BNL-228249-2025-TECH

EIC-ADD-TN-122

Electrical resistivity testing from 300K to 20K of some commercially available copper, aluminum and nickel

F. Micolon

May 2025

Electron-Ion Collider

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Nuclear Physics (NP)

DISCLAIMER

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F.Micolon, S. Nayak, B. Golden

Revision	Date	Main modification
1.0	5/29/2025	Initial release
2.0	10/16/2025	Addition of tellurium copper data (C14500) Addition of a table of content

Contents

1 Introduction

Through 2024-2025 some alloys of copper, aluminum and nickel were tested in a cryogenic electrical resistivity measurement bench, with the primary intent to help inform the design of superconducting current leads for EIC [1]. The measurement spans temperature from 293 K to around 20 K. The material tested are:

a) Brass 260 (UNS C26000)
b) Copper OFHC 101-O (UNS C10100)
c) Copper ETP 110-O (C11000)
d) copper ETP 110-H02 (C11000)
e) Copper ETP 110-H04 (UNS C11000)
f) Copper DHP 122-H02 (UNS C12200)
g) Copper Tellurium 145-H02 (C14500)
h) Aluminum 1100-O (UNS A91100)
i) Aluminum 2024-T4 (UNS A92024)
j) Nickel 200 (UNS N02200)

This report aims to detail the results and discuss by comparing them with literature data.
A table of the measured resistivity values is available in appendix 2 for future use.

1.1 Test bench description

The test bench used is described in Ref. [2].
The sample is cooled by a cryocooler and the electrical excitation of the samples is AC with a 5 Hz excitation frequency to filter out noise and thermoelectric effects. This means that highly conductive alloys at very low temperatures may be affected by skin depth effect. This effect is proportional to the square root of electrical conductivity. For this work the samples geometry of highly conductive alloys was adequate, and we made sure no skin depth effect was significant (material cross section <0.5x skin depth for all temperature).
The voltage is measured in a 4 wire arrangement and the current is set with precision by the power supply.

1.2 Samples geometry

Two geometries of samples were used, a flat ribbon and bent tubular samples.
Flat ribbon follow the drawing EIC-HSR-SCN-0112 available in annex 1.

Material	Sample thickness
Brass 260	0.032” (0.8 mm)
Cu ETP 110-O	0.01“ (0.254 mm)
Al 1100-O	0.01“(0.508 mm)
Al 2023 T3	0.02“(0.5 mm)

An adapter piece was later made to allow testing of square and tubular products.

Material	Sample dimensions
Cu ETP 110-H02	Square – width 0.09”
Cu ETP 110-H04	Rod OD Φ 0.125“ (Φ 3.175 mm)
Cu DHP 122-H02	Tube OD Φ 0.125“ / ID 0.097“ (Φ 3.18/2.46 mm)
Nickel 200	Strip 0.25” wide – 0.018” thick

2 Results and discussion

2.1 Brass 260 – H02 (UNS C26000)

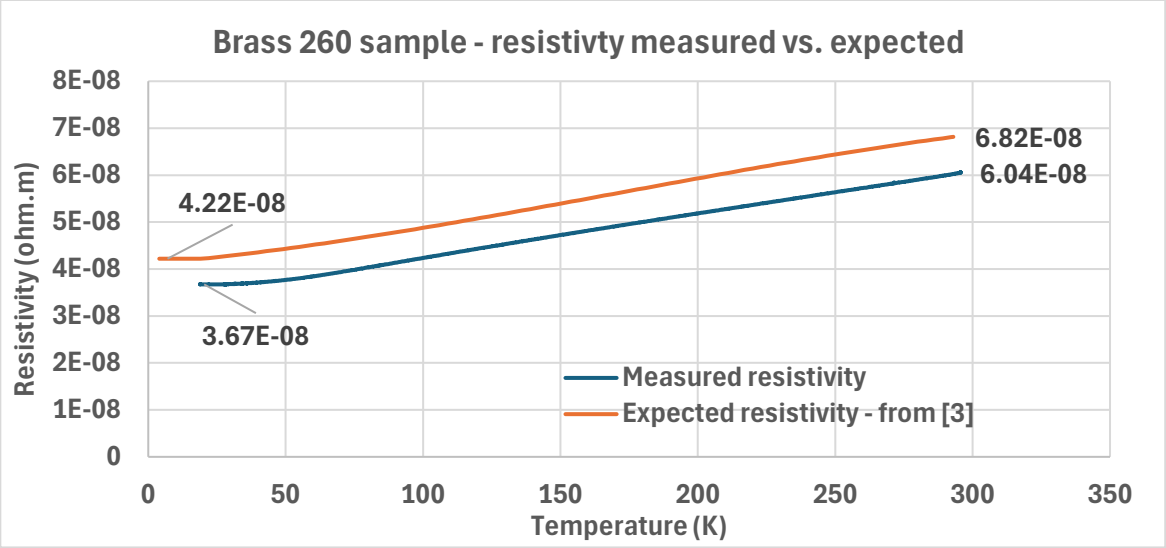


Figure 1 Brass 260 - Electrical resistivity 296 K to 20 K

The measured electrical resistivity of the brass 260 sample is lower than expected by about 13%. This is consistent along the temperature decrease. The brass from the literature data [3] is mentioned to be hardened to ¾ hard while the brass 260 sample we tested was given as ½ hard. The lower strain hardening in our sample may explain the lower resistivity observed throughout.

2.2 Copper OFHC 101-O (UNS C10100)

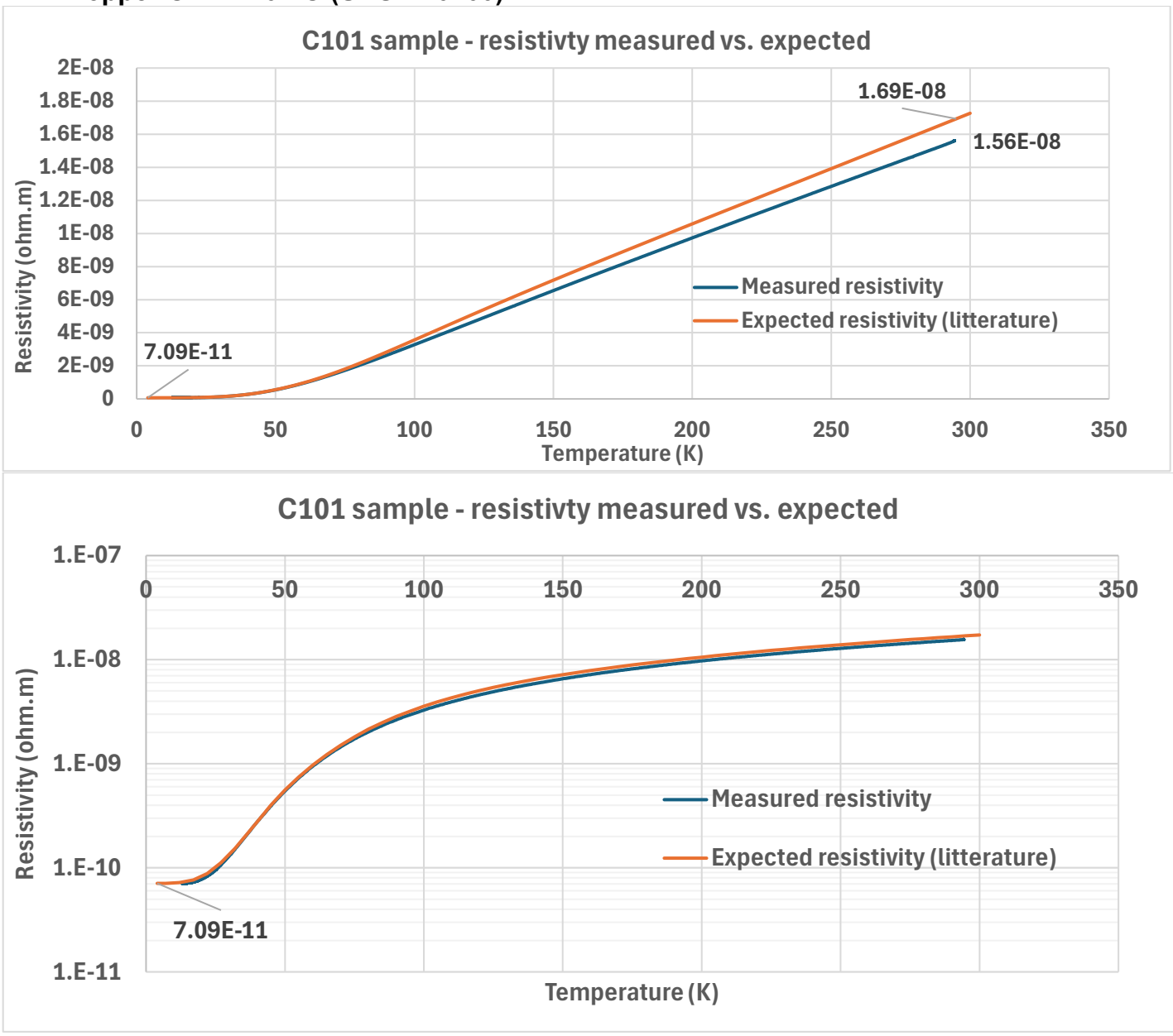


Figure 2 Copper 101-O - Electrical resistivity 296 K to 29 K – Linear scale (top) Log-scale (bottom)

The RRR measured is **219** which is consistent with a high purity annealed copper.
A small mismatch between the measurement and literature data [4] is present at warm temperature only. The room temperature resistivity of 1.56E-8 ohm.m seems low while 1.70E-8 ohm.m is typical for pure copper at 295K.

2.3 Copper ETP 110-O (UNS C11000)

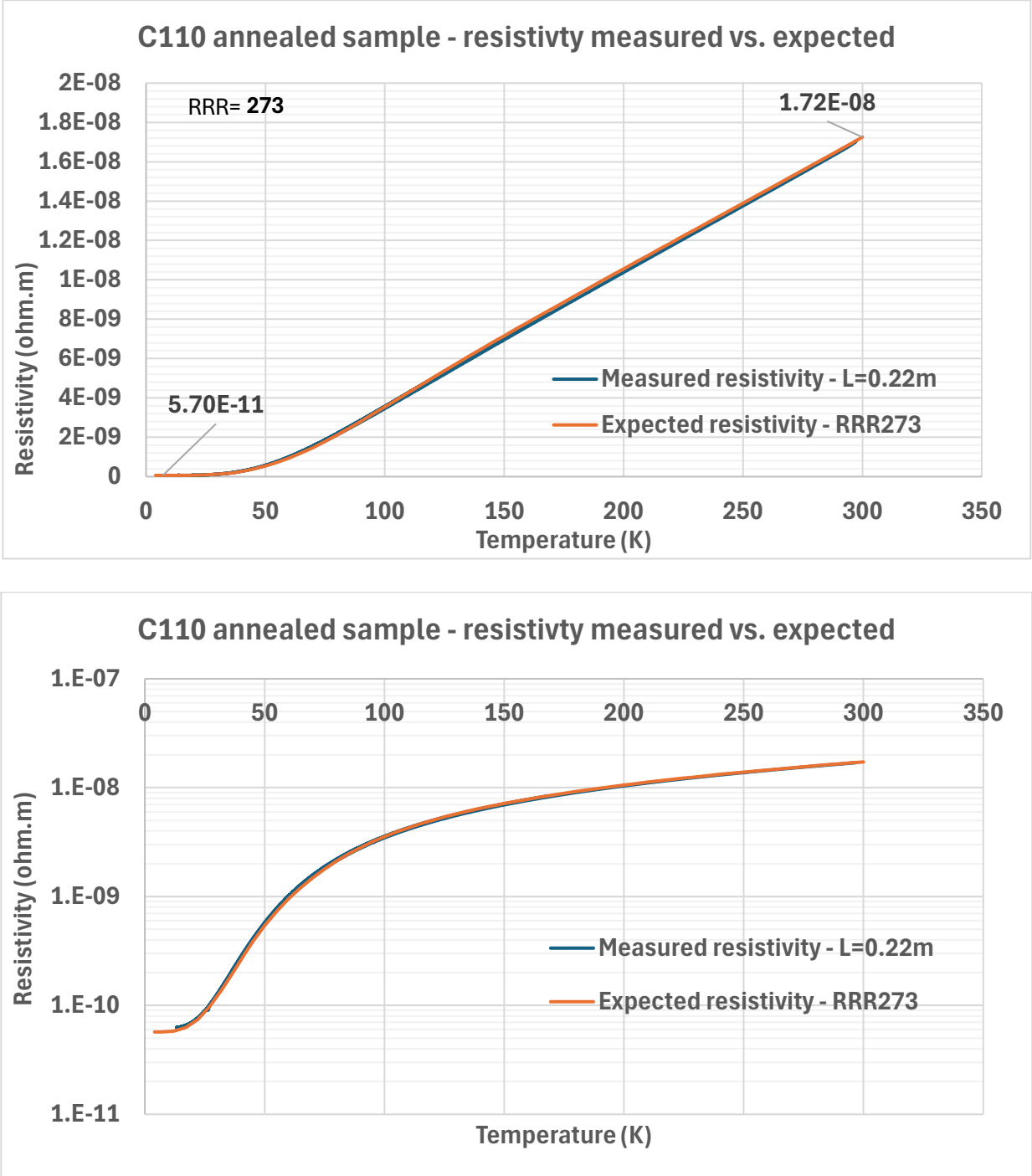


Figure 3 *Copper 110-O - Electrical resistivity 296 K to 29 K – Linear scale (top) Log-scale (bottom)*

The RRR measured is **273**. The match with literature data computed with a RRR273 [4] is excellent.

2.4 Copper ETP 110-H02 (UNS C11000)

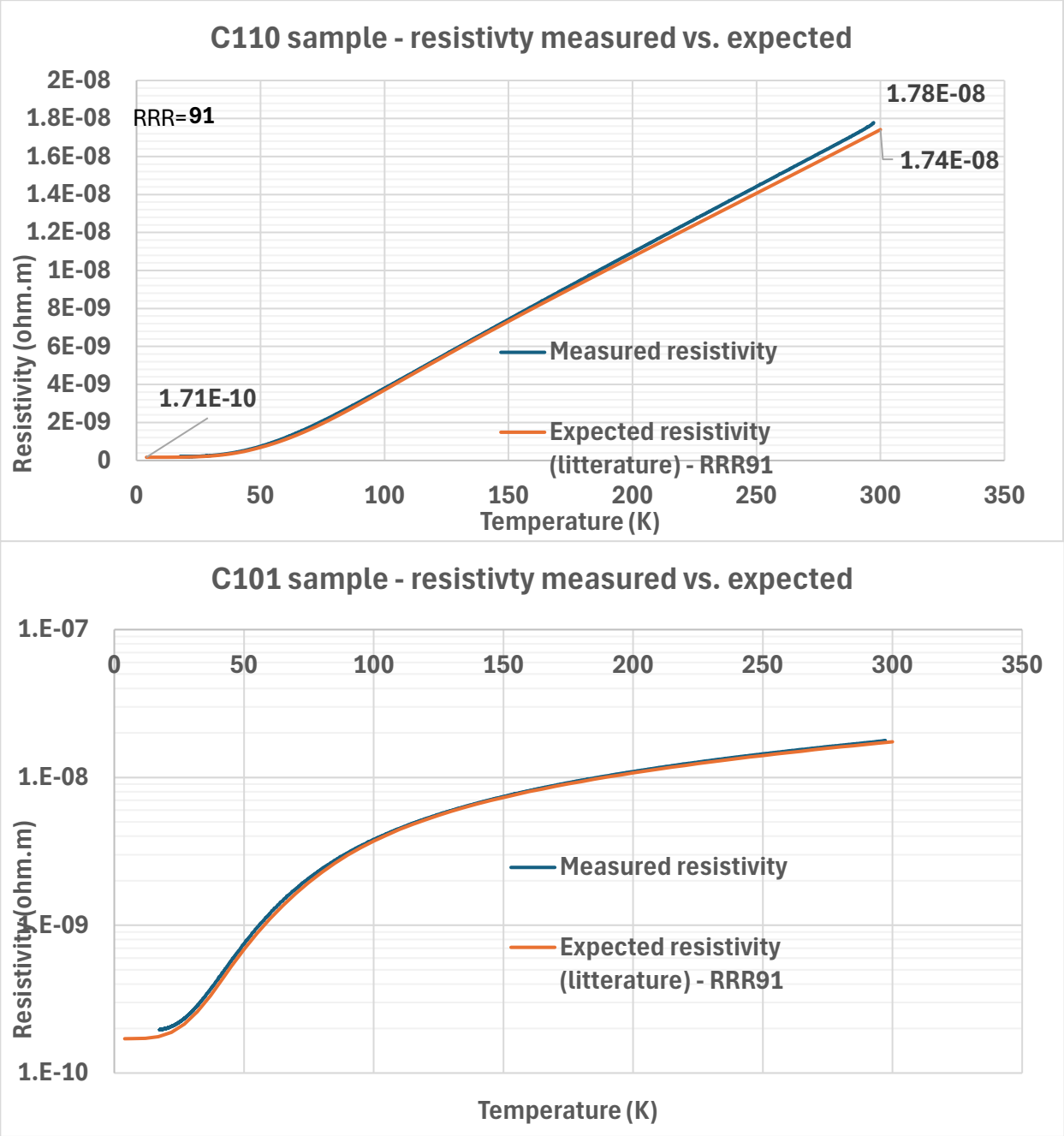


Figure 4 *Copper 110-H02 - Electrical resistivity 296 K to 29 K – Linear scale (top) Log-scale (bottom)*

The RRR measured is **91**, a significant reduction from annealed copper (see section b. and c.).
The match with literature data [4] is excellent. Although the actual hardness of this sample is unknown, it is specified as H02 which corresponds to about 20% of area reduction. Ref. [4] gives a estimate of RRR from cold work and the range for 20% cold work is around RRR 60-90 which is consistent with the results.

2.5 Copper ETP 110-H04 (UNS C11000)

Due to an acquisition issue, the cool-down resistivity data was not usable. However, the RRR measured is **61**. For a full hard H04 copper, the elongation is around 30%. The RRR obtained is consistent with the RRR predicted in [4] for the amount of cold work.

2.6 Copper DHP 122-H02 (UNS C12200)

Copper DHP has a relatively high level of impurity, in particular phosphorus, which is among the most effective impurity to reduce the electrical resistivity and RRR (Ref.[4] Fig 8.1). A RRR of **5.3** is measured.

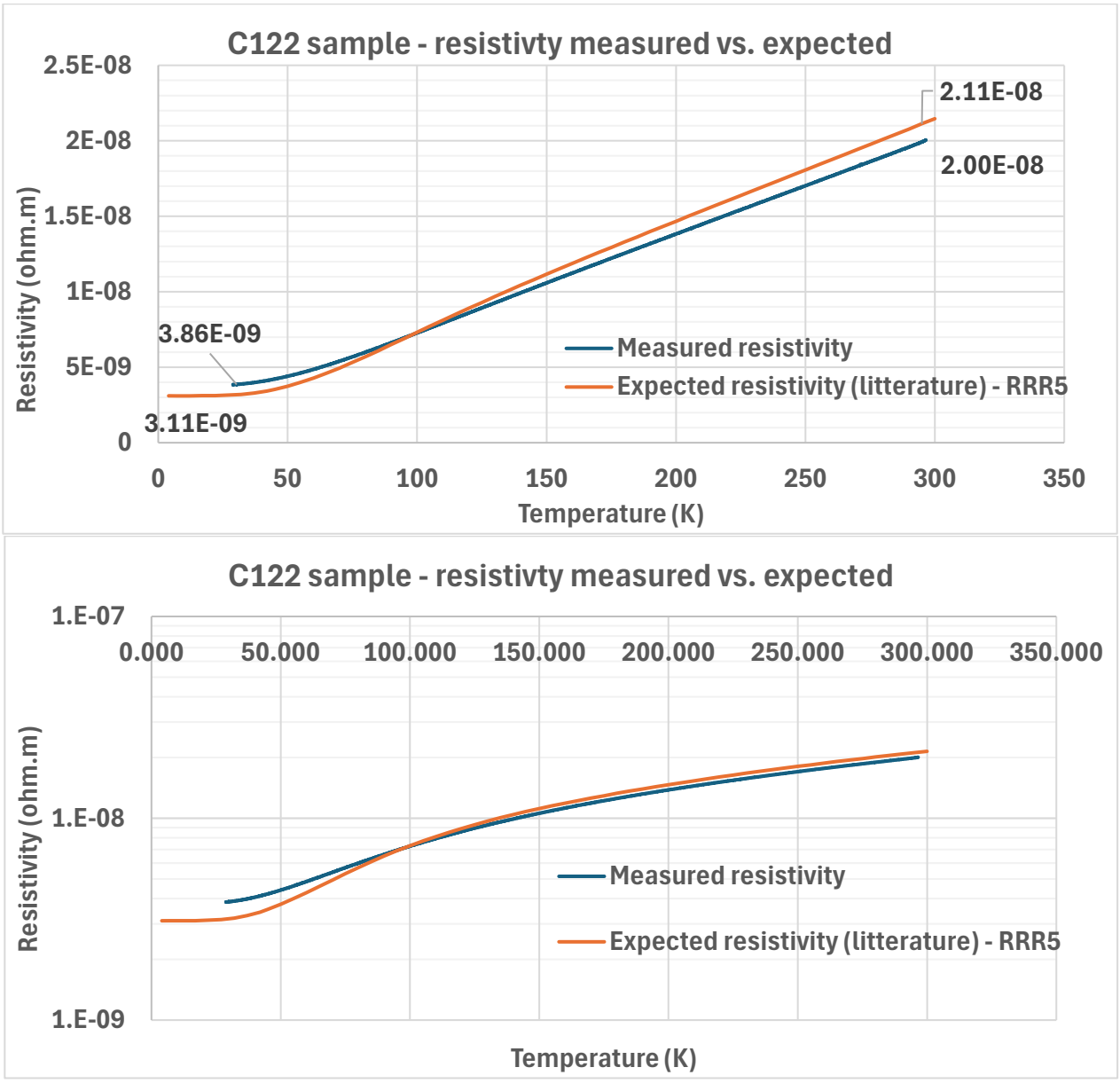
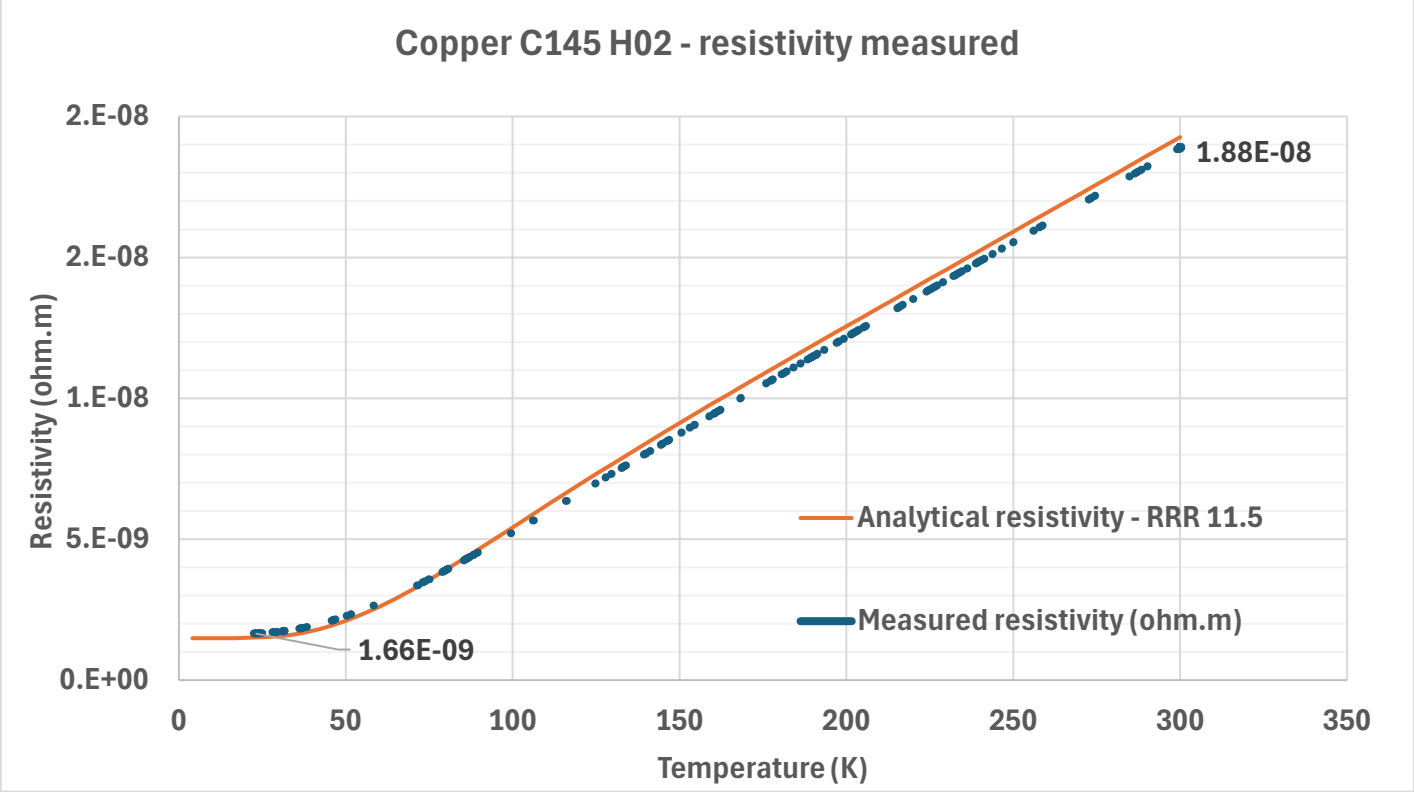
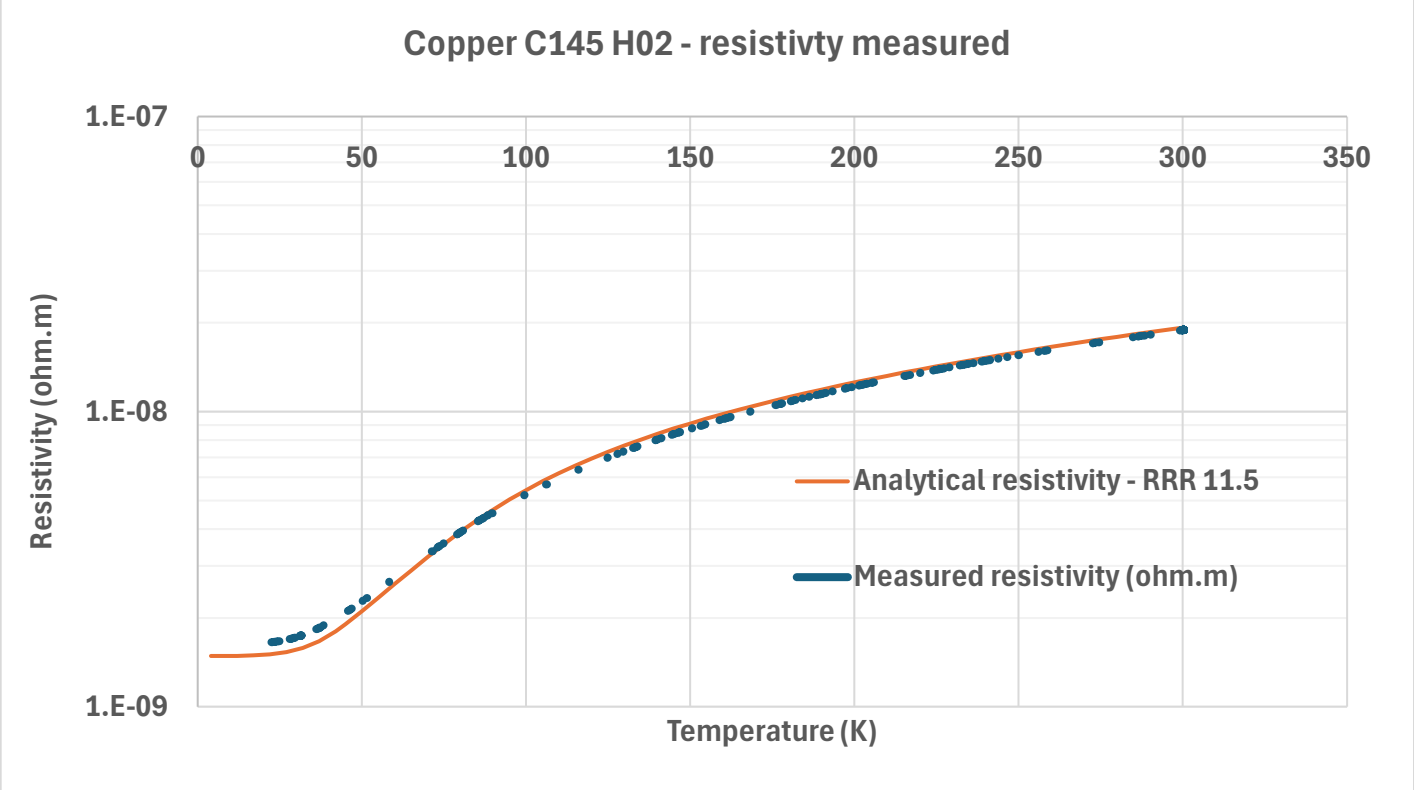


Figure 5 *Copper 122-H02 - Electrical resistivity 296 K to 29 K – Linear scale (top) Log-scale (bottom)*

2.7 Copper Tellurium 145-H02 (UNS C14500)





There is a very match between the measured and expected electrical resistivity.

2.8 Aluminum 1100-O (UNS A91100)

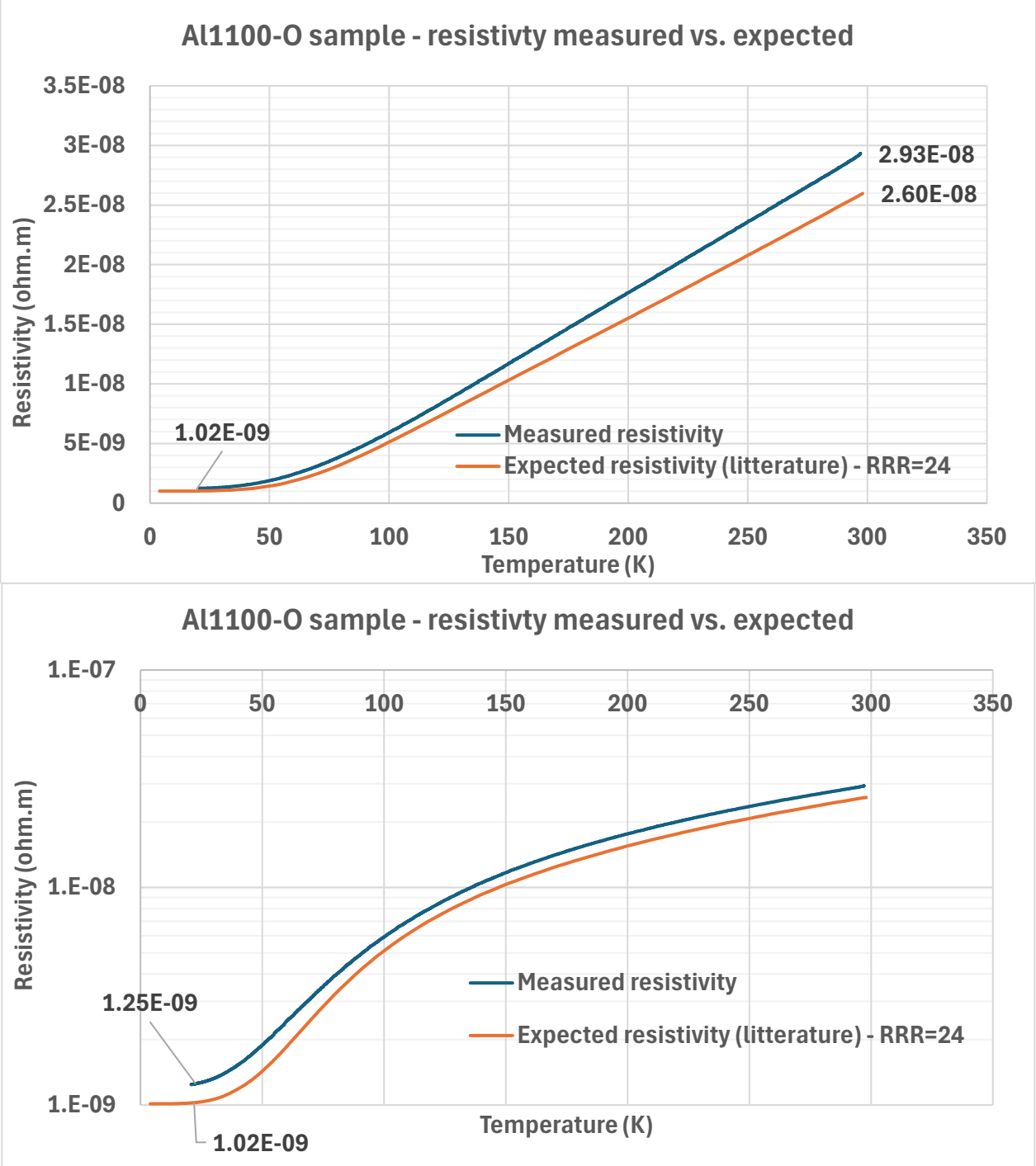


Figure 6 *Aluminum 1100-O - Electrical resistivity 296 K to 29 K – Linear scale (top) Log-scale (bottom)*

A slight discrepancy is seen all along the curve, it is particularly notable on the log-curve that the discrepancy is a proportion of the total resistivity between 12% (at room temperature) and 20% (at 20K). The RRR is **24**.

2.9 Aluminum 2024-T3 (UNS A92024)

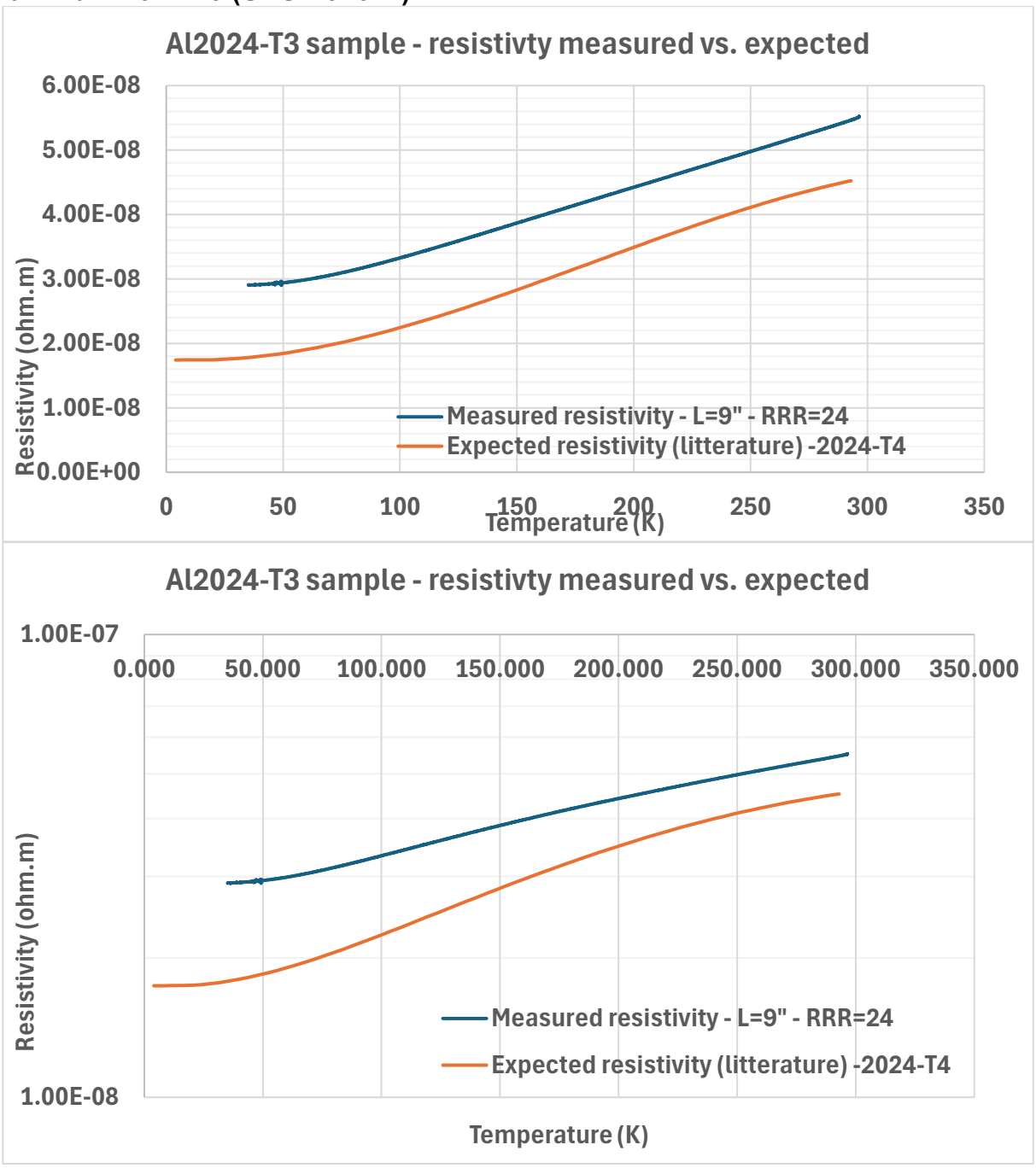
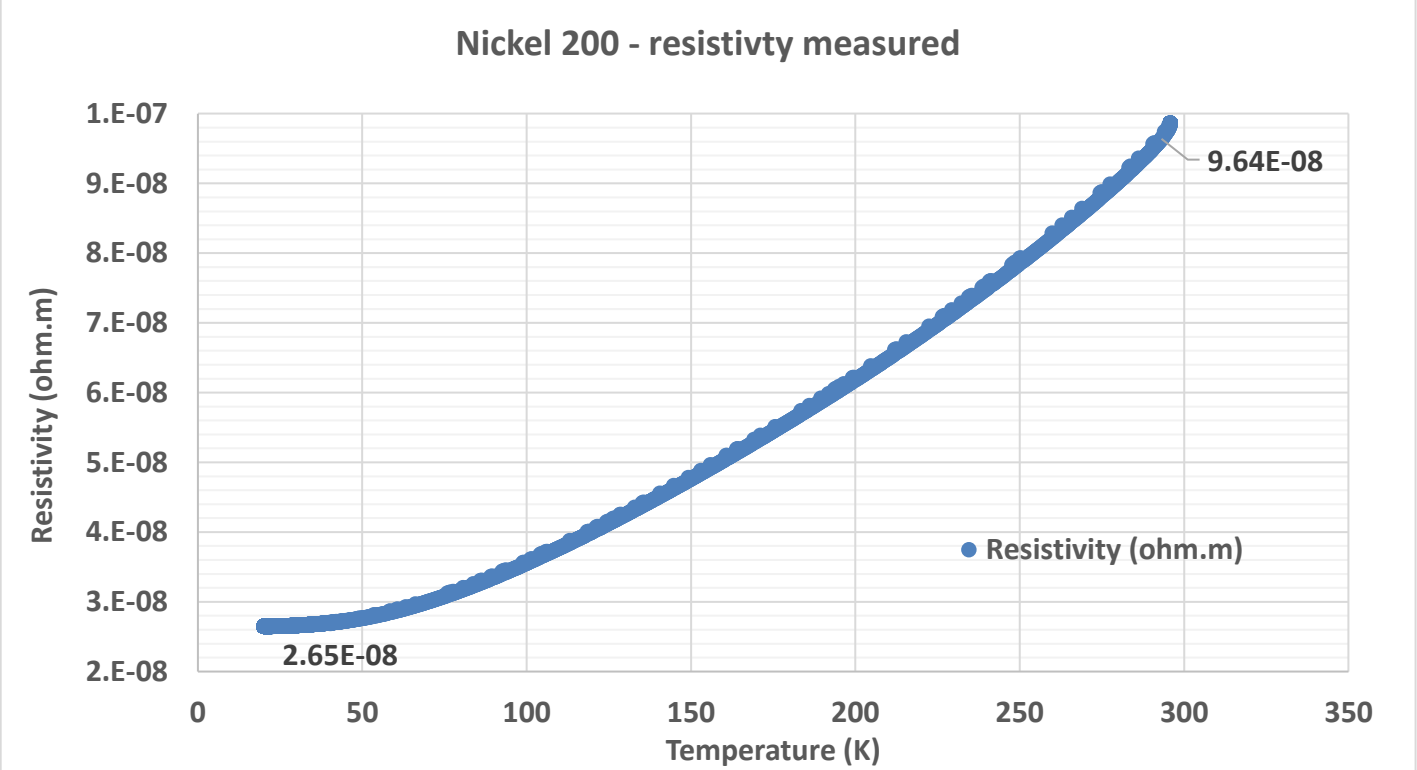
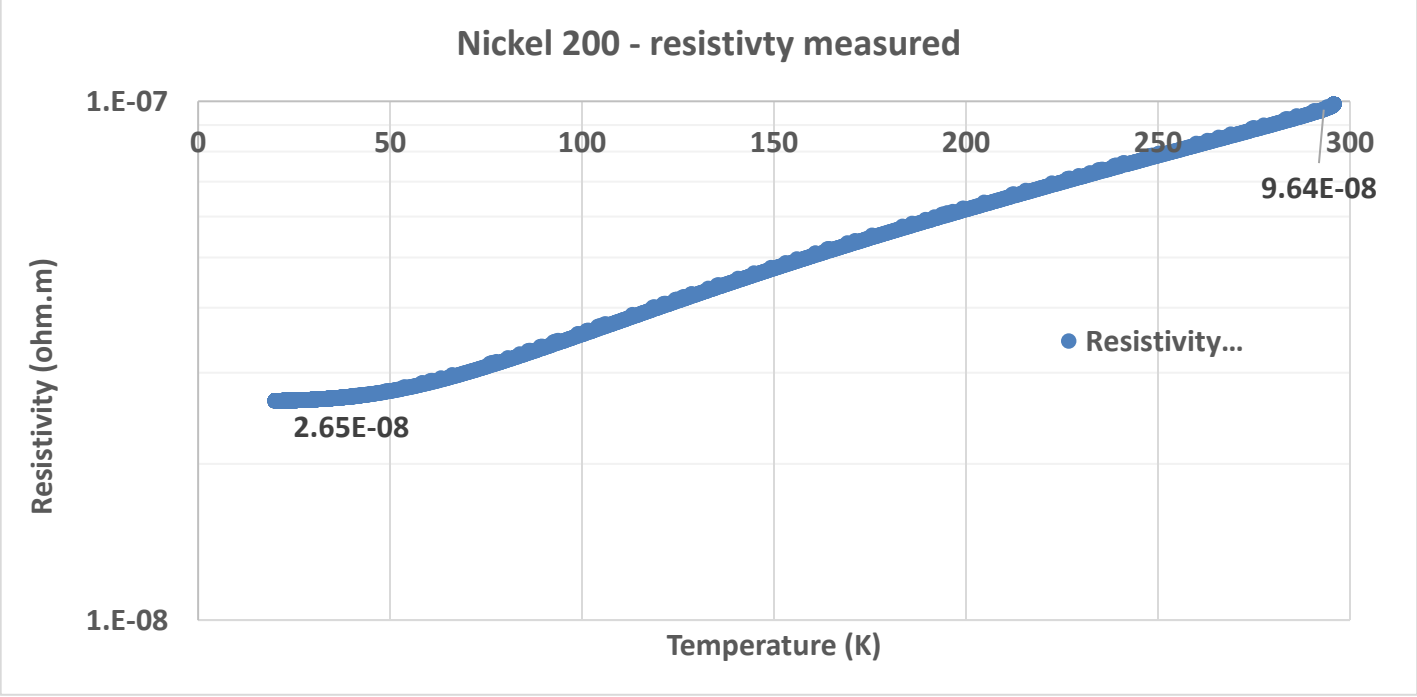


***Figure** 7 Copper 110-O - Electrical resistivity 296 K to 29 K – Linear scale (top) Log-scale (bottom)*

The match with literature data is not good. This may be in part due to the different heat treatment of the alloy tested and the alloy in the literature.

2.10 Nickel 200 (UNS N02200)





The measurement lowest temperature is around 20.4 K where the RRR is **3.7**. The room temperature resistivity is consistent with literature. No literature was found for cryogenic resistivity.

3 Summary

A series of metals and alloys have been tested to measure their electrical resistivity at cryogenic temperature and assess their predictability using literature correlations. The observations made are summarized in the following table :

Material	Room temperature (293 K) resistivity measured (ohm.m)	RRR measured	Match with literature data
Brass 260	6.06E-8	1.65	Poor
Copper OFHC 101-O	1.56E-8	219	Good
Copper ETP 110-0	1.72e-8	273	Excellent
Copper ETP 110-H02	1.75E-8	91	Excellent
Copper ETP 110-H04	N/A	61	N/A
Copper DHP 122-H02	2.00E-8	5.3	Good
Copper C145-H02	1.89E-8	11.5	Excellent
Aluminum 1100-O	2.92E-8	23.8	Good
Aluminum 2024-T3	5.52E-8	1.9	Poor
Nickel 200	9.64E-8	3.7	N/A

It is noted that copper are well described by literature correlations, especially for high purity copper. The correlations available for Aluminum was also satisfactory. No correlation has been found for Nickel 200. Alloys have shown significant dispersions from literature data.

4 Reference

[1] F.Micolon et al. “Design of a new 12x150A helium cooled current lead for EIC” Proc CEC-ICMC25, in publication

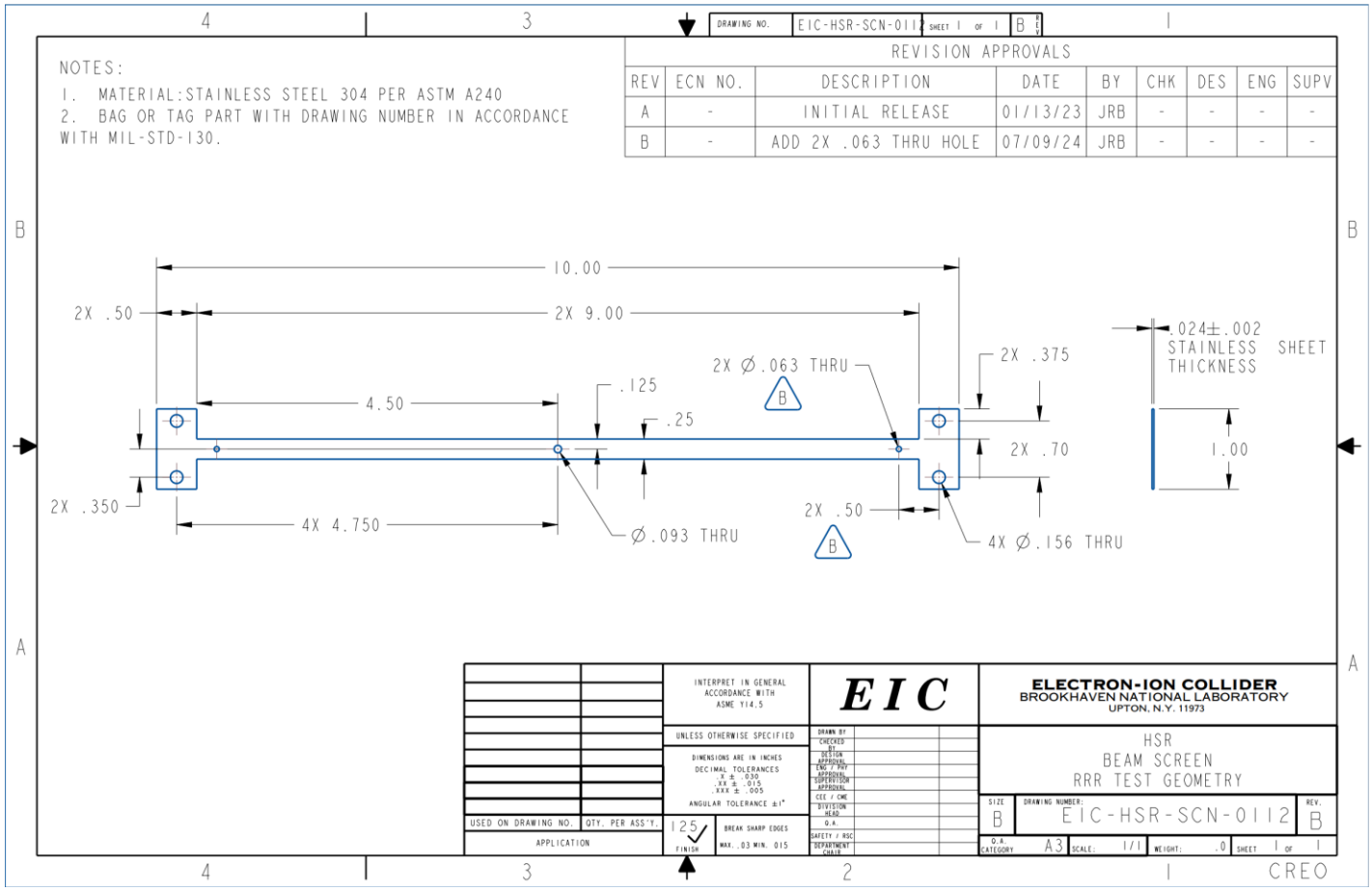
[2] S. Verdu-Andres “An apparatus to measure the residual resistivity ratio” BNL technical report BNL-226192-2024-TECH / EIC-ADD-TN-103

[3] A.F. Clark, G.E. Childs and G.H. Wallace, “Electrical resistivity of some engineering alloys at low temperatures” Cryogenics, v10, p295, August (1970)

[4] N. Simon, E. Drexler, and R. Reed, “Properties of copper and copper alloys at cryogenic temperatures. Final report,” Office of Scientific and Technical Information (OSTI) doi:10.2172/534030

[5] Hust, J. and Lankford, A. (1984), Thermal conductivity of aluminum, copper, iron, and tungsten for temperatures from 1 K to the melting point:, , National Institute of Standards and Technology, https://doi.org/10.6028/NBS.IR.84-3007

5 Appendix 1 – Drawing EIC-HSR-SCN-0112 Rev.B



6 Appendix 2 – Electrical resistivity measured summary table

Temperature	Brass 260	C101-O	C110-O	C110-H02	C122-H02	C145-H02	Al1100-O	Al2024-T3	Nickel 200
293	6.028E-08	1.552E-08	1.671E-08	1.743E-08	1.982E-08	1.841E-08	2.88E-08	5.470E-08	9.654E-08
290	5.998E-08	1.532E-08	1.650E-08	1.722E-08	1.960E-08	1.822E-08	2.84E-08	5.434E-08	9.489E-08
280	5.904E-08	1.471E-08	1.582E-08	1.652E-08	1.897E-08	1.754E-08	2.72E-08	5.317E-08	9.041E-08
270	5.817E-08	1.410E-08	1.514E-08	1.583E-08	1.833E-08	1.685E-08	2.6E-08	5.207E-08	8.626E-08
260	5.730E-08	1.348E-08	1.446E-08	1.513E-08	1.769E-08	1.619E-08	2.48E-08	5.095E-08	8.238E-08
250	5.637E-08	1.285E-08	1.379E-08	1.444E-08	1.705E-08	1.553E-08	2.37E-08	4.984E-08	7.930E-08
240	5.548E-08	1.225E-08	1.312E-08	1.375E-08	1.642E-08	1.490E-08	2.24E-08	4.870E-08	7.511E-08
230	5.460E-08	1.163E-08	1.243E-08	1.306E-08	1.579E-08	1.423E-08	2.12E-08	4.760E-08	7.158E-08
220	5.369E-08	1.101E-08	1.176E-08	1.238E-08	1.513E-08	1.353E-08	2.01E-08	4.649E-08	6.830E-08
210	5.278E-08	1.038E-08	1.109E-08	1.167E-08	1.450E-08	1.285E-08	1.89E-08	4.537E-08	6.503E-08
200	5.188E-08	9.751E-09	1.040E-08	1.097E-08	1.386E-08	1.216E-08	1.77E-08	4.427E-08	6.191E-08
190	5.099E-08	9.124E-09	9.730E-09	1.029E-08	1.322E-08	1.148E-08	1.65E-08	4.316E-08	5.893E-08
180	5.006E-08	8.467E-09	9.051E-09	9.587E-09	1.257E-08	1.081E-08	1.53E-08	4.206E-08	5.604E-08
170	4.913E-08	7.851E-09	8.364E-09	8.895E-09	1.192E-08	1.016E-08	1.41E-08	4.095E-08	5.319E-08
160	4.822E-08	7.217E-09	7.667E-09	8.171E-09	1.128E-08	9.466E-09	1.29E-08	3.984E-08	5.041E-08
150	4.727E-08	6.549E-09	6.981E-09	7.456E-09	1.062E-08	8.744E-09	1.17E-08	3.871E-08	4.772E-08
140	4.630E-08	5.922E-09	6.284E-09	6.738E-09	9.954E-09	8.048E-09	1.05E-08	3.761E-08	4.509E-08
130	4.536E-08	5.274E-09	5.584E-09	6.004E-09	9.300E-09	7.331E-09	9.39E-09	3.650E-08	4.257E-08
120	4.437E-08	4.617E-09	4.885E-09	5.274E-09	8.633E-09	6.641E-09	8.21E-09	3.541E-08	4.016E-08
110	4.342E-08	3.956E-09	4.182E-09	4.542E-09	7.973E-09	5.953E-09	7.06E-09	3.434E-08	3.779E-08
100	4.242E-08	3.308E-09	3.492E-09	3.839E-09	7.313E-09	5.254E-09	5.97E-09	3.329E-08	3.563E-08
90	4.139E-08	2.638E-09	2.798E-09	3.126E-09	6.648E-09	4.560E-09	4.92E-09	3.232E-08	3.354E-08
80	4.041E-08	2.051E-09	2.152E-09	2.448E-09	6.025E-09	3.912E-09	3.99E-09	3.141E-08	3.170E-08
77	4.007E-08	1.869E-09	1.957E-09	2.233E-09	5.837E-09	3.729E-09	3.71E-09	3.115E-08	3.117E-08
70	3.939E-08	1.472E-09	1.530E-09	1.786E-09	5.424E-09	3.370E-09	3.12E-09	3.061E-08	3.004E-08
60	3.848E-08	9.374E-10	1.008E-09	1.221E-09	4.879E-09	2.767E-09	2.46E-09	2.993E-08	2.889E-08
50	3.770E-08	5.341E-10	5.771E-10	7.624E-10	4.421E-09	2.291E-09	1.9E-09	2.943E-08	2.766E-08
40	3.716E-08	2.816E-10	2.870E-10	4.465E-10	4.076E-09	1.965E-09	1.54E-09	2.914E-08	2.699E-08
30	3.681E-08	1.324E-10	1.290E-10	2.669E-10	3.864E-09	1.731E-09	1.33E-09		2.662E-08
20	3.673E-08	7.896E-11	7.185E-11	2.018E-10			1.24E-09		2.647E-08
15		7.188E-11	6.380E-11						

7 Appendix 3 – Sample material certificates

1. Brass 260 (UNS C26000)

No certificate were available. The vendor website mentions they are half-hard (H02) with elongation 27%. Cu content is 68.5-71.5% and zinc content 28.38-31.38%.

2. Copper OFHC 101-O (UNS C10100)

No material certificates were supplied with this sample.

3. Copper ETP 110-O (C11000)

UNITED STATES BRASS & COPPER
QUALITY MILL PRODUCTS SINCE 1925

United States Brass and Copper
1401 Brook Drive
Downers Grove, IL 60515
USA

Product certification

Bill to:
Trinity Brand
280 Shore Drive
Burr Ridge, IL 60527
USA

Ship to:
Trinity Brand Industries
280 Shore Drive
Burr Ridge, IL 60527
USA

Sales order	20RSO62199	Packing slip	20RPS70007
Customer PO	19470 MRS	Shipment date	11/13/2023

Item number	COL0141	Product description	110 COPPER Soft 0.010 x 12.0000 x Coil ASTM B152 DFARS/RoHS/REACH Compliant Melt & manufactured USA
Heat number	258349		

Chemical analysis

Cu = 99.9600

Mechanical analysis

ASTM = B 152 / B152M-19 Conductivity = IACS 101.5% Elongation = 41.0% GrainSize = .025 mm
Other = Melt/Mfg: USA Resistivity = Rockwell = Surface =
Tensile = 34,100 Yield = 8,300

Other

Thickness =

I certify that the above figures are a true and correct copy of those contained in the records of this company.

Amy Peandro
QUALITY MANAGEMENT

4. Copper ETP 110-H02 (C11000)

The sample was a conductor salvaged from one of the original RHIC 12x150 A current lead.
No material certificates were available at the time of testing. It is mentioned to be half-hard (H02) per the original drawings.

5. Copper ETP 110-H04 (UNS C11000)

```
18Apr23 13:50          T E S T     C E R T I F I C A T E        No: BHM 671478

     THREE D METALS, INC.                  P/O No KA-26633400
     5462 INNOVATION DRIVE                 Rel
     VALLEY CITY, OHIO  44280              S/O No BHM 323075-001
     Tel: 330 220 0451 Fax: 330 220 0471   B/L No BHM 313083-002  Shp  18Apr23
                                           Inv No                 Inv


     Sold To:    ( 71416)                  Ship To:    (  3)
     MCMASTER CARR SUPPLY CO               MCMASTER CARR SUPPLY CO
     PO BOX 5516                           200 NEW CANTON WAY
     CHICAGO, IL  60680                    ROBINSONVILLE, NJ  08691


     Tel: 630-600-2878 Fax: 630-993-3085
--------------------------------------------------------------------------------
               CERTIFICATE of ANALYSIS and TESTS          Cert. No: BHM 671478
                                                                    18Apr23
Part No 100549
COPPER ROD HARD DRAWN ROUND ROD                                  Pcs      Wgt
 .1250 Nom X 12.0000"                                            168        8

Heat Number     Tag No                                           Pcs      Wgt
K74021110003    333014                                           168        8
                    HRF=<89.60>/IACS=<101.50>/BEND=<120:GOOD>/TSksi=<58.00>
                    ELONG=<12.20>/ASTM=<B187-20>


Heat Number          *** Chemical Analysis ***
K74021110003    Cu=<99.99>
                PERU


THIS IS TO CERTIFY THAT THE CHEMICAL ANALYSIS
AND/OR PHYSICAL TEST RESULTS EXHIBITED HEREIN ARE
CORRECT,  AS CONTAINED WITHIN THE RECORDS
OF THE COMPANY.
.
.
.
QUALITY MANAGER
.
.
.
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_____________________
John Bakuhn, Jr.
.
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6. Copper DHP 122-O (UNS C12200)

VITA NEEDLE
Stainless Steel NEEDLES & TUBING
SINCE 1932

CERTIFICATE OF COMPLIANCE WITH CHEMISTRY

CUSTOMER:	MCMASTER-CARR SUPPLY	**DATE:**	09/05/2023
CUSTOMER PO #:	KA-68437380	**LOT #:**	0235804

This document certifies that the furnished product shipped against the above purchase order meets all requirements and instructions as needed. Unless otherwise noted, material conforms to the appropriate specification referenced below for composition and mechanical properties or to the standards set forth in the purchase order submitted by the customer.

PART NO:	M1856
DESCRIPTION:	122 COPPER TUBING, SEAMLESS, 1/2 HARD TEMPER, 1/8"±.002" OD x .014"±.001" WALL, IN 1FT LENGTH, ASTM B251 ***ELECTRONICALLY DELIVERED CHEM CERT
SSPECIFICATION:	
QUANTITY:	183 EACH
COMMENTS:	
	Reference # 11762: Heat: 164017, , P: .0369, Cu: 99.956

NOTE: Raw material sold is not warranted for any particular application and liability is strictly limited to replacement only.

Sincerely,

Authorized Signature

7. Copper Tellurium 145-H02 (UNS C14500)

IUSA 1939

NO. DE SOC.: A046

INDUSTRIAS UNIDAS S.A. DE C.V. COBRE Y ALEACIONES

CERTIFICATE OF QUALITY PRESSES SACK

BUSBY METAL
Q.A. APPROVED
JUL 18 2024
Q.A. DESIGNEE

CODE: 318256
CUSTOMER: READING. PA

PRODUCT: BAR COPPER TELLURIUM.
ALLOY: 145
TEMPER: HALF HARD
SIZE: 0.125" (⅛")
QUANTITY: 1,087 LB.

FOLIO: 239
LOTE: 034
DATE: 31/03/22
BATCH: 20258

NORM OF REFERENCE: ASTM B-301
SHIPMENT: 11915
MACHINE: MEYER

ORDER : 4501330809
REMISSION R/3: 808915869
TRACEABILITY CODE: 202583C034

TEST.	SPECIFICATIONS	MAX.	AVERAGE	MIN.	STD. DESV.	DATA
CHEMICAL	%Cu 99.90 MÍN.	99.9533	99.9533	99.9533	0.0000	2
	%P 0.004-0.012	0.0084	0.0084	0.0084	0.0000	2
	Te- 0.40-0.70	0.5201	0.5201	0.5201	0.0000	2
DIMENSIONS	**THICKNESS:** 0.1243" – 0.1257"	0.1251	0.1251	0.1250	0.0001	2
	12.00 – 12.030 FT.	12.008	12.008	12.008	0.0000	2
	CAMBER: 1/8" EN 72"	0.021	0.019	0.016	0.0035	2
MECHANICAL	**TENSILE STRENGTH:** 38 KSI MÍN.	42.143	42.095	42.047	0.0679	2
	YIELD STRENGTH: 30 KSI MÍN.	37.892	37.658	37.424	0.3309	2
	% ELONGATION: 8 % MÍN.	22.5	22.5	22.5	2.5	2
ELECTRICAL	**CONDUCTIVITY:** 85.1 IACS MIN	90.40	89.05	87.70	1.9092	2

T A046 P322 I006 F035

OBSERVATIONS:

Hereby we certify that our products are free of Mercury and have been produced in a Mercury free environment.
COUNTRY OF SMELT AND MANUFACTURE: MEXICO

Busby Metal PO #119131
Order #6498754
Batch #R4203010IU

SOCORRO ÁNGELES SANTIAGO
ANALYST

8. Aluminum 1100-O (UNS A91100)

CERTIFICATE OF ANALYSIS

COMET METALS

Phone: (888) 539-5602
Phone: (440) 201-2235
Fax: (440) 201-2239
www.cometmetals.com
6225 Camp Industrial Rd, Solon, OH 44139

CUSTOMER #:	TRIIND	**PRODUCT:**	ALUMINUM	**SHIPMENT :**	04182022
PO # :	18676 MRS	**CMI LOT # :**	30.0A06 2636	**SO #:**	48674

BILL TO:	**SHIP TO:**
TRINITY BRAND INDUSTRIES 280 SHORE DRIVE WILLOWBROOK, IL 60527	TRINITY BRAND INDUSTRIES 280 SHORE DRIVE WILLOWBROOK, IL 60527

DESCRIPTION OF MATERIAL:	**COMET PO #: 21-2636**
ALUM 1100 ANN MF .020" +/- .0035" 24.000" WIDE X COIL 16" IDFC MAX 500 LBS / ROLL DOMESTIC MATERIALS PER ASTM B209 DFARS/ROHS/REACH COMPLIANT MIN 3500 PSI & MIN, 20% ELONGATION MIN	

QUANTITY:	2,608 LBS

CHEMICAL COMPOSITION:

Si + Fe	Cu	Mn	Zn	Other	Al
0.95	0.05 – 0.20	0.05	0.10	0.15	99.00
MAX		MAX	MAX	MAX	MIN

Based on Aluminum Association Standards

MECHANICAL COMPOSITION:

ULTIMATE TENSILE	YIELD	ELONGATION%
14.39 KSI	6.44 KSI	32.14%

MILL/HEAT#
1309189

The undersigned certifies that the material, process and testing used in the fabrication of this order meets all applicable specifications required in the item description.

Authorized Signature: Linda Gehrke

Date: 4/18/2022

9. Aluminum 2024-T4 (UNS A92024)

KAISER ALUMINUM *Best in Class*

CERTIFIED TEST REPORT
https://Online.KaiserAluminum.com

Kaiser Aluminum
Trentwood Works
PO Box 15108 Spokane Valley WA 99215-5108
15000 E Euclid
Spokane Valley, WA 99216
(509) 927-6317

CUSTOMER PO NUMBER:	WORK PACKAGE:	CUSTOMER PART NUMBER:	SHIP RUN/LOAD:	GOV'T CONTRACT NUMBER:
5400648752-R05-10		ALFLR01578-48	200659/9	

KAISER ORDER NUMBER:	SHIP DATE:	ALLOY:	CLAD:	TEMPER:	PRODUCT DESCRIPTION:
1374367-1	03/30/2023	2024	BARE	T3	HT Flat Sheet

WEIGHT SHIPPED:	QUANTITY:	TRUCK B/L #:	GAUGE:	DIAMETER/WIDTH:	LENGTH:
3147 LB	219 PCS EST.	20105111	0.0200 IN	48.000 IN	144.000 IN

SHIP TO:	SOLD TO:
COPPER & BRASS SALES 5545 CHET WAGGONER COURT SOUTH BEND, IN 46628 US	COPPER & BRASS SALES ATTN: ACCOUNTS PAYABLE P.O. Box 5116 SOUTHFIELD, MI 48086 US

MHU 2708897: LOT 475198B8: 59 pieces
MHU 2719260: LOT 481389B5: 160 pieces

Certified Specifications

AMS 4037/RevR~AMS-QQ-A-250/4/RevB~ASTM B209/B209M/Rev21A~CMMP 019/RevD~CMMP 025/RevW

LOT: 475198B8 CAST: 356 DROP: 07 INGOT: 1

Melted in USA
(ASTM E8/B557)
(EN 2002-1)

Tensile:	Temper	Dir/#Tests	Ultimate KSI (MPA)	Yield KSI (MPA)	Elongation %
	T3	LT / 02 (Min:Max)	66.0 : 67.0 (455 : 462)	44.3 : 44.8 (305 : 309)	15.3 : 15.8

(ASTM E1251)

Chemistry:	SI	FE	CU	MN	MG	CR	ZN	TI	V	ZR	OTHER
Actual	0.08	0.16	4.5	0.57	1.4	0.01	0.09	0.02	0.01	0.01	TOT 0.02

10. Nickel 200 (UNS N02200)

HUNTINGTON ALLOYS CORPORATION
A Special Metals Company
HUNTINGTON, WEST VIRGINIA 25705-1771

NOTE: THE RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL STATUTE.

HAL 0197

CERTIFIED MATERIAL TEST REPORT No. 05859

Exact Mill Duplicate

Exact Mill Duplicate

HA ORDER NO./ITEM	DATE	PAGE	OF
100045072 6	10/01/10	1	2
QUANTITY	INSPECTED BY		
2976 LBS	HA/SNC		
CHARGE ORDER NO.	MARK ORDER NO.		
L29117	.0183696200CR		
DESCRIPTION OF MATERIAL SHIPPED	NICKEL 200 AIM CR SHEET CR ANN .0180 IN 36.0000 IN 96.000 IN CUT		

THIS IS TO CERTIFY THAT ALL REQUIRED SAMPLINGS INSPECTIONS AND TESTS HAVE BEEN PERFORMED IN ACCORDANCE WITH THE ORDER AND SPECIFICATION REQUIREMENTS. THE TEST REPORT REPRESENTS THE ACTUAL ATTRIBUTES OF THE MATERIAL FURNISHED AND THE VALUES SHOWN ARE CORRECT AND TRUE. THE MATERIAL DESCRIBED BY THIS CERTIFICATE IS IN FULL COMPLIANCE WITH ALL ORDER AND INSPECTION REQUIREMENTS. WE HEREBY CERTIFY THAT THE BELOW FIGURES ARE IN ACCORDANCE WITH THE SPECIFIED CONTRACT REQUIREMENTS.

REV. 8/00

********THIS REPORT RELATES ONLY TO THE ITEM(S) TESTED AND MAY NOT BE REPRODUCED EXCEPT IN FULL.********

SPECIFICATIONS: ASTM B 162-99(2005)\ASME SB-162 2007 EDITION 09 ADDENDA\ UNS:N02200
MARK PER ORDER.\
QUALITY SYSTEM CERTIFICATION: ISO 9001:2008 (ABS-QE CERT. 30125);
EN 10 204/DIN 50049 (TYPE 3.1)

CHEMICAL ANALYSIS (WT. %)

HEAT#	C	MN	FE	S	SI	CU	NI
N39U8AC	0.07	0.15	0.15	0.001	0.08	0.03	99.52

COUNTRY OF ORIGIN: MELTED AND MANUFACTURED IN THE USA
MELT METHOD: AIM + ELECTROSLAG REMELTED

MECHANICAL PROPERTIES

HEAT/LOT - QUANTITY	HARD NESS	GRAIN SIZE	YIELD .2%PSI X 100	TENSILE PSI X 100	%ELG 2"	R/A %	DEG F
N39U8AG SP26N 150 PCS							
ROOM TEMP-HR15T -AS SHIPPED	76.9		0348	0697	39.8		

YIELD STRENGTH WAS DETERMINED USING A STRESS STRAIN CURVE

VISUAL AND DIMENSIONAL EXAMINATION SATISFACTORY.
MATERIAL, WHEN SHIPPED, IS FREE FROM CONTAMINATION BY MERCURY, RADIUM, ALPHA SOURCE, & LOW MELTING ELEMENTS.

"CHEMICAL ANALYSIS AS REQUIRED FOR CARBON,SULFUR,NITROGEN OR OXYGEN IS PERFORMED BY COMBUSTION TECHNIQUES. ALL OTHER REPORTED ELEMENTS ARE ANALYZED BY X-RAY AND/OR EMISSION SPECTROSCOPY."

"QUALITY SYSTEM MEETS REQUIREMENTS OF DIRECTIVE 97/23/EC (PRESSURE EQUIPMENT DIRECTIVE), ANNEX 1, CHAPTER 4.3 PER ABS GROUP LTD CERTIFICATE 41734 (EXPIRES JULY 31, 2011)."