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ruber@physics.uu.se

FREIA: Facility for Research Instrumentation and Accelerator Development

Roger Ruber, Volker Ziemann and Tord Ekelöf

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Abstract

Advanced research in fundamental physics and material science often requires high electro-magnetic fields generated with the help of superconducting devices. These superconducting devices require in return a sophisticated facility for their proper operation. We propose to construct FREIA: the Facility for Research Instrumentation and Accelerator development.

FREIA is to be located at the Uppsala University Ångström laboratory and equiped with the infrastructure required to accomodate research with high electro-magnetic fields. FREIA provides a unique opportunity for the university to acquire first hand access to an internationally competitive infrastructure with a huge potential for multi-diciplinary research. The facility needs a large capacity helium liquefier, cryostats for the superconducting devices as well as power supplies to drive the superconducting devices. This memo describes the concepts of the facility.

1 Introduction

Uppsala University intends to construct a large scale research facility, called FREIA, for research and development of accelerators and instrumentation. FREIA would be build-up in stages, starting with a helium cooling facility and a RF development facility for accelerator research. The helium cooling facility will be used to supply liquid helium to FREIA's users as well as external users at different locations inside the university.

The RF facility is intended for research and development of radio frequency (RF) power generation, distribution and control systems for superconducting accelerators. In particular for the design of the 704 MHz RF system for the proton linear accelerator (linac) of the European Spallation Source (ESS) to be constructed in Lund.

An important function of the helium cooling facility will be to continue reliable liquid helium delivery to external users. They use the helium, among others, for cooling of superconducting high field magnets and studies of materials under extreme conditions.

2 FREIA Helium Cooling Facility

The main parts of the facility include a

- helium liquefier (>170 l/h at 4 K),
- liquid helium distribution box and storage dewar (2000 l),
- 2 K cold box,
- impure helium gas recovery system.

The proposed layout of the facility is shown in figure 1. The helium liquefier plant provides a 2-phase mixture of gas liquid helium at 4.4 K, 1.3 bar at the output of its cold box. The temperature of the liquid helium can be decreased additionally in the 2 K cold box to a 2-phase flow of 2 K helium that is delivered to a small dewar inside the test cryostat. A sub-atmospheric pumping system is used to decrease the helium pressure to 31 mbar as required to keep the liquid bath temperature at 2 K.

The commercial helium liquefier plant consists of a 4 K cold box, a helium compressor (13 bar) as well as helium gas storage tanks, in volume equivalent to the 2000 l of liquid helium storage in the distribution box. An oil removal system to clean the helium gas leaving the compressor, a high pressure gas distribution panel and automatic control system are included but not shown in figure 1. In addition a liquid nitrogen storage tank and distribution system is required for pre-cooling of the 4 K cold box in order to reach maximum liquefaction capacity.

An intermediate helium distribution box provides liquid helium storage as well as the possibility to provide both the test cryostat as other users with liquid helium. This ensured upgrade possibilities to add other test cryostats as well as the delivery of liquid helium to external users through a dewar filling station. A 4 K liquid helium pot is included in the distribution box as a buffer supply of liquid helium when the required liquid helium flow exceeds the flow directly from the liquefier. This makes it possible to run experiments in the test cryostat with a required cooling power exceeding the liquefier power, as well as enhancing the filling speed for dewars.

The liquid helium used by external users returns as impure gas through the helium recovery system. We foresee that the experiments of all main external users are connected to this recovery system in order to recycle the helium and minimize losses. The recovery system consists of an ambient heater for cold gas recovered from the users, a low pressure gas bag and a small compressor. In addition a gas purifier is required to ensure removal of all contamination from the recovered helium gas. The same gas purifier system is also used during start-up of the helium liquefier plant to clean the helium gas inside the closed cycle of liquefier and test cryostat.

The helium cooling facility capacity is designed to provide 30 W cooling power at 2 K to the test device in the cryostat. The 2 K flow is created in the so-called 2 K cold box, connected to the output of the helium liquefier's 4 K cold box. The 2 K cold box can be integrated with the 4 K distribution box. To provide 30 W cooling power requires a 1.5 g/s 2 K liquid helium flow. Including losses and accounting for gas helium in the 2-phase flow, this requires a 2.5 times larger 2-phase flow from the 2 K cold box and a 1.5 times larger

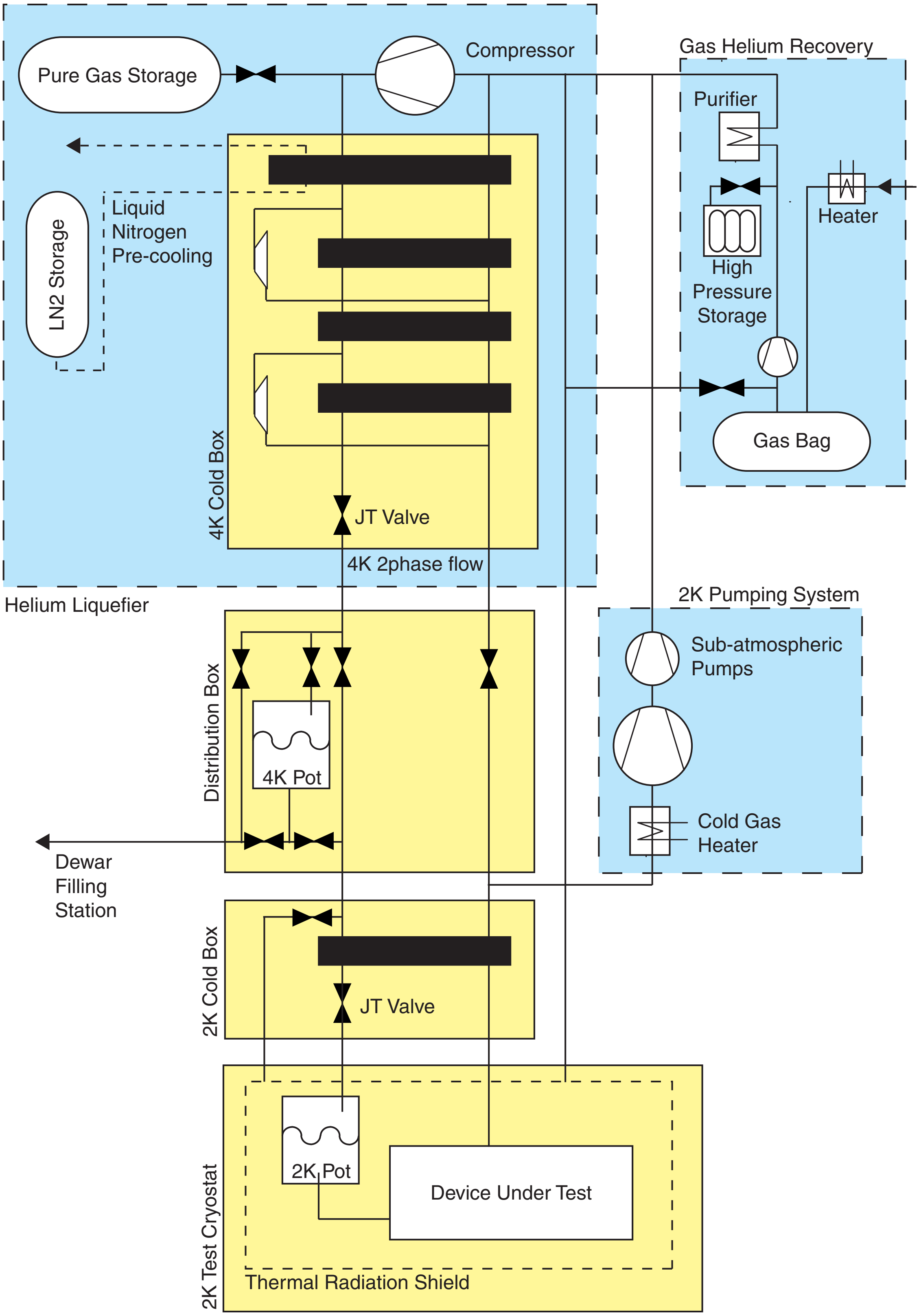

Figure 1: Layout of the helium cooling facility including a 2 K test cryostat.

2-phase flow from the 4 K liquefier cold box [1]. The required liquefier capacity is therefore 5.6 g/s at 4.4 K which is equivalent to 170 l/h.

Currently the university has at its disposal an old helium liquefier plant from 1989 with a capacity of 10 l/h and an annual production around 15,000 l liquid helium. A replacement of this plant is urgently needed to secure the supply of current and future needs of liquid helium at the university [2].

3 FREIA Test Cryostat Facility

The main part of the facility is a

- horizontal test cryostat for devices cooled to 2 K (effective device volume: 3.5 m length $\times$ 1.1 m diameter).

Initially the test cryostat facility will contain a single 2 K type cryostat with a horizontal vacuum tank. The cryostat will have a direct connection to the helium cooling facility and a vacuum pumping system. The facility will be designed such that other cryostats, with either horizontal or vertical vacuum tanks, can be added later on.

The design of the initial test cryostat will, with small improvements, be adopted from the BESSY HoBiCaT facility which can be cooled down to 1.8–2.2 K or 4.2 K. The HoBiCaT cryostat is shown in figure 2 [3]. Doors at both ends of the cryostat's vacuum tank allow easy

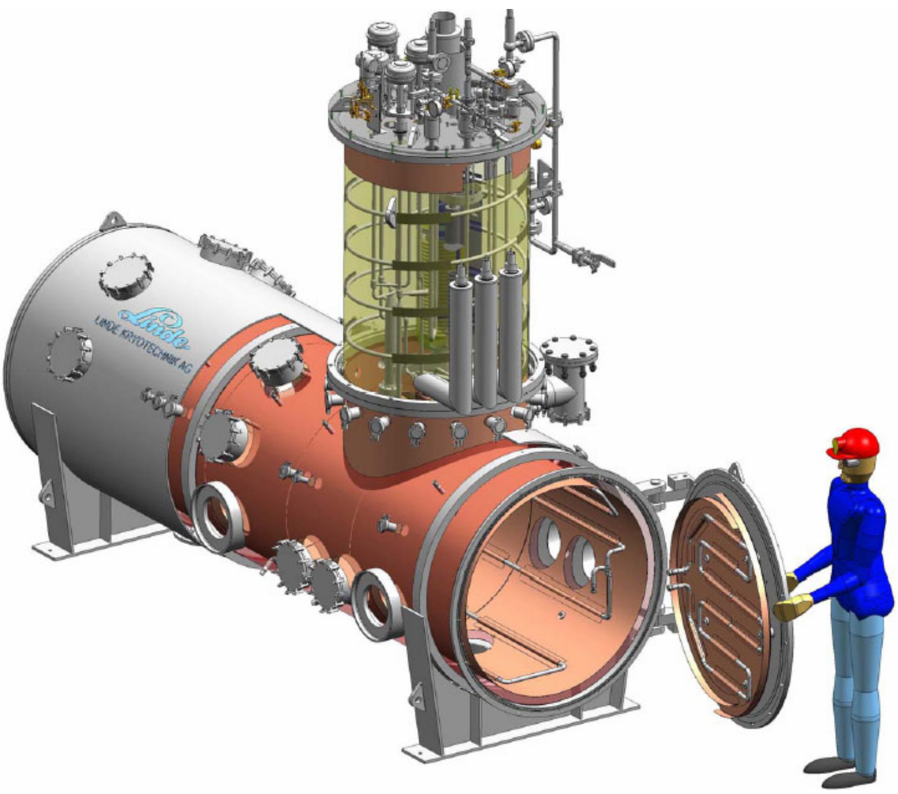

Figure 2: Layout of the HoBiCaT cryostat. The vertical feedbox includes a liquid helium reservoir and 2 K cold box.

access to the interior volume of 1.1 m diameter by 3.5 m length. This is sufficiently large to accommodate superconducting RF cavities in the frequency range 500 MHz and upwards, like two 1 m long 5 cell 704 MHz ESS/CERN SPL cavities or two 1 m long 9 cell 1300 MHz DESY TESLA/XFEL (ILC) type cavities. The cavities slide into the cryostat on a rolling table. Power couplers can penetrate the vacuum vessel through feedthroughs on the side. Diagnostic ports are provided for additional instrumentation.

The HoBiCaT cryostat design has an integrated 4.2 K 50 l liquid helium storage tank and a 2 K cold box in the top cryogenic feedbox. The thermal radiation shield is cooled by liquid nitrogen. The design of the integrated cryogenics and the cavity cooling scheme is shown in figure 3. For the FREIA facility the thermal radiation shield cooling could be done with cold helium gas from the liquefier cold box. In view of future upgrading of the FREIA facility with multiple 2 K test cryostats there is an investment advantage to keep the 2 K cold box separated from the test cryostat in order not to duplicate this part.

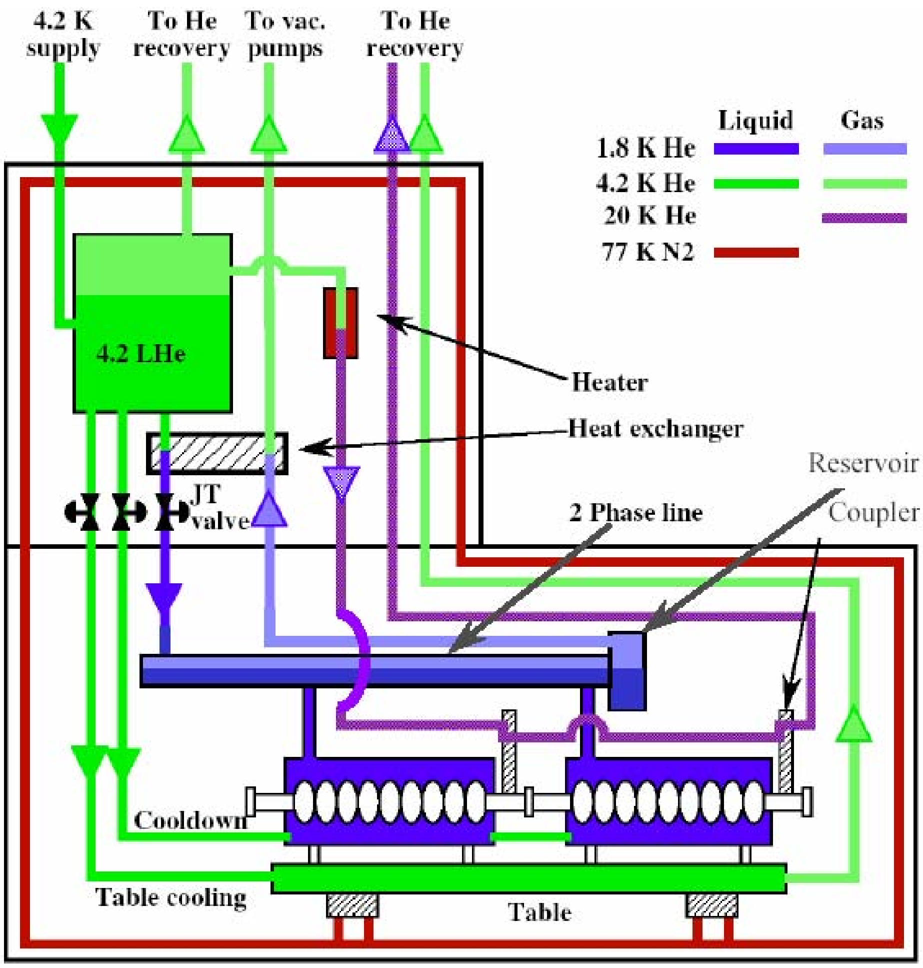

Figure 3: Layout of the HoBiCaT cryogenics. The vertical feedbox includes a liquid helium reservoir and 2 K cold box.

4 FREIA RF Test Facility

The main parts of the facility include a

- pulsed high voltage modulator power converter (140 kV, 50 A, 3 ms, 50 Hz),
- klystron high power microwave amplifier (704 MHz, 3.5 MW, 2.6 ms, 50 Hz),
- high power microwave distribution system to connect to two superconducting RF cavities inside test cryostat,
- two superconducting 5 cell 704 MHz elliptical accelerating cavities (cooled at 2 K), including mechanical tuner and input power coupler,
- low power microwave generation and control system (low level RF or LLRF).

The proposed layout of the facility is shown in figure 4. The high power RF generation part consists of the high voltage modulator (M) and a klystron (K) type microwave amplifier. The high power RF distribution part connects the RF power generator to two cavities installed in the horizontal test cryostat belonging to the helium cooling facility described in section 2. The LLRF system generates the low power RF signal to be amplified in the klystron and adjusts the individual amplitude and phase to the two RF cavities by means of the intermediate fast vector modulators in the RF distribution system. The LLRF also measures

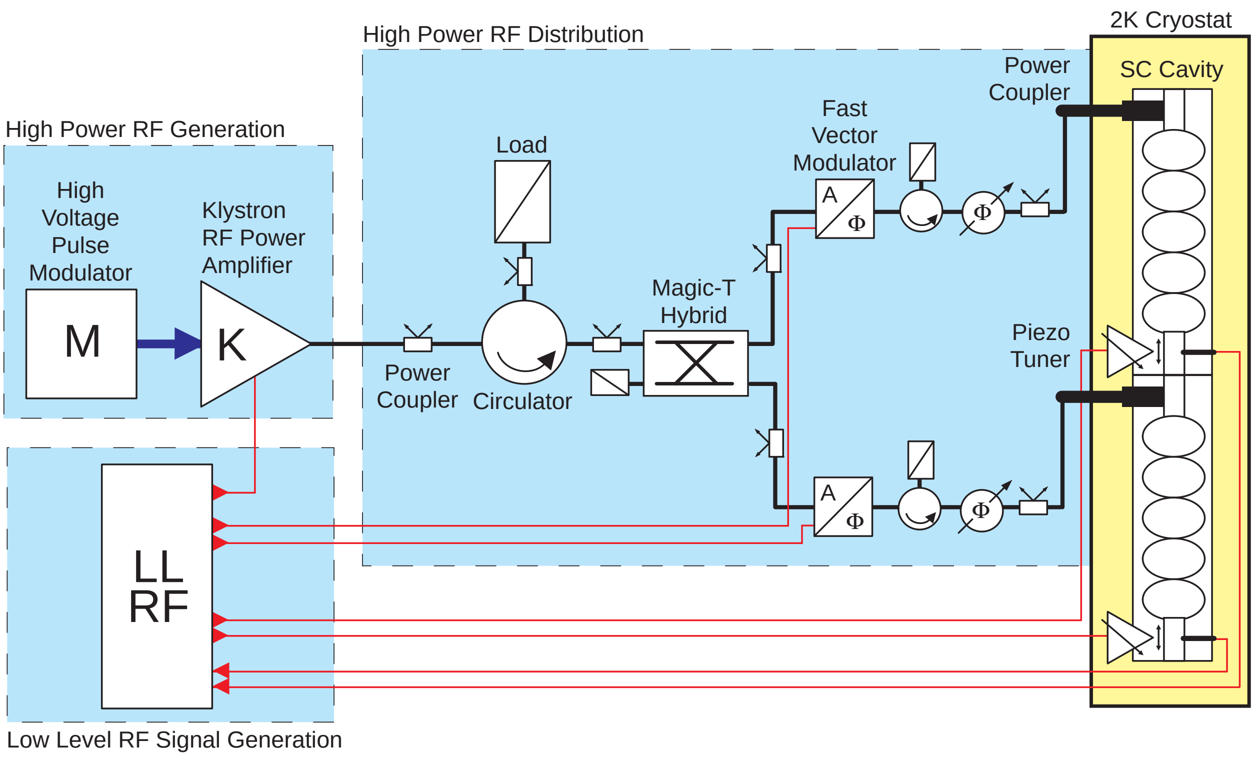

Figure 4: Configuration option of the RF test facility in which the two waveguide lines after the hybrid splitter are connected by vector modulators to superconducting cavities.

the field in the cavities and tunes the cavity frequency to adjust for so-called Lorenz force detuning caused when the high power RF pulse starts filling the cavity volume.

This creates a multi-functional test facility focused on the development of high power RF generation and control as well as a multiple cavities per klystron concept in which at least two cavities are powered by a single klystron. The test facility enables a reliable development of all RF system components and the multiple cavities per klystron concept as all components and the complete system are tested in a realistic environment.

The facility can be used for

- development and test of low level RF signal generation and control system for accelerators. Part of the ESS and CERN-SPL proton linac RF development.

- development and test of input power coupler and higher order mode damping for accelerating cavities. Part of the ESS and CERN-SPL proton linac RF development.

- development and test of fast high power RF vector modulators for RF power distribution. Part of the ESS and CERN-SPL proton linac RF development.

- RF breakdown, dark current and ion emission studies. These studies are of importance to understand the limitations of the accelerating gradient that can be reached in superconducting and normal conducting cavities.

- development and test of parts of the RF system for a future FEL at Uppsala University, or for the European XFEL (DESY, Germany) and the International Linear Collider (ILC).

An upgrade of the helium cooling facility with a vertical cryostat will enable testing of cavities in a liquid helium bath without their individual liquid helium pot as required in a horizontal cryostat. This enables different types of tests to be performed with the cavity such as temperature mapping and RF breakdown studies. Both are important to understand the limitations in present day superconducting cavities and enhance the development of higher accelerating gradients in the cavities.

A vertical test stand can be used for

- thermometry studies of superconducting cavities. These studies are of importance to understand the limitations of the accelerating gradient that can be reached in superconducting cavities.

- RF breakdown, dark current and ion emission studies. These studies are of importance to understand the limitations of the accelerating gradient that can be reached in superconducting and normal conducting cavities.

5 External Users

The main external use of liquid helium is in the solid state and material physics divisions of the department of engineering science and the department of physics and astronomy. The liquid helium can be transported by standard distribution dewars, supplied from the helium cooling facility's dewar filling station. All equipment is connected to a helium gas recovery system.

- Solid state physics: SQUID magnetometers and superconducting magnets up to 9 T. Liquid helium is required to cool the magnets and to provide low temperatures for the experiments down to 1.8 K.
- Physisc and astronomy: The material physics group investigates temperature dependent properties of materials.
- Photochemistry and molecular science: Uses liquid helium for ESR experiments and SQUID magnetometers.
- Biochemistry and organic chemistry (BMC): Uses liquid helium for cooling of the NMR systems.
- Geology: Occasional use for material science studies under extreme pressures and temperatures.

The annual production of liquid helium tops presently around 19,000 l with an increasing trend. There are planned projects within these groups that will increase the liquid helium usage in the coming years.

6 Conclusions

FREIA will be a useful extension of existing research facilities at Uppsala University.

7 Acknowledgements

The authors are gratefull to Per Nordblad of the engineering science department regarding discussions about the present helium liquefier plant and its usage.

References

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