

# HIGH RRR NIOBIUM COST REDUCTION PROGRAM FOR SRF LINACS

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## Abstract

This paper outlines the joint program involving CBMM, its subsidiary companies in the U.S.A., Germany and Japan, the Thomas Jefferson National Accelerator Facility in the U.S.A. and the Deutsche Elektroniken Synchrotron in Germany, to evaluate the influence of the tantalum content in the pure niobium used in the manufacture of superconducting RF cavities.

## 1 INTRODUCTION

High RRR bulk niobium cavities are the workhorses of all the SRF accelerators that are under construction (SNS) and/or in planning to be built (RIA and TESLA). The cost of high RRR niobium is a substantial fraction of these accelerators.

One reason for such high niobium costs is believed to be the low tantalum content specification, which in some cases is required to be <500ppm.

By specifying very low tantalum content it will be more difficult to rely on CBMM as a supplier, which is the largest and most consistent source of niobium in the world. Depending on the tantalum level in the niobium specified for the RF cavities, the only sources for these niobium units will be the niobium oxide obtained as a by-product of tantalum operations, which uses columbite/tantalite ores. (See box for more explanation on the niobium supply). Limiting supply may act a big barrier to price stability and reliability for large projects such as TESLA and other accelerators that may need large quantities of niobium units. Therefore, it seems reasonable to scientifically understand what is the necessary tantalum level for the final material.

CBMM and its subsidiaries have undertaken a research program, in collaboration with the Jefferson Lab and DESY, to scientifically evaluate the tolerable level of tantalum (which will reduce the high RRR niobium costs) without sacrificing the required high performance (high  $Q_0$  and  $E_{acc}$ ) of these accelerator structures.

## 2 NIOBIUM SUPPLY

Suppliers of niobium metal products can be grouped in three classes:

The first group would be comprised of companies with access to columbite, tantalite or loparite. In this case, niobium oxide is manufactured as a by-product of other operations (e.g. tantalum) and the output available is strongly dependent on the quality of the ores in the

manufacturing of the main-product, most frequently tantalum.

A second class of suppliers is formed by converters. These companies do not have their own niobium raw material. They will acquire standard grade ferroniobium or high purity niobium oxide and transform them into niobium ingots.

CBMM, Companhia Brasileira de Metalurgia e Mineracao, constitutes a class of its own. Fully integrated from the mine to the final products (standard grade ferroniobium, high-purity niobium oxide, vacuum grade ferroniobium, nickelniobium, niobium metal, optical grade niobium oxide, selected niobium compounds for chemical applications), CBMM is the most comprehensive supplier of niobium products for all industries. Its unlimited raw material supply and installed capacity that exceeds the world's demand of niobium products are the key elements to the stable supply and market price of niobium products enjoyed by the industry over the years.

Until 1980, niobium oxide was only obtained as a by-product of tantalum operations. As a consequence, price and availability were dictated by variables associated to the tantalum business.

In 1980 CBMM started its own operation to manufacture high purity niobium oxide. The initial production capacity was 2,000 tonnes per year, or approximately twice as much as the total world demand for niobium oxide. CBMM's current installed capacity corresponds to 3,000 tonnes of niobium oxide per year.

CBMM's technology to manufacture niobium oxide starting with pyrochlore instead of columbite/tantalite as in the past brought the current stability of niobium oxide availability to this industry. When CBMM started to supply high purity niobium oxide in 1980 the price for the product dropped more than 60% and was stabilized ever since.

## 3 CEBAF

CBMM's niobium has been used in several projects involving superconducting cavities. Bosch<sup>(1)</sup> reported the details related to the niobium used by Fansteel to supply the Continuous Electron Beam Accelerator Facility (CEBAF) in the U.S.A. According to the author more than 70% of all niobium used in the cavities were supplied by CBMM in the form of second-melt ingots which were further refined in a similar electron-beam furnace at Fansteel.

The range of RRR obtained for niobium from CBMM for the CEBAF project was the same in the as-cast ingot and in the final annealed sheets. The average residual resistivity ratio was 325 with the lowest value at 270 and the highest value at 520.

The specification for the niobium metal for that project required the tantalum content to be less than 1,000 wppm. Additional specifications for the material used for the CEBAF can be also found in the literature along with some of the results from each of the suppliers to the project<sup>(2)</sup>.

#### 4 PROJECT OUTLINE

The following major steps are being planned to study the influence of the tantalum content on the properties of the superconducting RF cavities:

- Manufacturing of four niobium metal ingots with different tantalum contents (<100, ~500, ~1000 and ~1400 wppm).
- Measurements of the thermal conductivity of high RRR niobium with different tantalum contents will be performed in the “as cast” stage (unwrought niobium ingots).
- Neutron activation analysis of full cross sections of each ingot will be carried out to evidence any tantalum segregation that may occur in the as-cast stage.
- Chemical analysis data will be reported to show that only tantalum content is substantially varied in this study, while other impurities (especially interstitial elements C, N, O and H) are kept very low.
- Ingots will be transformed into niobium sheets for cavity manufacture.
- Thermal conductivity measurement will be performed in the niobium sheets.
- Single cell cavities will be manufactured with niobium sheets for each heat with different tantalum content.
- Performance of single cell cavities in the presence of high RF fields will be measured.

#### 5 RESIDUAL RESISTIVITY RATIO

The residual resistivity caused by homogeneously distributed defects, such as residual impurities, is proportional to their concentration.

The proportionality constants determined for several impurities in niobium are presented in the following table as shown by Schulze<sup>(3)</sup>. The influence of each impurity is shown as a percentage of the influence of nitrogen.

<b>Relative influence of different impurities on RRR of niobium.</b>	
<b>Nitrogen</b>	<b>100</b>
Carbon	83
Oxygen	87
Hydrogen	15
Titanium	27
Hafnium	27
Zirconium	12 to 27
Tungsten	8 to 21
Molybdenum	4
<b>Tantalum</b>	<b>5</b>

Tantalum has an effect on the residual resistivity ratio which is twenty times smaller than the interstitial impurities such as nitrogen, carbon and oxygen.

In fact, the influence of 10<sup>8</sup> dislocations per cm<sup>2</sup> (which is a typical dislocation density for recrystallized materials) is twice of that of tantalum on the RRR of niobium.

#### 6 FINAL REMARKS

The considerations previously outlined justify a thorough examination of the issue involving the effect of tantalum content on the performance of superconducting RF cavities.

The proposed work is intended to help future decisions involving the chemical specification of niobium for superconducting RF cavities in an attempt to reduce the total cost of future accelerators relying on these materials.

#### 7 REFERENCES

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- [3] K. K. Schulze, “Preparation and Characterization of Ultra-High-Purity Niobium”, Journal of Metals, Vol.33, No.5, May 1981, p.33-41.