Bremsstrahlung Heat Load Scaling Measurements for Future ECRIS Cryostat

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Abstract – In order to push the intensities of beam production capabilities, 3rd generation ECR ion sources such as VENUS have implemented the use of superconducting radial and axial confinement magnets that allow for higher fields and higher frequency heating. VENUS' NbTi superconducting magnets are enclosed in a 4.2K liquid helium reservoir to maintain their temperature and prevent quenching. During operation, electron losses to the plasma chamber produce a significant amount of bremsstrahlung radiation, and these x-rays can deposit several watts of heating to the cold mass and cryostat. The amount of heat load these x-rays deliver is dependent on the total microwave power and the source's minimum B-field (B_{min}). The 4th generation MARS-D Ion Source is currently being developed at LBNL to meet the beam intensity needs of future heavy ion research. MARS-D uses NbTi magnets in a novel configuration, and will operate with 45 GHz heating and higher B_{min}, which are expected to produce higher energy electrons than VENUS. In order to anticipate and design MARS-D for this increased load, we have undertaken a series of cryostat heat load experiments with VENUS where we vary B_{min}, microwave power, and different heating frequencies. Measured results will be presented, as will heat load projections for expected MARS-D operating conditions.

Introduction – Bremsstrahlung radiation are x-rays produced by energetic electrons colliding with nuclei. During early use of VENUS, it was observed that electron losses to the plasma chamber walls produced an outward flux of x-rays that could pose a hazard to personnel or deposit a great enough heat load to the liquid helium cryostat to cause the superconducting magnets to quench.

- To mitigate the effects of these x-rays, a thin layer of tantalum was wrapped around the VENUS plasma chamber, reducing the dynamic heat load ten-fold. However this layer of tantalum is transparent to x-rays above a certain energy ~300keV[1].
- Because MARS-D will be operated with higher RF frequency, RF power, and B_{min}, we are trying to determine how much heat load will be entering the cryostat and what the cooling needs will be.
- **This study is focused on using heat load measurements from VENUS operating with several RF heating frequencies, to determine how the dynamic heat load will scale up for MARS.**

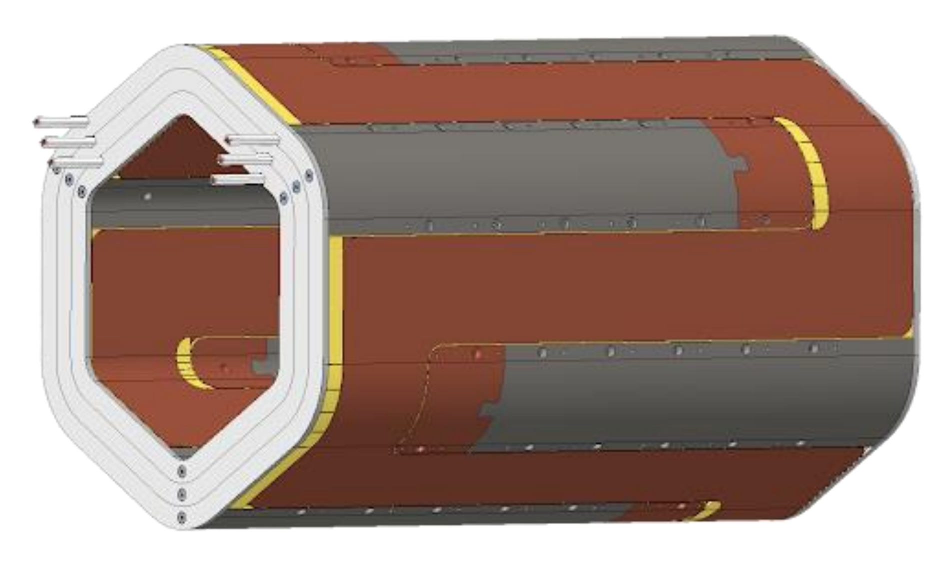


Fig. 4: MARS Closed Loop Coil magnet structure

MARS-D – The MARS-D ion source is a 4th generation source currently in the works at Lawrence Berkeley National Lab. MARS utilizes a closed loop magnet configuration, a design meant to extend the utility of NbTi magnets for plasma confinement.

The MARS cryostat structure is currently in the design stage. Much work is being put into optimizing the radial fields at the corners of the chamber while ensuring sufficient cooling. Studying the bremsstrahlung heating will help determine how thick the tantalum layer will need to be to attenuate x-rays produced by MARS.

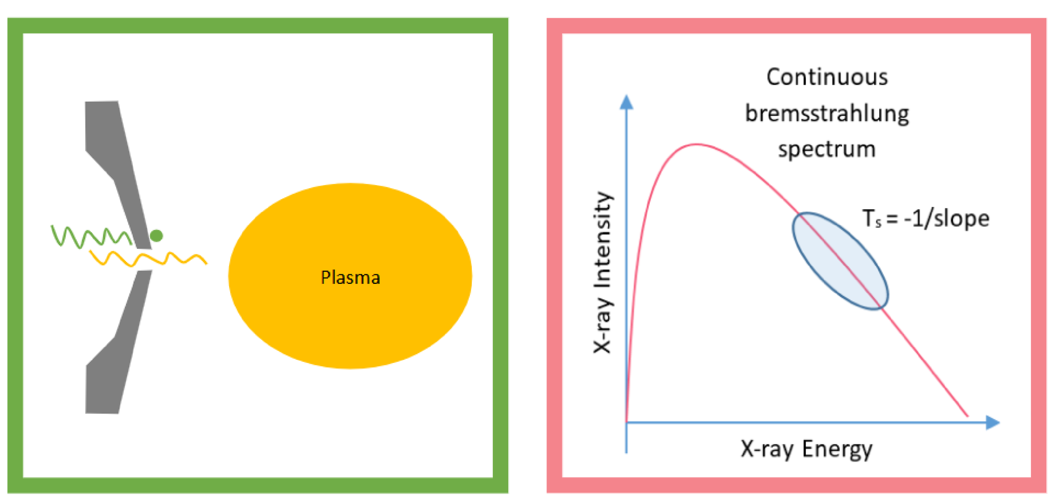


Fig. 1: Models of bremsstrahlung production and spectrum. X-ray energy axis is on a log scale

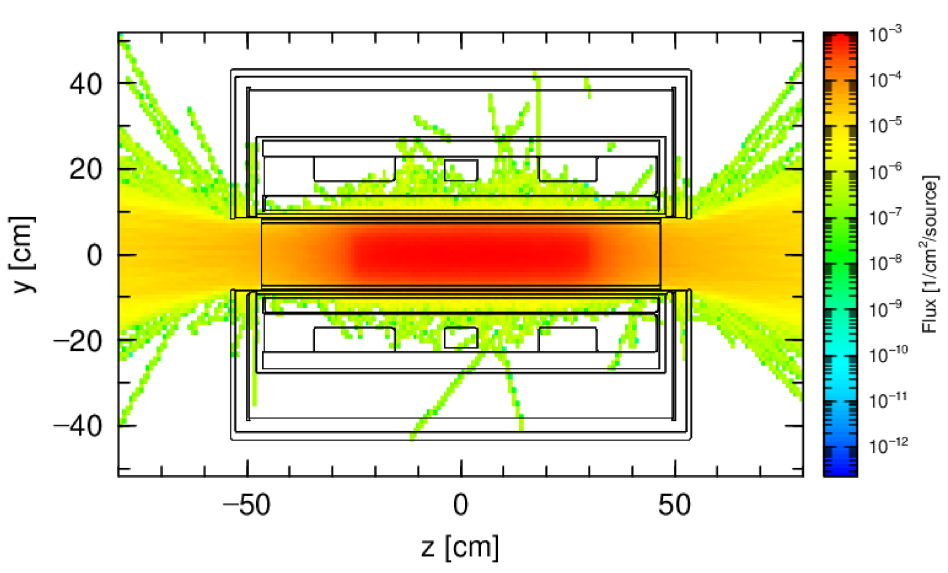


Fig. 2: Simulation of bremsstrahlung photon flux in source.

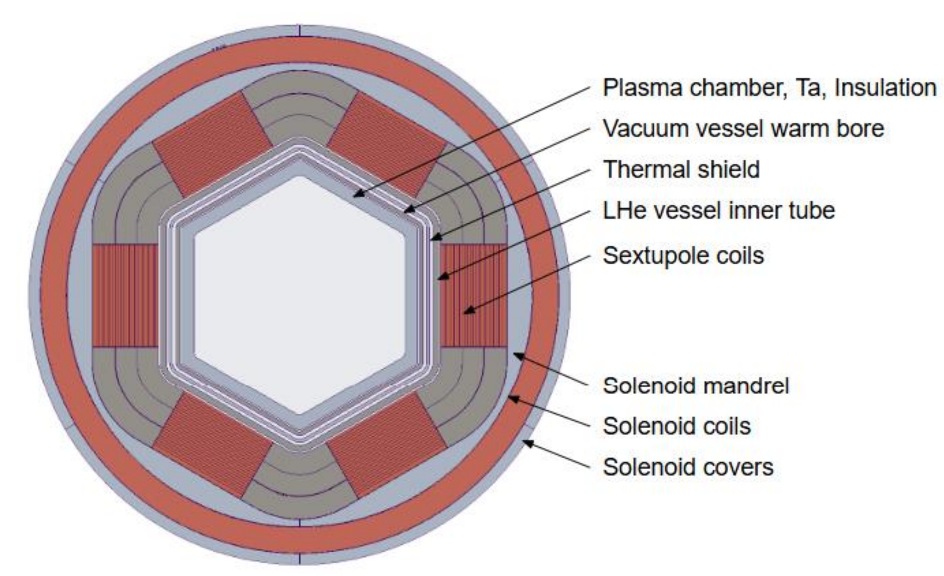


Fig. 3: Cross section of MARS-D Cryostat Structure

Source Parameters	VENUS	MARS-D
RF frequency	18GHz + 28GHz	45GHz
RF max power	10kW	10kW+
B_{ecr}	1T	1.6T
B_{min} *operating ranges	0.4-0.8T	0.5-1.2T
Dynamic Heat load limit.	3W	???

The bremsstrahlung spectrum is characterized by the electron spectral temperature (T_s), which is used as a relative indicator of electron temperature in the plasma. Previous experiments have demonstrated certain relationships between T_s and source parameters[2]:

- T_s increases linearly with B_{min}
- X-ray counts increase with RF power and frequency
- T_s does not depend on ∇B_{ecr} or B_{min}/B_{ecr}

Methods

- Heat load to cryostat was measured using a heater installed in the VENUS cryostat which maintains an equilibrium between the cryocoolers and heat loads.
- Frequencies 14, 18, and 28GHz were used and the field settings were scaled with frequency
- Study focused on heating due to single frequency heating
- Between 4-8 measurements taken for a given field and frequency setting, with increasing amounts of RF power.

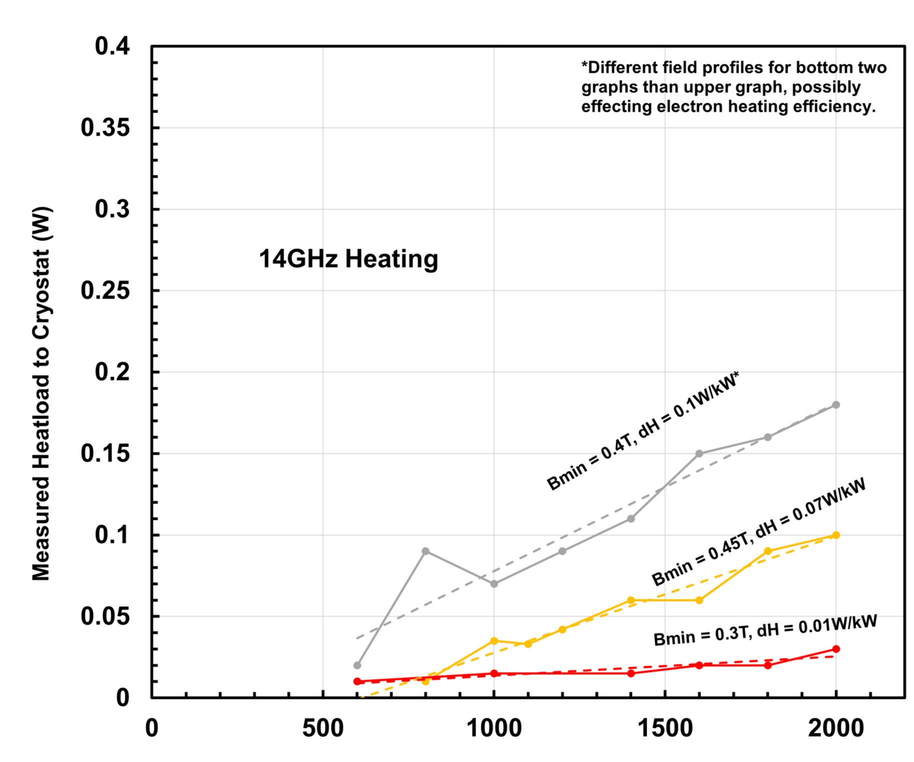


Fig. 5a: Heat load vs RF power for 14GHz

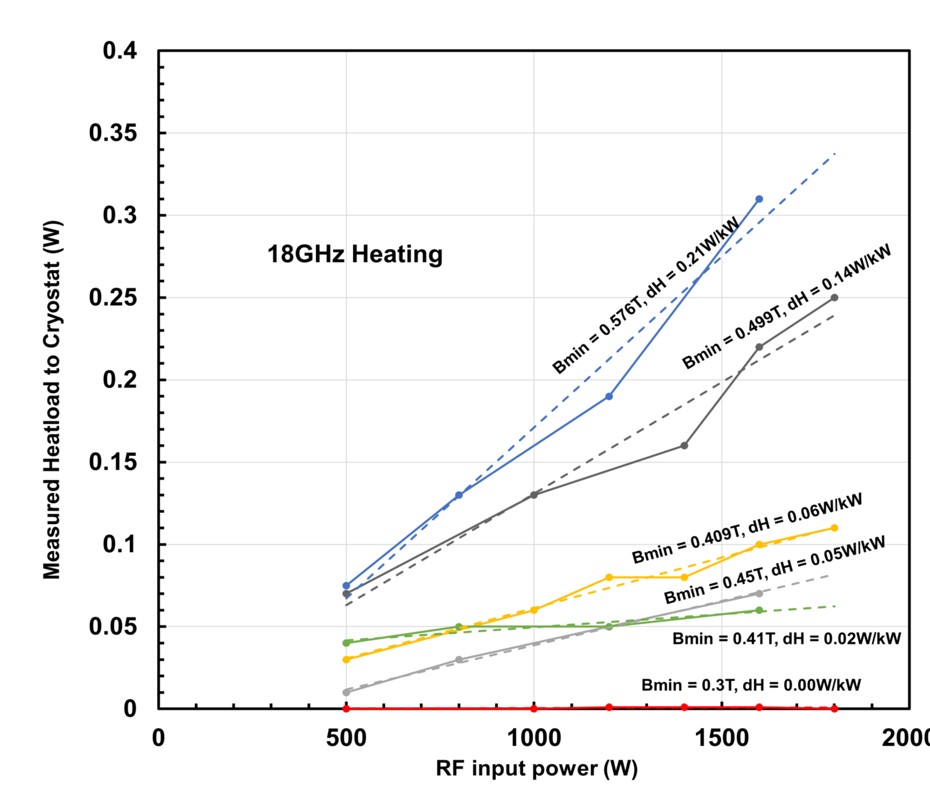


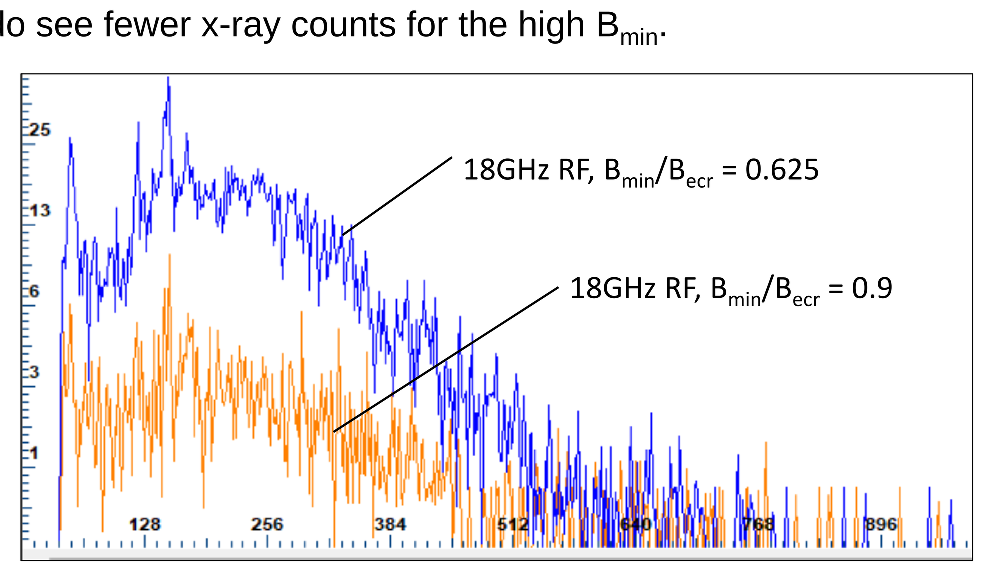
Fig. 5b: Heat load vs RF power for 18GHz

Discussions

The measured heat load plots in Figs. 4a-c show that there is an increased heat load for greater RF input power, and running with a higher B_{min} results in a greater heat load for the amount of input power.

In Fig. 5, looking at only 18 and 28GHz heating, we see this dynamic heating with B_{min} increases linearly. Around B_{min} ~ 80%B_{ecr} this increase falls off, possibly due to source instabilities causing inefficient electron heating and therefore a fall off in x-ray production.

- Comparing x-ray spectra for ECR operation with fields below and above this 80%B_{ecr} threshold with the same RF power, we do see fewer x-ray counts for the high B_{min}.



The difference in slope for 18 and 28GHz dynamic heating points to a strong dependence of heat load on the RF frequency. This makes sense, since hot electron density is proportional to frequency squared. These results suggest further investigations are needed on the B_{min} and RF frequency dependence of the bremsstrahlung heating, and particularly in how they effect the production rates of high energy x-rays.

Notes:

- Not all source parameters were held constant, and overall the heat load measurements contained a lot of noise.
- The 2mm Ta shielding was in place during these measurements. If a 45GHz source produces significantly more x-rays above 300keV, the heat load may jump up significantly from a prediction based directly on these measurements.
- Few results could be drawn from the 14GHz data. While taking measurements it was noted that heating with this frequency produced a near negligible amount of heating. Also a much steeper field profile was used since it was thought to increase the measurable heat load.

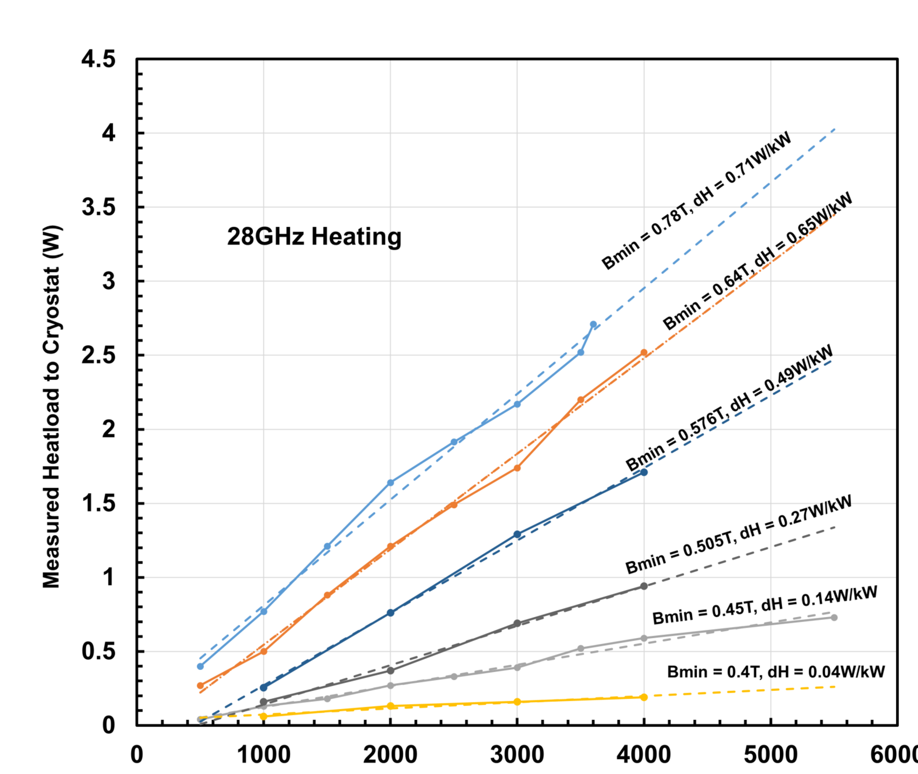


Fig. 5c: Heat load vs RF power for 28GHz

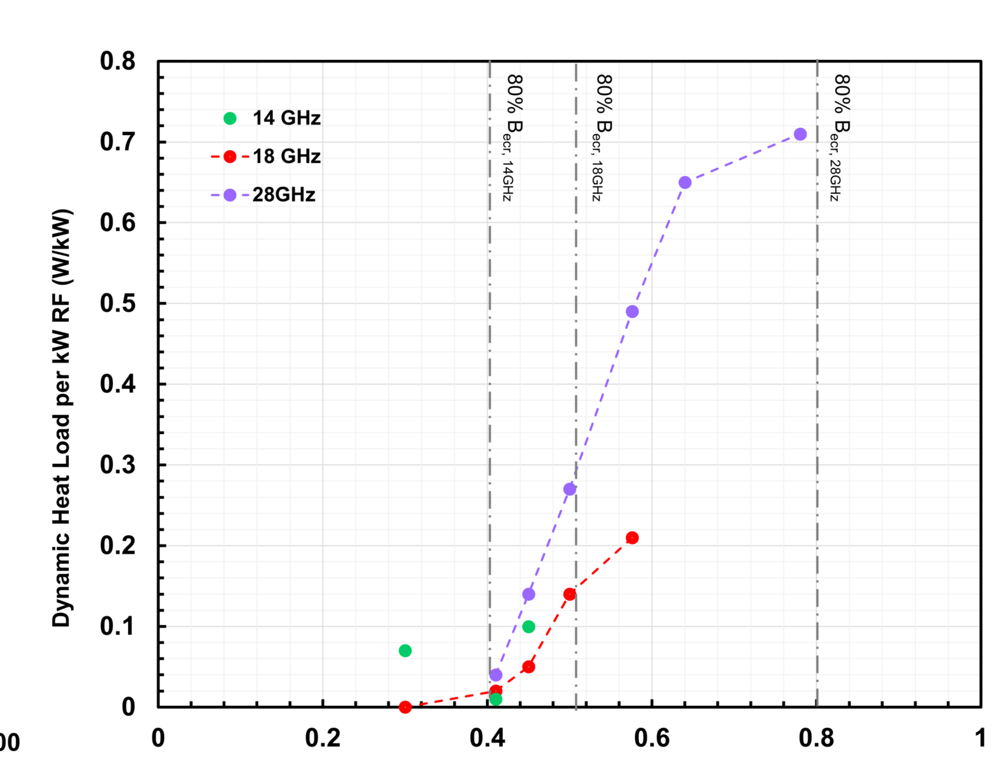


Fig. 6: B_{min} and RF frequency dependence of heat load.

Acknowledgements:

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References:

1. C. Lyneis et al. Measurements of bremsstrahlung production and x-ray cryostat heating in VENUS, *Rev. Sci. Instrum.* 77, 03A342 (2006). https://doi.org/10.1063/1.2163870

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