EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Addendum to the Letter of Intent INTC-I-246 to the ISOLDE and Neutron Time-of-Flight Committee

Yield measurements for lanthanide elements with Ta-foil target and a LIST ion source

September 26, 2023

Katerina Chrysalidis[1], Reinhard Heinke[1], Mia Au[1,2], Cyril Bernerd[1], Asar A H Jaradat[1,3], Ulli Köster[4], Ralitsa Mancheva[1,5], Bruce Marsh[1], Edgar Reis[1], Maximilian Schütt[1], Sebastian Rothe[1], Simon Stegemann[1], Julius Wessolek[1,3]

[1] *CERN, Switzerland*
[2] *Johannes Gutenberg-Universität Mainz, Germany*
[3] *The University of Manchester, Manchester, UK*
[4] *Institut Laue-Langevin, Grenoble, France*
[5] *KU Leuven, Institute for Nuclear and Radiation Physics, Heverlee, Belgium*

Spokesperson: Katerina Chrysalidis (katerina.chrysalidis@cern.ch)
Contact person: Reinhard Heinke (reinhard.heinke@cern.ch)

CERN-INTC-2023-065 / INTC-I-263
26/09/2023

Abstract: We present an addendum to our Letter of Intent INTC-I-246 submitted to the INTC concerning the yield measurements of lanthanides with a Ta-foil target coupled to a LIST unit. In addition to the shifts granted for LOI I-246, two more LOI (I-235 and I-226) were scheduled for the same running period, adding 3 and 6 shifts, respectively. This brought the total number of available shifts to 28 for the measurement of Dy, Tm and Pm (I-246), Gd and Er (I-235) and Yb (I-226). Yb was not covered within the envisaged elements of LOI 246, since only 11 lanthanides (isotopes to ± 5 amu around the Z=64 proton subshell closure) were requested.
During the beam-time scheduled in early 2023, the yields of a total of 6 elements were measured over the course of 28 shifts.

Requested shifts: 24 shifts

1 Results from target #777 Ta-foil LIST

In I-246 we described the preferred method for the yield measurements employing the ISOLDE fast tape station. The final method used for the yield determination was a series of mass scans where the ion current was either measured on the ISOLDE Faraday-cup YGPS.FC490 or a MagneToF-detector installed in the GLM beam-line. In addition, single ion counting was employed on the MagneToF detector with time-resolved data taking, gated on the laser ion signal.
After initial tests and attempts to measure the yields systematically with the Fast Tape Station, it became clear that, due to the slow release and high risk of contamination of the detectors with isotopes of unfavorable half-lives, this was not the best path for the yield determination. Finally, the employed method ended up consisting of the following cycle for each of the elements:

- laser setup to the required resonance ionization scheme
- optimization of the LIST parameters
- mass scan over the region of known isotopes of the element on YGPS.FC490
- mass scan over the same range of isotopes on the MagneToF detector in low-gain mode with DC current measurement
- direct yield measurement in single-ion counting mode of the MagneToF detector, gating on the laser ions only

Since the ion current readout of the Faraday-cup can be directly related to charges (= ions) per μC of protons with the known proton current delivered to the ISOLDE target, the yield for isotopes produced sufficiently well can be determined through two mass scans with lasers on and off (for background correction). Repeating this same scan on the MagneToF increased the number of accessible isotopes due to the enhanced sensitivity of this detector. The peaks visible in both of the scans (FC and MagneToF) can then be directly related to one another and the gain-factor of the MagneToF in DC current mode can be extracted. This gives access to the yields of all isotopes within the MagneToF mass scan, expanding the list of measured yields further. Finally, the MagneToF gain was increased to the point where single ion counting became possible. The time structure of the ion beam, which is a direct result of the pulsed nature of the lasers, gave additional means for decreasing the background of non-laser related ions. In single ion counting mode, yields were measured for the remaining isotopes to the point where no convincing laser on/off signal could be obtained.
Due to the strong contamination without the LIST, all yields were measured in so-called LIST-mode, meaning that ionization with the lasers took place outside the hot cavity. Surface ionized species were suppressed with the repellers situated outside the hot-cavity. Nevertheless, a good estimation of the "LIST loss factor" (ratio of yield from ionization within the hot cavity and in LIST-mode) can be given for the elements of Tm and Dy, since mass scans with laser ionized beams from target #812 (Ta-foil with Ta surface ion source) were obtained during beam times in 2023 for experiments IS688 and LOI245.

Release curves were obtained for most elements. Due to the slow release, the method used was as follows: a decay-shielded isotope with a half-live much bigger than the expected release-time was chosen and the ion beam taken to the MagneToF in DC current mode. The protons were stopped, with the ion beam continuing to go onto the detector. Due to the fact that no feeding occurred into the shielded isotopes, no such effect needs to be considered in the analysis of the release-curve. With isotopes with half-lives in the order of hundreds of days or more, the measurement times of ~30min were comparatively low and half-lives effects can also be neglected in the analysis of the release.
All the measured yields and release-curves will be published separately from this Addendum. However, yields are available to all interested individuals upon request and before publication. One such example is given in the proposal for Tm laser spectroscopy, where the yields have been made available to COLLAPS for preparing their proposal submitted to this same INTC for review. Yields for LOIs 235 and 226 have already been communicated to their spokespersons.

2 Summary of requested shifts

We have concluded the yield measurements requested by LOI 235 and LOI 226, in addition to the yields we proposed to measure in a first campaign described in LOI 246. After the completion of the shifts awarded to us, we have shown that the estimated times required for the measurements was slightly over specified. This is mainly due to the time expected for the yield measurements themselves, which had been estimated to 4 shifts per isotope. In the end, the time required was only about 2.5 shifts The fact that we succeeded in measuring 6 elements during a total of 28 shifts and within a single run gives us confidence that we can measure the remaining lanthanides (Pr, Nd, Sm, Eu, Tb, Ho) requested in LOI 246 within the same number of shifts, employing the same method used so far.

Requested shifts: 2.5 shifts for yields per element, 2 shifts per element laser setup and 1 shift for the machine setup gives a total of $2.5 \times 6 + 2 \times 6 + 1 = 28$ in one run with a LIST coupled to a Ta-foil target.

DESCRIPTION OF THE PROPOSED EXPERIMENT

Please describe here below the main parts of your experimental set-up:

Part of the experiment	Design and manufacturing
If relevant, write here the name of the fixed installation you will be using [Name fixed/present ISOLDE installation: e.g. COLLAPS, CRIS, ISS, Miniball etc]	☒ To be used without any modification ☐ To be modified
If relevant, describe here the name of the flexible/transported equipment you will bring to CERN from your Institute [Part 1 of experiment/ equipment]	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 of experiment/ equipment]	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]	

HAZARDS GENERATED BY THE EXPERIMENT

Additional hazard from flexible or transported equipment to the CERN site:

Domain	Hazards/Hazardous Activities		Description
Mechanical Safety	Pressure	☐	[pressure] [bar], [volume][l]
	Vacuum	☐	
	Machine tools	☐	
	Mechanical energy (moving parts)	☐	
	Hot/Cold surfaces	☐	
Cryogenic Safety	Cryogenic fluid	☐	[fluid] [m3]
Electrical Safety	Electrical equipment and installations	☐	[voltage] [V], [current] [A]
	High Voltage equipment	☐	[voltage] [V]
Chemical Safety	CMR (carcinogens, mutagens and toxic to reproduction)	☐	[fluid], [quantity]
	Toxic/Irritant	☐	[fluid], [quantity]
	Corrosive	☐	[fluid], [quantity]
	Oxidizing	☐	[fluid], [quantity]
	Flammable/Potentially explosive atmospheres	☐	[fluid], [quantity]
	Dangerous for the environment	☐	[fluid], [quantity]
Non-ionizing radiation Safety	Laser	☐	[laser], [class]
	UV light	☐	

	Magnetic field	☐	[magnetic field] [T]
Workplace	Excessive noise	☐	
	Working outside normal working hours	☐	
	Working at height (climbing platforms, etc.)	☐	
	Outdoor activities	☐	
Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			