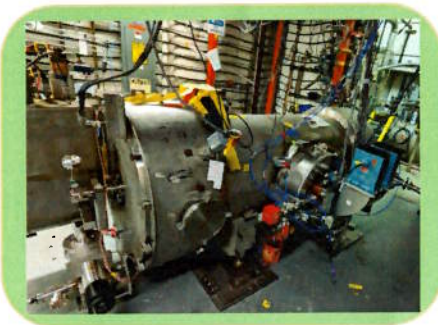


Background: With the investment of DOE Office of Science Nuclear Physics (DOE SC-NP) on Superconducting Radio-Frequency (SRF) R&D and Early Career Award to an early career SRF investigator, Jefferson Lab has been committed to developing the next generation SRF accelerator technology based on the new material niobium-tin (Nb_3Sn) since 2010 (see attached timeline and references). After decades of hard work, a milestone has finally been achieved: the first prototype niobium-tin cryomodule with two CEBAF-style SRF Nb_3Sn cavities completed its qualification test in the CMTF facility at Jefferson Lab. The cryomodule is now ready for beam test at Jefferson Lab. This once-in-half-a-century milestone represents the beginning of a new era of SRF technology for particle accelerators and potentially many other scientific instruments.

SRF S&T Highlights and Outlooks (1 of 3)

First Nb_3Sn cryomodule with two CEBAF-style 5-cell Nb_3Sn cavities

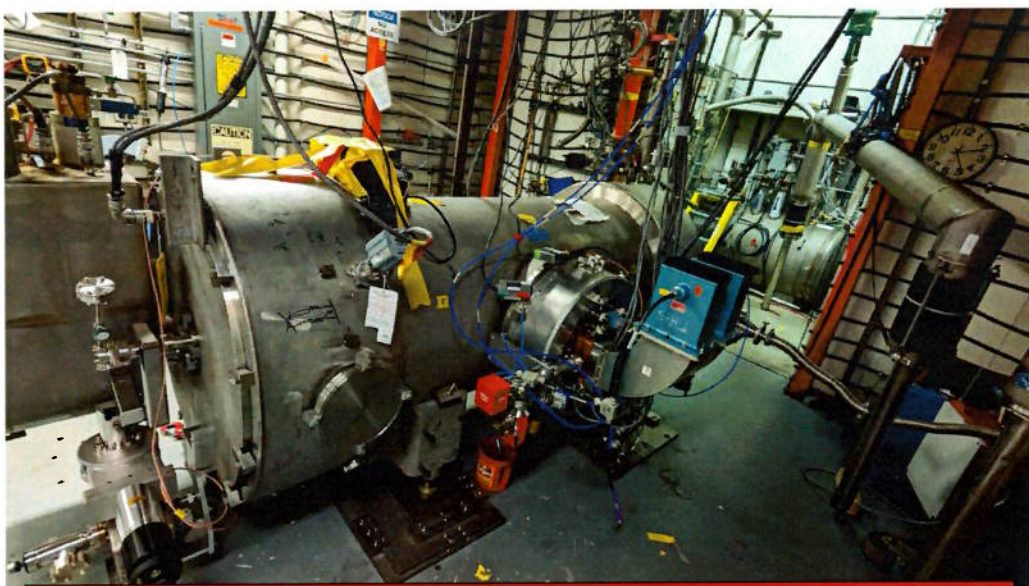
- Cavities reached acceleration gradient 8 & 13 MV/m, respectively at 4 K.
- Culmination of decade-long effort in Nb_3Sn SRF cavity development, since the first sample created by Grigory Eremeev 2010-2012 with the Elnik furnace "Big Blue" carrying a horizontal Nb chamber made in-house indicated a T_c of 17.9 K.



Thanks to SRF Ops and cryogenic colleagues for tireless effort in putting this landmark cryomodule together and carrying out the successful RF testing at 4 K. Next: Beam test of this cryomodule at UITF.

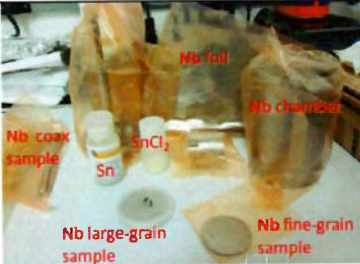
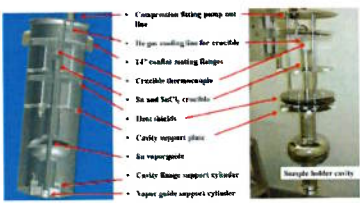



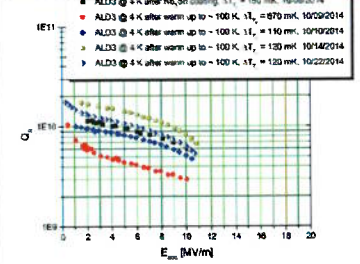
For 8/20/24 SRF Ops All Hands




Jefferson Lab





CEBAF-style quarter cryomodule with two 5-cell CEBAF-style Nb_3Sn cavities, May 2024

Jefferson Lab Nb₃Sn Cavity and Cryomodule Development Timeline

Year	Milestone	Funding & Project	Key personnel	Reference
2010-2012	<ul style="list-style-type: none"> Eremeev started ECA application for Nb₃Sn development via sputtering and ALD. Start of Nb₃Sn cavity development; Aim: 4 K operation; Approach: vapor diffusion deposition. First sample created with existing Elnik furnace "Big Blue" carrying a horizontal Nb chamber made in-house. Tc 17.9 K observed. Dedicated vertical Nb₃Sn furnace procured from T&M Vacuum. 	DOE BES Inverse Compton Light Source	G. Eremeev P. Kneisel J. Mammosser R. Rimmer	  <p>[1]</p>
2013	<ul style="list-style-type: none"> Vertical Nb₃Sn furnace received August 2013. Nb chamber (11.5 in OD x 32 in L) adapted to vertical. 		G. Eremeev	  <p>[2]</p>
2014	<ul style="list-style-type: none"> Vertical Nb₃Sn furnace commissioned. Eacc 10 MV/m with Q₀ 1E10 at 4 K in a 1.5 GHz single-cell cavity. 		G. Eremeev U. Pudasaini (as PhD student from W&M) M. Kelley (as Uttar's thesis advisor) P. Kneisel	  <p>[3]</p>

2015	<ul style="list-style-type: none"> • 2-cell cavity coated. • Eacc 13 MV/m with Q0 3E9 at 4 K in 2-cell cavities. 			 <p>[4]</p>
2016	<ul style="list-style-type: none"> • Ereemeev received ECA award; Aim: development of Nb3Sn coated 5-cell CEBAF cavities. 			
2017	<ul style="list-style-type: none"> • Nb3Sn furnace upgrade. • Larger chamber 17 in OD x 40 in L. • With encouragement from JLab Accelerator Division Director, Ereemeev ECA scope expanded with a vision of putting Nb3Sn cavities in a cryomodule, aiming for the first cryomodule test by end of 2018. • Achieved Eacc 15 MV/m with Q0 2E10 at 4 K in single-cell 1.3 GHz cavity RDT7. 	<p>DOE NP Early career award</p> <p>JLab R&D funding to support Pudasaini labor</p>	<p>G. Ereemeev U. Pudasaini</p>	 <p>[5]</p>
2018	<ul style="list-style-type: none"> • Demonstrated Eacc 2 MV/m with Q0 2E10 at 4 K in 5-cell CEBAF cavity IA320; 6 MV/m with Q0 4E9 at 4 K in 5-cell CEBAF cavity C75-000. • Demonstrated Eacc 7.5 MV/m with Q0 2E9 at 4 K in 5-cell cavity cavity pair (cavity IA016). • Vertical tested the cavity pair of two 5-cell CEBAF cavities IA110 & IA114. Eacc 2 MV/m with Q0 2E9 at 4 K; Observation of performance loss from stresses during pair assembly. 		<p>G. Ereemeev U. Pudasaini</p>	 <p>[6][7][8][10]</p>
2019	<ul style="list-style-type: none"> • Two new 5-cell C75-style cavities received and coated with Nb3Sn. 5C75-NbSn01 achieved Emax of 12 MV/m. 5C75-RI-NbSn02 achieved Eacc 12 MV/m initially at JLab, and later 15 MV/m following re-HPR and testing at FNAL. • Grigory Ereemeev moved from JLab to FNAL in August. 		<p>G. Ereemeev U. Pudasaini (thesis defended and obtained PhD)</p>	<p>[9] <i>Assistance provided by FNAL for HPR and cold test</i></p>
2020	<p>COVID19 pause</p>			
2021-2022	<ul style="list-style-type: none"> • Pair assembled with 5C75-NbSn01 & 5C75-RI-NbSn02 and tested. Observed performance degradation: gradient limited to 3 and 5 MV/m. • 5C75-RI-NbSn01 cavity reprocessed, re-coated, and vertical tested at Fermilab. Eacc 14 MV/m with Q0 4.5E9 at 4 K. • JLab provided large-grain Nb material for 5-cell cavity 5C75-RI-04 as replacement for 5C75-RI-NbSn02, which was lost due to weld joint failure. 		<p>U. Pudasaini (became JLab staff scientist in 2020) G. Ereemeev (FNAL) S. Posen (FNAL) B. Tennis (FNAL) Kurt Macha Tony Reilly C. Reece R. Rimmer</p>	<p><i>Assistance provided by FNAL for processing, Nb3Sn coating, and vertical testing.</i></p> <p><i>JLab SRF R&D funding supported processing, coating and qualification test for the large-grain cavity,</i></p>

	<ul style="list-style-type: none"> • 5C75-RI-04 coated, tested, and qualified. Eacc 13.3 MV/m with Q0~5E9 at 4 K. • Final re-qualification vertical test of two cavities after failed initial pair assembly due to leaking ceramic window. 5C75-RI-NbSn1 reached Eacc 13.6 MV/m with Q0 2.8E9 at 4 K; 5C75-RI-004 reached 9 MV/m with Q0 2.4E9 at 4 K. 			
2023	Pair assembled with two 5-cell Nb3Sn coated cavity 5C75-RI-NbSn01 & 5C75-RI-04. completed installation and assembly in a CEBAF-style quarter cryomodule with standard tuner and high-power RF couplers.		J. Fisher T. Reilly G. Ereemeev (FNAL) U. Pudasaini R. Rimmer	
2024	Demonstrated 13 MV/m and 8 MV/m in two each 5-cell CEBAF C75-style Nb3Sn coated cavities in a CEBAF-style quarter cryomodule tested in Test Lab cryomodule test facility CMTF at JLab.		M. Drury T. Reilly G. Ereemeev (FNAL) U. Pudasaini G. Ciovati R. Rimmer R. L. Geng	

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