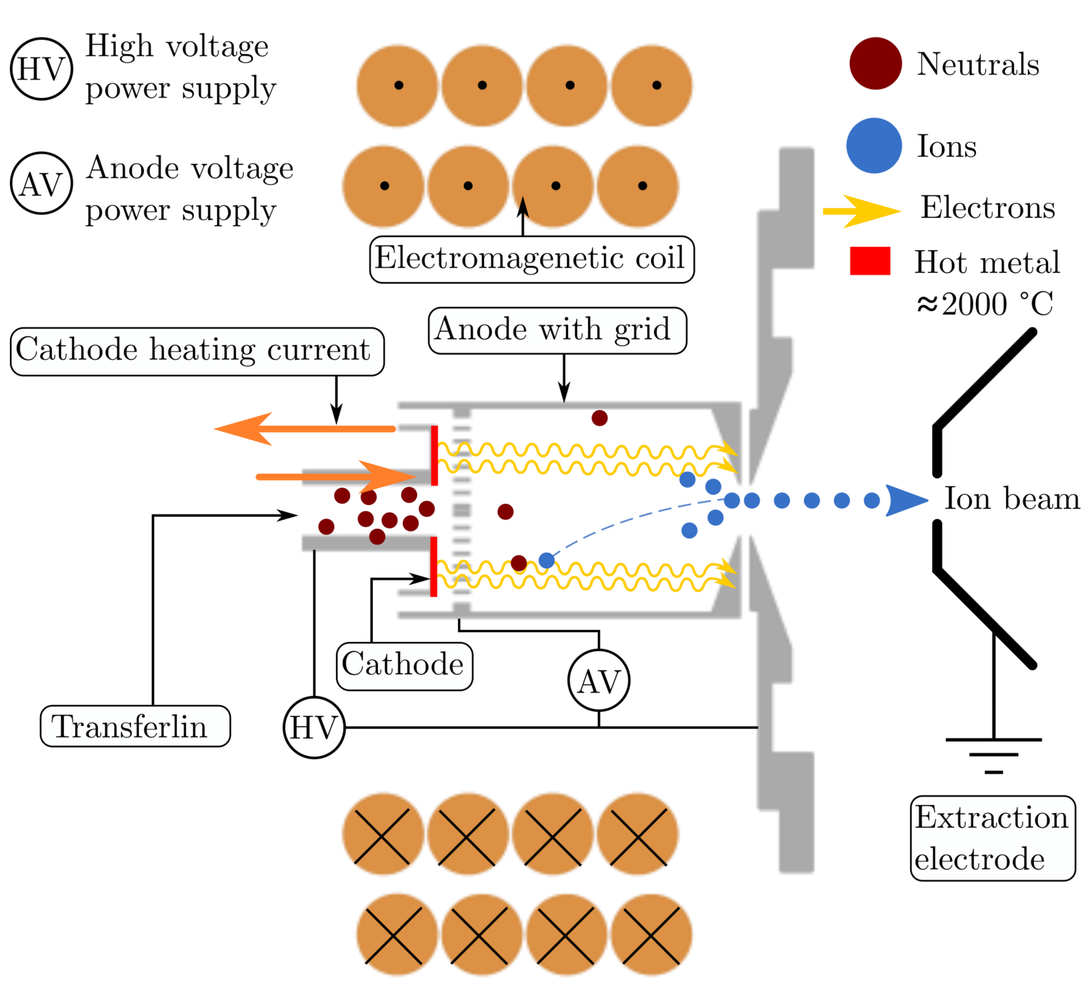
Experimental and numerical characterization of the TRIUMF-FEBIAD cathode used to produce radioactive ions.

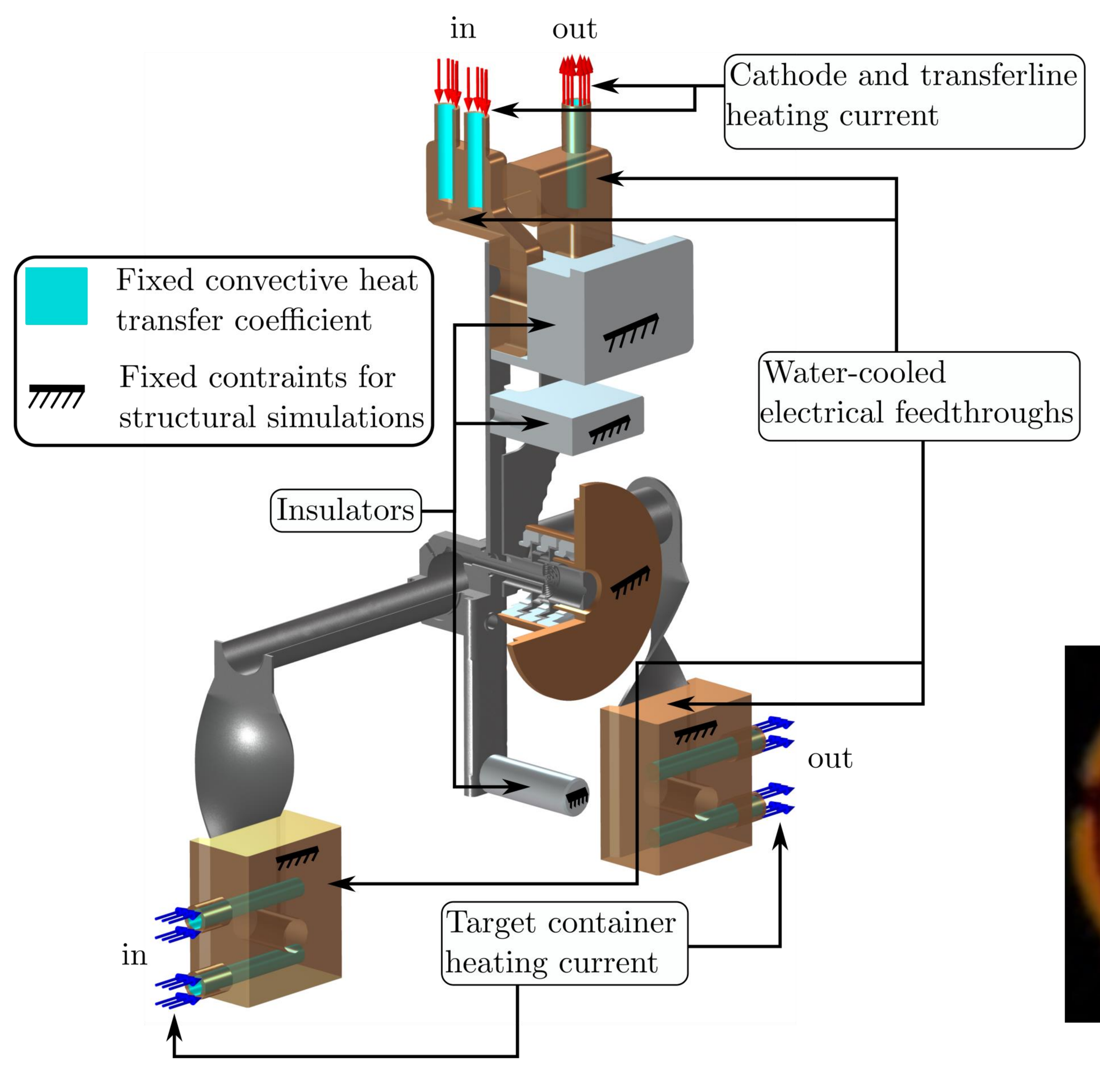
F. Maldonado Millan[1], C. Babcock[1], T. Day Goodacre[1,2], and A. Gottberg[1,2]
[1]TRIUMF, [2]University of Victoria.

The FEBIAD ion source [1] is routinely used to produce radioactive ions of halogens, molecules, and noble gases in several ISOL facilities worldwide. At TRIUMF, an extensive numerical and experimental campaign has been performed to fundamentally understand the source while improving its reliability and overall performance [2-5]. Particularly, the cathode temperature has been studied by pyrometric measurements and numerical simulations.

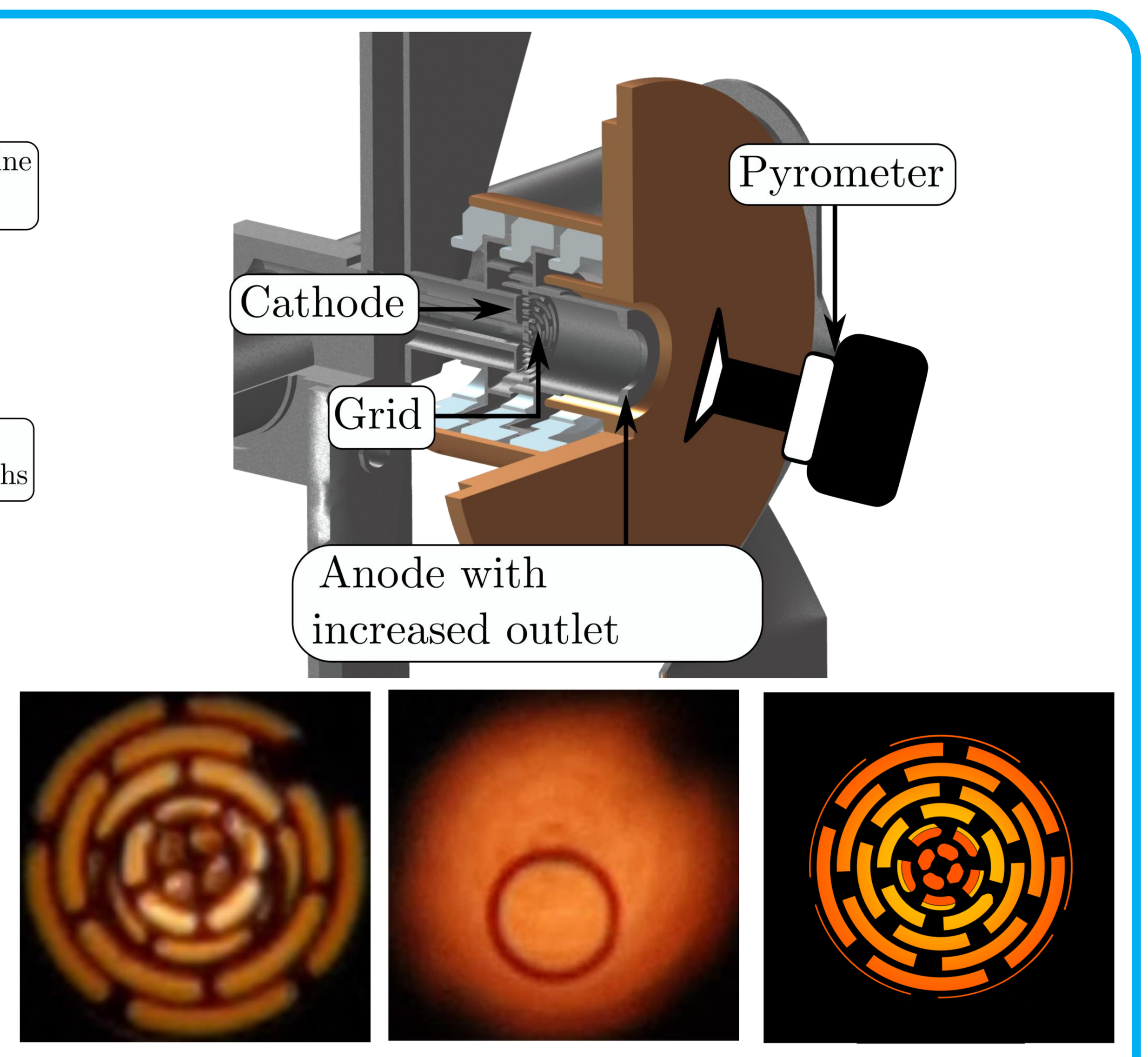


Schematic of a FEBIAD ion source. Thermally generated electrons are accelerated via a voltage difference into the anode. A magnetic field confines the electrons that ionize the neutrals entering the anode body. The ions are extracted via voltage difference to form the radioactive ion beam.

FEBIAD target-and-ion-source assembly



Example of boundary conditions imposed to study heat transfer, radiation heat transfer, conductive cooling, and resulting structural deformation. Imperfect electrical contacts exist between the copper (orange) and the target ion source assembly (dark gray).



Hot cathode observer though the pyrometer viewport during temperature measurements. An optically focused pyrometer provides the maximum temperature of the bodies on sight. The inner radius of the simulated cathode is hotter than the outer radius. Qualitatively, the bright yellow indicates a high temperature while the orange a colder temperature.

Thermionic emission

- Temperature driven
- Work function is material dependent

$$J_R(T) = A_0 T^2 e^{-\frac{W}{k_B T}}$$

Schottky effect

- Reduction in work function:

$$\delta W(E) = \sqrt{\frac{e^3 E}{4\pi\epsilon_o}}$$

Enhanced emission by Schottky effect

$$J_S(E,T) = A_0 T^2 e^{-\frac{W_{eff}(E)}{k_B T}}$$

where $W_{eff}(E) = W - \delta W(E)$

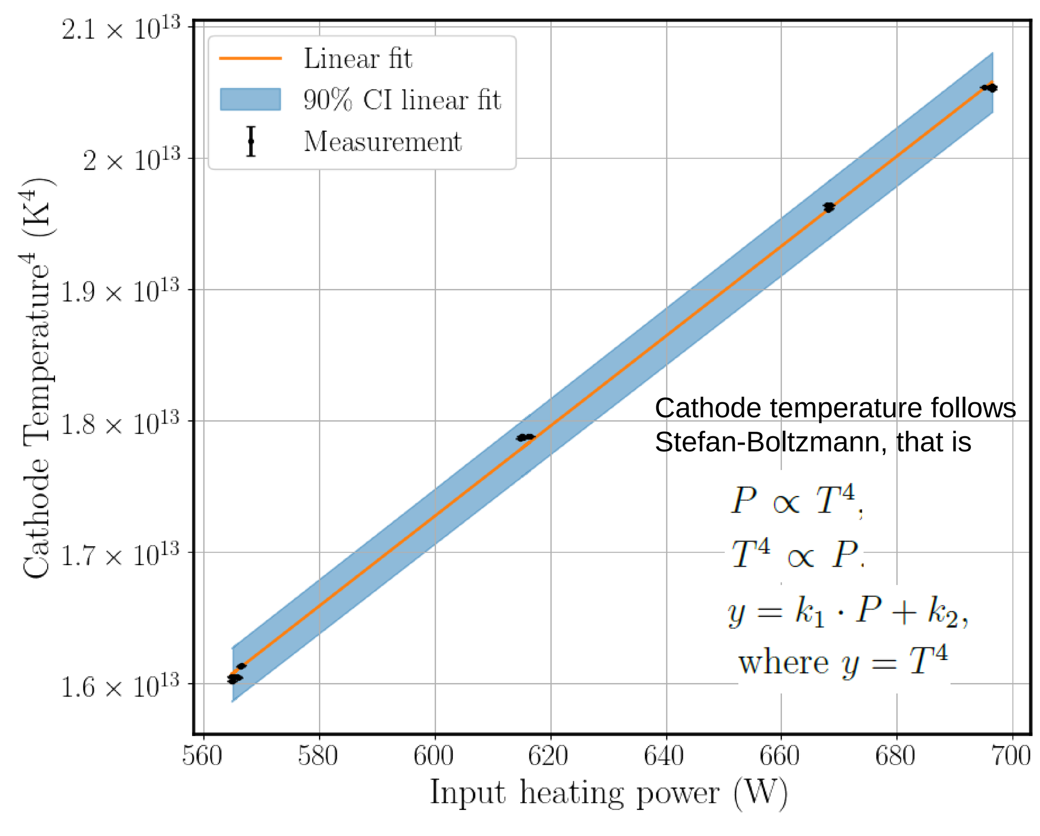
$$J_S(V,T) = J_R(T) e^{\frac{\delta W(V)}{k_B T}}$$

$$J_S(V,T) = J_R(T) e^{a_0\sqrt{V}}$$

- By plotting the natural log against square root voltage, we find the linear onset of the Schottky effect.

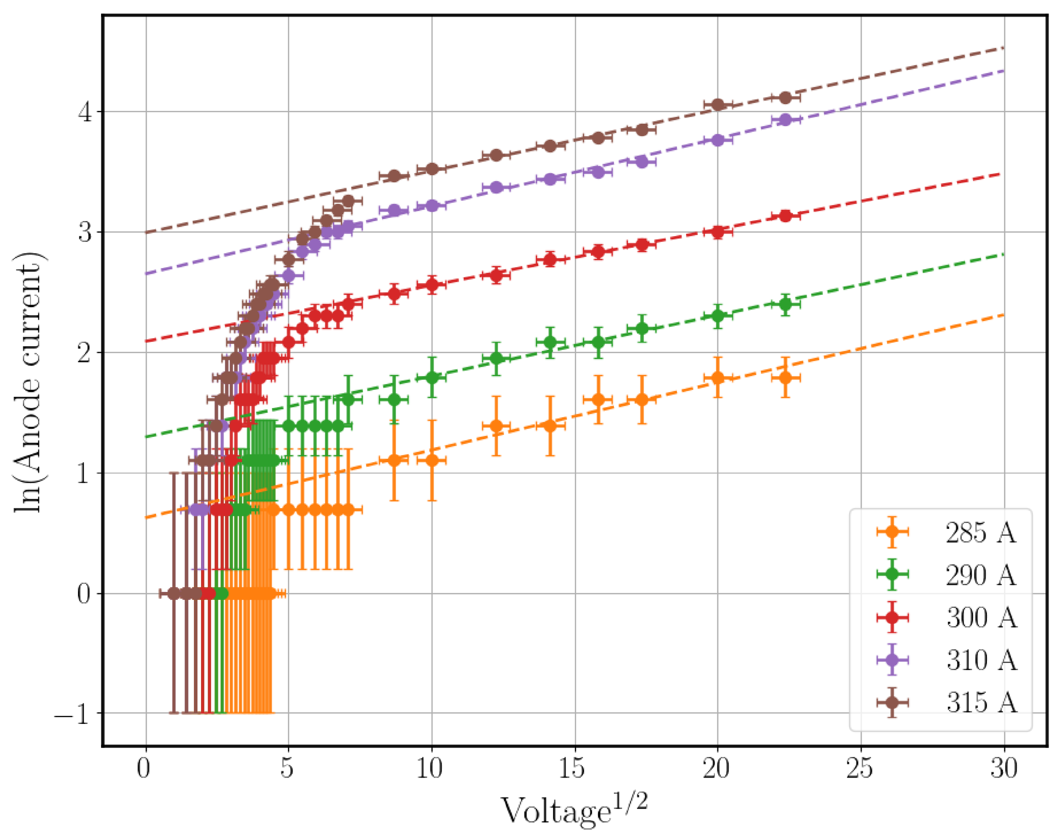
$$\boxed{\ln J_S(V,T) = \ln J_R(T) + a * \sqrt{V}}$$

Cathode temperature as a function of electrical input heating power



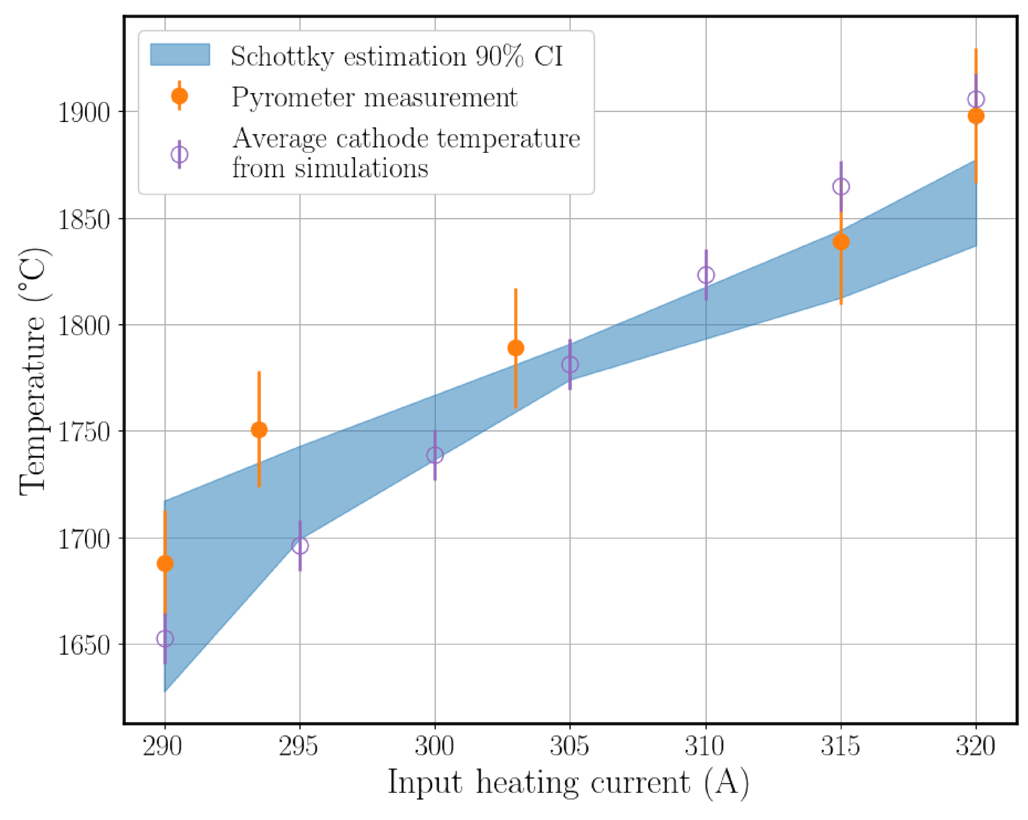
The linear fit describes well the data and serves as a calibration for predicting the temperature in other assemblies.

Natural logarithm of the electron current as a function of the square root of anode voltage.



By applying the methodology, the cathode temperature is estimated from a Schottky analysis.

Measured and simulated temperature as a function of cathode input heating current.



Both direct and indirect measurements are consistent with each other and validate the methodology.

Conclusions

- The linear trend in T^4 vs P indicates thermal equilibrium.
- Schottky analysis provides a secondary way of estimating the cathode temperature
- Measured resistance at room temperature with micro-ohmeter before and after heating to find imperfect contacts.
- Temperature simulation and measurements show good agreement.
- Benchmarked temperature is used for a more realistic electron emission.

[1] Kirchner R and Roeckl E. "A novel isol ion source". Nucl. Instruments Methods 39(C) 1976, pp. 291–296.
[2] Maldonado Millan F. "Comprehensive Ionization Model Development for the FEBIAD Ion Source and Its Application for TRIUMF's Radioactive Ion Beam Program". PhD thesis. University of Victoria, 2022.
[3] Maldonado Millan F, Day Goodacre T, and Gottberg A. "Multiphysics simulation of a FEBIAD ion source". NIMB 463 2020, pp. 302–304.
[4] Maldonado Millan F, Babcock C, Day Goodacre T, and Gottberg A. "Anomalous Ionization Regime in a Forced Electron Beam Induced Arc Discharge Ion Source for Singly Charged Radioactive Ion Beam Production". J. Phys. Conf. Ser. 2244(1) 2022, p. 012074.
[5] Maldonado Millan F, Babcock C, Day Goodacre T, and Gottberg A, Simulation-based optimization for the TRIUMF FEBIAD ion source, NIMB 542 2023, pp. 95-98

Discovery, accelerated