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HEAVY ION PHYSICS

On line Release Simulator of Radioactive Beams produced by ISOL technique

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Abstract. Target and ion source constitute the heart for the production of radioactive ion beams, RIBs. The goal of this work is to help in the development of reliable and efficient target and ion source systems for production of short-lived isotopes of a wide range of elements by the ISOL method. With this aim an oracle database of diffusion and desorption parameters with more than 10.000 entries has been built. The database is accessible on line and a web application has been developed allowing the retrieval of information from the database in order to assist in the configuration of the input parameters for a Monte Carlo code, RIBO, for the simulation of target-ion source systems.

Keywords: Radioactive ion beam, release, diffusion, effusion, desorption, oracle database
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1. Introduction

The Isotope Separation On Line, ISOL, method has been used since 1967 at the ISOLDE facility at CERN [1],[2]. With this method, high-energy proton, neutron, heavy ion, electron or γ beams bombard thick targets such as uranium, lead, tantalum, etc... producing secondary nuclides by spallation, evaporation, fission or fragmentation reactions [3],[4]. The target used in the ISOL method is thick enough to stop the produced radioactive atoms. The ISOL method provides a wide range of short lived isotopes of different elements, which allows for systematic studies of the properties of nuclei far from beta stability.
By means of the ISOL method very intense beams (up to several 10^{12} ions/s) of

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radioactive ions can be obtained [5]. The produced nuclei in the reactions inside the heated target diffuse and then effuse towards the ion source [6],[7]. Since the exotic nuclei are only produced in low amounts and have short half life, the release from the place of production has to be as fast as possible, i.e. the nuclei must reach the ion source, be ionized, accelerated and mass separated before they decay. The improvement in the release time is the major objective in the development of target and ion source units and it has been the goal of the TARGISOL project [8]. The release efficiency depends on the diffusion in the target, random walk effusion to the ion source and adsorption/desorption processes at the surface for each collision. In this paper we will present our approach to the simulation of the release mechanism of the radioactive ion beams. We discuss in section 2 the basic principles of the radioactive ion beam extraction focussing on the relevance of the diffusion and desorption parameters stored in the developed database DifEfIsol [8], essential for the improvement of the release parameters. In the subsections 2.1 and 2.2 the ion source and release efficiencies are described. After describing in section 3 the Oracle database DifEfIsol, in the last section 4, the Web Application that connects directly to a MonteCarlo code [9] to simulate the production process is illustrated. This tool offers an efficient way for designing and developing new targets and ion source systems.

2. Radioactive Ion Beam production

The unavoidable delay time of the produced species from the place of creation to extraction from the ion source depends on the radionuclide, target material, ion source, geometry and the experimental conditions as arrangement of the target material inside the target. The beam intensity, I, provided to the users in a ISOL facility is affected by these factors, and it can be written [5],[6]:

$$I = \phi\ \sigma\ N\ \varepsilon_{tr}\ \varepsilon_{is}\ \varepsilon_{r} \tag{1}$$

The production in the target is determined by the product $\phi\ \sigma$ N, where ϕ is the flux of primary particles, σ is the cross-section to produce the desired nucleus and N the number of target atoms exposed to the primary beam. The transmission loses of the mass separator and subsequent transport to the set up are represented by ε_{tr}, whose value is normally close to unity [5]. ε_{is} and ε_{r} are the ion source efficiency and the release efficiency, respectively.

2.1. Ion Source efficiency

There is no universal ion source suitable for all elements in the periodic table, but they can be put into groups according to their similar physical and chemical properties, and only in some cases the ion source efficiency, ε_{is}, needs to be optimized for each individual element [6]. The alkalis, alkaline earth and rare earth elements have in common their low ionization potential (3.9-6 eV), which allows a very efficient

Table 1. Measured ionization efficiencies from ISOLDE elements selected by different ion sources: Surface (S), Plasma (P) and Laser ion source (RILIS).

Elem	Ionization efficiency	Ionization Method	Ref	Elem	Ionization efficiency	Ionization Method	Ref
He	0.14	P	[12]	Sn	10	RILIS	[24]
Li		S	[13]	Sb		P/RILIS	
Be	>7	RILIS	[14]	Te		P	
C		P		I	∼50	Neg Surf	[16]
N		P		Xe	11	P	[12]
O		P		Cs		S	
F		P		Ba		S	
Ne	0.36	P	[12]	La		S	
Na		S		Ce		S	
Mg	10	RILIS	[14]	Pr		S	
Al	>20	RILIS	[15]	Nd		S	
Cl	∼50	Neg Surf	[16]	Pm		S	
Ar	2	P	[12]	Sm		S	
K		S		Eu		S	
Ca	0.45	RILIS	[15]	Gd		S	
Sc		S/RILIS		Tb		S/RILIS	
Mn	19	P/RILIS	[17], [18]	Dy		S/RILIS	
Co	>4	RILIS	[15]	Ho		S	
Ni	>6	RILIS	[19]	Er		S	
Cu	>7	RILIS	[20]	Tm		RILIS	[13]
Zn	5	RILIS	[21]	Yb	15	RILIS	[13]
Ga	21	RILIS	[15]	Lu		S	
Ge		P		Hf		P	
As		P		Au	>3	RILIS	[25]
Se		P		Hg		P/RILIS	
Br	∼50	Neg Surf	[16]	Tl	27	RILIS	[15]
Kr	4.3	P	[12]	Pb	3	RILIS	[26]
Rb		S		Bi	6	RILIS	[15]
Sr		S		Po		P	
Y		S/RILIS		At		P	
Pd		S		Fr		S	
Ag	14	RILIS	[22]	Ra		S	
Cd	10	RILIS	[23]	Ac		S	
In		P/RILIS					

ionization on a high temperature metallic surface (surface ionization, S). The low chemically active metals can be ionized by plasma ion source. A controlled electron beam of a few hundred eV removes the external electrons of the incoming atoms in a plasma filled high temperature cavity with a low magnetic field [10] (plasma ion source, P). In principle an individual ionization scheme for the resonance excitation with a laser in a high temperature metallic cavity (RILIS, Resonance Ionization Laser Ion Source method) can be developed for 75% of the elements [11]. Presently

at ISOLDE at least 25 elements have been successfully laser ionised with very high selectivity.
The Monte Carlo simulation code, RIBO, is able to simulate the surface ionization process of a combination of isotope and geometry of the ionizer, and the ionization efficiency is obtained as output of the program. Likewise the plasma ion source can be simulated, but the complete validation of the code is under progress. In order to help in the choice of the appropriate ion source, Table 1 shows a compilation of experimental ionization efficiencies of isotopes produced at ISOLDE. The type of ion source is shown for the produced elements indicating the obtained ionization efficiencies. It should be notice, that some elements can be extracted by more than one method. Practically all surface ionized can be ionized by plasma ion source as well, but with a lower selectivity (not shown in the table). Ca, Tl, Ga, Al and Yb can be ionized by surface ion source as well as by RILIS as is shown in the table, and Mg, Cd, Sn, Mn, Au, Pb and Bi and are ionized by a hot plasma ion source.

2.2. Release efficiency

In the experiments only a fraction of the nuclei are able to escape from the target-ion source unit before decay. Therefore, the decay probability, $e^{-\lambda_n t}$, has to be considered in the calculation of the beam intensity, I (see Eq.(1)) [27]. The simulation of the diffusion and effusion processes in the target-ion source unit with the Monte Carlo code [9] gives us the release function P(t) [28]. The product $e^{-\lambda_n t}$ P(t) represents the release probability at a time t for a nuclei with a decay constant λ_n to be released and not yet decayed at time t. Therefore, the release efficiency is given by [27]:

$$\varepsilon_r = \int_0^\infty P(t) e^{-\lambda_n t} dt \tag{2}$$

The individual release time of every produced isotope, i (history in the simulation), can be calculated as $T^i_{tot} = t^i_{diff} + t^i_{eff} + N^i_{col} t^i_s$. Where t^i_{diff} is the time spent in the diffusion process, t^i_{eff} is the effusion time, N^i_{col} the number of collisions with the surfaces and t^i_s the sticking time in the surfaces. It is noticeable that a fast diffusion in the target and rapid desorption from the surfaces will improve the release time and efficiency. The database DiEffIsol has been designed to help in the selection of the materials that form the target-ion source unit.

3. DifEfISOL: Diffusion Effusion Database

The choice of the target (material, structure, working temperature...) is one of the most challenging questions associated with ISOL facilities [29],[30],[31].
Target material selection begins by considering the physical, chemical and thermal properties of the target material in relation to those of the product species. In order to maximize the release of radioactive atoms from a target material, it is desirable to heat the target material to the limit set by the vapor pressure of the target

without compromising the ion source efficiency. The dependence of the diffusion coefficient D on the target temperature T is given via the Arrhenious equation $D(T) = D_0 e^{-E_a/kT}$, where D_0 is a constant dependent on the target and diffusing element, E_a is the activation energy and k the Boltzman constant. A compilation of more than 1500 diffusion coefficients is stored in the DifEfISOL database, accessible via the URL http://www.targisol.csic.es (for details see ref. [32]).
The residence time (sticking time), τ, of a particle on a surface is given by the Frenkel equation $\tau = \tau_0 e^{-H_{ad}/kT}$, where H_{ad} (negative) is the adsorption enthalpy required to evaporate the atom or molecule from the surface, k is the Boltzmann's constant, T is the absolute temperature, and τ_0 is the time required for single lattice vibration ($\sim 10^{-13}$s). The adsorption enthalpy increases with increasing bonding between the adsorbed atom and the surface where the adsorption takes place. This value varies widely depending upon the adsorbent/adsorbate combination. From the Frenkel equation it is clear that the choice of the materials for the construction of the container, transfer line and ion source is important. Refractory noble metals have low adsorption enthalpies and are used as coating materials for the interior surfaces [33], but there is practically no experimental data of H_{ad} and obviously its value depends strongly on the chemical treatment and surface structure of the material. Therefore, the database (DifEfISOL [32]) uses the semi-empirical Miedema Eichler model to calculate H_{ad}. This model is based on ab-initio quantum mechanical calculations as well as empirical correlations [34],[35]. The Web application [8] calculates the sticking time τ for a selected element in an array of materials for the specific temperature. In this way, a comparison can be done and facilitate the selection of the coating material.

4. IRES: Isotope RElease Simulator

Recently a Monte Carlo code has been developed for the simulation of these ISOL targets. The code tracks the nuclei produced within the target until they are released from the ion source (for details see [9]). The simulation follows the path of a created nucleus from different possible targets to a plasma (FEBIAD) or surface ion source. The code allows to simulate targets formed by powders or fibers with variable geometries. The Isotope RElease Simulator (IRES) is a user-friendly on line GUI interface for generating the input parameters for the Monte Carlo code, and the web interface to its invocation. PL/SQL language and JavaScript has been used to programm the web application. Its function is to collect the raw parameters with which the user wishes to run the simulation, make sure all parameter values are valid before submission to the web server where the code is running.
Once all the configuration parameters are sent, they are processed to match the simulation's input format via a Python CGI script. Finally a series of scripts make sure that the simulation runs and sends an email to the user with the results as well as a histogram of the release time.

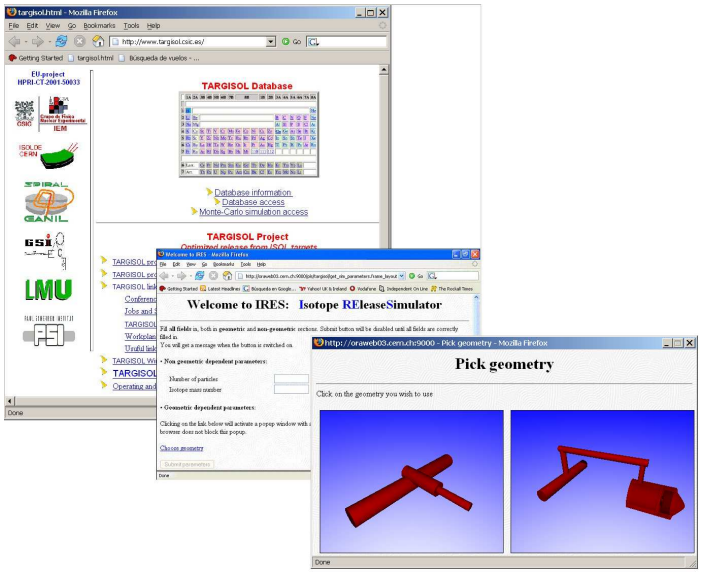

Fig. 1. View of the web page (http://www.targisol.csic.es) to access the database and the Monte Carlo simulation tool. The insert illustrates the page where the geometric and non-geometric parameters are required and the geometry to be selected by the user.

5. Conclusions

The release efficiency depends on the diffusion in the target, random walk effusion to the ion source and adsorption/desorption processes at each surface collision. Therefore a simulation of these three processes allows for the study of the optimal geometry and composition of the target and ion source system before its fabrication with entire reliability. The Monte Carlo code RIBO [9] simulates and tracks nuclei as function of the geometry and materials being used. The oracle database accessible via internet, DifEfISOL contains the diffusion parameter and adsorption enthalpy to be used for the choice of material and temperature in the target-ion source unit for the production of a radioactive ion beam. The web interface IRES provides remote access to the simulator allowing to specify the simulation parameters and run the simulation.

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Notes

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