6.1 General criteria for target and ion-sources

The ion-sources dedicated to the production of Radioactive Ion Beams (RIB) have to be highly efficient, selective (to reduce the isobar contamination) and fast (to limit the decay losses of short-lived isotopes). For radioactive beam generation, the source must operate stably for extended periods of time at elevated temperatures (up to 2000°C). The selection of the most appropriate choice for the target/ion source is of paramount importance since its performance determines the intensity, the beam quality, and the number of radioactive beams that can be provided for experimental use.

The world wide spread RIB facilities came up with a large variety of solutions to meet part or all of these requirements such as: surface, plasma, electron cyclotron resonance and laser ion-sources [1]. A figure of merit of the 1+-ion sources for RIB is presented in fig. 6.1 as a function of the ionization potentials.

![Figure 6.1: 1+ Ionization efficiencies measured with surface (black squares), plasma-FEBIAD (circles), laser (triangles) and ECR ion sources from Ref 1.](image)

The choice for SPES project to develop a Target-Ion Source Chamber unit based on the ISOLDE one, implies the possibility of using a great part of sources developed at CERN, with the ability to choose and then to plug one of those through the transfert tube of the multifoil SPES target. In a ISOL facility, the volatile nuclear reaction products are released from the target material and diffuse via a transfer line into the ion source, so the target and ion source system form a self-contained unit specifically optimized for each element or group of elements. The choice of ion source to be used has primarily been dictated by efficiency and secondarily by its...
capability of selective ionization. All ions produced are accelerated towards the ion extraction electrode by a potential of 60 kV.

We consider here three kinds of ion sources for SPES: the Surface Ion Source, the Forced Electron Beam Induced Arc Discharge (FEBIAD) and the Resonant Ionization Laser Ion Source (RILIS). All of these three sources are used at ISOLDE and they constitute a good reference point for further SPES goals in the ion-source development.

6.2 The Surface Ion Source

The concept of surface ionisation has proven to be particularly successful for production of singly charged positive and negative radioactive ion-beams due to its simplicity, high efficiency and selectivity [2]. As shown by the Langmuir equation ionisation efficiencies for positive ions of 50-100% may be obtained for elements with ionisation potential <5 eV and of negative ions for elements with electron affinity > 2 eV. Saha and Langmuir described the ionizing properties of a hot surface. Positive ions are produced when the minimal energy needed to remove an electron from a surface (its work function) is larger than the ionization potential, and negative ions are produced when the work function is smaller than the electron affinity of the atom impacting on the surface at thermal energies.

Surface ionization remains the most efficient ionization scheme for low ionization potential radioisotopes (alkalis and some lanthanides) that are currently produced with W, WO₃ and Re surfaces. Negative chlorine, bromine, iodine and astatine have been efficiently produced on LaB₆ Surfaces. In fig. 6.2 a picture of the EXCYT Positive surface Ion Source (PIS) is reported, successfully used to produce the first 8,9Li RIBs, it consists of a tungsten ionization tubular cavity connected to the target container transfer tube. This is a development of a MK1 ISOLDE ion source.

Fig. 6.2: EXCYT Positive ion source set-up (evolution of ISOLDE MK1).
6.3 The Plasma Ion Source: FEBIAD

The plasma ion-source currently used in several RIB facilities is based on the Forced Electron Beam Induced Arc Discharge (FEBIAD) concept originally developed by Kirchner [3] at GSI. The principle is based on the capability of electrons, coming from an indirectly heated disc-shaped cathode and accelerated into the anode chamber by means of a grid, to ionize any atoms, floating in the anode chamber, with ionization potential smaller than the energy of incident electrons. The source is well suited for ISOL applications it operates stably and efficiently in conjunction with high temperature thick target materials over a pressure range of $10^{-5}$ to $10^{-4}$ Torr.

The FEBIAD is particularly useful for the ionization of highly reactive or condensable elements for which wall sticking would limit their release from a surface ion source cavity. With electron impact energies of between 100 and 200 eV, also elements with very high ionization potentials (e.g. Xe and Kr) can be efficiently ionized. In fact the efficiency of the FEBIAD ion source is quite high for slow moving heavy ions; for low mass, fast moving atoms with high ionization potentials, the source is not as impressive. For example, the measured ionization efficiencies for the noble gas elements are, respectively: Ne: 1.5%; Ar: 18%; Kr: 36%; and Xe: 54%.

The FEBIAD ion source is also capable to produce multi-charged ions, but the limited selectivity offered by this kind of ion source can be improved by exploiting the chemical or physical properties of the atoms as they are released from the target.

The FEBIAD ion source developed at ISOLDE is named MK5 [4], and it could be used also in the SPES target-ion source assembly. The cathode is made of tantalum, and it consists of three parts welded together by means of electron beam welding and press fitted into the transfer tube; the cathode temperature, and thus thermionic electron emission, is controlled by a DC current (400 A max). The collimation of the electron beam is effected by adjusting the coaxially directed solenoidal magnetic field so as to optimize the ionization efficiency of the species of interest.

The discharge chamber and the anode assembly are made of molybdenum and screwed into a graphite cylinder rigidly fixed to the main target base as shown in fig. 6.3.

![diag](Image)

Fig. 6.3: The ISOLDE MK5 high temperature plasma ion source with target container.
The anode is insulated by means of three BeO insulators. The anode grid consists of a graphite disc with holes drilled through it to let electrons being accelerated into the discharge chamber. The source is surrounded by three heat screens made of molybdenum. A current flows through the transfer line via the cathode, the anode cylinder, the external graphite tube and back through the main target flange. The advantage of this design is that only one power supply is needed for heating the line, cathode and ion source. The same power supply can also be used for heating the tubular surface ionizers.

6.4 The Resonance Ionisation Laser Ion Source

The Resonance Ionization Laser Ion Source (RILIS) method is nowadays the most powerful tool for radioactive ion beam production at on-line facilities, because it provides a selective ionization process with inherent suppression of unwanted isobaric contaminations at the ion source. A photoionization scheme usually involves a few resonant photon absorption steps in which the valence electron is excited to a high lying Rydberg state close to the continuum before a final, often non-resonant ionization step. Using tuneable lasers (solid state or dye or a combination of the two) it is possible to match the photon energy of the laser light to the electronic transitions of a desired atomic species. For many elements, ionization by stepwise resonance photon absorption can provide an unmatched level of selectivity and rapidity. It is the unique electronic structure of different atomic species that gives this process its selectivity.

The ionization efficiency is heavily reliant on the saturation of the resonant photon absorption steps, therefore the spectral radiance requested to the laser system depends also from the physical parameters of the atomic sample released from the target. This task can be accomplished using pulsed laser that must also operate at high repetition rate in order to process all the fragments coming from the target.

Typical Laser sources are the RILIS (ISOLDE, Fig. 6.4) or, more recently, the FURIOUS (IGISOL) Resonance Ionization Laser Ion Sources [5,6] Fig. 6.5, which both provide beams for more than 20 elements. The laser beams are directed through a window in the ion beam line at the mass separator and focussed into the cavity of a standard surface ion source, shown in figure 6.4.
In this hot cavity the reaction products exist as a thermal atomic vapour at a temperature of around 2300 K. Under these conditions Doppler broadening adds to the natural width of the resonant transitions (typically 10MHz) raising the linewidth to the order of a few GHz. In addition, atomic physics effects such as the isotope shift and hyperfine structure, when present, can effectively broaden the width of the transition, by splitting the resonance position into different hyperfine or isotopic components spread over a range of possibly tens of GHz. In these cases optimal efficiency is therefore achieved by the use of plain broadband lasers. For instance, the dye lasers used at ISOLDE have a typical bandwidth of 20 GHz. Vice versa isotopes or hyperfine components (even isomers) of some elements can be isolated by operating the lasers in a narrower band mode, typically inserting an etalon into the laser cavity.

The technique is still in progress. Few years ago it has been proposed to add an ion repeller and to surround the photoionization region by a linear RFQ, improving by orders of magnitude the suppression of surface ions contamination while ensuring a high collection efficiency of photoions. This technique was named LIST, Laser Ion Source Trap [7], Fig. 6.5. Access to more than 80% of all known elements seems feasible with existing laser systems [7,8].
Fig. 6.5: The LIS system at Jyväskylä