c) minimum and maximum sample values

    d) range

    e) skewness

    f) kurtosis

    g) statistical tolerance intervals (non-parametric)

h) histograms showing empirical frequency distribution relative to the hardness specification.

i) Kolmogorov-Smirnov test for goodness-of-fit to a normal population.

4. SAI is providing a table identifying each stratum and test status.

3.6 Evaluation Methods

APTECH Engineering Services, Inc. (APTECH) is assisting Bechtel and CP Co personnel in the evaluation of test results.

APTECH has provided a listing (Table 3.6-1) of all LAQTS materials that provides acceptable hardness ranges (consistant with the ASTM specifications) for each grade and type of material. The hardness ranges were based on ASTM hardness limits or an engineering evaluation of ASTM specified tensile properties where hardness limits were not available.

APTECH is also developing an evaluation procedure that provides a method for determining design allowables, susceptibility to stress corrosion cracking and low toughness failure modes utilizing hardness measurements. This evaluation method is an extension of the methodology described in the "Assessment of Stud Integrity for the Reactor Coolant Pump Snubber Anchor Bolting" report transmitted to the NRC via CP Co letter dated May 17, 1982.

The methods for evaluating the LAQTS materials are as follows:

1. Materials are being allocated into specific stratum as described in Section 3.3.

2. Hardness testing is performed in accordance with the sampling plan described in Section 3.4.

3. Where the statistical results of the hardness testing indicates that the values are within acceptable limits no further evaluation is required.

4. Where the statistical results of hardness testing indicates that the values are above the acceptable limits they will be evaluated using the APTECH methodology to determine susceptability to stress corrosion cracking and low toughness failures.

5. Where the statistical results indicates that the hardness values are below the acceptable limits the results will be:

   a) evaluated using the APTECH methodology to estimate minimum ultimate tensile and yield strengths for the material. These strengths will then be compared to the Bechtel provided design information to assure that they are equal to or exceed the design bases.

   b) evaluated in some cases by tensile testing at the CP Co laboratory. Tensile testing will be performed on the softest identified and accessible materials, based on hardness measurements and the results will be compared to the ASTM specification or Bechtel design requirements to assure adequacy.

6. In cases where the evaluations described in 4 and 5 indicate the materials are unacceptable the materials will be identified as non-conforming and appropriate corrective action will be identified. The corrective action may be:

a) to remove and replace the unacceptable materials.

b) to modify the design to compensate for the reduced allowable loads.

3.7 Quality Control Receipt Inspection Hardness Testing

As discussed in Sections 3.1 and 3.2 purchase orders through June of 1982 were screened to identify safety-related LAQTS bolting and component support materials that required evaluation. A Quality Control Receipt inspection hardness testing program was established to provide evaluation of safety-related LAQTS materials purchased and delivered after May 15, 1982. This program provides assurance that new LAQTS material purchases are evaluated upon delivery (by hardness testing) and determined to be acceptable prior to release for installation. This program is consistant with the commitment to the NRC described in Section 1.0 of this report.

4.0 Evaluation Status and Results

In subsequent revisions to this report this section will be utilized to provide summaries of evaluation results and conclusions drawn from these evaluations.

For this initial submittal the following status of each major activity described in Section 3.0 is provided.

Section 3.1 - Quantification and Data collection.

This activity is virtually completed.

CAI is in the process of completing minor modifications to the listing of LAQTS materials.

Section 3.2 - Identification of Safety Related Bolting and Component Support Materials Requiring Evaluation.

This activity is virtually completed.

APTECH is in the process of preparing a final report that identifies materials to be evaluated. APTECH has incorporated the new materials identified by CAI.

Section 3.3 - Sampling Plan.

SAI is in the process of finalizing the sampling plan by incorporating minor comments and corrections to quantities. SAI has incorporated the new materials identified by CAI and APTECH. The resulting sampling plan

requires hardness testing of approximately 5,800 items from a total population of approximately 65,000 bolts/studs/component support items.

Section 3.4 - Implementation of Hardness Testing.

To date approximately 5,400 LAQTS items have been located and hardness tested. This represents approximately 90% of the total quantity of LAQTS items to be tested.

Section 3.5 - Processing of Hardness Test Data.

To date SAI has provided preliminary statistical data for approximately 5,000 LAQTS items which have been tested. CP Co is in the process of evaluating this data.

Section 3.6 - Evaluation Methods

1. CP Co is conducting preliminary evaluations on completed strata. These evaluations are considered preliminary since the APTECH evaluation method is not in a final form and due to the discovery of the following complicating factor.

   Based on preliminary hardness test results CP Co identified approximately 30 bolting material purchases containing material that appeared to be considerably softer than allowed by the ASTM specifications. Further evaluations and testing on a portion of these indicated that the bolts were actually within the acceptable hardness limits of the ASTM specifications. The differences were determined to be due to the existence of a decarburized layer on the bolts that had not been completely removed during field testing. Based on information provided by the CP Co laboratory these bolting

materials were retested with the decarburized layer removed. The results of the retesting indicated that only two bolting material purchases contained material that actually was considerably softer than allowed by the ASTM specifications. The remainder of these two material purchases will be located and replaced or verified by evaluation to be acceptable for each specific installation location.

2. The results of the retesting discussed above is also being used to develop a retesting program to verify that other strata previously tested are not in fact harder than measured due to decarburization.

3. Preliminary evaluations on completed strata have also resulted in the identification of one bolting purchase that contained material harder than allowed by the plant design criteria and the ASTM specification. This material will also be located and replaced or verified by evaluation to be acceptable for each specific installation location.

4. Completion of all hardness testing and preliminary evaluations (including the retesting due to decarburization) is currently forecast to be July 1983. This report will be reissued following completion of the LAQTS evaluation and disposition of identified problems.

Section 3.7 - Quality Control Receipt Inspection

This activity is fully implemented.

TABLE 3.1-1

SAFETY RELATED LAQTS BOLTING AND COMPONENT SUPPORT MATERIALS

(Preliminary quantities based on CAI Phase I & II data search)

Material Types (All Grades)	Bolting/Stud/Pins Quantities	Rod (Linear Feet)	Size Ranges
A193/SA193 B7	41,141	3,333 (LF)	.875" to 2.5" Dia
A354 BD	3,133	120 (LF)	1.125" to 3.5" Dia
A490	464	0 (LF)	1.5" to 2.5" Dia
A540/SA540	15,053	2,530 (LF)	.875" to 3.5" Dia (Bolts/Studs/Rod 2.5" to 8.25" Dia (Pins)
Total	59,791	5,983 (LF)	

LAQT STEELS CANDIDATE MATERIAL SPECIFICATIONS

ASTM/ASME SPECIFICATION	MATERIAL DESCRIPTION - CLASS OR GRADE
A7-66	Bolts or nuts when included with material purchased can be supplied to A325. See below for conditions when LAQT steels will be supplied to A325.
A36-77A	Bolts or nuts when included with material purchased can be supplied to A325. See below for conditions when LAQT steels will be supplied to A325.
A125-73	Grade designations for standard alloy steels are given in A689 and the low alloy grades are listed below (see Note 1). All grades are quenched and tempered.
SA155-75	Grade CMSH-80 will be required to meet the A537 Class 2 standards. See below for SA537 description.
A182-78	The ferritic grades labelled as F1, F2, F11, F12, F21, F22, and F22a are all low alloy steels and are usually supplied in annealed or normalized and tempered condition. However, liquid quenching followed by tempering can be permitted when agreed to by the purchaser. Parts that are liquid quenched and tempered will be marked QT.
SA182-78	Same as A182
A193-78a	The ferritic grades labelled as B7, B7M, and B16 are fabricated from low alloy steel. Grade B7M is supplied in the quenched and tempered condition; Grades B7 and B16 will be furnished in the quenched and tempered condition if ordered as such by the purchaser.
SA193-78a	Same as A193
A194-78	Grades 4, 7, and 7M are fabricated from low alloy steels. These grades of nuts will be quenched and tempered to meet the required mechanical properties.
SA194-78	Same as A194
A234-80	Low alloy steel would be used in Grades WP1, WP12, WP11, WP22, and WPR. Alloy steel grades are usually furnished in the full-annealed, isothermal-annealed, or normalized and tempered; however, quench and tempering can be permitted for all grades of alloy steel when approved by the purchaser.

ASTM/ASME SPECIFICATION	MATERIAL DESCRIPTION - CLASS OR GRADE
SA234-78	Similar to A234
A304-79	This specification provides for analyses which will ensure a level of hardenability for steel compositions that have the suffix letter "H" added to the conventional grade number. Although this specification has no specific applicational requirements (ie, required strength), it would seem that all material grades purchased with this specification would be candidate for a quenched and tempered treatment. Therefore, the AISI numbers listed below (see Note 1) are the low alloy grades which purchased under A304 would be quenched and tempered.
A320-80b	Grades L1, L7, L7A, L7B, L7C, L7M, and L43 are fabricated from low alloy quenched and tempered steels.
SA320-78	Same as A320 except for the deletion of Grade L1.
A322-80	Grade designations for low alloy steels are given in A29 and the low alloy grades are listed below (see Note 1). Steel bars are normally supplied untreated in hot rolled condition, however, quench and tempered treatment can be requested as a supplemental requirement.
A325-78a	Type 2 and all classes of Type 3 bolts are fabricated from low alloy steels and receive a quench and temper treatment.
SA325-78a	Same as A325
A331-74	Grade designations for alloy steels are specified in A29 and the low alloy grades are listed below (see Note 1). The bars can be furnished as quenched and tempered as specified by the purchaser.
A354-78a	All bolts purchased to A354 are low alloy and in the quenched and tempered condition.
SA354-78a	Same as A354-78a
SA420-78	Grades WPL9 and WPL3 are low alloy steels. All fittings can be furnished in the normalized, normalized and tempered, or quenched and tempered; however; if liquid quenching is used, the fact will be noted on the test report.
A434-76	Grade designations for alloy steels are specified in A29 and the low alloy grades are listed below (see Note 1). All bars are heat treated by quench and tempering.

ASTM/ASME SPECIFICATION	MATERIAL DESCRIPTION - CLASS OR GRADE
A487-80	Classes 1Q, 2Q, 4Q, 4QA, 6Q, 7Q, 8Q, 9Q, 10Q, 11Q, 12Q, 13Q, and 14Q are all LAQT materials. (Note that classes AQ, BQ and CQ are not considered LAQT since the specified composition is not low alloy although some residual amounts of alloy-type elements are allowed.)
A490-77	All bolts (Types 1, 2 and 3) purchased to A490 are quenched and tempered and are made from low alloy steel.
A514-77	All grades supplied will be low alloy steels in the quenched and tempered condition.
A519-80	Low alloy grades for A519 are listed below (see Note 2). Quenched and tempered treatment can be specified among other treatments by the purchaser.
A521-76	Classes CG, AD, AE, AF, AG and AH will be supplied in the quenched and tempered condition. Chemical composition is required to determine whether the material supplied is low alloy.
SA537-78	Material supplied as Class 2 will be in the quenched and tempered condition. Chemical composition is required to determine whether material supplied is low alloy.
A540-77a	All grades supplied will be low alloy steels in the quenched and tempered condition.
SA540-77a	Same as A540
A563-78a	Grade DH3 nuts are low alloy and will be heat treated by a quench and temper process. All classes of grade C3 nuts are low alloy and may be heat treated by quench and tempering.
A574-80	All materials used for A574 are alloy steel in the quenched and tempered condition. Chemical composition or AISI designations is required to determine whether material supplied is low alloy.
A668-79a	Alloy quenched and tempered and potential alloy steels are used in classes, F, FH, J, JH, K, KH, L, LH, M, MH, N and NH. Chemical composition or AISI designations are required to determine whether material supplied is low alloy. A few classes require heat treatment history.
A687-79	All grades supplied will be made from low alloy steels in the quenched and tempered condition.

ASTM/ASME SPECIFICATION	MATERIAL DESCRIPTION - CLASS OR GRADE
A739-76	All grades supplied will be low alloy steel. Cooling from austenitizing temperature is normally in air or moving air, however, quenching by spray or liquid can be performed when permitted by purchaser.
SA739-76	Same as A739
F568-79	Alloy and potential alloy steels in the quenched and tempered condition are supplied for Classes 8.8, 8.8.3, 9.8, 10.9, 10.9.3 and 12.9. Classes 8.8.3 and 10.9.3 are low alloy steels. Chemical compositions or AISI designations for Classes 8.8, 9.8, 10.9, and 12.9 are required to determine whether material supplied is low alloy.

NOTES:

1. Low alloy grades that can be supplied under specification are AISI Series 1300, 4000, 4100, 4300, 4400, 4600, 4700, 4800, 5000, 5100, 6100, 8100, 8600, 8700, 8800, 9200, 9300, and those in the Boron AISI Series 50B00, 51B00, 81B00 and 94B00.

2. Low alloy grades that can be supplied under specifications are AISI Series 1300, 3100, 3300, 4000, 4100, 4300, 4400, 4500, 4600, 4700, 4800, 5000, 5100, E50100, E51100, E52100, 6100, E7100, 8100, 8600, 8700, 8800, 9200, E9300, 9800, and AISI Boron Series 50B00, 51B00, 81B00, 86B00, and 96B00.

LAQTS MATERIALS EVALUATED

Notes

(1) LAQTS bolting/component supports have not been purchased to this specification per the CP Co commitment

(2) Bechtel identified non-bolting LAQTS purchases that are not component supports (not within the scope of the commitment)

(3) APTECH provided technical exclusions (as discussed in Appendix 3.2-1)

(4) A-490 will be tested except for structural steel connections (as discussed in Appendix 3.2-1)

Material Specification	Notes	Material To Be Tested	Type of Spec, Refer To Table 3.2-1 for LAQTS Material Grades
A-7	(3)		Steel Spec
A-36	(3)		Steel Spec
A-125	(3)		Steel Helical Springs (part of spring cans)
SA-155	(1)		Welded Pipe
A-182	(1)		Pipe Flanges/ Fittings/Valves
SA-182	(2)		Pipe Flanges/ Fittings/Valves
A-193		X	Bolting Spec
SA-193		X	Bolting Spec
A-194	(3)		Nut Specification
SA-194	(3)		Nut Specification
A-234	(1)		Pipe Fittings
SA-234	(2)		Pipe Fittings
A-304	(1)		Steel Bars
A-320	(1)		Bolting Spec
SA-320	(1)		Bolting Spec
A-322	(1)		Steel Bars
A-325	(3)		Bolting Spec
SA-325	(3)		Bolting Spec
A-331	(1)		Steel Bars
A-354		X	Bolting Spec
SA-354	(1)		Bolting Spec
SA-420	(2)		Pipe Fittings
A-434	(1)		Steel Bars
A-487	(1)		Steel Casting Spec
A-490	(4)	X	Bolting Spec
A-514	(1)		Steel Plate
A-519	(2)		Steel Tubing

Material Specification	Notes	Material To Be Tested	Type of Spec, Refer To Table 3.2-1 for LAQTS Material Grades
A-521	(1)		Steel Forging Spec
SA-537	(1)		Steel Plate
A-540		X	Bolting Spec
SA-540		X	Bolting Spec
A-563	(3)		Nut Specification
A-574	(1)		Cap Screws
A-668	(1)		Steel Forgings
A-687	(1)		Bolting Spec
A-739	(1)		Steel Bars
SA-739	(1)		Steel Bars
F-568	(1)		Bolting Spec

EXCLUSIONS FROM LAQTS REVIEW
(BASED ON TECHNICAL JUSTIFICATION)

1. Equipment Purchases

Purchase orders for equipment are considered to be outside the scope of the CP Co commitment for the following reasons:

a) The NRC August 18, 1980 letter to CP Co states that the commitment is to confirm that bolting and/or component support materials have been procured in accordance to proper codes and standards. Appendix A of that letter and the details of the NRC investigation indicate that the NRC concern is that of procurement practices for bolting materials and materials to be fabricated into component supports.

b) Vendor supplied equipment is produced according to a vendor Quality Assurance program which provides an additional level of control than is provided by direct bolting or component support material purchases.

Since vendor equipment so produced could be supplied to any nuclear installation it is not consistent to require that only those supplied to CP Co require detailed scrutiny.

c) In addition the NRC I&E programs in effect (information notices, circulars and bulletins) and 10CFR Part 21 provide adequate means for dispostioning problems related to specific vendors.

2. Exemption of Vendor Supplied Units to ASME Section III

In purchasing safety related units which fall within the terms of reference of ASME Section III the purchase order will specify performance required of the unit and that it be constructed in compliance with the relevant portions of the code. However, the purchaser will not, in these circumstances, specify which materials are to be selected for individual components in the units.

In order to comply with the requirements of the code safety related items will require to have one or more of the following stamps: N, NV, NPT, NA. For the case of units supplied complete the N or NV (in the case of valves) stamp is appropriate. For the case of component supports the NPT stamp applies. If the supplier holds a certificate of authorization he is responsible for the quality assurance program associated with his products in order to provide adequate assurance that these items will satisfactorily perform their safety functions. Having executed the quality assurance program the supplier will stamp the component or component support which will then be suitable for use in any compatible nuclear plant. Thus the components so produced could be supplied to any nuclear installation and it is not consistent to require that only those supplied to Consumers Power require detailed scrutiny with regard to the utilization of low alloy quenched and tempered material. Indeed it is the

function of the quality assurance auditor of the certificate holder to ensure that such items as are utilized are procured according to proper codes and standards.

Thus it is concluded that safety related components and component supports that were supplied complete with all the necessary stamps for installation at the Midland Plants are not to be considered a part of Consumers Power's commitment.

3. Nuts/Washers

   a. Principal stress is compressive therefore, no concern for low fracture toughness or stress corrosion cracking.

   b. High preloaded applications will screen out low strength materials.

   c. Failure of nuts is not a known problem.

   d. Receipt inspection of future purchases of LAQTS nuts will provide supporting evidence that nuts are sufficiently strong for application where high preload is not specified and Item (c) above.

4. Material Purchased to A-7 and A-36

   These two specifications allow A-325 bolting as appurtenant material. For exclusion justification refer to A-325 discussion.

5. Structural Steel A-325/A-490 Bolting

   a. Based on evidence generated by the US Department of Transportation (Boeing 1976 report) these are no concerns for problems due to low fracture toughness or stress corrosion cracking of A-325 or A-490 in Nuclear Plant environments.

   b. NRC finding in unresolved safety issue A-12 (NUREG 0577) exhonerates A-325 and A-490 from concerns of low fracture toughness or stress corrosion cracking.

   c. Midland installation techniques, per AISC, ensure that low strength bolts are eliminated at the time of installation.

   d. Millions of A-325 and A-490 bolts have been used to form structural steel connections. Clearly failures of such bolts, for whatever reason are sufficiently rare thus precluding concern.

APPLICATIONS OF LAQTS MATERIALS AT THE MIDLAND PLANT

Civil Applications

Computer Code Number	
1	Connection Bolts - Metal to Metal (Pipe Whip Restraints, Beam Attachments, Etc)
2	Pins (Pipe Whip Restraint)
6	U Bolts (Pipe Whip Restraints)
8*	Reactor Coolant Pump Snubber Anchor Bolts
14	Anchor Bolts (Embedded Bolts)
15	Anchor Bolts (Through Bolts)
18*	Reactor Vessel Anchor Bolts
19	Reactor Vessel Shear Pin

MECHANICAL APPLICATIONS

22	Pipe Supports/Hangers (bolts, studs, rod, pins - replacement parts or Bechtel purchased materials for the fabrication of supports)
23	Anchor Bolts (pipe supports, embedded/grouted or through)
25	Piping Flanges (flanges, orifice plates)

APPLICATIONS EXCLUDED

3	LAQTS Materials Less than 7/8" in Diameter or Thickness
4	Material not LAQTS or Non Bolting LAQTS Material not Utilized as a Component Support
5	Material Being Excluded by Technical Justification (discussed in Appendix 3.2-1)
20	A Purchase Order For Rework of Material Acquired Under Another Purchase Order (materials are identified and tested under the original purchase order)
21	Material Rejected and Returned Not Utilized On Site

*Items not to be included in sampling plan or testing due to previous 100% testing

Consumers Power Company

SP&LS
METALLURGICAL DEPARTMENT
Bolt/Stud Test

Proc No. MET-06
Attachment B
Revision 2

Page No. _____

(Do not duplicate this number on this date)

Date _____ Operator _____

Equotip or Instrument # _____

(If other, clarify in Comments Section)

Correction Factor Page Number _____ Reference Drawing _____

Application (Check One)

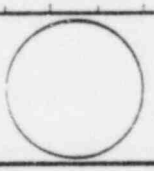
Civil	Mechanical	Other (Explain)
☐ Connection Bolt	☐ Pipe Support/Hanger	
☐ Pin (Pipe Whip Rstr)	☐ Anchor Bolts	
☐ Embedded Anchor	☐ Pipe Flanges	
☐ Through Anchor		
☐ U-Bolt		
☐ Reactor Vessel Shear Pin		

CAI Sequence Number _____

Material _____

Diameter (Inches) _____

Length (Feet) _____ (Inches) _____



Duplicate Bolt/Stud Markings Include Material, Type, Radial Lines, Underlines, etc

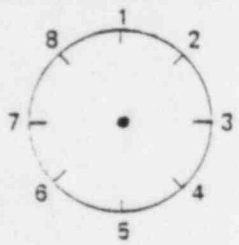
Thread End

Unique Bolt/Stud Location and/or Equipment Description ☐ Unit 1 ☐ Unit 2 ☐ Common

Page No. That Provides Above Data _____

Impacts on Bolt Head or Stud End Unless Noted

Impact Direction (Arrow on Clock Face)



All Field L-Values

(Minimum of Five, One in Each Area)

Center	Midradius	Outside	(Clarify in Comments) Other

Comments _____

SAMPLE STATISTICS

- STRATUM 23: A540 B23 C3, EMBEDDED ANCHOR BOLTS, 2.5 INCH DIA, LENGTH GREATER THAN 24 INCH.

- STRATUM SIZE: 448, SAMPLE SIZE: 50.

- ASTM SPECIFICATION: 31 HRC TO 39 HRC.

- DATA RANGE: 30.2 HRC TO 37.6 HRC.

- 98% OF OBSERVATIONS FALL WITHIN SPECIFICATION.

- MEAN = 34.6 HRC; STD DEVIATION = 1.6 HRC.

- NON-PARAMETRIC TOLERANCE INTERVAL (90% PROB, 95% CONFIDENCE, 2-SIDED): 31.2 HRC TO 37.1 HRC.

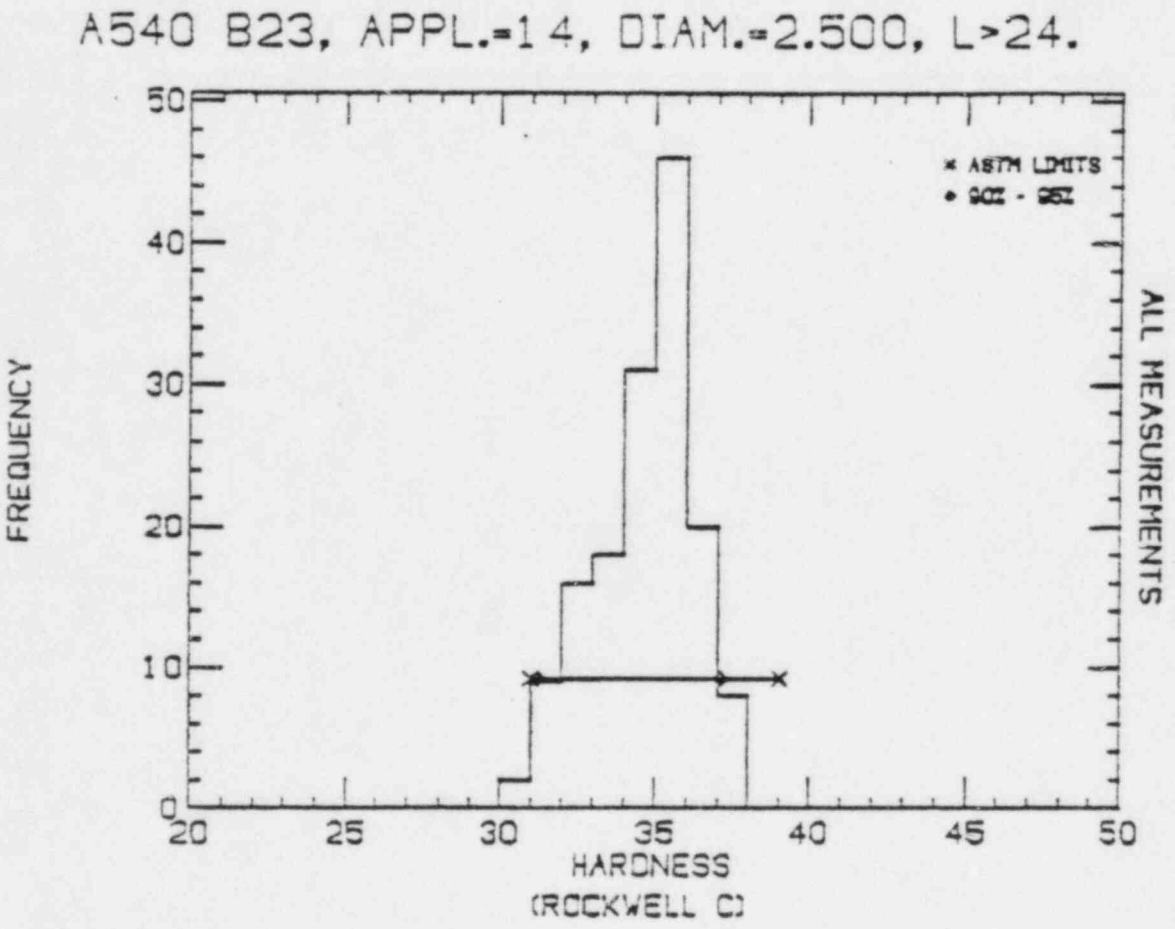
- TOLERANCE INTERVAL FALLS WITHIN SPECIFICATION.

_ HYPOTHESIS OF NORMAL POPULATION IS NOT REJECTED AT 5% or 10% LEVEL OF SIGNIFICANCE.

- 7 BOLTS HAVE HARDNESS VARIATION ACROSS THE HEAD GREATER THAN 2 HRC.

SAMPLE HISTOGRAM
STRATUM 23

(SAMPLE SIZE = 50)



RECOMMENDED HARDNESS LIMITS FOR LAQTS MATERIALS

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A7-66	(see Note 1)	-	-	-	-	-
A36-77a	(see Note 1)	-	-	-	-	-
A125-73	(see Note 2)	-	38HRC*	50HRC	634L*	731L
SA155-75	CMSH-80 (See Note 3)	≦2½" thick	86HRB* (~4HRC)	22HRC*	434L*	514L*
		Over 2½" to 4"	83HRB* (~1HRC)	22HRC*	421L*	514L*
A182-78/SA182-78	F1	-	78HRB	91HRB (~10HRC)	400L	462L
	F2	-	78HRB	91HRB (~10HRC)	400L	462L
	F11	-	78HRB	94HRB (~14HRC)	400L	479L
	F12	-	78HRB	94HRB (~14HRC)	400L	479L
	F21	-	82HRB	94HRB (~14HRC)	418L	479L
	F22	-	82HRB	94HRB (~14HRC)	418L	479L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A182-78/SA132-78 (Conitnued)	F22a	-	69HRB*	86HRB (~4HRC)	372L*	435L
A193-78a/SA193/78a	B7	≤2½" Dia.	26HRC*	36HRC*	544L*	618L*
		Over 2½" to 4"	22HRC*	33HRC*	514L*	596L*
		Over 4" to 7"	95HRB* (~16HRC)	28HRC*	485L*	558L*
	B7M	≤2½" Dia.	94HRB (~14HRC)	22HRC	473L	514L
	B16	≤2½" Dia.	26HRC*	36HRC*	544L*	618L*
		Over 2½" to 4"	20HRC*	31HRC*	500L*	581L*
		Over 4" to 7"	95HRB* (~16HRC)	28HRC*	485L*	558L*
A194-80a/SA194-80a	4	A11	24HRC	38HRC	529L	634L
	7	A11	24HRC	38HRC	529L	634L
	7M	A11	83HRB (~1HRC)	22HRC	421L	514L
A234-80/SA234-78	WP1	A11	65HRB*	92HRB (~12HRC)	361L*	468L
	WP12	A11	69HRB*	92HRB (~12HRC)	372L*	468L
	WP11	A11	69HRB*	92HRB (~12HRC)	372L*	468L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A234-80/SA234-78 (continued)	WP22	A11	69HRB*	92HRB (~12HRC)	372L*	468L
	WPR	A11	72HRB*	96HRB (~17HRC)	382L*	490L
A304-79	(see Note 4)	-	-	-	-	-
A320-80b/SA320-78[5]	L1	≤1" Dia.	26HRC*	36HRC*	544L*	618L*
	L7, L7A, L7B, L7C	≤2½" Dia.	26HRC*	36HRC*	544L*	618L*
	L7M	≤2½" Dia.	94HRB (~14HRC)	22HRC	473L	514L
	L43	≤4" Dia.	26HRC*	37HRC*	544L*	626L*
A322-80	(see Note 4)	-	-	-	-	-
A325-78a/SA325-78a	2, 3 (see Note 6)	½" to 1" Dia.	24HRC	35HRC	529L	611L
		1 1/8" to 1½" Dia.	19HRC	31HRC	497L	581L
A331-74	(see Note 4)	-	-	-	-	-
A354-78a/SA354-78a	BC	1/4" to 2½" Dia.	26HRC	36HRC	544L	618L
		Over 2½" Dia.	22HRC	33HRC	514L	596L
	BD	1/4" to 2½" Dia.	33HRC	38HRC	596L	634L
		Over 2½" Dia.	31HRC	38HRC	581L	634L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
SA420-78	WPL3	Plate (≤4")	74HRB*	95HRB* (~17HRC)	389L*	490L*
		Forgings (all sizes)	79HRB*	25HRC*	405L*	536L*
	WPL9	Forgings (all sizes)	72HRB*	22HRC*	382L*	514L*
A434-76	BB	1½" Dia. and less	20HRC*	31HRC*	500L*	581L*
		Over 1½" to 2½"	97HRB* (~19HRC)	28HRC*	496L*	558L*
		Over 2½" to 4"	95HRB* (~16HRC)	28HRC*	485L*	558L*
		Over 4" to 7"	93HRB* (~13HRC)	25HRC*	471L*	536L*
		Over 7" to 9½"	91HRB* (~10HRC)	22HRC*	460L*	514L*
	BC	1½" Dia. and less	28HRC*	38HRC*	558L*	634L*
		Over 1½" to 2½"	26HRC*	36HRC*	544L*	618L*
		Over 2½" to 4"	22HRC*	33HRC*	514L*	596L*
		Over 4" to 7"	20HRC*	32HRC*	500L*	588L*
		Over 7" to 9½"	97HRB* (~19HRC)	30HRC*	496L*	573L*

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A434-76 (continued)	BD	1½" Dia. and less	34HRC*	40HRC*	603L*	649L*
		Over 1½" to 2½"	33HRC*	38HRC*	596L*	634L*
		Over 2½" to 4"	31HRC*	38HRC*	581L*	634L*
		Over 4" to 7"	29HRC*	38HRC*	566L*	634L*
		Over 7" to 9½"	28HRC*	37HRC*	558L*	626L*
A487-80	1Q,2Q	-	91HRB* (~10HRC)	22HRC*	460L*	514L*
	4Q,11Q,12Q,13Q	-	97HRB* (~19HRC)	34HRC*	496L*	603L*
	4QA	-	22HRC*	33HRC*	514L*	596L*
	6Q	-	24HRC*	34HRC*	529L*	603L
	7Q	2½" thick	22HRC*	33HRC*	514L*	596L*
	8Q,9Q	-	95HRB* (~16HRC)	29HRC*	485L*	566L*
	10Q	-	25HRC*	34HRC*	536L*	603L*
	14Q	-	24HRC*	38HRC*	529L*	634L*

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A490-80a	All Grades	½" to 1½" Dia.	33HRC	38HRC	596L	634L
A514-77	All Grades	to 3/4" thick	22HRC	31HRC	514L	581L
		over 3/4" to 2½"	22HRC*	32HRC*	514L*	588L*
		over 2½" to 6"	95HRB* (~16HRC)	33HRC*	485L*	596L*
A519-80	(see Note 4)	-	-	-	-	-
A521-76	CG	≤4" Solid Dia. or Thick or ≤2" Bored Wall Thick	90HRB* (~10HRC)	22HRC	456L*	514L*
		>4" to 7" (Solid) or >2" to 3½" (Bored)	88HRB* (~7HRC)	96HRB* (~17HRC)	440L*	490L*
		>7" to 10" (Solid) or >3½" to 5" (Bored)	88HRB* (~7HRC)	96HRB* (~17HRC)	440L*	490L*
		>5" to 10" (Bored)	88HRB* (~7HRC)	96HRB* (~17HRC)	440L*	490L*
	AD	≤7" Solid Dia. or Thick or ≤3½" Bored Wall Thick	92HRB* (~12HRC)	25HRC*	468L*	536L*
		>7" to 10" (SOlid) or >3½" to 10" (Wall)	90HRB* (~10HRC)	22HRC*	456L*	514L*

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A521-76 (continued)	AE	≦7" Solid Dia. or Thick or ≦3½" Bored Wall Thick	95HRB* (∿16HRC)	29HRC*	485L*	566L*
		>7" to 10" (Solid) or >3½" to 5" (Bored)	94HRB* (∿14HRC)	29HRC*	479L*	566L*
		>10" to 20" (Solid) or >5" to 8" (Bored)	92HRB* (∿12HRC)	25HRC*	468L*	536L*
	AF	≦4" Solid Dia. or Thick or ≦2" Bored Wall Thick	25HRC*	34HRC*	536L*	603L*
		>4" to 7" (Solid) or >2" to 3½" (Bored)	22HRC*	32HRC*	514L*	588L*
		>7" to 10" (Solid) or >3½" to 5" (Bored)	97HRB* (∿19HRC)	31HRC*	497L*	581L*
	AG	≦4" Solid Dia. or Thick or ≦2" Bored Wall Thick	31HRC*	38HRC*	581L*	634L*
		>4" to 7" (Solid) or >2" to 3½" (Bored)	30HRC*	37HRC*	573L*	626L*
		>7" to 10" (Solid) or >3½" to 5" (Bored)	28HRC*	36HRC*	558L*	618L*
	AH	≦4" Solid Dia. or Thick or ≦2" Bored Wall Thick	36HRC*	43HRC*	618L*	673L*
		>4" to 7" (Solid) or >2" to 3½" (Bored)	36HRC*	43HRC*	618L*	673L*
		>7" to 10" (Solid) or >3½" to 5" (Bored)	34HRC*	42HRC*	603L*	665L*

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
SA537-78	2	≤2½" thick	86HRB* (~4HRC)	22HRC*	434L*	514L*
		over 2½" to 4"	83HRB* (~1HRC)	22HRC*	421L*	514L*
A540-77a/SA540-77a	B21, CL5	≤2½" thick	23HRC	30HRC	522L	573L
		over 2" to 6"	24HRC	32HRC	529L	588L
		over 6" to 8"	25HRC	33HRC	536L	596L
	B21, CL4	≤3" thick	28HRC	36HRC	558L	618L
		over 3" to 6"	29HRC	38HRC	566L	634L
	B21, CL3	≤3" thick	31HRC	38HRC	581L	634L
		over 3" to 6"	32HRC	40HRC	588L	649L
	B21, CL2	≤4" thick	33HRC	43HRC	596L	673L
	B21, CL1	≤4" thick	34HRC	46HRC	603L	698L
	B22, CL5	≤2" thick	24HRC	31HRC	529L	581L
		Over 2" to 4"	25HRC	32HRC	536L	588L
	B22, CL4	≤1" thick	28HRC	37HRC	558L	626L
		Over 1" to 4"	29HRC	39HRC	566L	642L
	B22, CL3	≤2" thick	31HRC	39HRC	581L	642L
		Over 2" to 4"	32HRC	40HRC	588L	649L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A540-77a/SA540-77a (continued)	B22, CL2	≦3" thick	33HRC	43HRC	596L	673L
	B22, CL1	≦1½" thick	34HRC	43HRC	603L	673L
	B23, CL5	≦6" thick	24HRC	33HRC	529L	596L
		Over 6" to 8"	25HRC	34HRC	536L	603L
		Over 8" to 9½"	27HRC	34HRC	551L	603L
	B23, CL4	≦3" thick	28HRC	37HRC	558L	626L
		Over 3" to 6"	29HRC	38HRC	566L	634L
		Over 6" to 9½"	30HRC	39HRC	573L	642L
	B23, CL3	≦3" thick	31HRC	39HRC	581L	642L
		Over 3" to 6"	32HRC	40HRC	588L	649L
		Over 6" to 9½"	33HRC	42HRC	596L	665L
	B23, CL2	≦3" thick	33HRC	42HRC	596L	665L
		Over 3" to 6"	33HRC	43HRC	596L	673L
		Over 6" to 9½"	34HRC	45HRC	603L	689L
	B23, CL1	≦3" thick	34HRC	45HRC	603L	689L
		Over 3" to 6"	36HRC	46HRC	618L	698L
		Over 6" to 8"	37HRC	47HRC	626L	707L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A540-77a/SA540-77a (continued)	B24, CL5	≦6" thick	24HRC	33HRC	529L	596L
		Over 6" to 8"	25HRC	34HRC	536L	603L
		Over 8" to 9½"	27HRC	34HRC	551L	603L
	B24, CL4	≦3" thick	28HRC	37HRC	558L	626L
		Over 3" to 6"	29HRC	38HRC	566L	634L
		Over 6" to 8"	30HRC	39HRC	573L	642L
	B24, CL3	≦3" thick	31HRC	39HRC	581L	642L
		Over 3" to 8"	32HRC	42HRC	588L	665L
		Over 8" to 9½"	33HRC	42HRC	596L	665L
	B24, CL2	≦7" thick	33HRC	43HRC	596L	673L
		Over 7" to 9½"	34HRC	45HRC	603L	689L
	B24, CL1	≦6" thick	34HRC	45HRC	603L	689L
		Over 6" to 8"	36HRC	46HRC	618L	698L
	B24V, CL3	≦4" thick	31HRC	39HRC	581L	642L
		Over 4" to 8"	32HRC	40HRC	588L	649L
		Over 8" to 11"	33HRC	42HRC	596L	665L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A540-77a/SA540-77a (continued)	B24V, CL2	≤4" thick	33HRC	42HRC	596L	665L
		Over 4" to 8"	33HRC	43HRC	596L	673L
		Over 8" to 11"	34HRC	45HRC	603L	689L
	B24V, CL1	≤4" thick	34HRC	45HRC	603L	689L
		Over 4" to 8"	36HRC	46HRC	618L	698L
		Over 8" to 11"	36HRC	47HRC	618L	707L
A574-80	(see Table 3.2-1)	≤½" Dia.	39HRC	45HRC	642L	689L
		≤5/8" Dia.	37HRC	45HRC	626L	689L
A563-78a	DH3	1/4" to 4" size	24HRC	38HRC	529L	634L
	C3	1/4" to 4" size	78HRB	38HRC	400L	634L
A668-79a	F, FH	≤4" thick	90HRB (~10HRC)	22HRC	456L	514L
		Over 4" to 7"	88HRB (~7HRC)	96HRB (~17HRC)	440L	490L
		Over 7" to 10"	88HRB (~7HRC)	96HRB (~17HRC)	440L	490L
		Over 10" to 20"	88HRB (~7HRC)	96HRB (~17HRC)	440L	490L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A688-79a (continued)	J, JH	≦7" thick	92HRB (~12HRC)	25HRC	468L	536L
		Over 7" to 10"	90HRB (~10HRC)	22HRC	456L	514L
	K, KH	≦7" thick	95HRB (~16HRC)	28HRC	485L	558L
		Over 7" to 10"	94HRB (~14HRC)	28HRC	479L	558L
	L, LH	≦4" thick	25HRC	34HRC	536L	603L
		Over 4" to 7"	22HRC	32HRC	514L	588L
		Over 7" to 10"	97HRB (~19HRC)	31HRC	497L	581L
	M, MH	≦4" thick	31HRC	38HRC	581L	634L
		Over 4" to 7"	30HRC	37HRC	573L	626L
		Over 7" to 10"	28HRC	36HRC	558L	618L
	N, NH	≦4" thick	36HRC	43HRC	618L	673L
		Over 4" to 7"	36HRC	43HRC	618L	673L
		Over 7" to 10"	34HRC	42HRC	603L	665L

ASTM/ASME SPECIFICATION	GRADE AND/ OR CLASS	DIAMETER OR THICKNESS	HARDNESS LIMITS (7) ROCKWELL-SCALE MIN.	ROCKWELL-SCALE MAX.	LEEB-SCALE (L) MIN.	LEEB-SCALE (L) MAX.
A687-79	All Grades	-	26HRC*	34HRC*	543L*	603L*
A739-76/SA-739-76	B11	-	79HRB*	25HRC*	405L*	536L*
	B22	-	82HRB*	25HRC*	417L*	536L*
F568-79	8.8	-	23HRC	34HRC	522L	603L
	8.8.3	-	23HRC	34HRC	522L	603L
	9.8	-	27HRC	36HRC	551L	618L
	10.9	-	33HRC	39HRC	596L	642L
	10.9.3	-	33HRC	39HRC	596L	642L
	12.9	-	38HRC	44HRC	634L	682L

NOTES (Table 3.6-1)

1 Bolts or nuts when included with material purchases can be supplied to A325.

2 The specified or indicated minimum hardness must be sufficient to develop the required strength to withstand the solid stresses of the spring design.

3 Same material grade as [illegible] Class 2.

4 Maximum surface Brinell [illegible]s, if specified by purchaser as a supplementary requirement, shall be agreed upon between the manufacturer and th[illegible]r. Mechanical strengths are not specified.

5 SA320-78 is identical to A320-76 except for the deletion of Grade L1.

6 Bolts shall not exceed maximum hardness specified. Bolts less than three diameters in length shall have a hardness valve not less than the minimum nor more than the maximum in hardness limits, as hardness is the only requirement.

7 Hardness values supplied are in HRC and L-scale numbers unless otherwise noted. Mechanical strengths are not specified.

* These limits are not ASTM specified limits, but based upon a review of yield and tensile strength requirements and a comparison with other ASTM materials with specified hardness requirements.