Laboratori Nazionali di Legnaro

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Preliminary Design of Vacuum System for the Fission Target EURISOL-DS

O. Alyakrinskiy, M. Barbui, Luigi B. Tecchio, M. Tonezzer
Laboratori Nazionali di Legnaro – V.le Università, 2 – 35020 Legnaro (PD) - Italy

Abstract

The preliminary design of vacuum system for the fission target option is discussed. The design is based on the reference option for fission target which includes the 4 MMW Hg neutron converter (Intermediate Solution, IS) and 8 Uranium Carbide fission targets around it to produce (in-target) more than 10^{15} f/s fission fragments. Eight independent radioactive ion beams are delivered in a direction anti-parallel to the incoming proton beam and prepared to be delivered to the users. The design of vacuum system considers different working conditions and safety requirements, in term of vacuum level, radiation resistance materials, remote handling and radioactive gas evacuation.

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Introduction

EURISOL is an accelerator-based research facility based on the ISOL (Isotope Separation On Line) technique dedicated to the production of very intense radioactive ion beams (RIB). One of the aim of the facility is to exploit an intense neutron flux to induce fission fragments in dedicated Uranium Carbide (UC) targets. Neutrons are obtained by bombarding a heavy metal (liquid mercury) converter with 1 GeV, 4 mA (4 MW) proton beam. The radioactive species coming from the targets or ion sources are ionized, extracted, and mass separated, forming high quality beams of isotopes. The isotopes can be either delivered directly to low energy experimental facilities or accelerated.

The vacuum system of the targets assembly consists of a volume containing the targets, the ion sources and the moderator. The vacuum is expected to be very contaminated by radioactive species produced in the target.

All the exhaust will be stored into a tank. In addition, to remove contaminated air a ventilation system for the target area will maintain the pressure differentials that prevent the inadvertent leakage of airborne radioactivity; nevertheless the latter is not discussed in this report.

This report covers the preliminary design of the vacuum system for the fission targets/ion sources assembly which actually is considered as the reference design.

Figures 1 and 2 show the reference set-up of the fission targets area and a cross-sectional view, respectively. A cooled stainless steel vessel houses eight UC targets and the related ion sources. The Hg converter can be inserted at the centre of the vessel and can be moved independently from this one. The vessel is evacuated through 3 vacuum channels, each of them has 200 mm diameter and 5 m long. Three 1000 l/s turbo pumps located in a shielded zone above the target area provide the evacuation of the vessel. In addition, close to the vessel three cryogenic panels of about 1m^2 each provide a good vacuum inside the vessel. The vacuum channels are characterized by a zig-zag geometry in order to minimize the activation of the pumps by neutron escaping from the target area. The vessel is used to keep the radioactive contamination in the vicinity of the targets and for preventing radioactive contamination of the different areas when the targets are moved out of the targets area for maintenance and target replacement. The vessel is sealed by UHV-valves which prevent the dissemination of radioactivity during its displacement in the hot cell.

During production the gas removed from the vacuum volume is temporarily stored in a operating storage tank which is located in a concrete bunker to reduce local radiation fields.

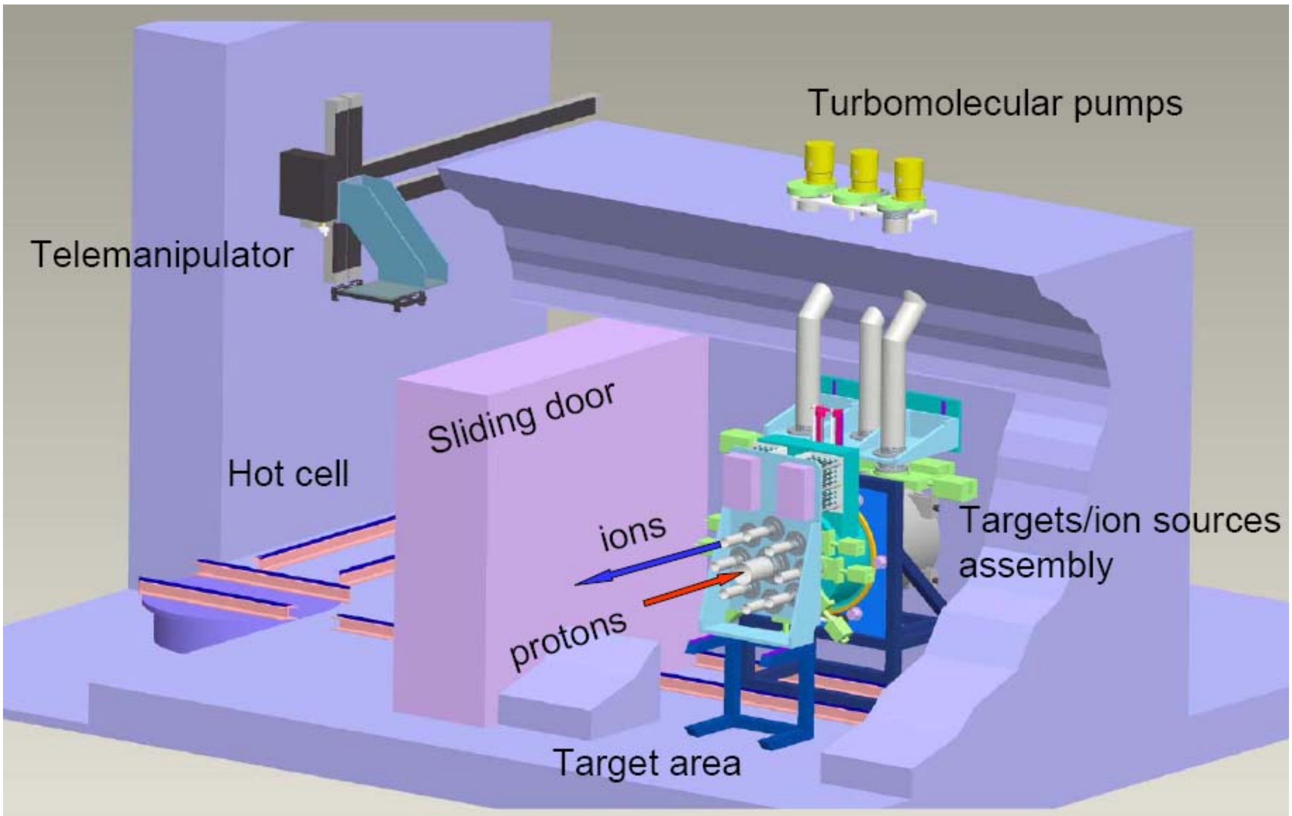


Fig. 1 – Reference set-up of the fission target for the EURISOL facility.

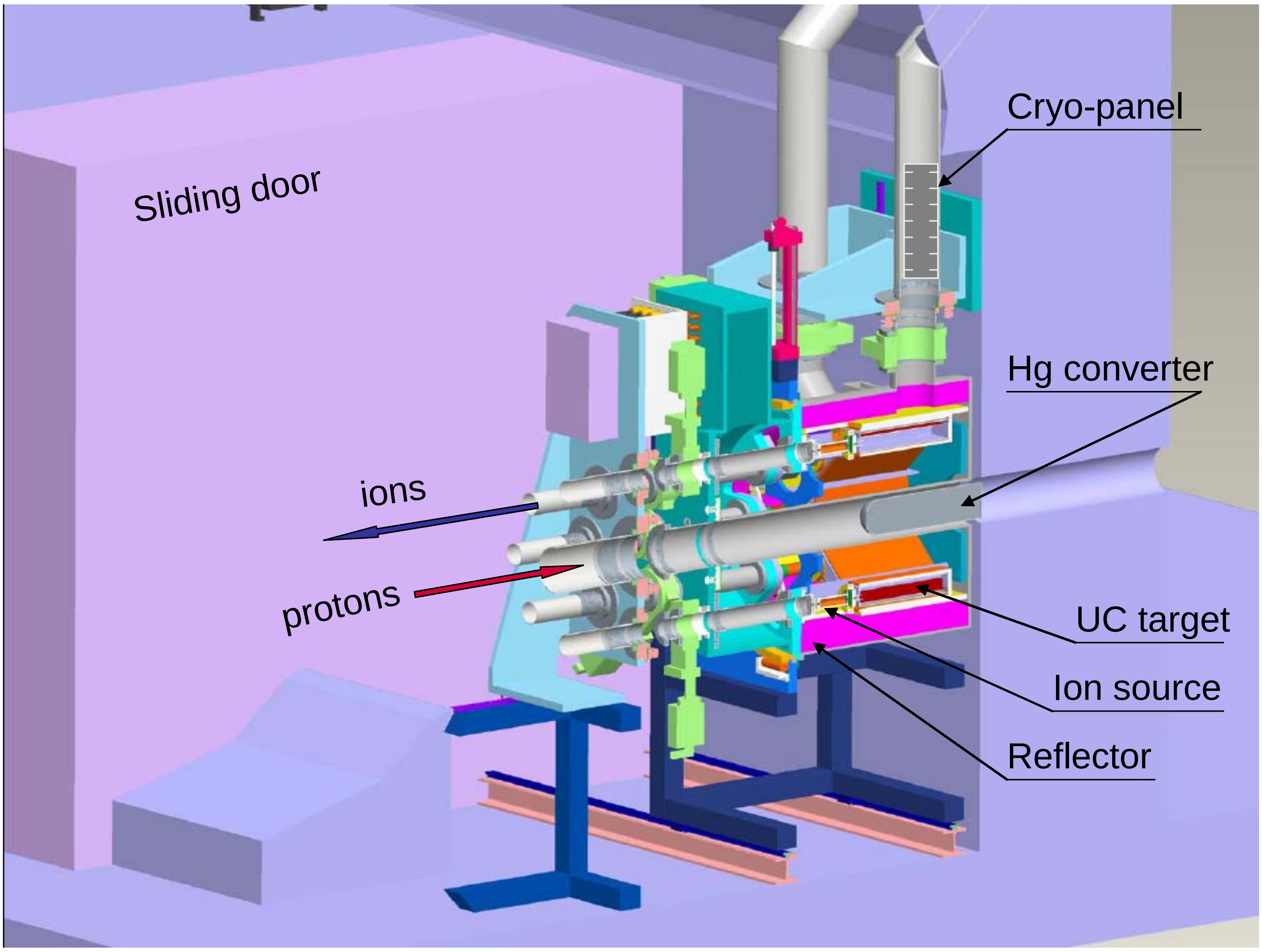


Fig. 2 – Cross-section of the reference design of the fission targets.

In according to the production schedule, gas is transferred from the operating storage tank to the decay storage tank for recycling. Gases released inside the hot cell during the maintenance of targets are also stored in the decay tank. After recycling and decay, when the radioactivity of the gas has sufficiently decreased, it is exhausted to the atmosphere through the nuclear exhaust filtering system.

Vacuum requirements

The vacuum system must ensure:

- a static barrier, with confinement under vacuum during transport of the vessel for operations inside the hot cell;
- a dynamic barrier during production;
- a vacuum level according to specifications.

The operational vacuum pressure level requirements have been analytically determined and summarized as follows:

Vessel volume	10^{-3} Pa
1+ ion beam channel	10^{-4} Pa
N+ ion beam channel	10^{-5} Pa

The availability and reliability requirements of the vacuum subsystem and their components are strictly associated with the vacuum pressure levels; this consideration implies the use of equipment and materials adapted to the radioactive environment, which are either low-maintenance or maintenance free.

The standardization of vacuum components utilized throughout the facility is envisaged because is beneficial from multiple perspectives (less number of spare parts, reduced costs, less training associated with servicing multiple unique types,….).

To protect equipment during operation, the pump units are located in a dedicated shielded area. This particular configuration involves a severe reduction of the pumping speed in the vessel volume. In order to obtain the minimum vacuum level in the target/ion source (TIS) in the range of 10^{-4} Pa, the total gas flow in this part should not exceed 5 x 10^{-4} Pa m^3 s^{-1}. This imply a good evaluation of the gas loading emanating from outgassing TIS components in this particular environment.

The subsystems design basis shall have a performance margin of 2, i.e. failure of any single pumping element may degrade the subsystem pressure level, but will not reduce it below the levels where the target operation are compromised. This fact implies that material yield strength shall be used for mechanical structural integrity.

The choice of material can greatly affect the performance of the vacuum and therefore material selection shall be an integral part of the vacuum standardization process. The principal factors which have to be considered when selecting a material for use in a vacuum environment are listed in the follow:

- to be sufficiently impermeable to gases;
- have low vapour pressures;
- be able to withstand baking temperatures without losing their mechanical strength or being chemically or physically damaged;
- not transmute from an apparently acceptable material to an unacceptable one due to the working conditions (i.e. radiation exposures, vacuum exposures, thermal treatments)
- not react adversely with other materials resulting in outgassing.

In the follow a preliminarily list of materials conform to the material standards and specifications acceptable for the EURISOL vacuum use is given. The resistance to radiation of such a materials is only in principle settled but a more detailed investigation on the subject is required.

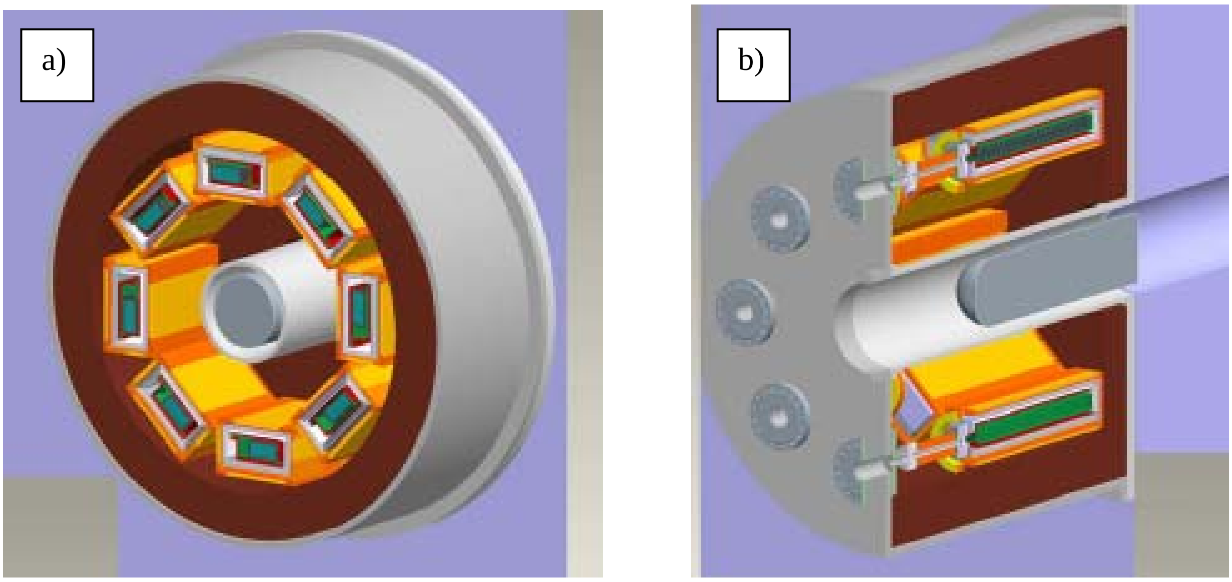
List of materials

- stainless steels – types 316, 316L, 316LN, 304, 304L, 304LN
- Molybdenum
- Tantalum
- Tungsten
- Titanium
- Copper –OFHC
- Copper alloys (CuCrZr)
- Aluminum
- Nickel and alloys
- Alumina ceramic
- Beryllium oxide
- Boron nitrite
- Titanium nitrite
- Graphite (reactor grade, high density, pyrolitic)

The processes utilized in manufacturing vacuum components have a greatest influence on its vacuum performance as regards to outgassing, leaks, etc. For that reason some standard manufacturing processes, mainly regarding the materials machining, joining (welded of brazed joints), finishing and cleaning, should be defined.

Fission targets vacuum system

The EURISOL fission targets are located in the target area, housed in the vacuum vessel and distributed around the Hg neutron converter, as shown in Figs. 1 and 2. The target assembly consists of eight independent modules coupled with its own ion source, see Fig. 3.



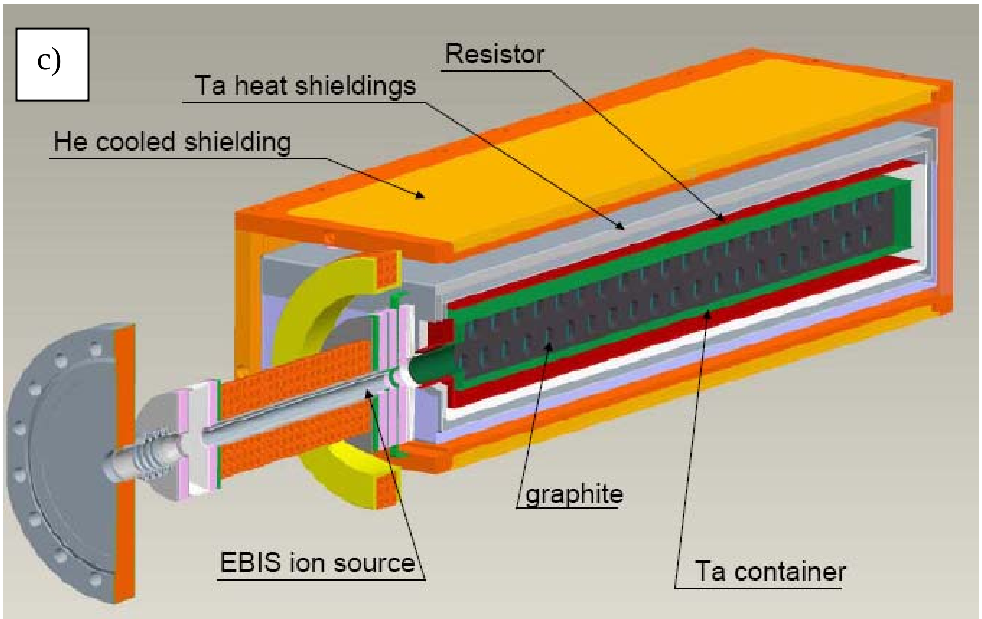


Fig. 3- Layout of the target/ion source assembly: a) transversal cut view of the fission target set-up; b) longitudinal cut view of the fission target set up; c) cut view of a single fission target/ion source assembly.

The vessel is made of stainless steel AISI 304 and has a volume of 0.95 m^3, developing a surface of about 6 m^2. The vessel is cooled down by He flux and operates at room temperatures.

Each fission target consists of 2.5 kg of Uranium Carbide (density 3 gcm^{-3}) distributed on 30 layers (1 x 70 x 400 mm). The UC is firstly encapsulated in a graphite container (2 mm thick) and secondly in a tantalum container of 0.5 mm thickness. During operation the target is keep to a constant temperature of 2000 °C. A tantalum heater is used to heat up the target for outgassing process, and to reach a constant temperature distribution along the target it self. Three tantalum layers (50 μm each) play the role of thermal shielding. An external He cooled panel helps to dissipate the thermal power from the target.

Each target is coupled with an ionizing ion source that can be of different type (surface ionizing, RILIS, EBIS, plasma,…) depending of ion beam requirements. In Fig. 3 the coupling with the EBIS ion source is shown. The vacuum level inside the ion source influences greatly the efficiency of the different typologies of ion sources. In particular, while standard FEBIAD and ECRIS operate efficiently up to 10^{-1} Pa l s^{-1} with extracted beam of few mA, Resonant-Ion Laser Ion Source (RILIS) can operate in relative bad vacuum level (> 1 x 10^2 Pa): however, the main disadvantage of the RILIS is that only about 80% of the ion species can be ionized.

Both target and ion source assemblies are electrically insulated from the ground potential (the vessel) and operate at 60 kV.

The vacuum vessel is pumped through vacuum pipes (ϕ = 200 mm) and the targets/ion sources are also pumped through the ion beam lines (ϕ = 150 mm). In this context the vacuum system is divided in two sub-systems: 1) the vessel vacuum and 2) the target/ion source vacuum. The second one is the most critical because has to provide evacuation of the majority of radioactivity.

The volume of the vessel is about 0.9 m^3, is made in stainless steel (double walls) and operates at room temperature (cooled vessel). The vessel develops a surface of about 7 m^2 and the outgassing from that surface produces a gas load of 1.4 x 10^{-1} Pa l/s. Internally to the vessel is housed a graphite reflector to thermalize fast neutrons coming from the MMW converter. The reflector temperature is close to the room temperature and its influence on vacuum level is irrelevant respect to the contribution of other materials; i.e. stainless steel and/or tantalum.

The volume occupied by each fission target and ion source assembly is of about 1.5 litres (totally 12 litres). The targets are operated at 2000 °C; the main source of outgassing is represented by the UC and by the fission fragments diffused from the target it self (10^{15} fission per second). The gas load from each UC target is of the order of 10^{-1} Pa l/s and is pumped separately from the ion extraction beam pipe.

Furthermore, to limit the increase of desorption rate due to radiation (i.e. gamma rays) all the materials employed on the construction must be cleaned and treated with specific procedures for ultra high vacuum applications.

To prevent a release of radioactive gases, the outlets of the rough vacuum pumps are sealed and the exhaust of the pumps is guided to a system for gases recovering. During the operation the gas removed from the fission target volume is temporarily stored in 2 tanks located in a concrete bunker to reduce local radiation fields. In according with the beam production schedule, gas is transferred from these storage tanks to the decay storage tank. After decay, when the radioactivity of the gas is below the value fixed by the safety rules, it is exhausted to the atmosphere through the nuclear exhaust filtering system.

For the initial pump down of the vessel volume a roughing pump with pumping speed of about 30 m^3/h is used. The ion beam lines are initially pumped with a pumping speed of 10 m^3/h for each channel. Subsequently, turbo pumps are used, both for the vessel and target/ion source vacuum.

The final pressure in the vacuum system is calculated from the effective pumping speed of the pumps and the leakage and the desorption rate. The vessel is pumped by 3 turbo pumps 500 l/s each located at 5 m from the vessel it self. With a tube diameter of 20 cm the conductance of the tube is 194 l/s. The effective pumping speed is reduced to about 140 l/s each channel. Being the vessel pumped through 3 channels the effective pumping speed is 420 l/s. To increase the pumping speed cryogenic pumps are required to pumps the channel in the vicinity of the vessel. The pumping speed of the cryogenic surface of 1 m^2 is of 10^5 l/s. With three cryogenic pumps at 1 m from the vessel the effective pumping speed down to about 3000 l/s, resulting in a final vacuum inside the vessel of about 5×10^{-5} Pa.

Analogue situation concerns the target/ion source system. The evaluation is done for a single beam line. Because of radiation flux the turbo pumps have to be located inside a heavy shielded area at least 5 m far from the gas source. With a tube diameter of 150 mm the conductance of the tube is 80 l/s. Thus the pumping speed of a 500 l/s turbo pump is reduced to 70 l/s. By using a cryogenic pump in the vicinity of the target/ion source assembly the pumping speed can be increased up to 410 l/s. The final vacuum inside the system can be estimated to be about 5×10^{-4} Pa.

The schematic layout of the Fission Target Vacuum System (FTVS) is shown in Fig. 4. Hermetic rotary vane pumps with high level of tightness against leaks of pumped gas are used for rough evacuation of the target vessel and ion beam lines connected to the targets. The pumps exhaust into two evacuated storage tanks which transfer the radioactive gas out of the fission target station.

Eleven 500 l/s turbo pumps (3 on the vessel and 8 on the ion beam lines) provide vacuum in the fission target station. All turbo pumps servicing the target station are air cooled. On each turbo pump two valves are installed, one of the valves remaining attached to the pump and the other attached to the line.

Each vacuum line is equipped with a cryogenic pump which guarantees the required vacuum level in the line. Cryogenic panels are installed on the vacuum lines in the vicinity of vessel and of the exit from the ion sources. The panels are kept at a temperature of 20 K. At this temperature the vapour pressure of volatile radioactive elements is low enough to confine the radioactivity on the cold surfaces of the cryogenic pumps.

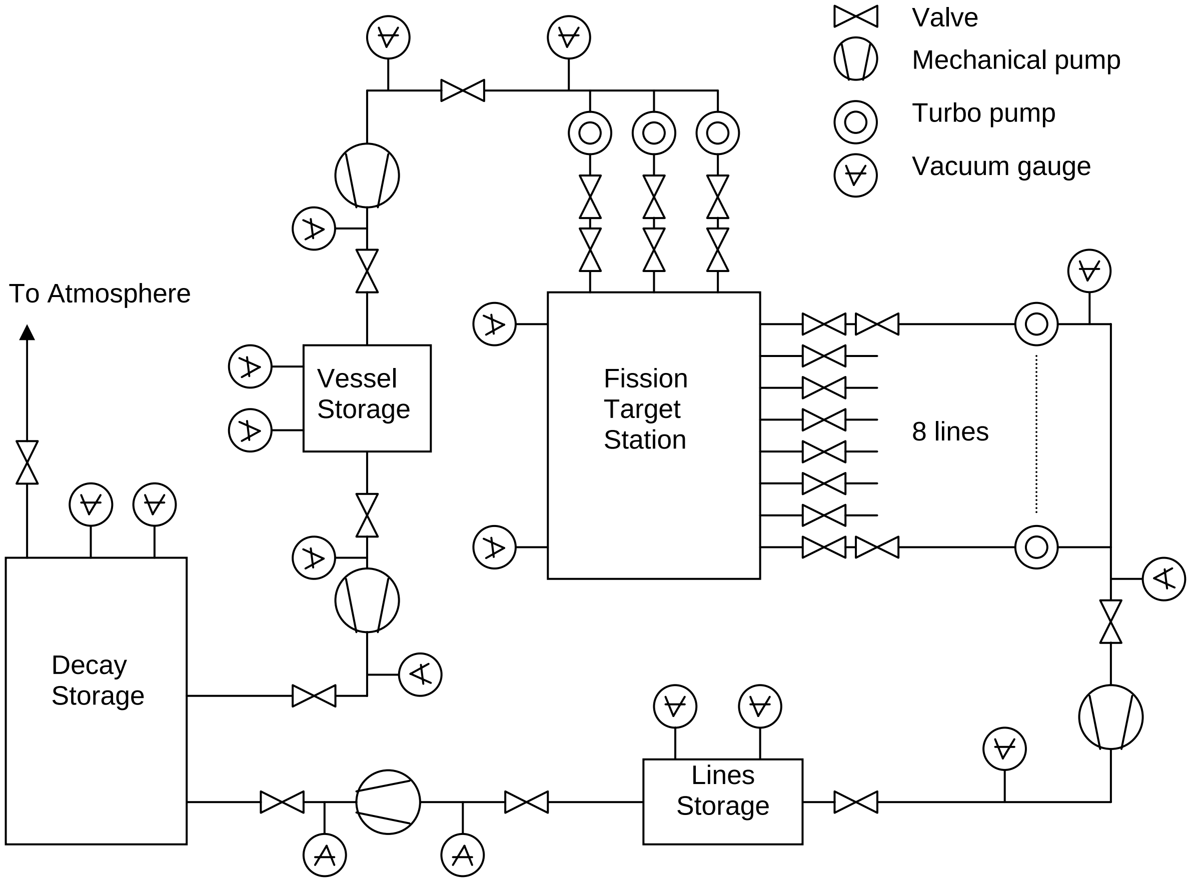


Fig. 4 – Schematic layout of the fission target vacuum system.

The low vacuum levels (from 2 x 10^2 to 10^{-2} Pa) are measured using Pirani type thermal conductivity gauges. Also conventional convectron gauges and diaphragm manometers may be used for monitoring the pressure in the fission target station and storage tanks. The high vacuum level (from 10^{-1} to 10^{-6} Pa) is measured using cold cathode type ionizing gauges; the vacuum gauging is necessary for both monitoring and safety interlocks.

The controls of the fission target station vacuum equipment are done via PLC based on the standard EPICS (Experimental Physics and Industrial Control System) protocol.

Vacuum components

To profit of practical benefit all the vacuum components are subject to standardization unless specific requirements exist necessitating customized applications.

Pumps. The roughing pumps shall be dry pumps, meaning oiless bearing configuration, and shall have a high level of tightness against leaks.
The turbo pumps shall be also dry and shall be capable of operating from a pressure above 10^{-2} Pa pressure in the case of an emergency.

Valves. The valves employed on the fission target vacuum system are only all-metal gate seals. The valves utilizes electro-pneumatic actuation.

Gauges. The gauges used to measure the vacuum levels within the fission target and control the operation of valves and pumps consists of three principle types, thermal conductivity, ionization and partial pressure. All gauges shall be non-particulate generating when operating.

Flanges. Because subject to elevated radiation and/or temperature levels all vacuum flanges shall be constructed of stainless steel and designed for metal seal application. The flanges located inside the fission target area are quick disconnected flanges and use a smooth compression sealing configuration.

Seals. Metal seals shall be utilized in areas subject to elevated radiation level and temperatures. Metal seals shall be constructed of Oxygen Free High Conductivity (OHFC) copper or aluminium. All seals are single application only.

Bellows. All bellows utilized in the fission target area where the radiation field is very high shall be constructed of Inconel. Both forming or welded construction are acceptable.

References

A. Roth; Vacuum Technology, North Holland 1986.

A. Blin; La Recuperation et Stockage des Gaz, CERN 1996.

S. Meunier ; Système de Recuperation et de Stockage des Gaz a ISOLDE, Vacuum Technical Note 03-11, June 2003.

MAFF : Physics Case and Technical Description, http://www.ha.physik.uni-muenchen.de.

D. Yosifov and I. Sekachev; J. Vac. Sci. Technol. A 24(4) (2006) 1601.

D. Hucknall; Vacuum Technology and Applications, Butterworth-Heinmann, Oxford, 1991.

A. Chambers, R.K. Fitch, B.S. Halliday; Basic Vacuum Technology, Adam Hilger, Bristol and New York, 1989.

C.B. Alcock, V.P. Itkin and M.K. Horrigan; Canadian Metallurgical Quarterly 23 (1984) 309.

J. Haines; Graphite / Carbon – Carbon Composite target R & D, Neutrino Factory and Muon Collider Collaboration Targetry R & D Meeting, Dec. 15, 2000, Brookhaven National Laboratory, Tandem Library, Bldg 901A.

J. C. Putaux et al. ; Graphite Target for the SPIRAL Project, Nuclear Instruments and Methods in Physics Research B 126 (1997) 113-116.

F. Pellemoine; APD – SPIRAL II – The Thermal Studies for the Carbon Converter, Rapport GANIL_SST_220.

G.D. Alton, J.R. Beene, Y. Liu, Nucl. Instrum. And Meth. In Phys. Res. A 438 (1999) 190-209.