A windowless supersonic gas jet target for basic research and applications at the Cyclotron Institute

M.R.D. Rodrigues[1] and A. Bonasera[1,2]
[1]*Cyclotron Institute, Texas A&M University, College Station, Texas*,
[2]*Laboratori Nazionali del Sud, INFN, Italy.*

The goal of the present project is to develop a portable supersonic gas jet target with cooling system. The target will be applied for Nuclear Physics studies at Cyclotron Institute and for plasma-laser experiments. The gas target system will be composed of a gas pulse valve, a nozzle, a skimmer and a catcher, with two differential pumping stages in a flow-through design feed from a compressed gas bottle. The valve will be cooled with a cooper jacket and the temperature will be controlled.

The target will be used in the development of research by our group: Medical radioisotope production using inverse kinematics, alpha cluster phenomenon on light and medium nuclei and plasma studies. The Medical radioisotope production using inverse kinematics research line pursues the investigation of an alternative production method for important isotopes for nuclear medicine in high demand worldwide, where the production in reactors are not enough to supply the demand. The production test of the radionuclide ^{67}Cu ($t_{1/2}$ =62h) with a beam of ^{70}Zn at 15MeV/nucleon produced by the K500 superconducting cyclotron on a hydrogen cell-target was already performed with success [1]. The well-known ^{99}Mo/^{99m}Tc generator system [2] was recently tested with a beam of ^{100}Mo at 12 MeV/nucleon on ^{4}He gas cell-target. In the short term, the next candidates for these studies are ^{47}Sc production, ^{44}Ca+ $\alpha \rightarrow {}^{47}$Sc + p, and an alternative production of ^{67}Cu, ^{70}Zn+d $\rightarrow {}^{67}$Cu + α + n. Note that, in the present experimental set-up the main source of radio impurities came from the interactions with the gas-cell windows. The implementation of a windowless supersonic gas jet target would improve considerably this problem besides the advantage of the high-density gas important for low cross section measurements.

Another project is the study of the experimental evolution of the a -cluster phenomenon on light and medium mass nuclei through (^{6}Li,d) transfer reactions. Data of the ^{12,13}C(^{6}Li,d)^{16,17}O [3] and ^{9}Be(^{6}Li,d) ^{13}C reactions were measured in São Paulo. The a -d angular correlations applied to the reaction ^{12}C(^{6}Li,d)^{16}O $\rightarrow \alpha + {}^{12}$C with $q_d = 0^o$ were performed at the Tandem- MAGNEX Large-Acceptance Spectrometer facility at LNS, INFN, Catania, Italy. The proposal is to perform measurements at TAMU using MDM spectrometer in inverse kinematics with the supersonic gas jet target. Applying ^{4}He and H_2 gas as target to study cluster phenomenon on light nuclei of C, O, N, F, and Ne where exist few experimental information on high exited stated near the clusters threshold.

Other studies, similar to the laser experiments at UT using the PW laser facility [4], will be performed using high intensity low energy ions from the Cyclotron ECR ion source. A systematic investigation of the beam range in a gas prepared near the critical point of the liquid-gas (LG) phase transition will be one of the applications of the gas-jet target.

In addition, the supersonic gas target can be a very important resource for the Cyclotron Institute Laboratory research program, in particular, for Astrophysics and exotic beam experiments where low background environment and high resolution are essential.

In order to have efficiency in low cross-section reactions induced by limited beam intensities and achieve high resolution measurements, the target should present: an optimized balance of target nucleus number density and thickness to maximize count rates but minimize reaction product energy loss and straggling, target size close to the beam spot and be chemically pure.

For light target isotopes, necessary in inverse kinematics, these properties are difficult to be produced. Solid targets, usually plastic thin-foils, degrades with exposure to beam and introduces unwanted contaminants. Gas targets with windows also introduces unwanted contaminations, besides the energy loss and the straggling. In addition, if the gas is static there are the degradation and the non-uniform heating due to interaction with beam. A supersonic gas jet target provides a spatially well-defined high density target using high purity gas, allowing a better efficiency production and a high resolution measurement. Other advantage of the target being well-defined spatially is the possibility of set up silicon detectors, γ-ray detectors, and heavy ion detectors to measure reaction products in the region around the jet. In addition, a cluster jet target has a high uniformity at long distance of the nozzle.

The present project has the aim to develop a supersonic gas jet target with cooling system that can be used as a supersonic gas jet target or a cluster jet target according with the experiment requirement. The portability of the gas jet target is also important in order to allow its use in different experimental lines of the Laboratory or used for plasma-laser experiments.

The main components for design a supersonic gas jet system are: the valve, the nozzle, the gas beam catcher and the vacuum pumping requirements. In particular, for experiments where cluster jet is required the cooling system is essential. In some situations, when cluster gas beams are used, the gas beam skimmer is also extremely important when low pressure is desired in the gas target chamber.

In the present project the system will use the Cryogenic Copper (Ni \Ti. Ni. plated) HRR, Even-Lavie valve [5] with the respective electronic driver. Initially the Trumpet shape, ~125μØ hole (43^{o} cone) nozzle will be tested and afterwards, different shape and diameter nozzles will be produced locally and tested. The valve will be cooled with a cooper jacket and the temperature will be measured and controlled with the 325 Temperature Controller and DT-670 Silicon Diode from Lakeshore Cryotronics together with two resistors heaters. A flow-through design will be used, where the pulse valve will be feed from a compressed gas bottle. Pressure diagnosis, needle and relieve valves will be used in the gas line for control and safety purposes. The precooled gas is expanded through the nozzle. A skimmer transfers the central part of the beam into the first differential pumping stage, a second skimmer serves as collimator which limits the divergence of the beam. The cluster beam arrives in the scattering region and afterwards the beam is absorber in the catcher in a second differentially pumped stage. The distance and shape of the skimmer and the catcher need to be tested for each experiment requirement.

[1] G.A. Souliotis, M.R.D. Rodrigues, K. Wang, V. Iacob, N. Nica, B. Roeder, G. Tabacaru, M. Yu, P. Zanotti-Fregonara, and A. Bonasera, Appl. Radiat. Isot. **149**, 89 (2019).
[2] B. Wolterbeek *et al.,* J. Radioanal. Nucl. Chem. **302**, 773 (2014).
[3] M.R.D. Rodrigues *et al.*, Phys. Rev. C **89**, 024306 (2014).
[4] G. Zhang *et al.*, Phys. Lett. A **381**, 1682 (2017).
[5] U. Even, Eur. Phys. J. TI **2**, 17 (2015).