

ALKALI SUPPRESSION WITHIN LASER ION-SOURCE CAVITIES AND TIME
STRUCTURE OF THE LASER IONIZED ION-BUNCHES

J. Lettry^{†*}, R. Catherall, U.Köster, U. Georg, O. Jonsson, S. Marzari, V. Fedosseev
and the ISOLDE collaboration

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The chemical selectivity of the target and ion-source production system is an asset for Radioactive Ion-Beam (RIB) facilities equipped with mass separators. Ionization via laser induced multiple resonant steps has such selectivity. However, the selectivity of the ISOLDE Resonant Ionization Laser Ion-Source (RILIS), where ionization takes place within high temperature refractory metal cavities, suffers from unwanted surface ionization of low ionization potential alkalis.

In order to reduce this type of isobaric contaminant, surface ionization within the target vessel was used. On-line measurements of the efficiency of this method is reported, suppression factors of alkalis up to an order of magnitude were measured as a function of their ionization potential.

The time distribution of the ion bunches produced with the RILIS was measured for a variety of elements and high temperature cavity materials. While all ions are produced within a few nanoseconds, the ion bunch sometimes spreads over more than 100 μ s. This demonstrates that ions are confined within high temperature metallic cavities. It is the internal electrical field of these cavities that causes the ions to drift to the extraction region and defines the dwell time of the ions in the cavity.

Beam optics calculations were carried out to simulate the pulse shape of a RILIS ion bunch and are compared to the actual measurements.

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The chemical selectivity of the target and ion-source production system is an asset for Radioactive Ion-Beam (RIB) facilities equipped with mass separators. Ionization via laser induced multiple resonant steps Ionization has such selectivity. However, the selectivity of the ISOLDE Resonant Ionization Laser Ion-Source (RILIS), where ionization takes place within high temperature refractory metal cavities, suffers from unwanted surface ionization of low ionization potential alkalis.

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Alkali suppression within laser ion-source cavities

The production cross-section for isotopes far from stability is orders of magnitude lower than for isobars closer to stability. As an example, neutron rich silver isotopes are ionized with the ISOLDE Resonant Ionization Laser Ion Source [1] (RILIS) with an efficiency of 14%. Unfortunately, the surface ionization of the 3.89 eV ionization potential Cs within the high temperature RILIS cavity is close to 100%.

The reduction of low ionization potential isobar contaminants from “high” ionization potential radioisotopes in RILIS ion-beams was tested via the natural surface ionization that occurs within the high temperature Ta-target vessel presented in Figure 1. The field across the target oven was of the order of 10 V/m for the 0.5 mm thick, 21 mm diameter and 20 cm long Ta-oven kept a 2100° by a 900 A current. The target vessel was filled with 6 μ m thick Ta-ribbons aligned parallel to the oven axis. The drift field generated by the dc heating current is oriented towards a dedicated extraction electrode placed at the extremity of the target vessel, opposite to the transfer line to the RILIS cavity. While the high ionization potential elements

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for which laser ionization was developed are not ionized on hot surfaces, the low ionization potential alkali ions are, and they will feel the internal electric field inside the tantalum oven. The extraction hole is of course a free opening for non-ionized atoms, and the diameter of the hole is kept small compared to the RILIS cavity section to minimize these losses. In first approximation, the geometrical effect of the so-called “rear” extraction is described by: $\epsilon_{neutral} = s_{LIS}/(s_{LIS}+s_{rear})$ where s_{LIS} is the section of the RILIS cavity and s_{rear} the one of the rear extraction. Given its ionization potential IP , the suppression efficiency of a chemical element $\epsilon(IP) = Y_{rear}/Y_{cavity}$ is obtained via the ratio of its isotope yields measured with orientations of the drift field towards the RILIS cavity (Y_{cavity}) respectively towards the rear extraction (Y_{rear}). The suppression factor of the beams of an element Z versus an alkali isobar is thus given by: $\chi = \epsilon_{neutral} \cdot \epsilon(IP_Z) / \epsilon(IP_{Isobar})$.

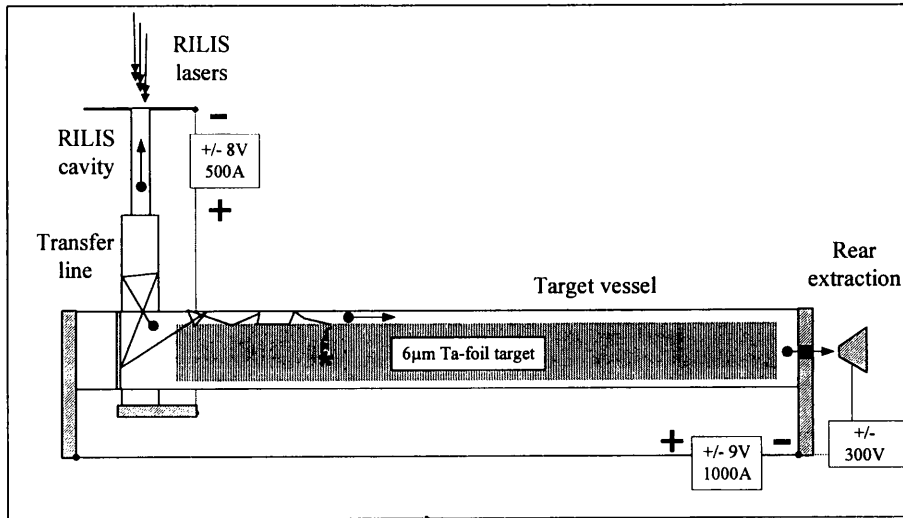


Figure 1 - Scheme of the ISOLDE target Ta-174 equipped with a laser ion source high temperature cavity, a target vessel allowing the reversal of the dc target heating current and a “rear” electrostatic extraction. The field across the target oven was of the order of 10 V/m for a 0.5 mm thick, 21 mm diameter and 20 cm long Ta-oven kept at 2100° by a 900 A current. The target vessel was filled with 6 μm thick Ta-ribbons aligned parallel to the oven axis. The target thickness was 30 g/cm².

The prototype was tested by measuring the release and yields of different radioisotopes with ionization potentials between 3.9 and 5.7 eV for two directions of the target container heating current. The ratios of the yields obtained are given in Table 1 and an example of the release data in Figure 2. The point-to-point ratios are shown for all elements in Figure 3. The increase of this ratio as a function of time shows a logarithmic behavior that may be related to the vacuum conditions within the target container following proton beam impact.

Table 1. Effect of a ~10 V/m drift field in an ISOLDE Tantalum foil target (heated by a 900A dc current at a temperature of 2100°) equipped with a surface ion-source. The suppression efficiencies $\epsilon(IP) = Y_{rear}/Y_{cavity}$ are presented in figure 3 as a function of the ionization potential IP together with the surface ionization efficiency $\epsilon_{Ta-surf}$ of a tantalum surface ion source (work function of tantalum: 4.5 eV).

	IP [eV]	$\epsilon_{Ta-surf}$	$\epsilon(IP)$
¹²⁶ Cs	3.89	89.0%	17.3%
⁸⁰ Rb	4.17	69.1%	17.1%
⁴⁶ K	4.24	51.2%	18.1%
²⁵ Na	5.14	2.5%	36.1%
¹³⁷ Ba	5.21	1.8%	53.8%
⁸ Li	5.39	0.79%	72.0%
¹⁴⁴ Eu	5.67	0.22%	75.1%

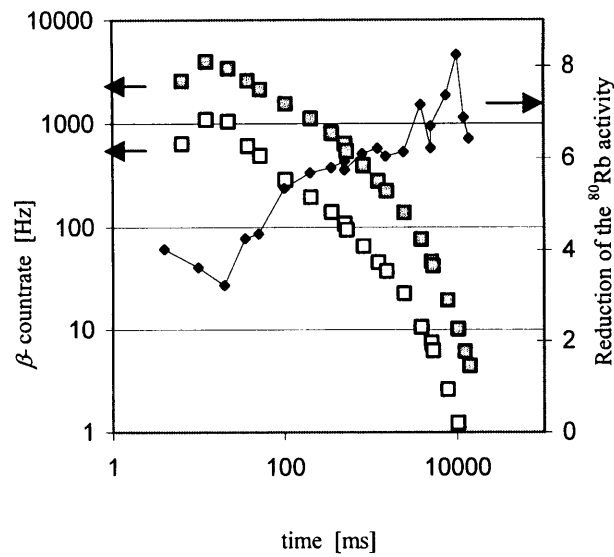


Figure 2 - Release of ^{80}Rb from the ISOLDE Ta-174 tantalum foil target. The time dependence was measured via β -counting of a few ms collections with a 4π plastic scintillator. The data presented were collected for orientation of the drift field towards the ion-source (black squares) and towards the rear extraction (white squares). The axis is the time elapsed from the previous proton pulse (2×10^{13} protons per $2.4 \mu\text{s}$ proton pulse, cycled every 14.4 s). The reduction of the ^{80}Rb ion beam is given by the ratio of the activities collected under opposite drift fields (diamonds).

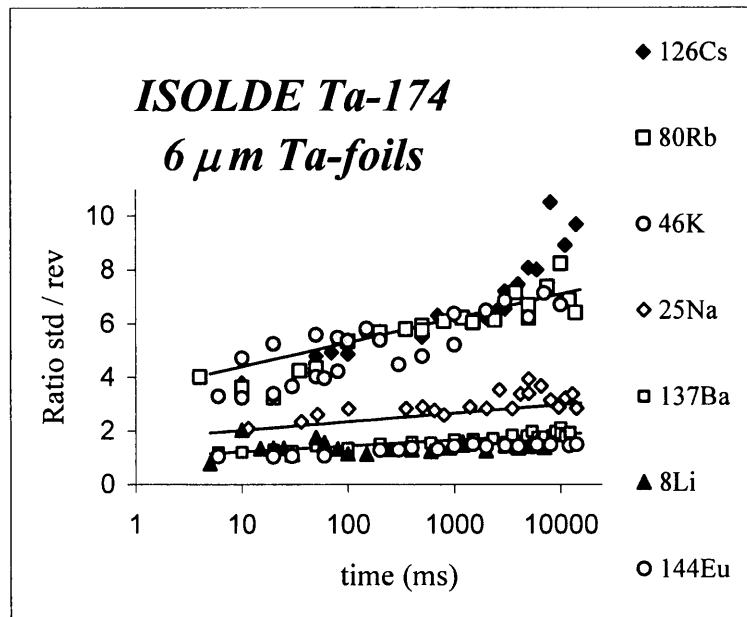


Figure 3 - Ratio of the activities collected under opposite drift fields ($Y_{\text{cavity}}/Y_{\text{rear}}$) for elements with ionization potential between 3.89 and 5.67 eV. The estimation of the net effect of the drift field in the target container was obtained from the ratio of the yields of the radioisotopes. A factor above 5 was measured for low ionization potential alkalis (Cs, Rb and K). The presented point-to-point ratio shows logarithmic time dependence.

The achieved χ -factor of 5 for potassium, rubidium and cesium confirms the alkali suppression method for tantalum foil targets. However, while most of the known alkali suppression tools were used to equip the ISOLDE ThO-184 thorium oxide target (neutron converter [2], 40 mm long and $60\mu\text{m}$ wall thickness RILIS radiation cooled niobium-cavity

and drift field system), its drift-field reduction factor was close to unity. This shows that the contribution of the target material to the work function cannot be neglected. As shown in the next section, it is a challenge that should be pursued to equip the transfer line to the RILIS cavity with an inverted drift field. ISOLDE high temperature plasma ion-source (MK5) transfer lines are suited for it, and ready for on-line tests. For plasma ion-sources, the rear extraction is placed at the extremity of the transfer line. The need for purity is such that an improvement of 2 or more orders of magnitude is sought.

Time structure of the laser ionized ion-bunches

The ISOLDE RILIS [2] produces close to 50% of the ISOLDE Radioactive Ion Beams (RIBs), of 14 elements. The RILIS operate at 10 to 11 kHz, the lasers beams are sent coaxially into a cylindrical high temperature metallic cavity. Beside the optimization of all the optics, wavelength, line width and power of the lasers themselves, the properties of the cavity should be optimized. The aim of this section is to compare existing data to simulations in order to add insight to the information available on efficiency and on the time structure of the RILIS ion bunch. The time structure is recorded using a current to voltage transducer with a 1 MHz bandwidth coupled to a digital oscilloscope. Because of fluctuations of laser power, the measurements are averaged over 1000 cycles. As an example, the time distributions of the ^{109}Ag ions extracted from a standard tungsten-cavity kept at 2000° are presented in Figure 4. The first thin peak corresponds to the atoms already placed within the extraction field during ionization, the second contains the bulk of ions that are accelerated and transported by the drift field to the extraction region. A better knowledge of this domain is a requirement to develop high drift field RILIS cavities of the order of 60 V/m, such as a sapphire cavity contained in a carbon oven [3] or thin foil cavities [4]. A list of cavities currently operated at ISOLDE is presented in Table 2.

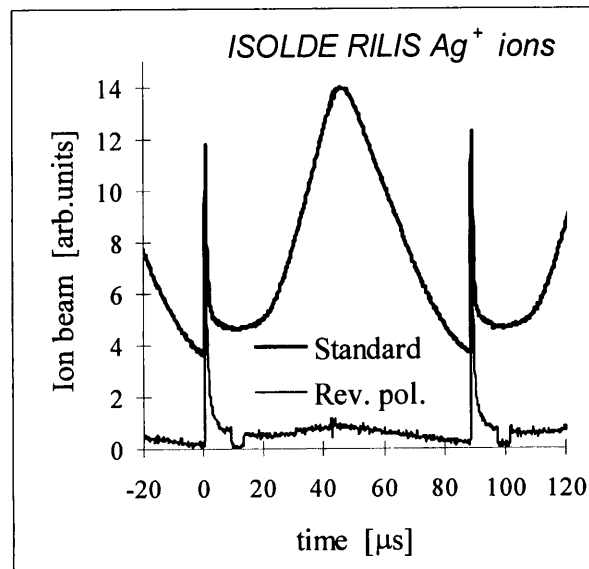


Figure 4 - Time distribution of $^{109}\text{Ag}^+$ ions extracted from a standard W-cavity kept at 2200° ; the measurement presented is the average of 1000 bunches. The first peak ($t=0$) corresponds to the atoms already placed within the extraction field during ionization and the second contains the bulk of ions that are accelerated and transported by the drift field to the extraction region. By reversing the ohmic heating current, the ions drift away from the extraction region and only the ions that are already oriented towards or placed in the extraction region are detected. During this "reversed polarity" measurement, a fast electrostatic deflector moved the beam away from the ion-current detection between 8 and 13 μs after the lasing of the RILIS in order to monitor the background.

Table 2: High temperature RILIS cavities currently used at ISOLDE.

Material	ϕ int [mm]	Wall thickness [mm]	Length [mm]	Temp. [°C]	equipment
W	3	1.0	30-60	2400°	Heat screens
Nb	3	0.2, 0.5, 1.0	30	2000°	Heat screens
Nb-foils 2×30 μ m	3	0.06	40-60	2000°	Nb-foils rolls + heat radiators
Sapphire	3	3.5	30	1800°	Carbon-resistor

The randomly generated ions were distributed according to effusion transport for a constant tube section (starting 2 cm before the RILIS cavity as shown in Figure 5), with thermal energy, $\cos(\theta)$ angular distribution and homogenous in ϕ . The geometry, temperature and heating current of the actual ISOLDE W-surface ion-source was used to determine the electric field within the cavity. The extraction field table was computed with SIMION [5] and the wall potential as described in [3]. The equation of motion for charged particles in an electrostatic field was integrated for typically 10^5 ions. The distribution of the original position is presented in Figure 5. The distribution of the time elapsed between ionization and detection is folded with itself (88 μ s delay) to account for the cyclic conditions of the 11.3 kHz laser repetition rate (Figure 6).

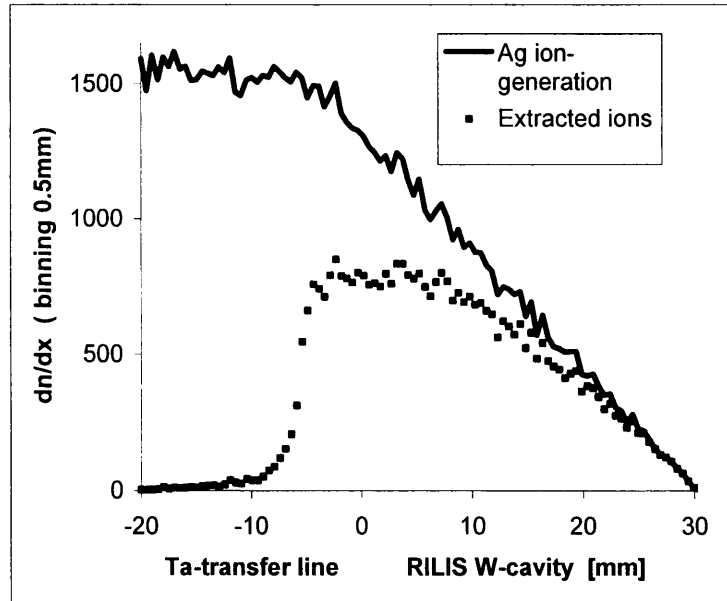


Figure 5 - Distributions of the randomly generated positions within the Ta-transfer line (-20 to 0 mm) and within the W-cavity (0 to 30 mm). The distribution of the origin of the ions leaving the cavity is indicated by black squares, obviously; only a small fraction of the ions present in the transfer line is extracted.

The simulation of $^{109}\text{Ag}^+$ ions presented in Figure 6, it is in good agreement with the data (figure 4) for both polarities of the cavity heating current. The analysis of time distribution measurements may shed light on the effective confinement conditions within high temperature cavities and eventually lead to improvement of the design of RILIS cavities.

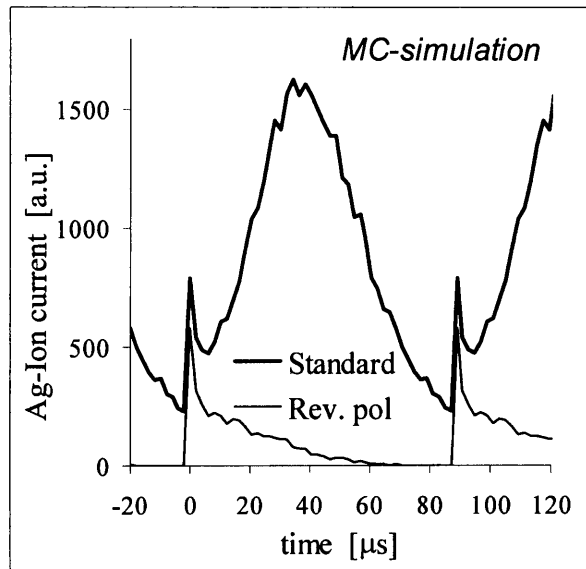


Figure 6 - The measurement presented in Figure 4 was simulated by Monte-Carlo generation of 10^5 ions respecting the energy distribution, and angular distribution of atoms leaving a 2200° hot tubular surface. The distribution along the axis of the cavity was linear according to effusion transport. The geometry, temperature and heating current of the actual ISOLDE W-surface ion-source was used to determine the electric field within the cavity. The extraction field table was computed with SIMION [5] and the wall potential as described in [3,6,7]. The tail of the previous ion-bunch was added to reproduce the 11.3 kHz cycle of the laser ion-source.

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