BROOKHAVEN NATIONAL LABORATORY
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Specification for Superconducting RF Components

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1.0 Scope

Purpose - The purpose of this specification is to define the configuration, materials, applicable Brookhaven National Laboratory (BNL, hereafter) Quality Assurance (QA), workmanship, cleaning, fabrication and packaging for Superconducting (SC) radio frequency (RF) components needed for the Relativistic Heavy Ion Collider (RHIC) at BNL. The scope of this document includes, but is not limited to, the fabrication, test and delivery to BNL, or BNL's designee, of the components.

Attention to strict quality control in all phases of the manufacturing process is essential to the manufacture of successful components. Conversely, poor workmanship, such as improper handling and/or inspection of materials, material contamination, poor quality control, deficient electron beam welds, brazes and other problems associated with implementing the detailed specifications, can measurably degrade the performance capability of these types of components. Although this should be known by component fabricator, it is noted here to stress its importance. The final cleaning and, at BNL discretion, acceptance testing of the component shall be done at BNL or a BNL-selected facility. The seller shall be responsible for designing and building the container used to ship the component. The container shall be constructed such that transport from the seller's facility to BNL or the BNL-selected facility and from the BNL-selected facility to BNL shall be completed without damage to the component.

2.0 Applicable Documents

The following documents form a part of this specification to the extent specified herein. Exceptions must be approved in writing by BNL. Unless otherwise specified, the issue date or revision level shall be that in effect on the date of the invitation to quote.

2.1 Applicable Codes, Standards and Publications - With the proposal, the seller shall furnish BNL a list of all applicable international, national and industrial codes that will be used in the construction of the component. It is the seller's responsibility that the whole assembly and seller-made components meet all laws, regulations, and standards of good practice commonly accepted in the cryogenic industry. The documents, in section 2.4, form a part of this specification to the extent specified herein. Unless otherwise specified, the issue date or revision level of the particular code or standard followed in section 2.4 shall be current on the date of the Request for Quote. Exceptions must be approved in writing by BNL.

2.2 Priorities - For all equipment and services covered by this Specification, the requirements of this Specification shall apply in addition to, and not in lieu of, the requirements of the Industry Code or Standards referenced in this Specification. In no case shall the requirements of this Specification be considered a relaxation of the Industry or Code requirements. In all cases, the most stringent of the requirements shall apply.

2.3 Abbreviations - Specifications or standards of the following organizations are referred to in the remainder of this specification:
AISI - American Iron and Steel Institute
ANSI - American National Standards Institute
ASTM - American Society for Testing and Materials
ASME - American Society of Mechanical Engineers
AWS- American Welding Society
EJMA - Expansion Joint Manufacturers Association
ISO - International Organization for Standardization
IEEE- Institute of Electrical and Electronic Engineers
NBS - National Bureau of Standards (Now NIST)
OSHA - Occupational Safety and Health Act

2.4 Associated Specifications - The latest editions of the following codes, specifications and standards, with their latest revisions, shall form a part of this specification. The Seller shall notify BNL, in writing, of any requirement contained in this Specification which conflicts with the requirements of the various Industry Codes and Standards referenced in this Specification.

ASME BPVC Sections VIII & IX

ASTM F2358-04 Standard Guide for Measuring Characteristics of Sapphire Substrates

ASTM E23 Methods for Notched Bar Impact Testing of Metallic Materials

ASTM E427-71 (81) Standard Practice Mass Spectrometer Leak Test Inside-Out Test Mode

ASTM E498-73 (80) Standard Practice Mass Spectrometer in Tracer Probe Mode

ASTM A370-10 Standard Test Methods and Definitions for Mechanical Testing of Steel Products

BNL QA-101 - Quality Assurance Requirements (BNL document)
OSHA Applicable Regulations
C-AD-1138 Specification for Niobium (RRR Grade) (BNL document)
C-AD-1139 Specification for Niobium (Reactor Grade) (BNL document)

3.0 REQUIREMENTS

3.1 General Requirements

3.1.1.1 RF Component General Requirements - The seller shall fabricate the niobium-based component conforming to BNL-defined dimensions (see drawing package).
The component shall be leak tested as described below in section 3.1.6 by the seller.

3.1.2 Materials -The component shall be fabricated from materials defined by the drawings such as high purity niobium (RRR), reactor grade niobium (Nb) and niobium-titanium alloy (Nb55Ti), and single crystal aluminum oxide (Sapphire). The seller shall provide material required to fabricate and test the components. The seller shall be responsible for any schedule slip due to the ordering of material. Niobium lead times can be lengthy, often 16 – 20 weeks.
The following material will be furnished by the seller in accordance with this specification and the applicable drawings.

3.1.2.1 Niobium
RRR - Grade Niobium – The RRR - Grade Niobium, with a RRR value > 250, to be used in the fabrication of this component is specified in BNL specification C-AD1138. The material for the component shall be checked individually for defects. Techniques shall include the "water-staining" test. Each plate or sheet used in the component body shall be submerged in water for a period of not less than 24 hours. The material shall be inspected for signs of stains due to contaminates in the material. Any niobium material exhibiting a stain trail shall be rejected.
The seller will mark the "outer" surface of the material by a method to be agreed on by BNL and the seller. This mark should be visible after deep drawing, forming, rolling, welding and chemical cleaning.
The opposite surface will be the "inner" surface, which carries the RF current. This inner surface shall not be contaminated or degraded by any handling procedure (see sections 3.1.3 and 3.1.4) or marking.
The seller is required to thoroughly re-inspect the material upon receipt and prior to use for surface scratches, indentations or other surface imperfections that would affect the requirements of section 3.1.3.
The same thorough inspection is required for supplied subassemblies, if applicable.

3.1.2.1.2 Reactor-grade Niobium – The Reactor-grade Niobium to be used in the fabrication of this component is specified in BNL specification C-AD1139. This material may be required for the manufacture of end group parts and stiffeners. It is usually supplied in form of plates.

3.1.2.1.3 Niobium-Titianium Alloy (Nb55Ti) - Niobium-Titanium Alloy (Nb55Ti) is needed for flanges, helium vessel end dishes and stiffeners for the end dishes. Material specification requires a certificate of chemical constituents to verify composition as well as material properties: tensile and yield strengths and elongation for each heat/lot of material used and Charpy V-Notch Impact testing at 77K. All testing is to be done in accordance with ASTM A370.

3.1.2.1.4 Sapphire – Sapphire is needed as the dielectric. This shall be ultra-pure, single crystal aluminum oxide. Alumina is not acceptable.

3.1.2.1.5 Material Coupons – Serialized samples from component material are required for quality control samples for thermal conductivity/RRR measurements and braze /weld testing of all pressure boundary niobium material. Samples are required from each heat used. The seller is cautioned to be certain sufficient material is ordered to meet this requirement.

3.1.2.1.6 Acceptance of Material by the Seller - The seller shall specify the quantity and dimensions of RRR niobium, reactor grade niobium and Niobium-Titanium alloy -material needed for all requirements of this specification, e.g. the fabrication of all component components, stiffeners and weld samples. The seller shall carefully inspect and accept accountability for the material.

3.1.3 Chemical Treatments - It is important to note that the superconducting properties of an RF component are very sensitive to surface imperfections or foreign material inclusions. Therefore, each niobium sheet used for RF body fabrication shall be scanned for defects by the Eddy Current method.
However, during subsequent fabrication steps the accepted material can be damaged. QA steps are necessary throughout the chemical treatment and fabrication process to ensure the integrity of the material with the emphasis on detecting any surface irregularities, embedded particles, loose niobium shavings or surface scratches. These imperfections shall be removed by the means described in Appendix C and subsequent buffered chemical polishing treatments.
All foreign material inclusions, visible surface oxides and surface damage layers shall be removed prior to electron beam (EB) welding (See Appendix C). Weld joint areas are particularly sensitive to inclusions.

3.1.3.1 Degreasing, Rinsing, Drying of Parts - In preparation for welding, the parts shall be degreased in a detergent ("Micro" or equivalent) under ultrasonic agitation for a minimum of 30 minutes. Subsequently, rinsing with de-ionized (DI), filtered (0.2 micron particle size) water precedes all etching operations. Drying of components shall be carried out in laminar airflow in a clean room of class 100 or better.
The parts shall not be touched or supported in places close to an electron beam weld joint or an RF surface to avoid contamination by drying stains. Wearing appropriate clean gloves when handling the parts is required.

3.1.3.2 Buffered Chemical Polishing - Buffered chemical polishing (BCP) of niobium parts or Nb55Ti components shall be accomplished by the seller in a mixture of electronic grade acids consisting of HF (48% conc.), HNO_3 (65% conc.) and H_3PO_4 (85 % conc.) mixed in a volume ratio of 1:1:2.
During the etching operation the parts are immersed in the solution, which shall not exceed a temperature of 15° C. At this temperature the removal rate in fresh acid is approximately1μm/minute for niobium and ~ 50 % higher for Nb55Ti, but removal rate also depends on agitation of the parts. Sealing surfaces of Nb55Ti flanges shall be masked during BCP to avoid pitting.Initial material removal is expected to be 150 μm to 200 μm from the inner surface of the component. The parts shall then be immersed in de-ionized (DI), filtered (0.2 micron particle size) water within 10 seconds to avoid overheating of the surfaces during reaction with the acid films on the surfaces. High Pressure Rinsing (HPR) of the RF-carrying surfaces of the component shall be performed with de-ionized (DI), filtered (0.2 micron particle size) water multiple times until the effluent exiting the component has a resistance > 17.5 MΩ.

High pressure rinsing (HPR) of the inner surfaces of the component shall be performed with de-ionized (DI), filtered (0.2 micron particle size) water after BCP. Inlet pressure of the rinsing system shall be between 1000 psi and 1200 psi. Drying of components shall be carried out in laminar airflow in a clean room of class 100 or better. After the initial buffered chemical polishing, the component shall vacuum fired to 450ºC for a minimum of
16 hours. The temperature ramp rates up and down in shall not exceed 75ºC / hour. The furnace must be clean of any residue that might evaporate at this temperature and then adhere to the component surfaces.
Cleaned parts shall be stored in nylon bags. Electron beam welding shall be carried out within 24 hours after BCP cleaning of the parts. An exception is the circumferential welds on the component. The circumferential welds shall be executed within 8 hours after BCP treatment. If this is not possible, an additional "refreshing" of the surface by the removal of 3 µm shall be done prior to welding.

If subsequent BCP operations are required, all component surfaces, which will be exposed to RF fields during operation of the component, shall have a layer of 20 µm removed (removal rate and thickness refers to a single surface only). For external surfaces (Nb55Ti – flanges, Helium vessel end dishes, stiffening beams…) removal of 5 µm is sufficient. After each BCP operation, high pressure rinsing (HPR) and drying of the inner surfaces of the component shall be performed as sited previously in this section.
Acid baths for Nb parts and Nb55Ti parts shall be separated; the acid mixtures shall be replaced when the niobium content reaches 15 g/l and the removal rate is roughly reduced to half of its value for fresh acids.
When the component assembly or component subassemblies undergo BCP operations the Nb55Ti flange sealing surfaces shall be protected by covers made of high density polyethylene (HDPE) or polypropylene with Teflon-coated Viton o-rings suitable to isolate the sealing surfaces from the BCP fluids. With BNL approval prior to use, other cover and seal materials may be used.

3.1.3.3 Preparation for final circumferential welds - The assembly of components for welding of the circumferential joints shall be done in the class 1000 clean room; it is recommended to blow-clean between the welding steps with filtered (0.2 µm), ionized, clean and dry nitrogen gas prior to assembly.
If circumferential welds cannot be completed in one step, the weld steps must be re-cleaned by carrying out a buffered chemical polishing of 3 µm.

3.1.4 Niobium Fabrication

3.1.4.1 Machining Parameters - Oxygen diffuses into niobium at temperatures above 150 °C; this interstitially dissolved oxygen deteriorates the superconducting properties of pure niobium. Therefore, during machining it is essential to keep the surface temperature of the niobium at the tool below 150 °C. This can be achieved with adequate lubrication. "Flood" cooling is very advantageous since it quickly removes any cuttings ("chips") of material while cooling the workpiece.
The best surface finishes can be obtained with 1,1,1, trichloroethane as a lubricant. However, because of environmental and health concerns, less damaging lubricants have been developed.

Recommended tools and cutting parameters are listed in Appendix A. In addition, references to several publications on fabrication experiences at various labs are collected in Appendix B.
All sealing surfaces of the component (beam pipe flanges, fundamental damper flange and field probe-type flange) shall have a surface finish of 32 microinches circular peak-to-peak or smoother. The sealing surface must be free of scratches, particularly in radial direction. The seller-selected machining method (e.g., lathe) for the flanges will have a large impact on meeting this requirement. Sealing surfaces of the flanges must be protected during any chemical treatment that might pit or otherwise damage these critical surfaces.
To avoid any scratches after the machining, extreme care shall be taken to protect the sealing surfaces by appropriate means. As required by section 5.0, the seller shall provide soft plastic covers, made from polyethylene or other non-chloride containing material. No adherent covering shall be used unless a suitable solvent is available to remove residue without harming the material or finish or changing material properties.

3.1.4.2 Deep Drawing or Forming - Dies for deep drawing for the RRR niobium are to be free of scratches, burrs, and surface contamination by particulates, which might be embedded into the niobium parts during the forming process.
A tough aluminum alloy, such as Al 7071, has been used successfully as die material. Whatever material is selected it is recommended to use copper in the first deep drawing tests to confirm the validity of the die shape.
It must be assured that the marked surface of the niobium shall be the outer non-rf surface after deep drawing or forming. The "inner" surface of the niobium sheet shall be handled with the greatest care to avoid damage by the forming process.
For the deep drawing process, fresh, clean motor oil (10W30 or 10W40) is recommended as a thin film lubricant. This lubricant has the advantage of being transparent so that particulates can be seen and removed prior to the stamping of the part.

3.1.4.3 Rework- Rework in the form of re-stamping, hand filing, grinding and mechanical straightening (e.g. after welding of stiffening ribs) is permitted. This can be done at any stage of the assembly (including weld touch-up or removal of accidentally inflicted surface irregularities) in order to upgrade the parts.
The seller shall remove imperfections affecting the requirements of section 3.1.3 in accordance with Appendix C.
However, extensive stretching or compression of the component during the tuning procedure to achieve the required frequency of the component is prohibited. In particular, the overall length of the component body shall be adjusted to tune the component to the correct frequency. It is permitted to make final adjustments to the overall length by trimming the beam-line flange/beam-line subassembly such that the overall component length falls within the permitted tolerance.

3.1.5 Welding Requirements - The preferred welding method for the components is high vacuum electron beam welding. With BNL prior written approval, exceptions shall be in locations where it can be proven that it will not effect the inner RF surface of the component. In these exceptions, gas tungsten arc welding may be permitted with a sufficient purge gas atmosphere in place.

3.1.5.1 General Requirements

3.1.5.1.1 Because of the high affinity of niobium to oxygen, the vacuum pressure in the EB welding chamber shall be less than 5 x 10^{-5} Torr during welding and any time the temperature of the niobium parts is > 150^{0} C. The welding chamber shall not be vented before the temperature of the Nb parts in the chamber is < 100^{0} C.

3.1.5.1.2 Weld joint configuration can be interlocking step joints or butt joints. The minimum material thickness at the gap shall be as indicated in the drawing package. The welds shall be full penetration without voids that may cause virtual leaks.

3.1.5.1.3 Recommended weld parameters are a low energy density beam, accomplished by defocusing or a "rhombic raster" beam pattern. No vapor column, which might introduce voids in the weld, is permitted when producing welds which are exposed to the component interior.

3.1.5.2 Weld & Braze Joint Requirements

3.1.5.2.1 No cracks are permitted at the interior component surface at any weld or braze joint. A full penetration weld is required, with a smooth underbead, free of weld splatter and excessive drop-through.

3.1.5.2.3 A cosmetic pass for smoothing a weld joint is permitted, provided that no crack is present prior to or after this pass.

3.1.5.2.4 No obviously visible beam start/stop marks (craters) on underbeads are allowed. Overlap of weld and tapering out at the overlap are required.

3.1.5.2.4 Internal Welds

3.1.5.2.4.1 For internal welds (welding executed from inside the component) without full penetration to the outside, an outside pass is required in order to close the outside crack. Interpenetration of the two welds is required to avoid the possibility of a virtual leak or voids. The surface of the internal weld being exposed to the RF currents shall be smoothed with a "cosmetic" pass as noted in paragraph 3.1.5.2.3 above.

3.1.5.2.4.2 If a cosmetic pass is not possible, a full penetration weld is required. A sputter screen/sputter alert device is recommended for a full penetration weld. This simple device protects the surface opposite of the joint being welded while alerting the welder to excessive sputtering that might ruin the inner component surface. An electrical schematic of this device is available from BNL upon request.

3.1.5.2.5 Completed welds must be free of voids and foreign particles or material inclusions. No cracks at the heat affected zone shall be present. Cracks and inclusions are indications of chemically contaminated material.

3.1.5.2.6 The electron beam welding shall not degrade the RRR-value of the niobium by more than 10% due to oxygen pick-up from the chamber atmosphere. This is especially important for body welds. The chamber shall not be vented until all surface temperatures are < 100^{o} C.

3.1.5.2.7 In the case of a defect in a weld, such as a hole or cratering, repair by melting in additional material is allowed as long as the requirements in section 3.1.5.2.6 above are not violated. For a defect in an RF body weld, niobium of RRR-quality must be used as filler material. Cleaning procedures equivalent to those used on the original parts prior to welding shall be applied.

3.1.5.2.8 Any repair or re-weld of components shall add to the weld shrinkage of this part. The shrinkage in the final weld must be taken into account when the frequency of the component is adjusted (see section 4.2.3)

3.1.5.2.9 Braze Joints

3.1.5.2.9.1 Braze joints shall be accomplished using a vacuum brazing technique with a vacuum pressure of < 5X 10^{-5} Torr. The seller may request the use of a different process, but any change in technique must be approved by BNL in writing prior to being used on any component components.

3.1.5.2.9.2 Brazing filler materials must have a proven record of successful use with the base materials employed in this SRF component. The filler material must fill the braze gap uniformly without excessive material, staining of the mating flange or insufficient material producing an undercut. Braze material tracking across the dielectric is prohibited.

3.1.5.3.1 Welding - A list of all welds to be executed in the fabrication of the component shall be compiled. The listed welds shall then be separated into types of welds and weld joints (e.g. butt weld joint, angled butt weld joint, interlocking weld joint, etc.) and materials. Of the welds in each joint category the extremes of each shall be selected for weld tests (i.e, material type being joined, the thinnest material, the thickest material, the greatest weld angle, etc.). Weld samples, fabricated by the seller, shall be tested by a certified laboratory. This weld testing shall be provided by the seller. A Procedure Qualification Record (PQR) shall be made by the seller for each weld test sample produced (see ASME Section IX, QW-200.2). All welders welding on the component shall be qualified in accordance with ASME Section IX, QW- 301. A list of weld samples to be tested shall be submitted to BNL for approval prior to test.

3.1.5.3.2 Brazing - A list of all braze joints to be executed in the fabrication of the component shall be compiled. The braze list shall separate the joints by types, material being joined and other distinctions (e.g. tube diameter, tube wall thickness, joint orientation, etc.). Of the joints in each joint category the extremes of each shall be selected for testing (i.e, the thinnest material, the thickness material, etc.).
Brazing samples, fabricated by the seller or the seller's subcontractor, shall be tested by a certified testing laboratory. A Procedure Qualification Record (PQR) shall be made by the seller for each braze test sample produced (see ASME Section IX, QB-200.2). All BPS used on the

component shall be qualified in accordance with ASME Section IX, QB-300. A list of braze samples to be tested shall be submitted to BNL for approval prior to test.

3.1.5.3.3 Required Weld and Braze Testing and Examination

3.1.5.3.3.1 Acceptance of Welds - The seller shall, after development of the weld parameters and the optimization of the welds, demonstrate on test welds that the RRR-value has not degraded by more than 10% in comparison to the original niobium and that the requirements in section 3.1.5.2 are met. It is recommended that during the sample weld development the seller monitor the gas composition in the welding chamber throughout the welding process.

3.1.5.3.3.2 Weld Inspection – All required weld inspections including visual inspections and radiography of welds and shall be performed and the welds approved by an AWS certified weld inspector (CWI).

3.1.6 Vacuum Integrity Requirements

3.1.6.1 The component shall be leak tight when checked with a helium mass spectrometer with a minimum sensitivity of 5×10^{-12} Atm.cc (He)/sec. Leak tight is hereby defined as an allowable leak rate of $\leq 2 \times 10^{-11}$ Atm.cc (He)/sec when the component is sealed with supplier-provided gaskets of the type to be used during final component operations.

3.1.6.2 The component leak test shall be accomplished without the use of silicon grease at the gaskets. It is recommended to use original $AlMg_3$ gaskets or fully annealed ConFlat-type copper gaskets in accordance with applicable drawings for the all flange configurations used. The seller is responsible for all seals, blank-off flanges and fixtures required during vacuum leak checking. Repair of leaks other than at gaskets requires, in all cases, prior approval by BNL’s Technical Representative regarding the method and possible risks.

3.1.6.3 During the leak test, all seams, welds and joints shall be probed with helium gas. Subsequently, an integral leak test shall be administered by enclosing the test item and completely surrounding it with helium gas for a duration of 5 minutes, while being leak checked internally. The indicated leak rate shall not exceed the allowable leak rate throughout the 5 minutes duration.

3.1.7 Component Performance Requirements

3.1.7.1 Manufacturing Drawings – The component shall conform to the drawing set provided by BNL to the seller.

3.1.7.2 Component Dimensions – A major requirement of component fabrication is to meet the design performance. Performance is dependent upon component dimensions. In the provided drawings component dimensions are provided in detail. The component shall comply with the dimensions in the drawings.

3.1.8 Design Objectives - BNL's optimum performance values for the component are expected. Although these performance values are not a part of the technical requirements for acceptance of components, BNL will utilize test results as an indicator for possible defects. (Experience indicates that components carefully produced in accordance with the technical requirements covered by this specification will achieve the desired performance levels.)

3.1.8.1 Possible Causes of Manufacturing Defects - Flaws in workmanship normally cause reduced component performance and can usually be traced back to one of the following problems (this is noted here for the seller's information):

- Electron beam welds not being executed properly.
- The presence of weld beads or spatter sticking to the surface.
- Foreign material inclusions found at the surface.
- Niobium removed during forming is embedded in base material.
- The presence of sharp edges or points caused by improper handling or machining.
- Excessive interstitial or grain boundary contamination of the niobium, caused by improper handling.

3.1.9 Tracing of Parts - a method of labeling and tracing component parts through the manufacturing process shall be implemented. Particularly it is important to serialize the component conductor parts such that they can be identified and traced back to the niobium pieces scanned for defects by the Eddy Current method. These pieces shall have been identified with respect to material manufacturer and material lot/heat. (It is proposed that the identification number for the plates be engraved near the edge on the outer / non-rf surface.)

4.0 <u>Verification/Acceptance Testing</u>

4.1 <u>Classification of inspection/tests</u>. The test requirements specified herein are as follows:
- In process
- Pre-Shipment / Inspection

4.2 <u>In process Inspections</u> - The inspections required herein are the minimum required by BNL and are not intended to supplant any controls, examination, inspections or tests normally employed by the seller to assure the quality of the equipment. The following inspections are required:

4.2.1 <u>Material Receipt</u> - All material used by the seller in the fabrication of the component (RRR niobium, Nb55Ti, reactor grade niobium, etc.) shall be inspected by the seller in accordance with section 3.1.2.1.

4.2.2 <u>Visual</u> - All subcomponents shall be visually inspected after forming, machining and cleaning, including buffered chemical polishing – operations, listed in 3.1.3., 3.1.4, and 3.1.5.

4.2.3 <u>Process Hold Points</u> - Subcomponents shall be visually inspected after electron beam welding operations, brazing operations, dimensional measurements and leak checking.

4.2.4 Pre-shipment - Prior to shipping the system, the seller shall perform a series of tests that verify the design, fabrication, assembly, and performance of the component. The testing shall include, but not be limited to, the following:

4.3.1 Component Testing – Acceptance testing of components to verify the manufacturers specifications shall be performed prior to installation into the system. An example of this would be leak checking prior to installation.

4.3.2 Cold Shocking - The seller shall perform liquid nitrogen cold shock and He mass spectrometer leak test on each welded assembly. No leakage shall be observed with a sensitivity of 1×10^{-9} Torr liter/sec. of helium.

4.3.3 Pneumatic Testing – The component has a design pressure of 20 psid. Therefore, the component assembly shall be pneumatically tested by the Supplier to an internal pressure of 23 psid.

4.3.4 Vacuum Leak Checking - The seller shall perform Helium Mass Spectrometer Leak Tests on the component. No leakage shall be observed with a sensitivity of $\geq 2 \times 10^{-11}$ Torr liter/sec. of helium.

4.3.5 Component Acceptance - Final acceptance test shall include:
- Visual inspection of each component and the total system for shipping damage.
- Pressure and vacuum tests for the complete system.
- Functional check of component performance.

5.0 Shipping & Preparation for Shipping

5.1 Shipping - The finished component shall be carefully packed to avoid any mechanical or chemical damage during transit to and from the BNL-selected location and / or to BNL. In particular, the component shall be secured against axial displacement and mechanical distortions. The design of the shipping container and its parts shall be submitted for approved by BNL at least one month prior to shipping of the component.
All sealing surfaces on the components shall be protected by covers if not sealed to a mating flange. These covers shall also be fabricated from the acceptable materials listed in paragraph 3.1.3.2.
The components shall be shipped in as complete a form as possible. Seller shall design and fabricate packaging with adequate performance to ensure protection against natural and induced environments during delivery and storage of the components. The components shall be blocked, braced and protected from damage during shipment. Two sets of recording accelerometers for three directions of motion shall be firmly attached for each truck loading. The seller shall provide lifting eyes suitable for lifting the component skid/crate from above, as well as provisions for lifting via forklift.
The components shall be shipped assembled in a protective container that is fully evacuated. The component shall be supported against damage and distortion while evacuated. The protective container shall be fitted with a small vacuum valve to allow testing and to assure that no loss of vacuum has occurred during shipment.

6.0 Notes

6.1 Performance Objectives - Simplicity in fabrication, ease of maintenance, and an improvement in the performance and reliability shall be considered in the production of this component. Where it appears a substantial improvement in these areas will result from the use of materials, parts and processes other than those specified, it is desirable that their use be investigated. When investigation shows advantages can be realized, a request for approval shall be submitted to BNL for consideration. Each request shall be accompanied by complete supporting information. Changes in configuration may be made by the seller only with the written approval of a representative of BNL Procurement and Property Management Division, in consultation with the SRF engineering staff of the Collider-Acceleration Department.

Apendix A
Recommended Tools and Cutting Parameters

The following machining parameters have been successfully been used at various laboratories for the machining of niobium. They are collected as a general guideline and are provided for information only.

Milling

Tool:	2 flute high helix aluminum cutter, high speed steel
Cutting Speed:	Maximum 80 ft/minute
Feed Rate:	4 inches / minute to 8 inches / minute (0.002 inches / revolution)
Thickness of Cut:	≤ 70 mils / cut
Lubricant:	1,1,1 Trichloroethane, Cimcool, Blue Mist, Flood-cooling

Turning on a Lathe

Tool:	Carbide, back rake 70º (almost like a knife)
Speed:	3-5 ft. /sec.
Feed Rate:	0.05 mm / revolution (fine cut)
Thickness of Cut:	0.05 mm (fine cut)
Lubricant:	1,1,1 Trichloroethane, Cimcool, Blue Mist, Flood-cooling

Tools wear quickly and lose dimensions before breaking. Cutting chips should be immediately removed from the work piece.

Information provided by Jefferson Laboratory, Newport News, VA.

Appendix B
Several Technical Publications on Niobium / Component Fabrication Experiences at Various Laboratories (included for general information)

H.Peil, “Fundamental Features of Superconducting Components for High Energy Accelerators”, Report WUB-86-14, Gesamthochschule Wuppertal, Fachbereich Physik (1986).

J. Kirchgessner, “Forming and Welding of Niobium for Superconducting Components”, in Proceedings of the Third Workshop on RF Superconductivity, Report Nr. ANL-PHY-88-1, Vol. II, p. 533, Argonne National Laboratory, Argonne, IL 60439

J. Brawley, et al.; “CEBAF Experience with In-House Production Fabrication of Niobium Parts”, in Proceedings of the 6th Workshop of RF Superconductivity, Report Vol. II, p. 1133, CEBAF, Newport News, VA (1993)

P. Bramham, “Measured and Computed Fields in the Niobium Accelerator Structure”, HEPL Report # 639, Stanford University, Stanford CA.

G. Kreps, et al.; “Half-Cell and Dumb-bell Frequency Testing for the Correction of the TESLA Component Length”, in Proceedings of the 8th Workshop on RF Superconductivity, paper.

J. Sekutowicz, et al.; “A Different Tuning Method for Accelerating Components”; in Proceedings of the 4th Workshop on RF Superconductivity, KEK Report 898-21, Vol. P. 849, KEK Tsukuba, Japan (1989)

Information compiled by Jefferson Laboratory, Newport News, VA.

Appendix C

Removal of Inner Surface Imperfections in Niobium

The seller shall remove imperfections with a metallic grinding tool or an aluminum oxide wheel (e.g. Wheel #7 AM or AF, 3M-company). Recommended grinding wheel material is an aluminum oxide abrasive embedded in fibrous material or equivalent and shall be approved by BNL’s Technical Representative.

Cutting, grinding and abrasive tools shall be niobium dedicated and shall not be used on other materials. Grinding of defects at the “inner” surface shall produce a smooth surface and a smooth transition to the untreated surrounding area. During rework operations surface temperatures on niobium surfaces shall not exceed 150° C.