

FRIB cryogenic system status

**F Casagrande¹, V Ganni¹, P Knudsen¹, S Jones¹, A Sidi-Yekhlef¹, H Tatsumoto¹,
C Nguyen¹, A Fila¹, G Vargas³, C Dudley¹, N Joseph¹, S Stanley¹, K Dixon², R
Norton², N Laverdure² and S Yang²**

¹ Facility for Rare Isotope Beams (FRIB), Michigan State University (MSU), East
Lansing, MI 48824 USA

² Thomas Jefferson National Accelerator Facility (TJNAF or 'JLab'), Newport News,
VA 23606 USA

³ Jacobs, Houston, TX 77058 USA

E-mail: knudsen@frib.msu.edu

Abstract. Construction and installation of the FRIB 4.5 K helium refrigeration system is nearing completion, with compressor system commissioning and 4.5 K refrigerator commissioning on schedule to occur in late 2017. The LINAC 4.5 K helium distribution system, all major process equipment, and the cryogenic distribution for the sub-systems have been procured and delivered. The sub-atmospheric cold box fabrication is planned to begin the summer of 2017, which is on schedule for commissioning in the spring of 2018. Commissioning of the support systems, such as the helium gas storage, helium purifier, and oil processor is planned to be complete by the summer of 2017. This paper presents details of the equipment procured, installation status and commissioning plans.

1. Introduction

The cryogenic system at Michigan State University's (MSU's) Facility for Rare Isotope Beams (FRIB) is on schedule for a cool-down to 4.5 K at the end of 2017, as reported previously [1]. All of the cryogenic sub-systems required for operation at 4.5 K have been delivered from the suppliers and are in place at FRIB. The sub-systems for 2-K operation are in the final stages of assembly (e.g., 2-K cold box, guard vacuum skid) at FRIB. The majority of cryogenic and warm piping are installed. The overall cryogenic plant layout is shown in Figure 1. Presently, the commissioning and integration of the refrigeration and support sub-systems are on schedule and progressing to support the scheduled cool-down to 4.5 K.

2. Design basis

The FRIB cryogenic system reflects the cumulative project execution and technical experience gained from similar systems, such as at the National Superconducting Cyclotron Lab (NSCL) at MSU [2], the Spallation Neutron Source (SNS) at Oak Ridge National Lab [3], the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab (BNL) [4], NASA's Johnson Space Center (JSC) [5], and Jefferson Lab (JLab) [6]. The acquired knowledge has been applied with respect to the planning, design, fabrication and delivery of the major sub-systems while coordinating the funding profile and civil



construction. The team members industrial and 24/7 operational experience enabled them to develop standardized designs for the major sub-systems, such as the compressor skids, oil removal, and gas management. Several of these have already been operating successfully for many years at other facilities. The compressor skid design, initially developed for NASA-JSC and further developed into a standardized design for JLab's 12 GeV upgrade, is improved and being used for this project (FRIB) and for others [7, 8]. The previously mentioned projects, just to cite a few, have implemented the 'Ganni Cycle – Floating Pressure Technology' [9], which enables a cryogenic system to efficiently, automatically, and stably adjust to different load capacities and changes in operating modes (i.e., mixed modes of liquefaction, refrigeration, and cold compressor, with varying shield loads). However, it was not until the development of the standardized compressor skid for NASA-JSC and JLab's 12 GeV upgrade with new features for variable pressure operation that the full potential of this floating pressure technology was realized [5, 10].

The FRIB cryogenic distribution to the cryo-modules is different from JLab and SNS due to the 4.5 K magnets in the cryo-modules [11, 12]. The cryogenic distribution from the cryogenic plant to the cryomodules are standardized to the extent practical for simplicity and economy. The modularized and subdivided procurement approach, which was used for the FRIB, SNS, JLab and NASA-JSC cryogenic systems, has been recognised to be the lowest technical risk and is more cost-effective than a single turnkey approach [13]. This is the case when the user has experience and expertise in each sub-system and understands how to integrate these together. The main technical design differences in the cryogenic plant and distribution system between FRIB and the other previously mentioned installations are discussed in literature [13, 14]. The technical team which will be operating the cryogenic system is integrally involved in the design, procurement, installation, and commissioning stages; which has proved to be productive and efficient from the previous operational and maintenance experience gained from similar systems.

Close coordination and planning with the civil construction streamlined the installation of the electrical feeds of all the cryogenic sub-systems. This provided an integrated approach during the final connection of equipment to the electrical system. The controls systems have been baselined on experience obtained from other laboratories with additional improvements such as incorporating dual feeds and power supplies for the main control cabinets. The dedicated cryo-control room and cryo-network are fully operational at the present time.

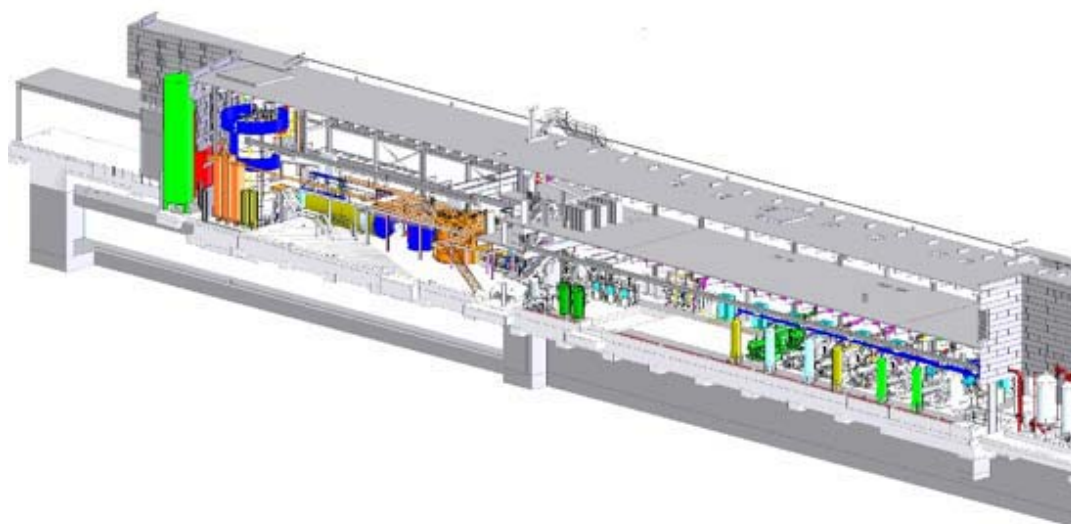


Figure 1. Cryogenic plant overall layout

3. Background

The layout of the FRIB accelerator was driven by the requirement to integrate the existing cyclotron and experimental areas while keeping it on the MSU campus within the FRIB/NSCL site. Of course, this directed the civil construction requirements and the accelerator sub-system layouts including the cryogenics.

In addition to conforming to these requirements, the equipment and sub-systems for the cryogenic plant were located and oriented to maximize operability, access, and anticipated future expansion needs. As agreed upon between FRIB and the general contractor at the beginning of the cryogenic system planning in 2013, it was possible to install the major sub-systems before the building beneficial occupancy date (BOD) in March 2017. The scheduling of the sub-system procurements was very successfully coordinated with the fabrication schedule while matching both the funding profile and building construction progress. The design and ordering had to be coordinated such that the delivery dates of all major components, were ‘just in time’ when the final location spaces in the building were ready. This eliminated unnecessary storage, maintenance, and double handling of these large sub-systems.

The cryogenic distribution system encompasses: the tunnel cryogenic distribution transfer lines that include 49 standardized sections to interface with the cryo-modules; three tunnel-shaft cryogenic transfer lines that connect the cold box room to the tunnel distribution; and the cold box room cryogenic transfer lines that connect the refrigeration system. Most warm interconnecting piping, the critical parts of the tunnel-shaft cryogenic transfer lines, and the tunnel cryogenic distribution were coordinated with the building construction and completed well before the BOD.

Table 1. Refrigeration sub-system status (2017)

Sub-system	Status
Helium gas storage	Commissioned
Warm compressors	In the process of commissioning
4.5 K cold box	In the process of commissioning
2-K cold box and cold compressors	Under construction at FRIB
Cold box room cryo-distribution lines	In the process of installation
Tunnel-shaft cryogenic transfer lines	In the process of commissioning
Tunnel cryogenic distribution lines	In the process of commissioning
LHe storage	In the process of commissioning
LN Storage	Commissioned
Helium purifier compressor	Commissioned
Helium purifier cold boxes	Commissioned
Compressor oil processor	Commissioned
Helium warm piping	Commissioned
LN/GN piping	Commissioned
Electric power (4160V/ 480V/ 208V)	Commissioned
Cooling water	Commissioned
Instrument air	Commissioned
Controls	Progressing with each sub-system

4. Refrigeration system status

As outlined in the previous section, except for the 2K cold box, the main cryogenic sub-systems have been installed. The six 114 m³ helium gas storage vessels are located on the roof top of the SRF high-

bay building, with the interconnecting piping routed via a pipe-bridge between the SRF high-bay and the FRIB building (which are adjacent to each other). These tanks are commissioned containing clean helium and are planned to be operated remotely. The upper and lower 4.5 K cold boxes [13] are installed having their overall configuration shown in Figure 2. The six main compressors and main oil removal vessels are installed as shown in Figure 3. Auxiliary equipment, such as the compressor oil processing system, the purifier compressors, and purifier cold boxes are shown in Figure 4. Table 1 summarizes the present status of all the sub-systems. Figure 5 shows bayonet cans and tunnel cryogenic line relief valve skids that are fabricated but not presently attached to the tunnel-shaft transfer lines. The centrifugal cryogenic (cold) compressor units have been delivered and are in the process of being assembled into the 2-K cold box at FRIB. The 2-K (sub-atmospheric) cold box is under construction (shown in Figure 5, as it is anticipated to look when complete).



Figure 2. 4.5 K cold box and the cold box room



Figure 3. Main compressors and oil removal



Figure 4. Auxiliary support equipment

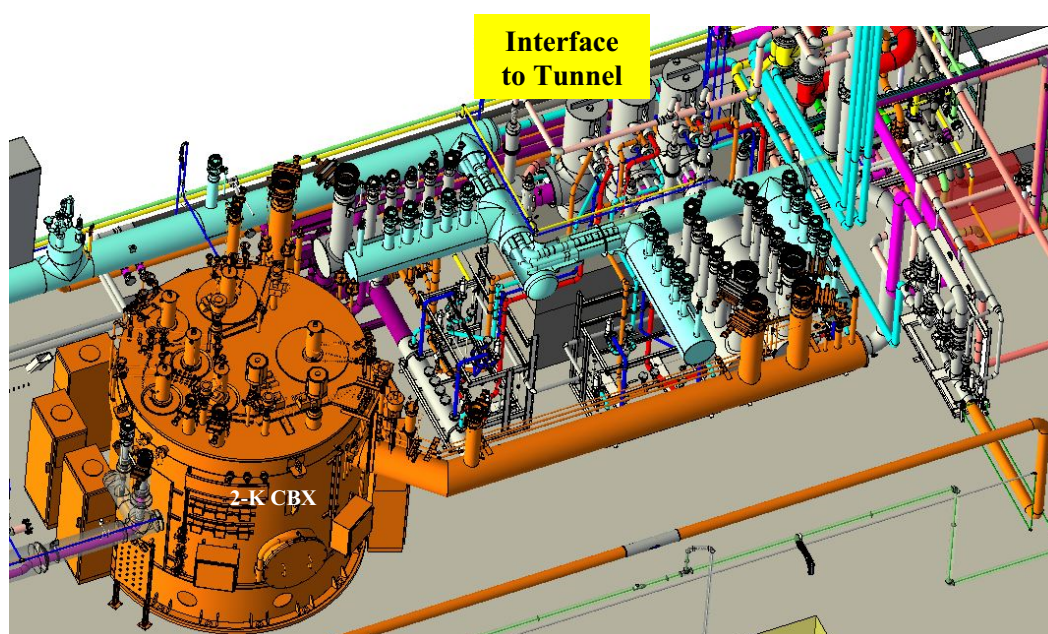


Figure 5. 2-K cold box and the tunnel interface

5. Distribution system status

The original FRIB cryogenic distribution system plan in 2013 to divide the LINAC into three segments was previously presented [12] and the progress described [14]. Presently, the three 9.1 m long tunnel-shaft transfer lines, the three lines connecting these tunnel-shaft lines to each LINAC segment (LS) at the “T” section, and each “T” section are installed. The first LINAC segment, LS1 is shown in Figure 6, and consists of multiple standard transfer line sections which are installed and connected to the “T” section. All of the standard transfer line sections which interface to the cryo-modules are in the tunnel. The transfer line from the 4.5 K refrigerator to the bayonet cans in the refrigeration room is presently being installed. Similarly, another transfer line connecting the 4.5 K refrigerator to the 10,000 liter liquid helium dewar and the 2-K cold box is being installed. Table 2 summarizes the cryogenic distribution system status.



Figure 6. Tunnel cryogenic distribution system installation

Table 2. Cryogenic distribution systems status (2017)

Transfer line (TL) section	Number of units	Status
Standard cryo-module TL sections	49	Delivered / LS1 installed
Tunnel-shaft TL's	3	Installed
TL's connecting shaft to "T" sections	3	Installed
LINAC "T" sections	3	Installed
Cold box room tunnel-shaft bayonet cans	3	In process of installation

6. Conclusions

Most of the FRIB cryogenic plant sub-systems have been installed and are in various stages of commissioning. The sub-system design, fabrication, acquisition, and installation followed closely to the initial plan and schedule. It is anticipated to commission the 4.5 K refrigerator by the end of 2017 and have the 2 K cold box operational in 2018.

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