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TRITIUM TARGET QUALIFICATION PROJECT

TPBAR COMPONENT CHARACTERISTICS AND RELATED IMPORTANCE FACTORS

TTQP-1-046

REVISION 3

JULY 1997

EFFECTIVE DATE 7/9/97

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July 1997

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TPBAR COMPONENT CHARACTERISTICS AND RELATED IMPORTANCE FACTORS

The proper design and fabrication of tritium producing burnable absorber rods (TPBARs) is vital to the success of the Lead Test Assembly (LTA) mission of demonstrating safe, reliable, and economic tritium production in a commercial light water reactor. The following describes the significance of the TPBAR and its components to the success of the LTA mission.

TPBAR LTA Safety-Related Function. In all respects, with the exception of tritium production, the TPBARs function as burnable absorber rods. Burnable absorbers are an essential element of a reactor core design. The presence and the location of the absorber rods, in conjunction with soluble boron and control rods, determine the appropriate level of reactivity to keep the reactor in a safe state. TPBAR LTAs have no active reactivity control function but do have passive reactivity characteristics. Therefore, the TPBAR LTAs are integral part of the reactivity control system and are safety-related.

Because the TPBAR LTAs perform a safety-related function, the 10 CFR 50, Appendix B, quality assurance program and 10 CFR Part 21 are applied to the design, procurement, fabrication, assembly and handling of the TPBAR LTAs.

Individual TPBAR component failures cannot result in the inability of the TPBAR LTAs to perform their safety function. However, there are fabrication and installation errors associated with TPBARs that could affect the TPBAR LTA safety-related function if the reactivity characteristics or location of multiple TPBARs are substantially different from that assumed in core design. In addition, the TPBARs must maintain their mechanical integrity in order to ensure the location of the absorber within the TPBARs.

Table 1 lists the individual TPBAR components, their safety function, and critical characteristics. Critical Characteristics are defined as those important design, material and performance characteristics necessary to provide reasonable assurance that the item will perform its intended safety function. 10CFR50, Appendix B, Criterion II provides for the application of quality control over activities affecting the quality of structures, systems, and components to an extent consistent with their importance to safety. This graded approach has been used in the selection of critical characteristics and acceptance criteria for the TPBAR components.

The "importance factors" defined later in this document identify the level of inspection criteria applied to provide reasonable assurance that the component will perform its intended safety function, based on the impact of the component on the overall safety function of the TPBAR.

Radiological Significance. The radiological significance of the TPBAR is not safety related because TPBAR failure cannot result in potential offsite exposures comparable to those referenced in 10 CFR 100.11. The TPBARs produce tritium and, therefore, the tritium retention performance of the TPBAR can affect occupational and offsite radiological doses. The TPBAR assembly, TPBAR cladding (cladding tube, end plugs, and aluminide coating), lithium aluminate pellets, and getter can affect tritium retention performance of the LTAs.

Mission Performance. The TPBARs must produce design goal amounts of tritium without adverse impacts or limitations on fuel assembly fabrication, shipment, or LTA host plant operations. These requirements must be satisfied while demonstrating a consistent and cost effective TPBAR fabrication process.

Manufacture of TPBARs involves the purchase of materials and components. Components will undergo processing, fabrication, and inspection, both at offsite component vendors and at the Pacific Northwest National Laboratory (PNNL). These components have design characteristics that are required to meet the Functional Requirements for the LTA.

Verification of these characteristics is vital to the success of the LTA mission. Because not all TPBAR component characteristics are of equal importance, the level of inspection and verification will vary. This document lists the TPBAR components and their characteristics and categorizes the characteristics according to their importance to safety and program success.

Five "importance factors" have been defined. In descending level of importance, they are termed Category A through E[a].

Definitions:

<u>Category A</u> - A TPBAR characteristic that, if not within specified limits, can affect the ability of the TPBAR LTAs to perform their function of maintaining the reactor core in a safe state.

<u>Category B</u> - A TPBAR characteristic other than Category A that, if not within specified limits, could (1) significantly affect the mechanical integrity of the TPBAR, or (2) result in incremental tritium releases and either onsite or offsite doses, or (3) result in localized core power peaking.

<u>Category C</u> - A TPBAR characteristic other than Categories A or B that, if not within specified limits, could minimally impact safety, or result in excessive costs for fuel and plant operations, or result in substantial delays in scheduled shipping dates.

<u>Category D</u> - A TPBAR characteristic other than Categories A, B, or C that, if not within specified limits, may result in unacceptable rates of defects or rework, and/or poor fabricability, and/or could minimally impact safety.

<u>Category E</u> - A TPBAR characteristic other than Categories A, B, C, or D that, if not within specified limits, does not significantly impact cost or schedule, and could minimally impact safety.

Note: All Category A characteristics are important to safety. However, Category B includes characteristics that are important to both safety and program success. Therefore, not all Category B characteristics are important to safety. There are characteristics categorized as Category C, D, and E that are important to program success and/or have a minimal impact on safety. These characteristics are also included in Table 1.

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[a]These categories were formerly titled Critical, Major 1, Major 2, Minor 1 and Minor 2 in earlier versions of this document.

The importance factors defined in this document are used as a basis to determine the type and frequency of inspection tests to be performed by both the offsite component vendors and PNNL. This document does not specify where the verification will occur (i.e., vendor or PNNL), simply that it must occur prior to final TPBAR acceptance. Note that this document gives the minimum characteristics that must be sampled. Additional characteristics that are not specified in this document may be sampled "for information only." Fabrication shall have the responsibility to ensure that adequate tests and inspections are performed, at the vendor and/or after receipt inspection. TTQP-2-014 lists the inspections and tests that will be performed and the responsible organizations.

This document establishes guidelines for developing statistical sampling requirements for verifying TPBAR and TPBAR component design characteristics. The standards for implementation of these statistical sampling requirements are set forth in ANSI/ASQC Z1.4-1993 (Sampling Procedures and Tables for Inspection by Attributes), ANSI/ASQC Z1.9-1993 (Sampling Procedures and Tables for Inspection by Variables), and ANSI/ASQC Q3-1988 (Sampling Procedures and Tables for Inspection of Isolated Lots by Attributes). These references provide the methodology for statistical sampling and acceptance/rejection of product as a function of the following criteria:

- Limiting Quality Level (LQL), which is the percentage of variant (defective) units in a batch or lot.

- Probability of Acceptance (P_a), which is the probability that a lot will be accepted under a given sampling plan. The probability of acceptance is a function of the LQL.

The above ANSI references contain plots of P_a versus LQL. The assigned values of 100 - P_a(LQL) and 100 - LQL corresponding to the importance factors are tabulated in Table 2. The use of Table 2 may be illustrated by the following example. For Category D, there is a 95% probability that a lot containing 75% or less acceptable items will be rejected. (Or in other words, for a lot containing 25% or greater unacceptable items, the probability the lot will be accepted is 5%.)

The sampling guidelines identified in Table 2 are default guidelines. However, for certain component characteristics, the default sampling guidelines are not appropriate. Some of the tests being required follow recommended ASTM/ASME standards; therefore, a lower number of inspections or tests can be administered than specified in the default guidelines. In these instances, a "lot qualification" is more appropriate than statistical sampling. Also, the default sampling guidelines are not intended to apply to design characteristics that are verified through either destructive examinations or established through process parameter controls or special processes.

The long term optimization of design parameters and related fabrication processes requires a quantitative knowledge of the relationship between the statistical process capability span and the specified product tolerance for the various specified characteristics. For this reason, the inspection density may be higher initially than required by the statistical guidelines set forth above and may be expected to change over the course of time.

Table 3 lists the TPBAR components, their characteristics, importance factors, and justification for these importance factors. It is noted in parentheses when a characteristic will not be verified according to the default sampling guidelines (lot qualification, destructive test, etc.) In these instances, the sampling plan followed may be found in the applicable specification. Endnotes give the justification for the deviation from Table 2.

Table 1. Safety Function of TPBAR Components

Component	Safety Function	Critical Characteristic(s)
Lithium Aluminate Pellet/Stack	The lithium aluminate pellet/stack provides the reactivity control function of the TPBAR.	Lithium-6 weight per unit length
Cladding Tube	The cladding is a principal structural component of the TPBAR and therefore its integrity is essential to ensure the location of the absorber within the TPBAR.	Tensile Properties Intergranular Attack Wall Thickness Cladding Flaws Circularity or Ovality Residual Wall Thickness ID of Prep Zone Radial Depth of Aluminide Removed
End Plugs/Bar Stock	The end plugs are a principal structural component of the TPBAR and therefore their integrity is essential to ensure the location of the absorber within the TPBAR.	Dimensions (weld fitup) Volumetric Integrity End Defects
Getter Tube	The getter tubes affect the position of the pellets and therefore the location of the absorber within the TPBAR.	Thickness Etched Weight
Getter Disks	The getter disks minimally affect the position of the pellets and therefore the location of the absorber within the TPBAR.	Disk Thickness

Component	Safety Function	Critical Characteristic(s)
Liner	The liner affects the position of the pellets and therefore the location of the absorber within the TPBAR.	Dimension of Flange OD Dimension of Tube OD
Compression Spring	The compression spring prevents movement of the pencils during shipping and handling prior to irradiation, preventing possible damage to the pellets. Damage to the pellets could affect the location of absorber material within the TPBAR.	Load at Compressed Length Spring Rate
Target Rod Assembly	The final target rod assembly ensures the performance of the reactivity control function.	Pellet Placement Pellet to Pellet Gaps Pencil Orientation Closure Weld Penetration Closure Weld Integrity Closure Weld Surface Appearance

Table 2. Default Sampling Guidelines

IMPORTANCE FACTOR	100 - P_a(LQL)	100 - LQL
Category A	95	95
Category B	95	95
Category C	95	90
Category D	95	75
Category E	95	75

Table 3. Importance Factors by Component Characteristics[b]

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
LTA STAINLESS STEEL BAR STOCK (FOR CLADDING AND END PLUG BAR REDUCTION)[1]	Chemical Composition[2] Inclusions[2]	Category C	The failure of this characteristic to meet specifications could increase costs.

[b]The "safety related" column has been deleted in this revision and incorporated into Table 1.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
LTA SEAMLESS 316 STAINLESS STEEL CLADDING TUBE	Tensile Properties (lot qualification)[3] Intergranular Attack (lot qual.)[3] Wall Thickness Cladding Flaws	Category B	The failure of these characteristics to meet specifications could result in a cladding breach, absorber relocation, and tritium release.
	Chemical Composition (lot qual.)[3] Inclusions[4]	Category C	The failure of these characteristics to meet specifications could increase costs.
	Hardness (lot qual.)[3] Dimensions of OD and ID Circularity or Ovality Straightness	Category D	The failure of these characteristics to meet specifications would not cause the cladding to breach or significantly increase tritium permeation, although fabricability would be impacted.
	Carbide Precipitation (lot qual.)[3] Grain Size (lot qual.)[3] Residual Halides (lot qual.)[3] Surface Roughness Surface Condition Surface Cleanliness End Configuration	Category E	The failure of these characteristics to meet specifications would not cause the cladding to breach or significantly increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
LTA COATED STAINLESS STEEL TUBING	Apparent Aluminide Thickness Aluminide Integrity (batch qual.)[5] Intermetallic Phases	Category B	The failure of these characteristics to meet specifications could allow tritium to permeate the cladding in excess of the design limits.
	Circularity or Ovality	Category B	An oval tube accelerates creep collapse, increasing potential for cladding failure, absorber relocation, and tritium release.
	Straightness	Category C	A non-uniform tube could become lodged in a fuel assembly and significantly impact costs to the utility.
	Dimensions of OD and ID	OD: Category C ID: Category D	The OD could cause the TPBAR to become lodged in a fuel assembly if it is too large. The ID would affect fabricability if it is out of spec.
	Outer Surface Condition Residual Halides on Outer Surface (batch qual.)[6]	Category E	The failure of these characteristics to meet specifications would not cause the cladding to breach or significantly increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
COATED STAINLESS STEEL TUBING END PREPARATION	Residual wall Thickness ID of Prep Zone Radial Depth of Aluminide Removed Residual Aluminide Content	Category B	The failure of these characteristics to meet specifications could cause rod failure, absorber relocation, and tritium release.
	Axial Depth of Aluminide Removed Perpendicularity of Tube Ends Trimmed Length Machined Surface Condition	Category D	The failure of these characteristics to meet specifications would not cause the cladding to breach or significantly increase tritium permeation, although fabricability would be impacted.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
END PLUG BAR STOCK	Volumetric Integrity End Defects	Category B	The failure of these characteristics to meet specifications could cause a loss of TPBAR integrity and/or tritium release.
	Chemical Composition (lot qual.)[7]	Category C	Important to component function. The failure of this characteristic to meet specifications would not lead to increased tritium release.
	Dimensions of Bar OD	Category D	The failure of this characteristic to meet specifications would not cause the end plug to breach or significantly increase tritium permeation, although fabricability would be impacted.
	Intergranular Corrosion Susceptibility (lot qual.)[8] Surface Condition Surface Roughness Surface Marring Grain Size (lot qual.)[9] Carbide Precipitation (lot qual.)[9] Mechanical Properties (lot qual.)[7] Surface Cleanliness Inclusions[4]	Category E	The failure of these characteristics to meet specifications would not significantly increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
TOP AND BOTTOM END PLUGS	Dimensions	Category C	The failure of this characteristic to meet specifications could lead to improper weld fitup and absorber relocation. In addition, costs could increase (stuck rod).
	Surface Roughness Surface Defects	Category D	The failure of these characteristics to meet specifications would not significantly increase tritium permeation, although fabricability could be impacted.
	Surface Cleanliness Residual Halides (lot qual.)[10]	Category E	The failure of these characteristics to meet specifications would not significantly increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
GETTER TUBE (UNPLATED)	Thickness[11]	Category B	The failure of this characteristic to meet specifications could allow absorber relocation and/or tritium release.
	Chemical Composition (lot qual.)[12]	Category C	Important to getter function. The failure of this characteristic to meet specifications would not increase the tritium release rate because the gettering rate is not highly sensitive to the Zircaloy composition.
	Straightness	Category D	The failure of this characteristic to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, although fabricability would be impacted.
	Length Surface Finish Tube End Perpendicularity Oxygen, Hydrogen, Nitrogen Concentration (lot qual.)[12] Grain Size (lot qual.)[13] Surface Defects[14]	Category E	The failure of these characteristics to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
NICKEL PLATED GETTER TUBE	Ni Thickness (destructive on ID, lot qual. on ID)[15] Ni Adhesion (destructive, lot qual.)[15] Trimmed Length Ni Plating Coverage (destructive on ID, lot qual. on ID)[15]	Category B	The failure of these characteristics to meet specifications could impact the gettering rate and cause tritium release to the coolant in excess of the design parameters.
	Etched Weight (destructive, lot qual.)[15]	Category B	The etched weight is related to the getter tube wall thickness. Loss of tube integrity could cause absorber relocation. In addition, the failure of this characteristic to meet specifications could lead to tritium release.
	Dimensions of OD and ID	Category D	The failure of these characteristics to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, although fabricability would be impacted.
	Ni Purity (destructive, lot qual.)[15]	Category E	The failure of this characteristic to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
GETTER DISK	Chemical Composition (lot qual.)[16]	Category C	Important to getter disk function. The failure of this characteristic to meet specifications would not increase the tritium release rate because the gettering rate is not highly sensitive to the Zircaloy composition.
	Surface Finish Disk Diameter Oxygen, Hydrogen, Nitrogen Concentration (lot qual.)[16] Disk Flatness	Category E	The failure of these characteristics to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, or significantly impact cost or schedule.
	Disk Thickness	Category E	The disk thickness has an extremely minor impact on the location of the absorber. In addition, the failure of this characteristic to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, or significantly impact cost or schedule..
NICKEL PLATED GETTER DISK UPPER & LOWER	Dimensions of Disk OD Thickness	Category D	The failure of these characteristics to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, although fabricability would be impacted.
	Ni Thickness Ni Adhesion (destructive, lot qual.)[15] Ni Plating Coverage Ni Purity (destructive, lot qual.)[15]	Category E	The failure of these characteristics to meet specifications would not measurably decrease the gettering rate or increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
LITHIUM ALUMINATE PELLET/STACK	Li-6 Weight per Unit Length Lithium Assay Li-6 Isotopic Ratio Stack Length Stack Weight	Category A	The Li-6 weight per unit length is a calculated quantity that is based upon several parameters, that are listed here. An improper Li-6/inch loading in multiple TPBARs could affect the ability of the TPBARs to perform their safety function.
	Moisture Content[1/]	Category B	The failure of this characteristic to meet specifications could cause getter loading and incremental increase of tritium release to the coolant.
	Impurity Chemistry	Category C	Important to pellet function. The failure of this characteristic to meet specifications would not increase tritium permeation.
	Concentricity of ID and OD Li/Al Ratio or aluminum assay Bulk Density Pellet Dimensions of OD and ID	Category D	The failure of these characteristics to meet specifications would not measurably increase tritium permeation, although fabricability could be impacted.
	Equivalent Boron Concentration of Impurities Grain Size Dimensional Stability Perpendicularity Surface Condition	Category E	The failure of these characteristics to meet specifications would not measurably increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
LINER	Chemical Composition[18]	Category C	Important to liner function. The failure of this characteristic to meet specifications would not increase the tritium release rate because the gettering rate is not highly sensitive to the Zircaloy composition.
	Dimension of Bend Radius Dimension of Tube ID Length Straightness Flanged End Perpendicularity	Category D	The failure of these characteristics to meet specifications would not measurably increase tritium permeation, although fabricability would be impacted.
	Dimension of Flange OD Dimension of Tube OD	Category D	The failure of these characteristics to meet specifications could impact the location of the absorber and impact fabricability.
	Oxygen, Hydrogen, and Nitrogen Concentration (lot qual.)[19] Surface Defects	Category E	The failure of this characteristic to meet specifications would not measurably increase tritium permeation, or significantly impact cost or schedule.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
COMPRESSION SPRING	Chemical Composition[20]	Category C	Important to spring function. The failure of this characteristic to meet specifications would not increase the tritium release rate because the spring is not related to tritium permeation.
	Load at Compressed Length Spring Rate	Category E	The failure of these characteristics to meet specifications could cause damage to the pellets during shipping and handling. Damage to pellets could affect location of absorber material. However, cost, schedule, and tritium permeation would not be impacted.
	Dimensions of Spring OD and Free Length Cleanliness	Category E	The failure of these characteristics to meet specifications would not measurably increase tritium permeation, or significantly impact cost or schedule.
GETTER PENCIL ASSEMBLY	Dimension from Coined Getter to Top of Pellet Straightness Outer Surface After Coining	Category D	The failure of these characteristics to meet specifications would not measurably increase tritium permeation, although fabricability would be impacted. (Note that the pellet to pellet gaps are verified later in the target rod assembly.)

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
PLENUM GETTER AND DISK SUBASSEMBLY	Spot Weld Integrity Surface Condition Straightness Dimension of Coined Rim for both Pencil and Plenum Dimension of OD for both Pencil and Plenum Coined Length for both Pencil and Plenum Tube	Category D	The failure of these characteristics to meet specifications would not measurably increase tritium permeation, although fabricability would be impacted.

COMPONENT	CHARACTERISTICS	IMPORTANCE FACTOR	JUSTIFICATION
TARGET ROD ASSEMBLY	Pellet Placement	Category A	The failure of this characteristic to meet specifications could affect the ability of TPBARs to perform their safety function if multiple TPBARs were affected.
	Pellet to Pellet Gaps Pencil Orientation	Category B	The failure of these characteristics to meet specifications could cause small power peaking if the axial gaps between components were too large.
	Closure Weld Penetration Closure Weld Integrity[21] Closure Weld Surface Appearance	Category B	Weld failure may result in local power changes only and affect TPBAR integrity. The failure of these characteristics to meet specifications could cause a release of tritium to the coolant.
	Residual Halides on Outer Surface	Category B	Excessive residual halides could impact other reactor components.
	Top End Plug Perpendicularity Closure Weld Overhang Straightness Surface Cleanliness	Category C	The failure of these characteristics to meet specifications could increase costs, primarily through a stuck TPBAR.
	Length Outer Surface Condition Exclusive of Weld He Fill Gas Purity[22]	Category D	The failure of these characteristics to meet specifications would not measurably increase tritium permeation, although fabricability would be impacted.
	He Back Fill Pressure	Category E	The failure of this characteristic to meet specifications would not measurably increase tritium permeation, or significantly impact cost or schedule.

Notes

1. The cladding tubes and end plugs were manufactured from the same stock material. However, the diameter of this stock was reduced prior to manufacture of the end plugs. This reduced "end plug bar stock" is treated separately in this document.

2. The chemical composition and inclusions are tested per an approved material reverification plan.

3. Sampling plans of components that are established by lot qualification are generally material orientated characteristics, i.e. grain size, chemical composition, tensile properties, etc. They are uniform for the entire lot. Sampling plans for characteristics believed to be especially critical to performance, e.g. defect inspection, may be performed with up to 100% inspection.

   This methodology was developed and refined by Westinghouse Hanford Company over a period of ten years during their development of core component procurement programs for the FFTF reactor. The sampling plan used in TTQP-1-003 "Specification For Stainless Steel cladding Tubes" was taken form WHC's cladding tube specifications HEDL-S-0020 (1981) "Austenitic Stainless Steel Tubing For Breeder Reactor Core Component" and HS-V-P-04046 (1992) "Stainless & Heat-Resisting Tubes for Use in FFTF."

4. Measured on starting material.

5. "Aluminide Integrity" is shorthand for several characteristics that are classified. See PNNL-TTQP-1-1007 for more information.

6. This characteristic is sampled lower than the default sampling plan because it is tested later on the final TPBAR assembly.

7. The sampling plan follows ASTM A-831/A-831-M

8. This test may be viewed as an overcheck of the carbide precipitation test. Sampling is based on the uniformity of a finished bar from a lot.

9. The sampling plan follows HWS-1946 Rev. 0.

10. The number selected per batch must allow sufficient surface area for testing.

11. The thickness is calculated based on measurements of the tube OD and ID.

12. The sampling plan follows ASTM B-353-91.

13. Lot qualification adequate because the grain size will not change appreciably between lots.

14. Visual inspection.

15. Because this test is destructive to the specimen, only one sample per lot is tested for this property.

16. The sampling plan follows ASTM B-352-92.

17. Controlled by process parameters.

18. Based on tube hollow material certification, per ASTM B-353-91.

19. The number sampled per lot reflects the uniformity of oxygen, hydrogen, and nitrogen concentrations in the final lot.

20. Based on spring wire material certification.

21. Special process controls.

22. Certified by vendor.