ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF001

REQUIREMENTS FOR THE CRYOGENIC REFRIGERATOR AND THE HE DISTRIBUTION SYSTEM FOR THE MYRRHA 100 MeV ACCELERATOR

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Abstract

MYRRHA is an ADS demonstrator for the long-lived radioactive waste transmutation. It is composed of a High Energy CW Linac Accelerator (600 MeV - 4mA) coupled to a Subcritical Reactor of 100 MW thermal power. The main challenge of the Linac is a very high reliability performance to limit stress and long restart procedures of the reactor. Within the MYRRHA project phased approach for the construction, a 100 MeV-4 mA Linac (Injector up to 17 MeV and SC Linac between 17 MeV and 100 MeV) will be constructed in the Phase 1, covering 2016-2024. The SC Linac is composed of 60 Single-Spoke SC cavities, housed in 30 cryomodules. The cavities operates at 352 MHz, in a superfluid Helium bath at 2K. This article, presents the preliminary requirements for the Linac Cryogenic System. The analysis of high thermal loads induced by the CW mode operation of cavities, leads to a Cryogenic Refrigerator with a power of 2700 W (equiv. power capacity at 4.5 K). Each cryomodule is connected through a dedicated Valve Box to the Helium transfer line running along the Linac tunnel. A description of the cryogenic system features and initial models of the tunnel and associated buildings are presented.

INTRODUCTION

The research on a European accelerator-driven system has started in 2001 with a study of an Experimental ADS (European Project PDS-XADS, 2001-2005) within the 5th Framework Program EC project. From 2005, within the FP6, two large integrated projects namely EUROPART dealing with partitioning and EUROTRANS dealing with ADS design for transmutation, the SCK•CEN (Mol, Belgium) proposes the MYRRHA [1] concept aiming to demonstrate the feasibility of large-scale transmutation. A 600 MeV, 2.4 MW cw proton linear accelerator will be coupled with a 100 MWth subcritical reactor, keff=0.95, is presented Fig.1. MYRRHA will be an important milestone on the way to an European Facility for Industrial Transmutation (EFIT). More recently, it was followed by MAX (MYRRHA Accelerator Development and Experiment, 7th Framework, 2010-2014). Presently the latest steps toward the MYRRHA design are prepared within MYRTE (MYRRHA Research Transmutation Endeavour Horizon 2020, 2015-2019).

In 2016 the SCK•CEN decided to initiate the MYRRHA Phase 1 construction (2016 – 2024), which includes a first LINAC section of 100 MeV and 4 mA continuous proton beam, with one Injector [1].

An initial prototyping period is starting on the basis of the previous Euratom R&D programmes.

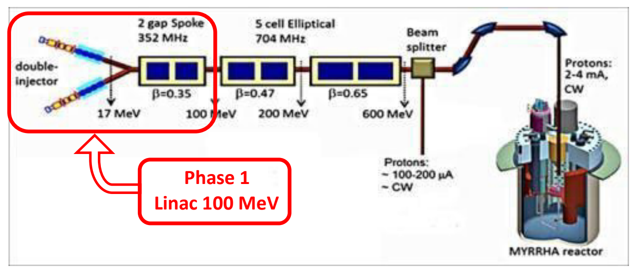

Figure 1: MYRRHA project configuration.

CRYOGENIC PARAMETERS OF THE MYRRHA SC LINAC

Spoke Cavities

The RF design was achieved following the experience feedback from previous Spoke developments [2]. RF parameters were optimized to operate the cavity at very conservative electromagnetic field (E_{peak}<40 MV/m and B_{peak}<80 mT) and to decrease manufacturing difficulties. Table 1 below summarizes the RF parameters of the cavity.

Table 1: Spoke Cavities Performances

Spoke cavity β=0.375 fo=352.2 MHz T=2 K	
Number of cavities	**60 (30 cryomodules)**
Eacc (MV/m)	**6.4**
Qo @ Eacc (minimum expected)	**2.10^9**
Pcav (W) @ 2K (including +1 W coupler RF losses)	**8.9**

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Heat Loads

Due to the beam operation in CW mode, the dynamic RF losses are largely dominant compared to other SC Linac, operating in pulsed mode with beam duty cycle of only 5 %. The evaluation of heat loads for the Spoke SC Linac is presented in Table 2.

Table 2: Spoke Linac Heat Loads

Spoke Linac 100 MeV	
Spoke cavities	**60 (grouped in 30 cryomodules)**
Heat loads @ 2 K (dynamic+static+couplers)	**960 W**
Total equivalent @ 4.5 K (cryomodules)	**2180 W**
Other Heat Loads equiv. @ 4.5 K (couplers, thermal shields)	**610 W**
Total equiv. @ 4.5 K	**~ 2800 W**

Cryogenic Temperature

An important choice is the operation temperature of the 600 MeV SC Linac. Given the RF surface losses on the high energy elliptical cavities walls, operated at 704 MHz frequency (94 cavities over a total of 154 cavities in the SC Linac), these cavities must operates at 2 K, in order to reach the accelerating fields with reasonable heat loads and RF power. The spoke cavities, working at a lower frequency (352 MHz), could eventually be operated at 4K, but a detailed analysis [3], comparing the two possibilities (2K or 4K) concluded on an overall SC Linac operation at 2K. Efficiency analysis show that the electrical power required to operate the cryogenic system was very similar for the two options. An additional advantage of operation at 2K is stability of spoke cavities operation.

CRYOGENIC REFRIGERATOR REQUIREMENTS

Cryogenic Refrigerator Capacity

The Heat Loads at various temperature levels are all expressed as an equivalent load at 4.5 K. This is roughly estimated using the Carnot coefficient at the different levels of temperature. This approach allows a simple comparison with other installations in terms of size, capital cost, and operational demand.

Following the philosophy of similar big cryogenic facilities: LHC [4] or ESS [5], considering uncertainties in the heat loads, enhancement of cool-down speed and eventual additional equipments, it is proposed to adopt an **overcapacity factor of 1.5 leading to a maximum Heat Load of 4000 W @ 4.5 K.**

The size of the cryogenic plant (electrical power needed to operate the system), can be estimated from the practical efficiencies of the main components, in particular the room-temperature compressors. This is represented by the CoP (Coefficient of Performance) which gives the refrigerator efficiency with respect to an ideal Carnot cycle. In large cryoplants the measured CoP is around 250 W/W. For the MYRRHA 100 MeV with a total Heat Load of 4000 W at 4.5 K, it corresponds to 1 MW of electrical input power (Table 3) Compared to an ideal Carnot coefficient of 65.6 W/W, it represents an efficiency of 28.5 %.

Table 3: Cryogenic Refrigeration Requirements

Cryogenic refrigerator requirements
Heat load @ 4.5 K : 4200 W (with 1.5 overcapacity factor)
Input power 300 K (CoP 250) : 1.05 MW
4.5 K Cold Box: including valves, heat exchangers and cold compressons
2K subcooling circuits (HX and JT valves) located in the Linac tunnel (Valve Box associated to each cryomodule)
3 Room Temp. Compressors (20 - 4 - 1 bar)
Gas storage : 3 x 70 m^3 (20 bar) Liquid storage : 10 m^3 (1.5 bar)

The main components of the Cryogenic systems proposed for MYRRHA 100 MeV are presented in Fig. 2:

- Liquid and Gas storage
- Room Temperature Compressors with purifiers and oil removing systems
- 4.5 K cold box, including all heat exchangers, turbine expanders and cold compressors
- Cryomodules (cavities) with associated Valve Boxes (heat exchangers and cryogenic valves)

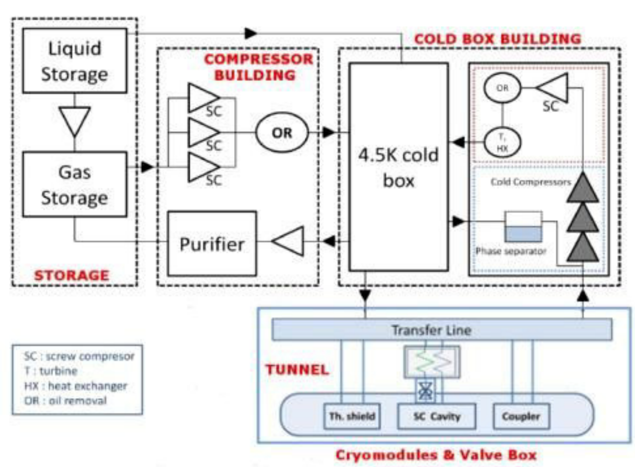

Figure 2: Cryogenic refrigerator configuration.

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This scheme is based on a "**distributed subcooling systems"** concept**.** The main cold box produces supercritical He (i.e. 4.5 – 5K, 3 bars) for cavities and couplers. Each cryomodule will be associated to a cryogenic interface (Valve Box) incorporating the subcooling heat exchanger to reduce the temperature and the Joule-Thomson valve to expand and obtain the nominal He bath at 2 K and 30 mbar.

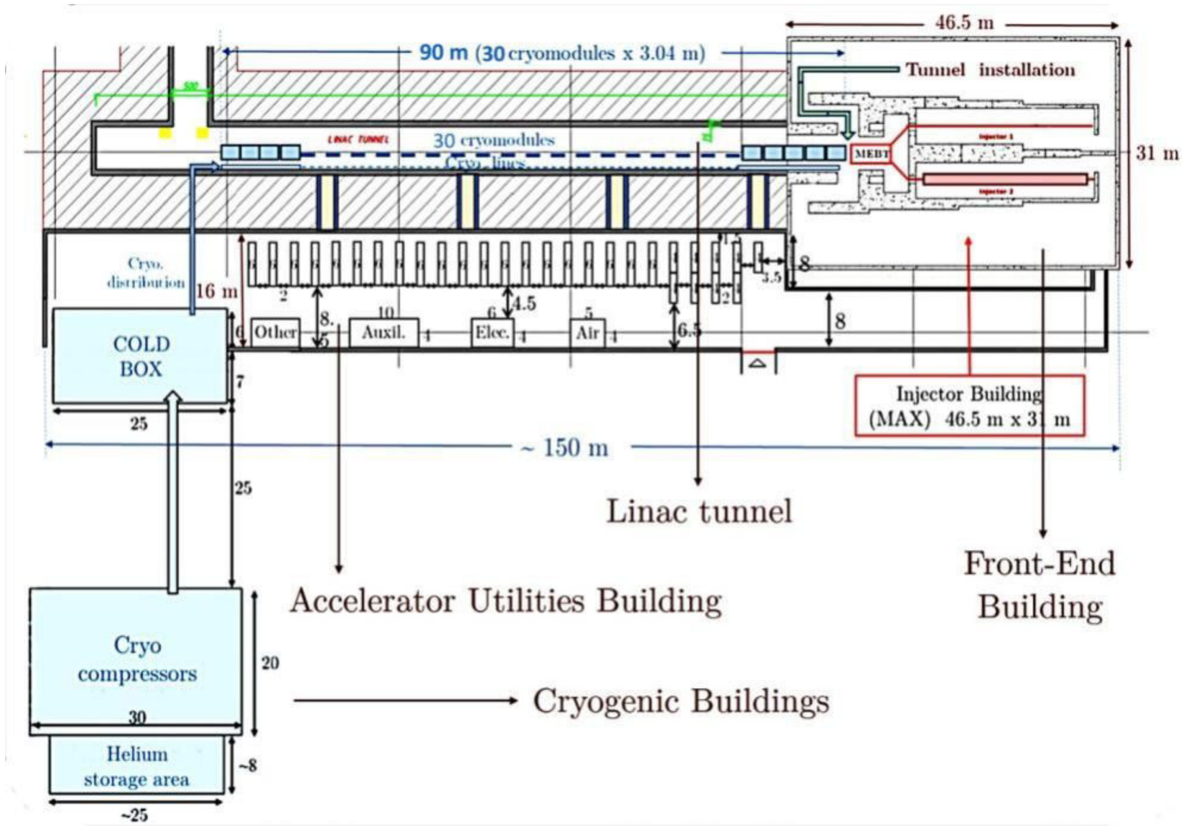

Figure 3: Myrrha 100 MeV Linac and Cryogenic Plant Buildings.

MYRRHA 100 MeV CRYO PLANT BUILDINGS

In Fig. 3 it is proposed an initial installation of the Cryogenic Plant main components. It is based on the ESS approach, with two separate buildings: 1) Room Temperature Compressors, eventually with extension for 600 MeV, and an outdoor area for gas storage, 2) Cold Box Building and connection to the Linac Tunnel (building that could be integrated or close to the RF gallery

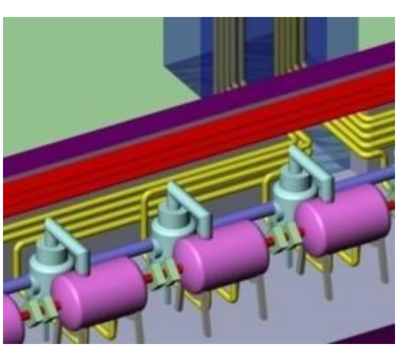

Figure 4: View of the SC Linac tunnel.

The Cold Box is connected to the Linac tunnel transfer line through a small connecting tunnel located at the 100 MeV high energy section.

An initial view of the Linac tunnel is presented in Fig.4 showing the Cryomodules and associated Valve Boxes, connected to the main cryogenic line running along the tunnel.

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