THE FRIB PROJECT AT MSU*

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Abstract

The Facility for Rare Isotope Beams (FRIB) is ready to start construction. The facility will utilize a high-intensity, heavy-ion driver linac to provide stable ion beams from protons to uranium up to energies of >200 MeV/u and at a beam power of up to 400 kW. The superconducting cw linac consists of 330 individual low-beta (beta = 0.041, 0.085, 0.29, and 0.53 at 80.5 MHz and 322 MHz) cavities in 49 cryomodules operating at 2 K. This paper discusses the current development status of the project with emphasis on the linac SRF acquisition. SRF coldmass and cryomodule component designs are briefly summarized. A SRF production facility, currently under construction, is described.

INTRODUCTION

The Facility for Rare Isotope Beams (FRIB) is a new national user facility for nuclear science research, funded by the U.S. Department of Energy Office of Science (DOE-SC) and operated by Michigan State University (MSU). FRIB has been baselined by DOE-SC at a total project cost of $ 730M with project completion in June 2022 (early completion Dec 2020). The main mission of FRIB will be the production and study of rare isotopes not commonly found in nature. These isotopes are produced by the fragmentation technique where a primary beam of high-energy, stable ions impinges on a graphite target producing a shower of isotopes. These isotopes are subsequently mass analyzed in a high-resolution mass separator and transported to the respective nuclear science experiments.

At its core FRIB requires a unique cw superconducting heavy-ion driver linac [1] which combines features typically only associated with operation of high power proton accelerators with the distinct operational flexibility commonly required of heavy ion facilities, see Fig. 1. Following list summarizes several unique characteristics which – as a combination - push the state of the art for heavy ion accelerators:

- The FRIB driver linac needs to provide stable ion beams from protons to uranium up to energies of >200 MeV/u and at a beam power of up to 400 kW raising heavy-ion beam power by two orders of magnitude from current radioactive heavy-ion beam facilities.
- Concerns about beam loss in cavities and machine protection become main design drivers which require specialized design solutions. For instance, FRIB will utilize cold beam position monitors inside the cryomodules to allow active (software-controlled) beam steering. Temperature sensors inside the cryomodule beamline sections in combination with beam halo monitors between cryomodules will be utilized as diagnostics elements for machine protection.
- For the same reason, and due to the length of the driver linac involved, cavity and magnet alignment within the cryomodules becomes a critical design requirement. As described below, FRIB developed a new cryomodule concept to achieve superior alignment capabilities.
- Once complete FRIB will be the largest superconducting heavy-ion linac incorporating 330 low-beta cavities. Due to the heavy mass and correspondingly low velocity of the accelerated ions involved FRIB needs four different low-beta SRF resonator designs to reach the required energy range.
- As a consequence, for low-beta structures FRIB will most likely be the first facility requiring industrially

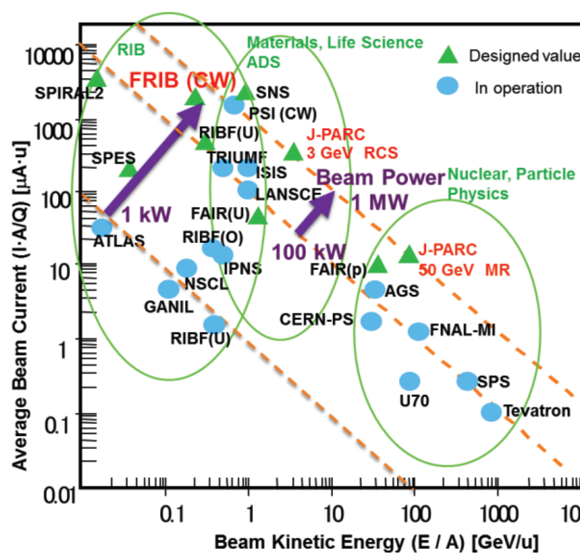

Figure 1: The FRIB driver linac will uniquely combine features of a heavy-ion with a high-power accelerator. By raising available cw heavy-ion beam power by two orders of magnitude the linac design has to address challenges related to heavy-ion accelerator operation, e.g. multi-charge beam transport and flexibility in accelerated ions, as well as related to high-power beam transport, e.g. machine protection system and diagnostics. This paper summarizes the impacts to the SRF subsystem designs.

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produced components on a larger scale. Mechanical designs and procurement strategies have been optimized accordingly [2].

- Contrary to current high-power accelerator facilities FRIB science experiments will require ion beam changes every two weeks to one month. Ultimately a set of 20-40 pre-developed ion beam tunes will be needed. Table 1 lists ten ion beams which will be required during first year of facility operation.
- To allow such flexible operation FRIB will utilize two electron-resonance-cyclotron injector ion sources installed above ground for ease of maintenance. The ion beam is directed to the linac tunnel level ten meters below ground. The rest of the FRIB front-end [3] consists of a multi-harmonic buncher and a room-temperature 500 keV/u four-vane radio frequency quadrupole accelerator. The front end is designed for a mass to charge ratio of 1/3 to 1/7 and will provide typical beam currents of 350 electrical μA for the heaviest masses. To achieve the highest possible currents for the heaviest masses a capability to prepare and accelerate two charge states is provided. A medium energy transport section including two additional bunchers and superconducting focusing solenoids prepares the ion beam for injection into the linac.
- To increase the acceleration efficiency of the linac a liquid metal lithium stripper [4] is installed at the optimum stripping energy of approx. 16 to 20 MeV/u. The stripper will increase the ion charge state by a factor of 2 to 3 (depending on ion). The subsequent linac sections will accept five charge states from the stripper for simultaneous acceleration.
- To ease identification of the radioactive isotopes in the fragment separator the FRIB driver linac needs to

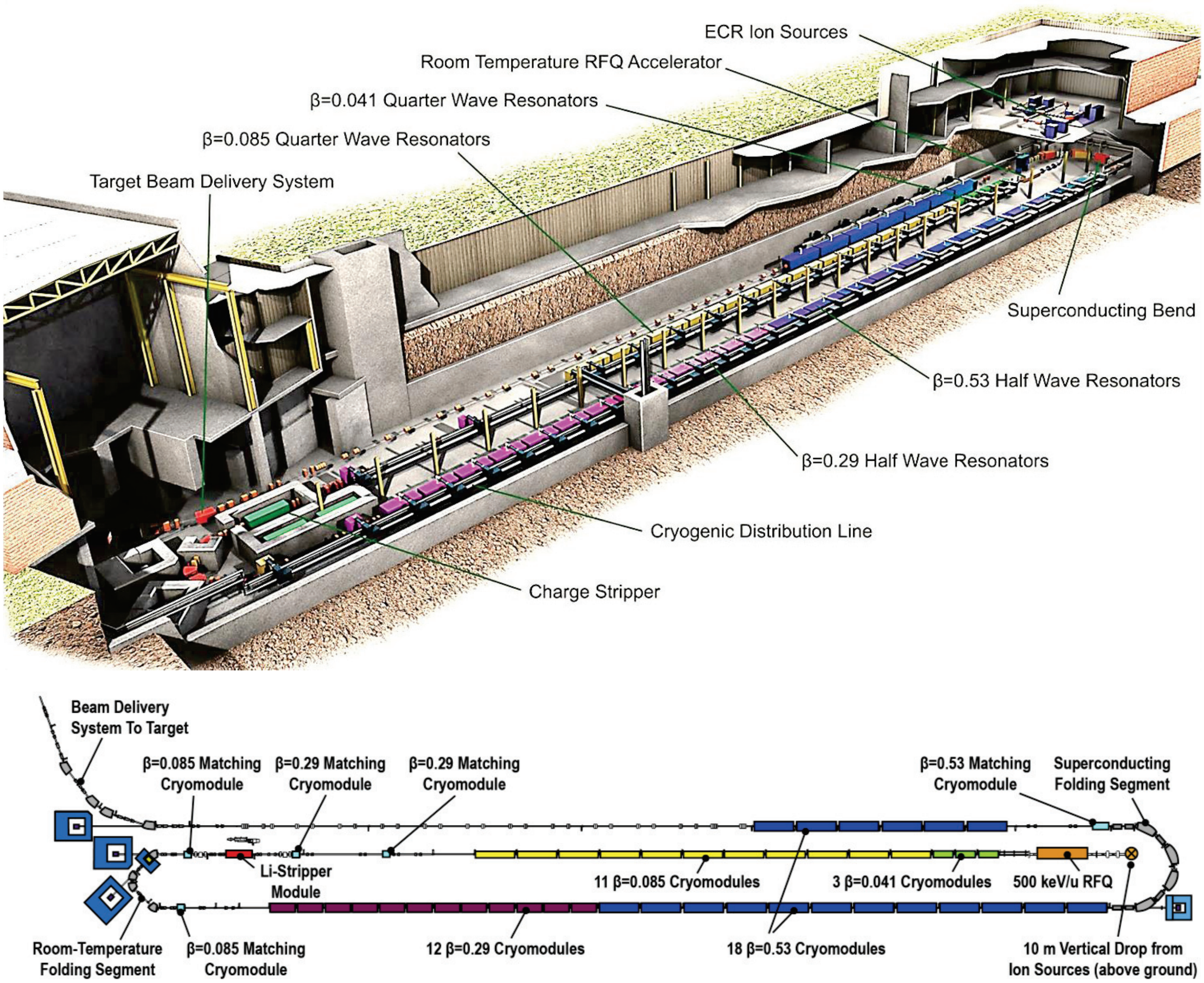

Figure 2: 3D rendering and schematic layout of the FRIB driver linac. For easier maintenance the ion sources are located on ground level. The room-temperature RFQ accelerator and the superconducting linac are located approx. 10 m below ground. To minimize conventional building construction cost the linac has been folded into three sections each approx. 150 m in length. By combining the technical features of a heavy-ion with a high-power accelerator the FRIB linac becomes uniquely challenging in several aspects as outlined in the text.

Table 1: FRIB ion beams and respective ion source parameters as required during first year of operation

Ion	Mass [amu]	Charge State	Current [eμA]	Type
Krypton	78,86	16	560	Gas
Argon	40,36	11	750	Gas
Oxygen	16,18	6	900	Gas
Neon	22	6	730	Gas
Xenon	124	24	600	Gas
Calcium	40,48	10	600	Metal
Germanium	76	x		Metal
Tin	124	x		Metal
Bismuth	209	x		Metal
Uranium	238	33	550	Metal

provide flexible and fast output energy adjustments between 0% to -20%.

- The FRIB linac lattice has been optimized for transverse solenoid focusing primarily driven by the required capability to accelerate multiple charge states. 8 Tesla superconducting solenoids are installed inside the cryomodules which requires a careful cavity magnetic shielding design to guarantee optimum resonator performance.
- FRIB will operate a large cryoplant with a nominal facility heat load of 12 kW normalized at 4.5 K (using Carnot cycle coefficient of performance; the explicit heat loads are projected to be 2.5 kW at 2K, 3.2 kW at 4.5K, and 13.5 kW at 38/55 K). All cavities including the quarter wave resonators will be operated at 2 K. FRIB superconducting magnets including the solenoids in the cryomodules will be operated at 4.5 K.

Under the current project baseline schedule cryomodule construction will start in fall of 2014. Cryomodule installation in the tunnel will start in 2016 and will last until 2019. 45% of the total project cost of $ 730M are allocated towards the linac hardware, 28% towards the conventional building, and 10% towards the target and fragment separator with the remaining distributed to management, pre-operations and R&D. During peak construction time the accelerator assembly and installation will need approx. 180 employees.

Above driver linac requirements are reflected in the design choices for the superconducting accelerator technology developed for FRIB. The rest of the paper will summarize the detail design status of the FRIB superconducting RF sub-systems.

SRF SYSTEMS

Table 2 summarizes the cavity and cryomodule count required for the FRIB driver linac. The FRIB cryomodules have two cryogenic circuits operating cavities at 2 K and solenoids at 4.5 K. Due to the low velocity of the ions at the beginning of the linac the β=0.041 and β=0.085 cryomodules incorporate 2 or 3 solenoids respectively. They also include cold beam position monitors after each solenoid to enable predictive beam steering. The half-wave cryomodules which are operated at higher optimum β=0.29 and β=0.53 require only a single solenoid each. The cryomodule length, which is approx. 5 m depending on type, is a result of combined beam physics, RF power, maintainability, and SRF gradient optimization and is driven by a compromise between warm diagnostics requirements and mechanical design constraints and the desire to minimize cryomodule count.

Table 2: Cavity and cryomodule counts required for the FRIB driver linac as shown in Fig. 2

Type	Quantity of Cavities	Quantity of Modules	Quantity of Solenoids
β=0.041	12	3	6
β=0.085	88	11	33
β=0.29	72	12	12
β=0.53	144	18	18
Additional Bunching Modules	6 4 4	2 (β=0.085) 2 (β=0.29) 1 (β=0.53)	n/a
Total	330	49	69

Cavities

FRIB had to develop and prototype four different cavity types as summarized in [5]. As described in [2] the additional need to industrialize fabrication of more than 330 cavities constitutes one of the main challenges for the

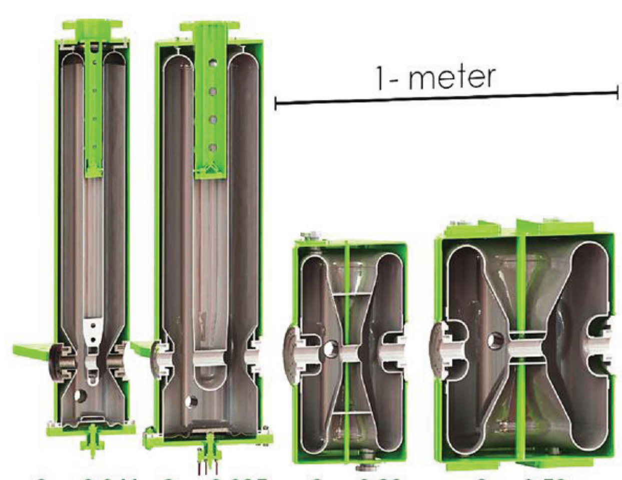

Figure 3: The FRIB driver linac requires four different low-beta cavity types as shown. Due to the large quantity of cavities in the driver linac the current development effort focuses strongly on minimization of fabrication costs [2].

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Table 3: Main FRIB cavity parameters (QWR … quarter wave resonator, HWR … half wave resonator)

Type	QWR #1	QWR #2	HWR #1	HWR #2
β	0.041	0.085	0.29	0.53
Frequency [MHz]	80.5	80.5	322	322
Temperature [K]	2	2	2	2
Aperture [mm]	36	36	40	40
Cavity $Ø_{inner}$ [m]	0.18	0.27	0.29	0.46
$\beta\lambda$ [m]	0.16	0.317	0.27	0.493
R/Q [Ω]	401.6	455.4	224.4	229.5
G [Ω]	15.3	22.3	77.9	107.4
Avg. Accel. V_a [MV]	0.81	1.78	2.09	3.7
$V_a/\beta\lambda$ [MV/m]	5.1	5.6	7.7	7.5
V_a/Cavity $Ø_{inner}$ [MV/m]	4.5	6.6	7.2	7.5
E_p at V_a [MV/m]	30.8	33.4	33.3	26.5
B_p at V_a [mT]	54.6	68.9	59.6	63.2
Dissipation at V_a [W]	1.32	3.88	3.55	7.9
Max. Beam Power [W]	313	690	1526	2701
Min. RF Bandw. [Hz]	40	40	30	30
Installed RF Power [kW]	0.7	2.5	3.0	5.0

project. Table 3 summarizes the main operational design parameters for the FRIB cavity types. The final FRIB cavity shapes are shown in Fig. 3 and have been optimized to increase safety margin on gradient by limiting B_{peak} and E_{peak} to less than 70 mT and 35 MV/m respectively for a conservative point of operation.

FRIB cavities are BCP processed and furnace treated at 600 °C. The helium vessels are made out of titanium. All cavities are sufficiently stiffened to withstand material yielding below a pressure of 2.2 atm at room temperature. This requirement is more stringent than pressure vessel code requirements which are consequently also fulfilled. The pressure relief system is designed to limit the helium pressure at the cavity during cold operation to below 10.8 atm in case of an accidental vacuum leak to the beamline vacuum (the most severe accident scenario). Due to the significant increase in material yield strength at cold temperatures the cavities can withstand that pressure.

Currently, FRIB has successfully tested eight β=0.041, eleven β=0.085, and five β=0.53 prototype cavities incorporating all features and final shapes compared to the production cavities. The production cavity designs have a slightly increased outer diameter (e.g. for β=0.085 from Ø=0.24 m to 0.27 m; for β=0.53 from Ø=0.4 m to 0.46 m) to increase safety margin on B_{peak} or to allow future operation at higher gradients if so desired.

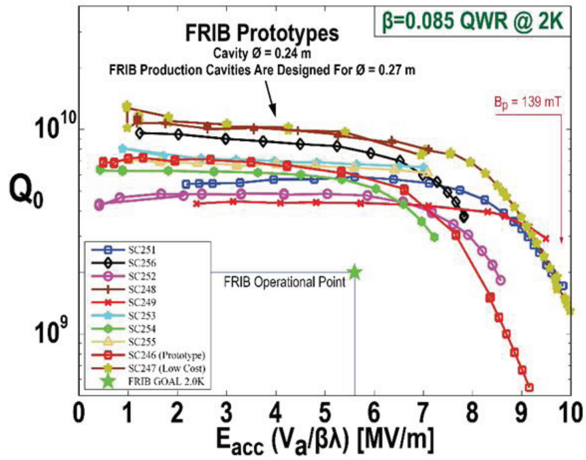

Figure 4: Typical Q_0 vs. E_{acc} ($V_a/\beta\lambda$) curves measured during vertical tests of β=0.085 FRIB prototype cavities which will be used in a Re-Accelerator cryomodule [6]. The final FRIB cavity designs will have an increased outer diameter (from Ø=0.24 m to 0.27 m) to further increase the operational safety margin or to allow future operation at higher gradients if so desired.

The actual FRIB production cavities are procured from industry in a phased approach:

- 2 development cavities (without helium vessel) to confirm the final design,
- 10 pre-production cavities (with helium vessel) in order to validate production capabilities,
- Full production quantity.

So far we have received and tested development cavities for β=0.29 and β=0.53 (made by Roark Welding, Inc.). The β=0.085 development cavities will be completed in spring

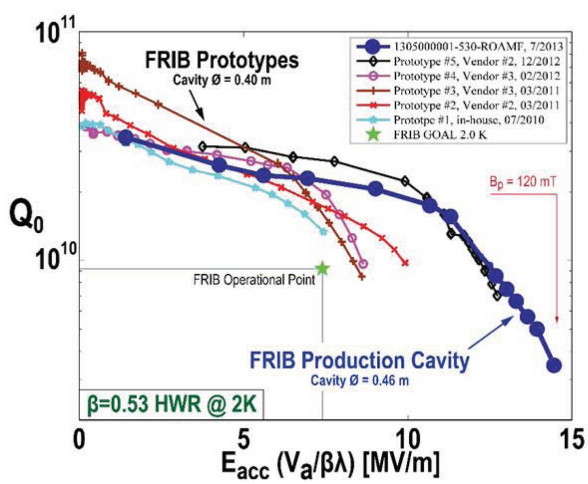

Figure 5: Q_0 vs. E_{acc} ($V_a/\beta\lambda$) curves measured during vertical tests of β=0.53 FRIB prototype cavities as well as test results from a β=0.53 production cavity which incorporates all final FRIB design features. The outer diameter of the final cavity design has been increased from Ø=0.4 m to 0.46 m compared to the prototypes

Figure 6: Pictures of the β=0.085 prototype cavity as well as the β=0.53 FRIB production cavity. The β=0.53 production cavity incorporates all final FRIB design features, e.g. stiffening structures, as visible in the picture, to satisfy pressure vessel requirements.

2014 (made by Pavac Industries, Inc.). The final FRIB production contracts for all cavity types will be placed by end of 2013.

Fig. 4 shows typical Q_0 vs. E_{acc} ($V_a/\beta\lambda$) curves measured at 2 K during vertical tests of β=0.085 FRIB prototype cavities which will be used in a Re-Accelerator cryomodule [6]. The final FRIB cavity designs will have an increased outer diameter (from Ø=0.24 m to 0.27 m) thereby increasing the operational safety margin.

Fig. 5 shows Q_0 vs. E_{acc} ($V_a/\beta\lambda$) curves measured at 2 K during vertical tests of β=0.53 FRIB prototype cavities as well as test results from a β=0.53 development cavity which incorporates all final FRIB design features. The outer diameter of the final cavity design has been increased

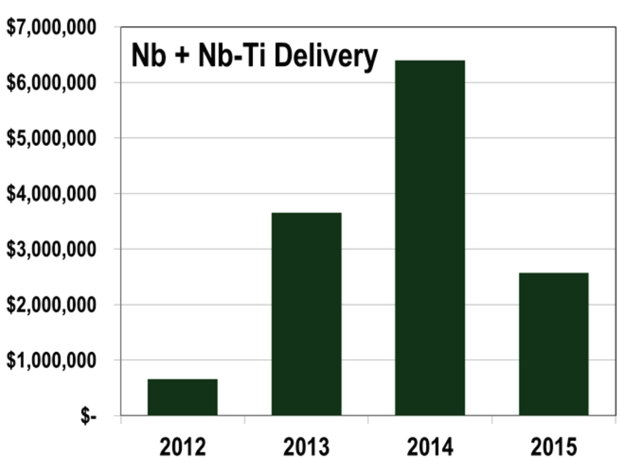

Figure 7: FRIB has already procured the entire niobium material at a purchase value of $ 13.2M. The material is delivered in four task orders as shown in the graph.

Figure 8: FRIB requires mass-production of large sizes of niobium sheets (up to approx. 1 m times 1 m) due to the dimensions of the low-beta cavities. The image shows a typical sheet size during final vendor inspection.

from Ø=0.4 m to 0.46 m compared to the prototypes. As can be seen in Fig. 5, the final cavity design reaches FRIB design specifications by a safe margin.

Fig. 6 shows pictures of the β=0.085 prototype cavity as well as the β=0.53 FRIB production cavity. As shown in table 2 the largest quantity of cavities are required in these two types which are also the most expensive ones (due to the size). Therefore, most development effort went into these two cavity shapes.

Niobium

To fulfill the cavity production schedule FRIB has already procured the entire niobium material at a purchase value of $ 13.2M. The material is delivered in four task orders. Their time-phasing is summarized in Fig. 7. The material production is divided between three vendors: Tokyo Denkai for Nb sheets, Ningxia for Nb sheets and Nb tubes, and Wah Chang for all NbTi material.

As for all large niobium procurements efficient quality control procedures at the vendor as well as receiving inspection procedures at FRIB become critically important. In addition to visual inspection of all sheets FRIB examines detailed material properties of minimum two samples per production lot. Following material properties are collected

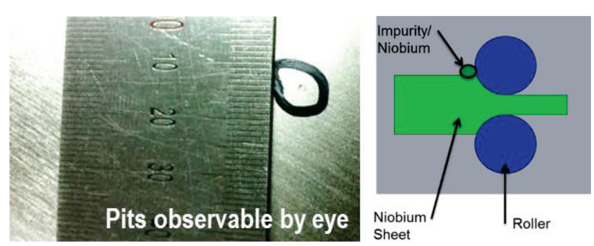

Figure 9: A fraction of the initially delivered large sheets included visually observable pits as shown. FRIB investigated the pit structures and surrounding material properties [7] and could identify the cause of pitting. Loose niobium particles, most probably originating from rough-cut sheet edges, get caught on the sheet rollers and become subsequently imprinted during the next rolling steps.

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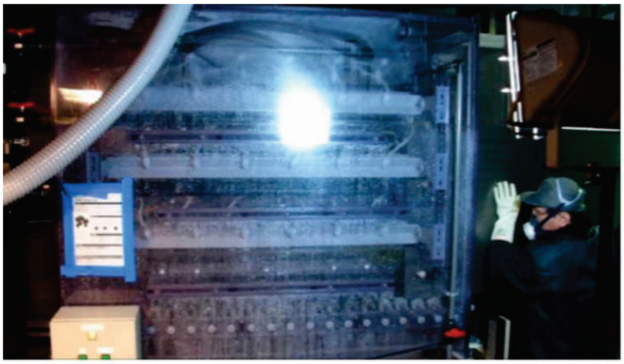

Figure 10: Tokyo-Denkai has developed a custom etching cabinet for automatic and safe processing of large and heavy niobium sheets without cross-contamination

and compared to vendor-supplied data: Ultimate strength, yield strength, elongation, hardness, grain size, crystal orientation, recrystallization, residual resistivity ratio. First material acceptance results are discussed in detail in [7].

FRIB requires mass-production of large sizes of niobium sheets (up to approx. 1 m times 1 m) due to the dimensions of the low-beta cavities. Fig. 8 shows a typical sheet size during final vendor inspection. A fraction of the initially delivered large sheets included visually observable pits as shown in Fig. 9. FRIB investigated the pit structures and surrounding material properties [7] and could identify the cause of pitting. Loose niobium particles, most probably originating from rough-cut sheet edges, get caught on the sheet rollers and become subsequently imprinted during the next rolling steps, see Fig. 9. This particle contamination issue is significantly more severe for the larger sheet sizes. FRIB is supporting the vendors in identifying and alleviating the contamination sources.

Etching and rinsing of large and heavy niobium sheets become another challenge, which the vendors have to address. For instance, Tokyo-Denkai has developed a custom etching cabinet for automatic and safe processing without cross-contamination, see Fig. 10.

Power Couplers

FRIB utilizes two different power coupler designs for the quarter-wave resonators and the half-wave resonators. Table 4 summarizes the respective coupler specifications and heat loads.

The FRIB quarter-wave cavities utilize a co-axial, side-mounted coupler close to the bottom of the cavity. This coupler is developed by Argonne National Laboratory [8]. The coupler is designed for a power rating of 4 kW and has the ability for manual coupling adjustment facilitated by copper-plated bellows. The side-mounting requirement lead to the use of a cold window design with a 90-degree bend since the RF transmission line is connected at the bottom of the cryomodule. As shown in Fig. 11 the coupler is optimized for 2 K operation with a liquid-cooled 4.5 K thermal intercept close to the cavity flange, and a 38/55 K liquid-cooled, cold window which constitutes the vacuum boundary to the cavity.

Table 4: Coupler specifications and heat loads for both FRIB coupler designs for the quarter-wave resonators and the half-wave resonators

Coupler Type	QWR β=0.085	HWR β=0.53
Frequency [MHz]	80.5	322
Cavity RF Bandwidth	40	30
Installed RF Power [kW]	2.5	5
Max. Coupler Power Rating [kW]	4	10
Manual Coupling Adjustment	½ To 2 Times Bandwidth	
Coupler Interface	1-5/8” EIA	3-1/8” EIA
Total Heat Load To 2 K At Nominal RF Power [W]	0.13	0.6
Total Heat Load To 4.5 K At Nominal RF Power [W]	1.3	2.7
Total Heat Load To 38/55 K At Nominal RF Power [W]	7.1	6.2

The FRIB half-wave cavities utilize a modified SNS-style, coaxial coupler with a single warm window. Fig. 12 illustrates the mechanical design of the coupler with the thermal intercept locations indicated. This coupler incorporates copper-plated bellows for manual coupling strength adjustment. Figure 12 also shows pictures of the coupler mounted on a cavity as well as installed on its RF conditioning teststand.

The FRIB half-wave coupler is designed for a nominal power rating of 10 kW. The coupler possesses several electron multipacting levels due to its original 50 Ω co-axial geometry. It is possible to go through the multipacting levels during conditioning. However, we want to reduce the risk for prolonged or repeated conditioning needs during FRIB operation since the linac has 216 half-wave resonators installed. Therefore, FRIB is currently developing a modified, “multipacting-free” coupler design which maintains the current cavity flange as well as RF

Figure 11: The FRIB quarter-wave cavities utilize a co-axial, side-mounted coupler close to the bottom of the cavity. This coupler is developed by Argonne National Laboratory [8].

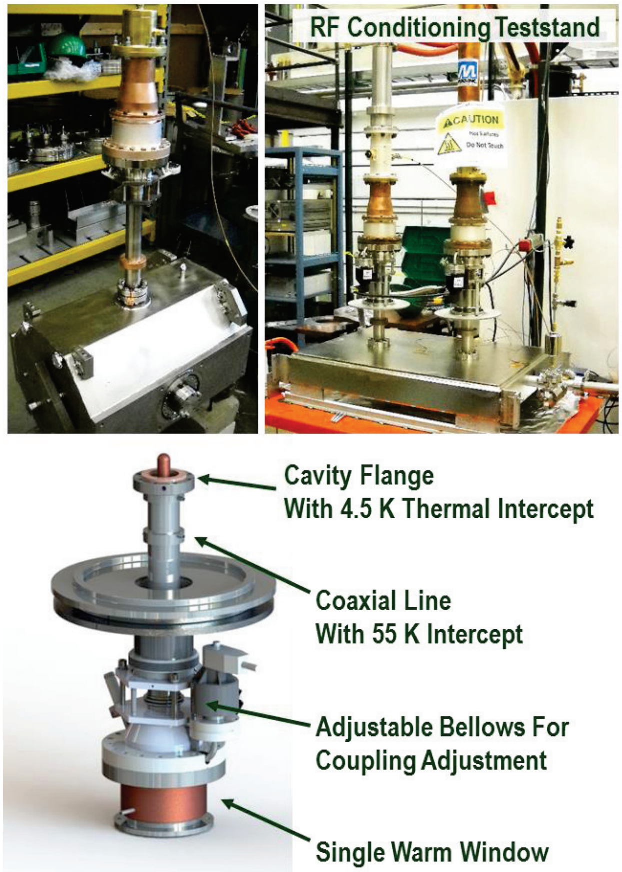

Figure 12: The FRIB half-wave cavities utilize a modified SNS-style, coaxial coupler with a single warm window. Also shown are pictures of the coupler mounted on a cavity as well as installed on its RF conditioning teststand.

connection flange sizes. Fig. 13 shows schematically the new coupler design which incorporates tapered sections to transition the line impedance from 50 Ω to 75 Ω at which, according to simulations, multipacting levels are suppressed up to FRIB operational electric fields.

Tuners

Fig. 14 and 15 display the mechanical tuners for the FRIB quarter-wave and half-wave resonators. Table 5 summarizes the main design parameters.

The quarter-wave cavities utilize a standard, stepper-motor-driven drive system to move a tuning plate inside the

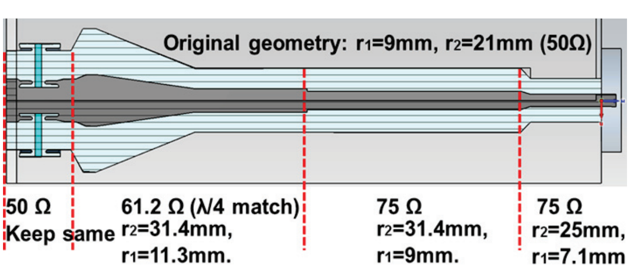

Figure 13: A modified half-wave coupler design which incorporates tapered sections to transition the line impedance from 50 Ω to 75 Ω suppresses multipacting levels up to FRIB operational electric fields.

Table 5: Main tuner design parameters for the quarter-wave and half-wave resonators

Tuner Type	QWR β=0.085	HWR β=0.53
Minimum Tuning Range [kHz]	30	120
Tuning Resolution (2% of Bandwidth) [Hz]	0.8	0.6
Maximum Backlash (5% of Bandwidth) [Hz]	2	1.5
Cavity Tuning Sensitivity (calculated) [kHz/mm]	~ 3.2	~ 236.2
Maximum Displacement [mm] (*) port-to-port	±7.5	±0.5 (*)
Cavity df/dp (Free Tuner) (calculated) [Hz/torr]	~ -1.4	~ -3.43
Cavity LFD (Free Tuner) (calculated) [Hz/(MV/m)^2]	~ -0.7	~ -3

bottom of the cavity. The tuning plate is shown in Fig. 14. Due to the required tuning range of 15 mm the plate needs convolutions and slots for stress-relief. Also visible is a niobium "puck" welded in the center of the tuning plate. The height of that puck can be dimensioned after all cavity frequency stack-up operations have been completed for additional, final frequency adjustment of ±30 kHz.

The original half-wave tuner utilized an external, scissor-jack style design with flex-pivot bearings. However, operation of that tuner transferred vibrations to the cavity during prototype cryomodule testing. In addition, the flex-pivot bearings are made out of magnetic material, which cannot be located close to the cavity. Instead of redesigning the scissor-jack tuner we decided to incorporate a pneumatically driven tuner design as already successfully operated at the Argonne National Laboratory ATLAS facility. That tuner can apply significant force to the cavity at much lower cost than a scissor-jack tuner.

Fig. 15 shows a pneumatically driven tuner mounted on a FRIB half-wave cavity. A piston filled with helium gas at

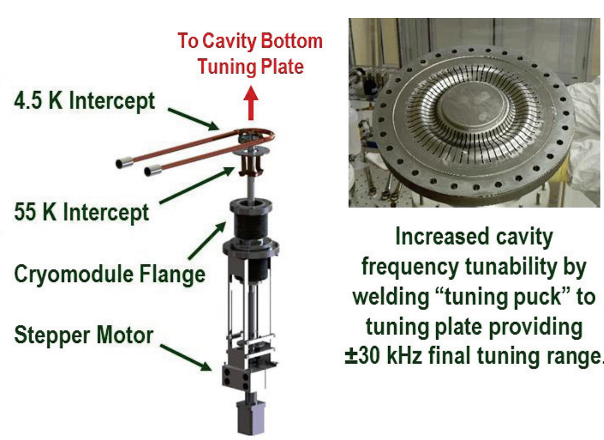

Figure 14: The FRIB quarter-wave cavities utilize a standard, stepper-motor-driven drive system to move a tuning plate inside the bottom of the cavity.

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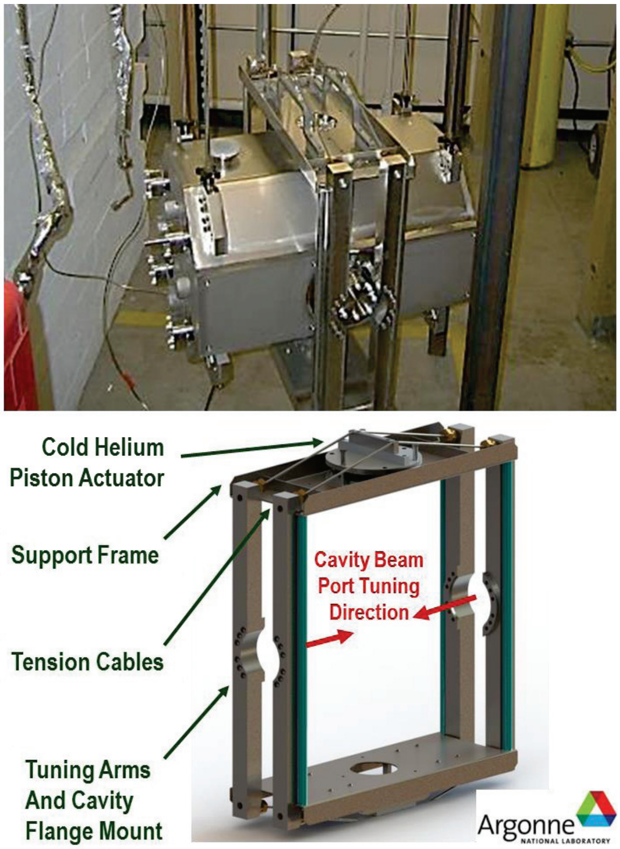

Figure 15: A pneumatically driven tuner is mounted on a FRIB half-wave cavity prepared for vertical testing. The design is adapted from a tuner developed at the Argonne National Laboratory ATLAS facility.

Table 6: Projected cryogenic heat load for the FRIB β=0.085 quarter-wave cryomodule

Projected Heat Load	Static	Dynamic
2 K	5.8 W	32.0 W
4.5 K	30.4 W	2.1 W
38/55 K	168.1 W	33.4 W

adjustable pressure stretches a system of tension cables which transform the tuning force to the cavity flanges. As demonstrated during first experiments the slow tuning capacity of a pneumatic tuner is sufficient for 2 K operation where pressure fluctuations are minimal.

CRYOMODULE

FRIB is currently working on completing all cryomodule detail design drawings after successfully finalization of the SRF sub-systems as described above. The SRF department will build two more cryomodule prototypes before 2015 at which point cavity and cryomodule mass production will commence.

Fig. 16 illustrates the main components of a FRIB-style β=0.085 quarter-wave cryomodule currently under construction. FRIB cryomodules are optimized for mass-production and for use in large-scale linac installations. They incorporate significant innovations as described in [9]. Table 6 summarizes the projected cryogenic heat load for the β=0.085 quarter-wave cryomodule.

The FRIB cryomodule is assembled on top of a steel bottom plate and includes three stainless steel rail sections

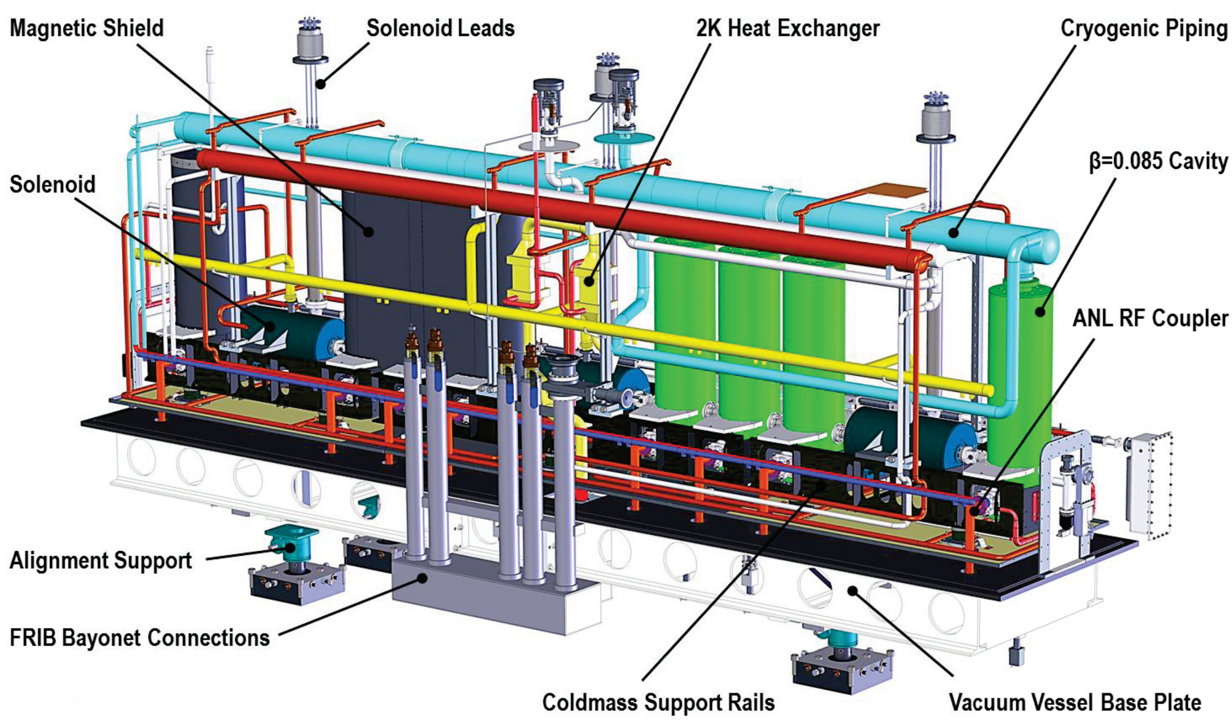

Figure 16: Illustration of the main cryomodule components for a FRIB-style β=0.085 quarter-wave cryomodule currently under construction. FRIB cryomodules are optimized for mass-production and for use in large-scale linac installations.

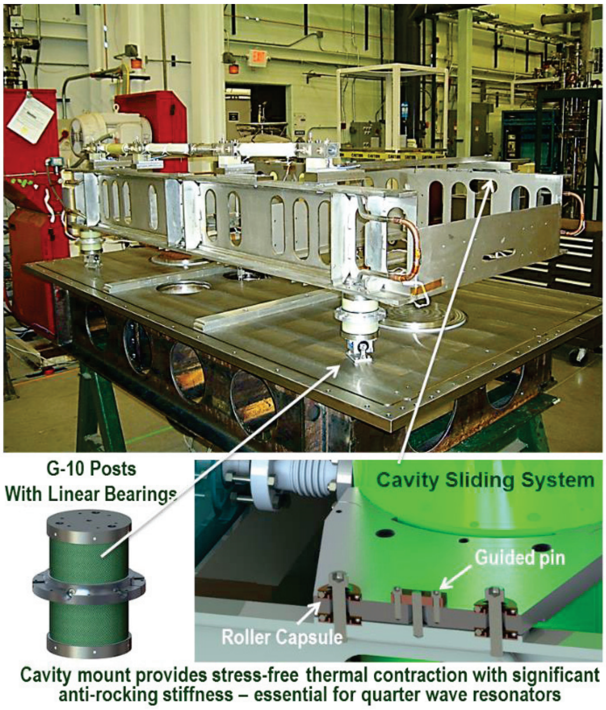

Figure 17: One particular innovation in the FRIB cryomodule design includes a self-aligning cavity support system built of stainless steel rails supported on G-10 posts. To ease assembly and alignment the precision machined rails are sat on top of pre-assembled G 10 posts which are mounted on a structurally solid steel bottom plate

as support for the coldmass components. Cryogenic connections are made via a bottom-mounted bayonet assembly. This allows warming up and disconnecting the cryomodule from a cold linac string. The cryomodule includes two cryogenic circuits for 2 K cavity and 4.5 K solenoid operation. A cold magnetic shield is wrapped locally around the cavities. That configuration is more versatile than a global magnetic shield at the cryomodule vacuum vessel wall since it reduces the need for excessive inspection of cryomodule components for magnetization. In addition, for a long cryomodule a local magnetic shield requires significantly less material than a global shield making it by far the cheapest option available.

One particular new development includes a self-aligning cavity support system built of stainless steel rails supported on G-10 posts. To ease assembly and alignment the precision machined rails are sat on top of pre-assembled G-10 posts which are mounted on a structurally solid steel bottom plate as shown in Fig. 17. The G-10 posts limit rail contraction in a kinematic and pre-determined way as shown in Fig. 18. One rail corner is fixed in space whereas the rest of the G-10 posts are mounted on linear bearings allowing thermal contraction towards the predefined static point. Cool-down experiments on a test cryomodule have validated the accuracy of that support system. Cavity alignment could be maintained within 0.003 inch as independently measured by optical targets as well as a wire position monitoring system. Previous cryomodules

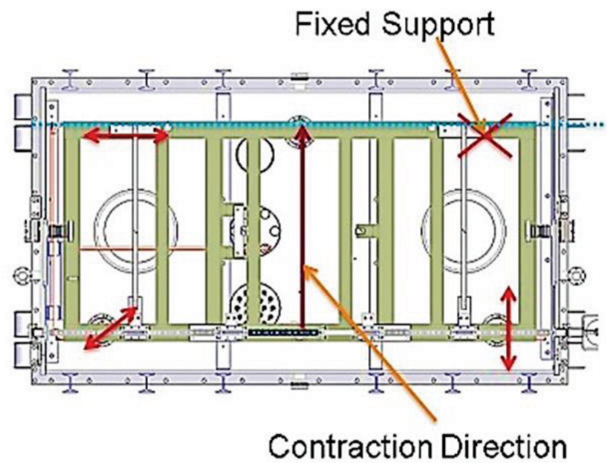

Figure 18: The support rail G-10 posts limit rail contraction in a kinematic and pre-determined way. One rail corner is fixed in space whereas the rest of the G-10 posts is mounted on linear bearings allowing thermal contraction towards the predefined static point.

utilizing hanging cold masses took days up to a week to precision align. The new self-aligning support system took on the order of hours to fully assemble and align within a test cryomodule.

The cavity mount on the support rails has to allow differential thermal contraction between the cavities (made out of niobium and titanium) and the rails (made out of stainless steel for cost reasons). Fig. 17 indicates a roller-bearing solution which allows in-plane thermal contraction but limits rocking motion. Latter mode of motion is especially harmful due to its potential in amplifying vibration transmission to the tall quarter wave resonators.

SRF PRODUCTION FACILITY

FRIB is currently constructing a 27,000 sqft SRF production facility to prepare for mass-production of 330 cavities and 49 cryomodules. A 3D CAD model of the facility is shown in Fig. 19. The high bay will include following systems to enable certification of one cavity per day:

- A large cleanroom which can incorporate two high pressure rinse stations and two coldmass assembly lines.
- A new chemical etch room with automated etch tools and enclosed acid storage.
- A chemical scrubber and an ultra-pure water system.
- Four vertical pits including the vertical test dewars. Removable shielding blocks will allow operation of two dewars simultaneously while servicing the rest.
- A test insert preparation area.
- A control room with RF amplifiers.
- A coupler conditioning area with several RF conditioning stands plus their own control racks.
- Two cryomodule bunkers which allow operation of one cryomodule while preparing a second one.
- The cavity heat treatment furnace.

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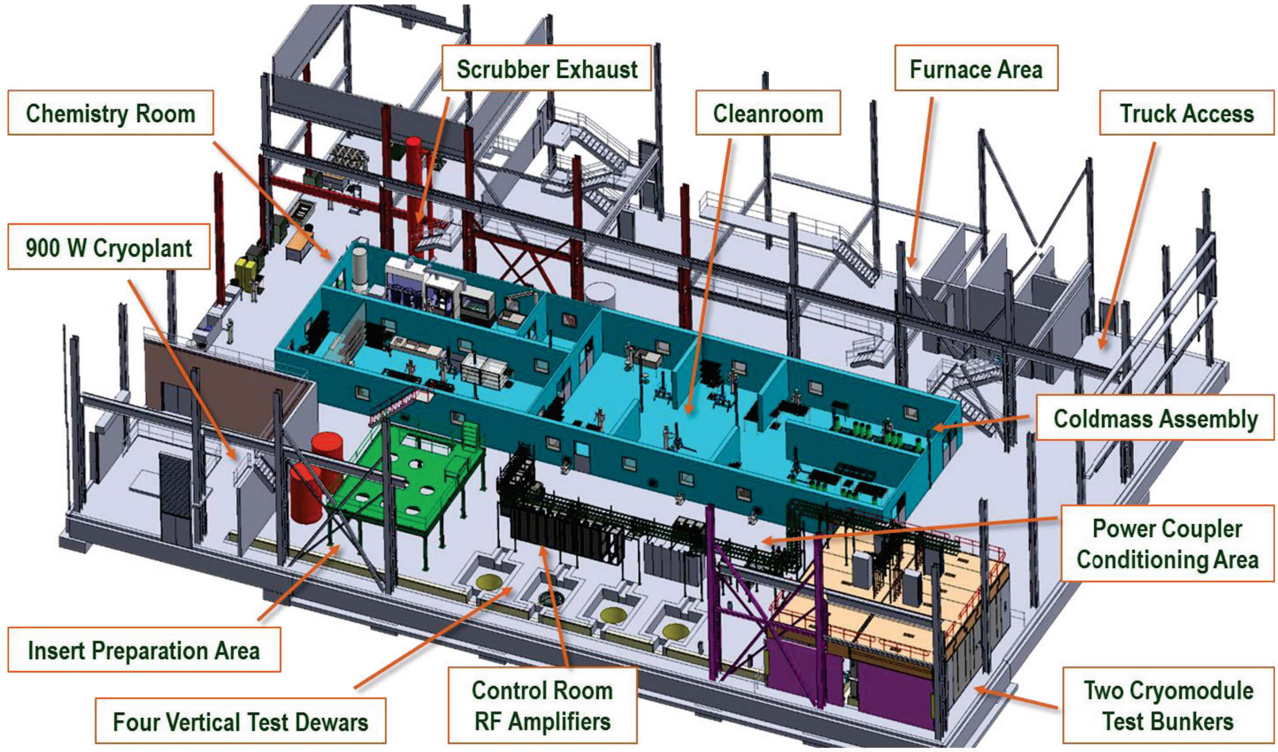

Figure 19: FRIB is currently building a 27,000 sqft SRF production facility to prepare for mass-production of 330 cavities and 49 cryomodules at a processing and vertical testing rate of 1 cavity per day.

- A 900 W cryoplant which will service the vertical test facility as well as the cryomodule bunkers.
- An R&D area with smaller dewars, a cavity preparation area, and storage space.

After completion of FRIB construction this infrastructure is planned to be transformed into a general-use SRF research facility. It will establish a future low-beta SRF center promoting Michigan State University campus-wide synergies and innovation.

SUMMARY

The U.S. Department of Energy – Office of Science has baselined the FRIB construction project at a cost of $ 730M at an earliest completion in 2020. All FRIB SRF subsystem designs have been finalized and prototypes have been successfully tested. To date FRIB industrial production contracts have been awarded for all niobium material as well as all linac β=0.53 cavities. The FRIB cryomodule design incorporates innovative design features. The SRF department will build two more cryomodule prototypes before 2015 at which point cavity and cryomodule mass production will commence.

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