

Opportunities for neutrino experiments at ISOLDE

Tânia Melo Mendonça^{1,2}, Rastilav Hodák³ and Thierry Stora¹

¹ CERN, 1211 Geneva 23, Switzerland

² IFIMUP and IN - Institute of Nanosciences and Nanotechnologies, Rua do Campo Alegre 687, 4169-007 Porto, Portugal

³ Department of Nuclear Physics and Biophysics, Comenius University, Mlynská dolina F1, SK-842 15 Bratislava, Slovakia

E-mail: taniamel@mail.cern.ch

Abstract. A molten salt target is currently proposed for the production of high rates of ^{18}Ne required for the beta beams project. Intermediate proton energy beams at close to 1 MW power are used on a circulating molten NaF eutectic to produce and extract 1×10^{13} $^{18}\text{Ne}/\text{s}$.

A conceptual design of such a circulating loop is presented. The application of a molten salt target for the monitoring of noble gas production is discussed with respect to the planned experimental program, which will be used to validate the proposed concept. Furthermore, a systematic experimental study on the production and release of gaseous and volatile elements from molten sodium-based targets, in preparation at CERN-ISOLDE, is presented.

1. Introduction

The beta beams concept for the production of highly energetic pure electron neutrino (ν_e) and antineutrino ($\bar{\nu}_e$) beams coming from the β decay of radioactive ions was first proposed in 2002 [1]. Such concept would allow the measurement of ν_e to ν_μ oscillation with exceptional sensitivity for the determination of the θ_{13} mixing angle and CP-violating phase. This type of facility could be advantageously located at CERN making use of the PS and SPS to accelerate the radioactive ions, allowing the production of neutrino beams from their β decay in a dedicated ring with straight sections directed towards an underground detector [1, 2]. Fig. 1 shows the proposed beta beam baseline to be implemented at CERN.

The feasibility of the beta beams has been studied within the EURISOL-DS project, where the production of ^6He and ^{18}Ne was investigated [3]. Both radioisotopes, otherwise known as baseline isotopes, can in principle be produced in large quantities and do not have any long-lived daughter products. A top-down approach showed the need for production of about 6×10^{13} ^6He and 1×10^{13} ^{18}Ne ions per second which would lead to rates of 2.9×10^{19} $\bar{\nu}_e$ and 1.1×10^{19} ν_e over a running period of 2 and 8 years, respectively [3].

As presented in fig. 1, different production schemes are proposed depending on the ion type. The production of ^6He has been successfully validated using the isotope separation online (ISOL) method [4]. ^6He ions have been obtained with fast neutrons, produced with a compact tungsten converter, on a thick beryllium oxide target [3] through the $^9\text{Be}(n, \alpha)^6\text{He}$ reaction. Online tests performed at CERN-ISOLDE showed that this figure validated the production of 10^{14} $^6\text{He}/\text{s}$ with 100 μA , 2 GeV protons and an optimized geometry [6].

The production of the required 10^{13} $^{18}\text{Ne}/\text{s}$ was found to be more problematic. A first approach investigated the reaction of 1 GeV proton beam onto oxide targets, alike the standard

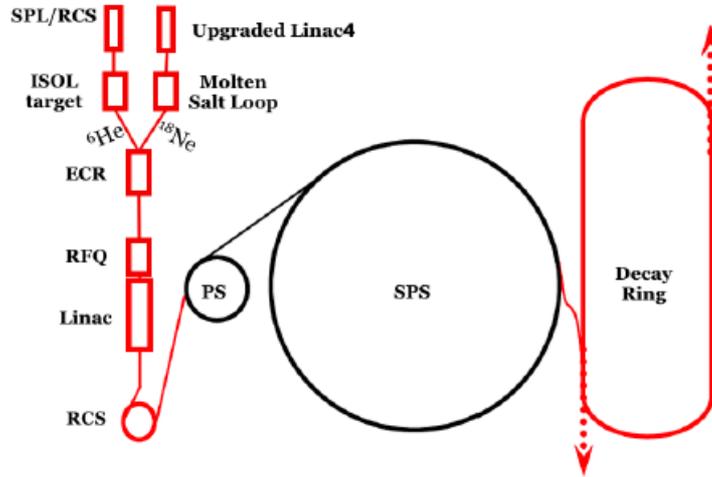


Figure 1. Proposed beta beam baseline implementation at CERN for the production of ${}^6\text{He}$ and ${}^{18}\text{Ne}$ ions.

procedure at CERN-ISOLDE, and kW beam power [5]. The production cross-sections have been evaluated numerically, which resulted in a production shortfall of more than one order of magnitude at a power of 100 kW showing the need of a more favorable approach. Alternatively, low energy beam interacting with solid oxides such as magnesium oxide have been also investigated [6]. The reaction cross-sections have been determined experimentally and the production yields have been computed for protons and ${}^3\text{He}$ in the 5 to 20 MeV range. An in-target production rate of 1×10^{13} ${}^{18}\text{Ne}/\text{s}$ is expected for 85 mA, 21 MeV beam. The required intensity is expected to decrease when increasing the beam energy to 30 MeV.

Another approach to produce ${}^{18}\text{Ne}$ beams was inspired by the method applied at Centre de Recherche sur les Cyclotrons, Louvain-La-Neuve by using a 9 kW, 30 MeV proton beam on molten lithium fluoride salt cased in a graphite disk [7]. Extrapolation of the results show that 35 mA proton beam at 50 MeV and multi-megawatts proton driver and target would be needed to deliver the required 1×10^{13} ${}^{18}\text{Ne}/\text{s}$, assuming 100% isotope extraction efficiencies.

In this paper, an alternative route to produce ${}^{18}\text{Ne}$ beams is presented. This route consists on a circulating loop of molten salt analogous to the one proposed for a molten metal loop at EURISOL-DS [3]. A schematic representation of the proposed loop is shown in fig. 2. The proton beam energy range is between 50 and 160 MeV, which is also relevant for the production of radioisotopes used for proton emission tomography imaging and cancer treatments.

2. Production of ${}^{18}\text{Ne}$ using a circulating loop of molten sodium salts

The production of ${}^{18}\text{Ne}$ can be performed by (p, X) (or $({}^3\text{He}, X)$) reaction on Na, F or Mg targets [8]. Therefore, the use of targets which contain any of these elements would present direct advantages on the production of Ne. Moreover, the use of sodium molten salts would present several other advantages since these compounds have been extensively studied due to their application as coolants in nuclear reactors [9, 10], and their physical and chemical properties are very well known.

Amongst the extensive list of available molten salt systems, the best candidate to the present application would be sodium fluoride (NaF). Nevertheless, the high melting point of this salt (995°C) limits its applications and the choice of a binary system containing NaF presents even more advantages. In order to choose the most adequate binary system, several physical properties have been compared. Table 1 summarizes some candidates for the present application together

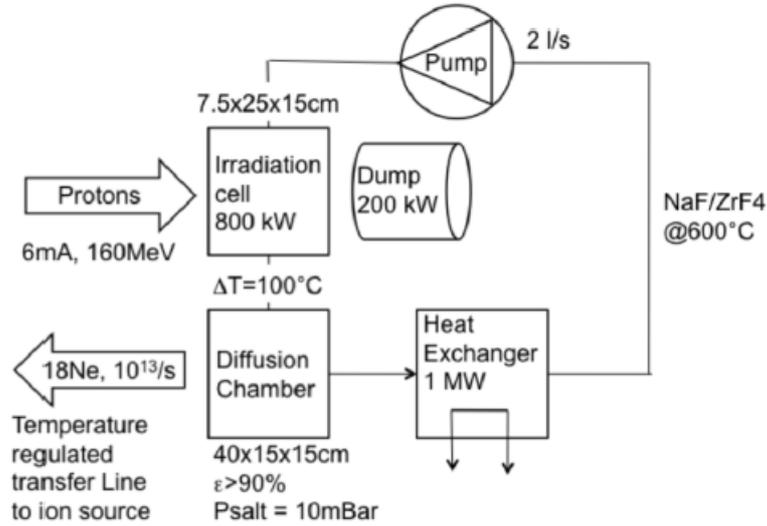


Figure 2. Conceptual layout of a molten salt loop for ^{18}Ne production.

with the respective physical properties at 700°C . The calculated production yields indicates that the composition to obtain the highest ^{18}Ne intensity for a given beam power is the mixture of sodium and zirconium fluorides (NaF-ZrF_4). One shall note that the production yields have been calculated assuming 6 mA, 160 MeV proton beam.

Table 1. Physical properties at 700°C , vapor pressure at 900°C and respective production yields for ^{18}Ne of several sodium salts [9–11].

Salt	Composition (% mol)	Melting Point ($^\circ\text{C}$)	Density (g/cm^3)	Viscosity (cP)	900°C vapor pressure (mmHg)	Production yield $^{18}\text{Ne}/\text{s}$
NaF-BeF_2	57-43	340	2.01	7	1.2	8.8×10^{12}
NaF-ZrF_4	60-40	500	3.14	5.1	5	1×10^{13}
NaF-NaBF_4	8-92	385	1.75	0.9	9500	8.4×10^{12}

Accounting for the high reactivity and corrosive nature of the fluoride salts, the choice of the container material is an important issue. It is well known that nickel is one of the most resistant elements to dissolution in these salts. Therefore, the container shall be made from a nickel rich alloy, which is resistant to fluoride environments at high temperatures.

The dimensioning of the irradiation and diffusion chambers has been performed accounting for the materials, heat transfer and diffusion coefficients. Refined calculations and dimensioning of the production unit is still ongoing.

3. Online tests at ISOLDE using a static target unit

A first test on the feasibility of the production of ^{18}Ne using molten fluoride salts will be performed using a static target unit at CERN/ISOLDE with an experiment scheduled in November 2011.

The target material was synthesized at LPSC/Grenoble by heating a mixture of stoichiometric quantities of NaF and ZrF_4 above the eutectic point of this system. The target unit consists of a nickel-rich alloy container equipped with a condensation tube to connect the target to the ion

source. The container will be filled up to 3/4 of its volume with the melt, allowing a free surface for the isotopes to diffuse out of the target. The target unit will be connected to a versatile arc discharge ion source (VADIS) via a temperature controlled transfer line.

The foreseen online measurements will allow a systematic study of the production and release of ^{18}Ne . Several tests will be performed with different target temperatures and proton beam intensities. The forthcoming results will give an important contribution for the design and test of the molten salt circulating loop.

4. Conclusions

In this paper, a molten fluoride salt target is proposed for the production of the required rates of ^{18}Ne for the beta beams project. Intermediate proton energy beams at close to 1 MW power are used on a circulating NaF-ZrF₄ eutectic to produce and extract 1×10^{13} $^{18}\text{Ne}/\text{s}$.

The application of a molten fluoride salt target for the monitoring of noble gas production is discussed with respect to the planned experimental program. Furthermore, a systematic experimental study on the production and release of volatile radioisotopes from a static target unit, in preparation at CERN/ISOLDE, is presented.

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