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Letter of Clarification to the ISOLDE and Neutron Time-of-Flight Committee

Absolute charge radii of radioactive isotopes measured by muonic x ray spectroscopy at PSI

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Abstract: Following the presentation of proposal INTC-P-552 at the 64^{th} meeting of the INTC, a clarification letter is now presented on the specific needs from the facility for the most appropriate physics case, namely ^{108m}Ag.

Requested shifts: 1 collection of ^{108m}Ag over 30 shifts

1 Context of the original proposal

At the 64^{th} meeting of the INTC, members of the muX Collaboration from the Paul Scherrer Institute, together with other ISOLDE users presented a proposal to separate long-lived radioisotopes or isotopes with extremely low natural abundances using the CERN ISOLDE and/or MEDICIS infrastructure [1]. While not requiring any proton irradiation from CERN, this proposal suggested a non-negligible use of the ISOLDE resources, which warranted its discussion before the INTC.
The proposal addressed the issue of extracting the mean-square charge radius information from laser spectroscopy measurement in nuclear structure studies. The atomic transitions that are studied, e.g., at ISOLDE, should ideally be benchmarked to experimental absolute radii, whether from muonic x-ray spectroscopy or from other techniques, using at least 3 isotopes: 1 reference point and 2 measurements to fit a line [2]. However, no odd-Z element features 3 or more stable isotopes with which such studies could be performed up to now. Thanks to the advances of the muX setup, it is now possible to perform muonic x-ray spectroscopy with samples of only 1.5×10^{16} atoms deposited on a surface, with a relative isotopic(isomeric) purity of 99% [3, 4].
The original list of isotopes included ^{108m}Ag, ^{137,138}La, and ^{157,158}Tb. The discussions initiated by this proposal prior to its presentation to the INTC identified alternative approaches for some of the requested activities, so that the involvement of the CERN infrastructures would be limited to the separation of ^{108m}Ag and ^{138}La. While ^{138}La is stable and thus available naturally, ^{108m}Ag is a radioactive isotope that can be produced in the high neutron flux from the ILL research reactor in Grenoble (France) via the ^{107}Ag(n,γ)^{108m}Ag reaction. This reaction would, however, produce both the ground and isomeric state, but the nuclear ground state is so short lived ($T_{1/2} = 2.37\,\text{min}$) that it would decay prior to separation.

2 Recommendation from the INTC and clarification

Following the review of the original proposal, the INTC issued the following recommendation:

> The committee [...] urges the proponents to focus on [the scientific motivation] of ^{108m}Ag. This well-justified case has a clear connection both to the CRIS proposal submitted to the INTC and to the existing optical data within the Ag chain. New atomic factors obtained via a King plot would shed light on the apparent mismatch between the existing trend in the charge radii, the DFT calculations and the trend exhibited by neighboring elements.
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> However, it was not clear to the committee the final time which would be required for the preparation of this sample and the commitment expected from the ISOLDE technical teams. A clarification letter is requested which justifies the time expected for this preparation in addition to the resources required and also concentrating on the case of ^{108m}Ag.

2.1 Production of ^{108m}Ag

The ^{107}Ag(n,γ)^{108m}Ag reaction will be in competition with the ^{107}Ag(n,γ)^{108g}Ag reaction, with respective cross sections $\sigma_m = 0.41$ b and $\sigma_g = 34.4$ b. Based on these cross sections, a sample of 1 mg of enriched ^{107}Ag (99% purity) can yield 12 MBq of ^{108m}Ag after 50 days of irradiation followed by 10 days of cooling. This corresponds to 2.3×10^{17} atoms and represents 4% of the total Ag abundance in the sample. The rest of the sample will consist of the remaining target material (^{107,109}Ag, 99 : 1 relative abundances) and the other isotopes produced via neutron capture with a long half-life (^{110m}Ag).

2.2 Separation of ^{108m}Ag

The ionization of Ag at CERN ISOLDE is best performed via laser resonance ionization using the RILIS, with a reported efficiency of 14% in online conditions, according to the RILIS database. Considering the full sample as described in the previous section, this would allow the extraction of 3×10^{16} atoms, representing a suitable sample size to allow for the further radiochemistry work.
The Ag isotopes will be separated with the ISOL technique using laser-ionized beams. Because of its $5s$ atomic ground-state valence electron, the Ag element features a particularly large hyperfine field, resulting in very broad hyperfine structures. Given the large difference in spin and magnetic dipole moment between the odd-A isotopes ^{107,109}Ag ($I = 1/2^-$, $\mu \sim 0.12\mu_N$) and even-A isomers ^{108m,110m}Ag ($I = 6^+$, $\mu \sim 3.6\mu_N$), the RILIS in broadband operation is able to separate those two groups directly in the ion source - see simulation in Fig.1. From this, it can be safely concluded that the ion source will not be saturated by the highly abundant target material.

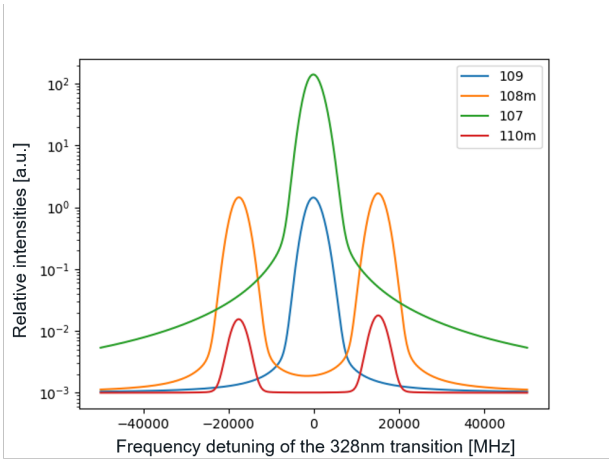

Figure 1: Simulated hyperfine structure of the silver isotopes of interest with relative abundances representative of the sample for this project.

The total sample to be extracted and collected corresponds to 1333 nAh. The collection time depends on the highest reasonable collection rate without reducing the efficiency. Such effects are known but poorly quantified, and a reasonable operation condition, as

established with the recent work at CERN MEDICIS, is at a few nA collection rate. This translates to 10 days of continuous collection at an average rate of 5.5 nA.
Faster collection can be achieved by increasing the throughput of the ion source, but at the risk of reducing the total efficiency of the process.
The preparation of the target unit for such a collection is well under control within the ISOLDE technical team from the recent work performed at MEDICIS with ^{169}Er samples from ILL [5] or with ^{153}Sm samples from SCK CEN in Mol (Belgium).

Summary of requested shifts: To complete the collection of ^{108m}Ag and perform muonic x-ray spectroscopy with these isotopes at PSI, 30 shifts of offline separation without protons at ISOLDE or MEDICIS are requested.

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: a collection point, either at GLM or at MEDICIS.

Part of the	Availability	Design and manufacturing
SSP-GLM chamber	☒ Existing	☒ To be used without any modification
MEDICIS collection chamber	☒ Existing	☒ To be used without any modification

HAZARDS GENERATED BY THE EXPERIMENT

Hazards named in the document relevant for the fixed SSP-GLM chamber and for the MEDICIS installation.

Additional hazards:

Hazards	^{108m}Ag	-	-
Ionizing radiation			
Target material [material]	silver		
Beam particle type (e, p, ions, etc)	-		
Beam intensity	-		
Beam energy	-		
Cooling liquids	-		
Gases	-		
Calibration sources:	-		
Use of activated material:			
• Description	Enriched ^{107}Ag irradiated with neutrons to produce ^{108m}Ag		
• Dose rate on contact and in 10 cm distance	≤ 1 mSv/h at 10 cm		
• Isotope	^{108m}Ag		
• Activity	7 MBq delivered prior to separation		