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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

UC_x Prototype Target Tests for ActILab-ENSAR

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Abstract:

Within the framework of ActiLab in FP7-ENSAR: Integrating R&D on ISOL UC targets, several uranium carbide target materials are under development. Although uranium carbide targets are commonly used for radioactive ion-beam production in various facilities, only very little is known about the influence of microstructure in terms of crystallography, morphology and chemistry on the isotope release properties. Systematic investigations of phase and chemical evolution of this material in the length scale of its crystallographic grains while pulsed high energy proton irradiation in combination with methodical variation of surfactants and micro structure will provide important missing insights for the synthesis of future target materials, needed in order to satisfy the increasing demand of exotic radioactive ion beams at ISOLDE and future ISOL facilities. Towards this systematic approach a new UC_x target material shall be tested at ISOLDE, which is subject of this letter of intent. Yields and release curves of representative isotopes will be measured at both tape stations with the beta-gamma detector systems and collections will be made for long-lived isotopes. Data will be analyzed in details and compared to the results for conventional ISOLDE UC_x targets for the same target and ion source geometry.

Requested shifts: 12 shifts, (split into 2 runs over 2 years)

1 Introduction

Uranium carbide matrices brought to high temperatures (>2000 °C) produce a wide range of radioisotopes through fragmentation, fission and spallation reaction channels. At ISOLDE such targets are brought to interaction with a pulsed proton beam of $1.4\,GeV$ provided by CERN's proton synchrotron booster. Even Europe's next-generation facilities currently under construction such as HIE-ISOLDE at CERN, SPIRAL 2 at GANIL in France or SPES in Italy will be operated using this principle. The material developed at ISOLDE and now used at RIB facilities around the world is made out of stacked cold-pressed pellets produced by carbothermal reduction of UO_2 and graphite powder. The final stoichiometry is believed to be $UC_2 + 2C$, with coexistence of UC, UC_2 and graphite phases all together with a low density of only $3.5\,\frac{g}{cm^3}$. Although the release properties are expected to be closely related to the material's microscopic structure [1] only little is known about the influence of porosity, grain size, microscopic chemical impurities, and microscopic phase coexistence. Open porosity is a well established parameter for the release of isotopes [2] while more recent investigations have proven that micro-crystallinity and grain size are of enormous importance as well [3]. Material characterizations done or commissioned by CERN reveal coexisting phases of UC_2, UC and C and a large distribution of grain sizes from 3 to $50\,\mu m$.
Towards more defined materials, a uranium monocarbide target was tested at ISOLDE (CERN) by an international collaboration in the framework of ActiLab in FP7-ENSAR and EURISOL in FP6-ENSAR, in October 2010. This material is made of monophasic UC grains from 3 to $9\,\mu m$ in diameter and a density of $12.3\,\frac{g}{cm^3}$. During these successful tests the material was found to release alkali and silver isotopes in similar quantities while there were evidences for shorter release times compared to the ones of conventional UC_x material used at ISOLDE [4].
To combine the advantages of short diffusion lengths and the high mobility between the material's grains provided by a high degree of open porosity it is now foreseen to perform similar online tests at ISOLDE with a self-synthesized UC_x matrix of less than $1\,\mu m$ average grain size. Therefore a methodology similar to the standard ISOLDE preparation will be applied, but the initial material will be preprocessed in order to control the particle size, before the cold-pressing takes place. Similarly a new kind of UC_x material has been developed at TRIUMF comprising support materials for better thermo-mechanical properties [5], which will also need to be tested at ISOLDE in well-controlled conditions. Together with systematic investigations of the material's micro-structural and micro-chemical properties, both before and after high intensity pulsed proton beam irradiation the impact of these tests on the RIB production is believed to be verifiable in the short term, and will serve present and future generation radioisotope production facilities within the ActiLab collaboration and worldwide.

2 Tests to be performed

Targets and Ion sources are tested at ISOLDE in a systematic way with a tape station equipped with a combined beta-gamma detector set-up. Thanks to the pulsed nature of the proton beam available at the PSB, release curves can be obtained for different isotopes with suitable yields and half-lifes, figure 1. This can conveniently be fitted by a three exponential function or a more detailed function which takes analytical expressions for diffusion and effusion phenomena into account [6, 7].

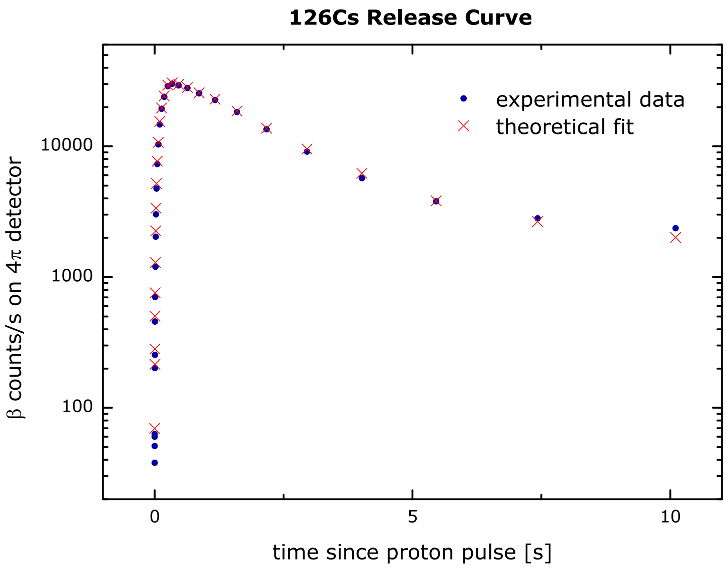

Figure 1: Release function for 126Cs obtained at ISOLDE from an high density UC target brought to 2000 °C, coupled to a tantalum surface ion source. The theoretical points are obtained by the best fit to the experimental points with the three exponential function: $P(t) = \left(1 - e^{-\frac{t}{t_r}}\right) \cdot \left(\alpha e^{-\frac{t}{t_f}} + (1-\alpha) e^{-\frac{t}{t_s}}\right)$, $t_r = 50\,\text{ms}$, $t_f = 2.3\,\text{s}$, $t_s = 5.9\text{s}$, $\alpha = 0.13$

Systematic studies of release properties for a given series of chemical elements is possible thanks to the high production cross-sections provided by fragmentation, spallation and fission reactions of 1.4 GeV protons, which covers most of the periodic table, either on the proton or on the neutron-rich side. It is thus possible to obtain yields and release properties of Li, Na, K, Rb, Cs and Fr alkali isotopes using a surface ion source and of He, Ne, Ar, Kr, Xe and Rn noble gas using a FEBIAD ion source coupled to a cold transfer line. The use of the RILIS ion source allows furthermore to selectively ionize diverse other elements of potential interest such as Ag, Sn, Ga or Ni isotopes [8].

Summary of requested shifts:
We envisage to test two different Uranium Carbide materials in two separate target and ion source units in a standard configuration. In both cases, density, open porosity and stoichiometry will be controlled and tailored. First we will operate a Uranium Carbide target material, prepared at ISOLDE and as quoted before, coupled to a surface ion source for alkali elements and RILIS for the tests of Ag and Ni isotopes. In a second stage, we intend to test the UC_x+graphite discs composite developed at TRIUMF coupled to a surface ion source to study alkali elements. Tests will done by direct proton

irradiation or by neutron induced fissions for suitable elements.

Target and Ion Source	**Beam Time**
new sub-micro UC_x, ISOLDE design, RILIS, surface ionizer (W), n-converter,	one shift stable beam set-up + one shift to set up RILIS + 5 shifts for radioactive beam tests (direct p-irradiation and n-induced fission)
UC_x on exfoilated graphite TRIUMF design surface ionizer (W), RILIS	one shift stable beam set-up + one shift to set up RILIS + 5 shifts for radioactive beam tests (direct p-irradiation)

3 Conclusion and Summary

It is of primary importance for the various planned or operating worldwide ISOL-type facilities to carry out tests for the quoted newly developed uranium carbide targets in a systematic and standardized approach. The ISOLDE facility offers a unique place to perform such tests thanks to the large available database, the pulsed time structure and to the intense $1.4\,GeV$ proton beam. The performance of these units is expected to be better than the ISOLDE standard units at least for certain isotopes, and therefore appropriate for further use for physics experiments.

References

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises:

Part of the	Availability	Design and manufacturing
"Old" ISOLDE tape station	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
Fast ISOLDE tape station	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
SSP-GLM chamber	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT: Hazards named in the document relevant for the fixed SSP-GLM chamber, SSP-GHM chamber installation.

Additional hazards:

Hazards	"Old" tape station	Fast tape station
Thermodynamic and fluidic		
Pressure		
Vacuum	$1 \cdot 10^{-6}$ mbar	$1 \cdot 10^{-6}$ mbar
Temperature	77 K	77 K
Heat transfer		
Thermal properties of materials		
Cryogenic fluid	none	LN2: 1 bar, 100 l
Electrical and electromagnetic		
Electricity	3000 V, 10 mA	3000 V, 10 mA
Static electricity	none	none
Magnetic field	none	none
Batteries	☐	
Capacitors	☐	
Ionizing radiation		
Target material	UC_x	UC_x

Beam particle type	ions	ions
Beam intensity	$\leq 100\,\mathrm{pA}$	$\leq 100\,\mathrm{pA}$
Beam energy	$30-60\,\mathrm{keV}$	$30-60\,\mathrm{keV}$
Cooling liquids	none	none
Gases	none	none
Calibration sources:	☐	
• Open source	☐	
• Sealed source	☐ [ISO standard]	
• Isotope		
• Activity		
Use of activated material:		
• Description	☐	
• Dose rate on contact and in 10 cm distance	[dose][mSV]	
• Isotope		
• Activity		
Non-ionizing radiation		
Laser	none	none
UV light	none	none
Microwaves (300MHz-30 GHz)	none	none
Radiofrequency (1-300 MHz)	none	none
Chemical		
Toxic	none	none
Harmful	none	none
CMR (carcinogens, mutagens and substances toxic to reproduction)	none	none
Corrosive	none	none
Irritant	none	none
Flammable	none	none
Oxidizing	none	none
Explosiveness	none	none
Asphyxiant	none	none
Dangerous for the environment	none	none
Mechanical		
Physical impact or mechanical energy (moving parts)	none	none
Mechanical properties (Sharp, rough, slippery)	none	none

Vibration	none	none
Vehicles and Means of Transport	none	none
Noise		
Frequency	none	none
Intensity	none	none
Physical		
Confined spaces	none	none
High workplaces	none	none
Access to high workplaces	none	none
Obstructions in passageways	none	none
Manual handling	none	none
Poor ergonomics	none	none

Hazard identification: no hazards involved

Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): approx. 2kW per setup