SELECTION OF TARGET MATERIALS FOR RADIOACTIVE ION BEAM GENERATION

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In order to successfully perform nuclear physics and astrophysics research with radioactive ion beams (RIBs) at ISOL based facilities, intensities ranging from 10^5 to 10^{13} particles/s must be delivered to the experimental station in a time commensurate with the lifetime of the species in question. Since the time required for diffusion of the isotope of interest from a solid material depends exponentially on the target temperature, it is desirable to heat the target to temperatures as high as practical. The RIB intensity is determined by the production rate which, in turn, depends on the product of the reaction cross section and the primary beam intensity. The primary beam intensity is set by the maximum permissible, on-target, power-density that can be used without exceeding the limiting temperature of the target material at which the vapor pressure of the target material begins to compromise the ionization efficiency of the source. Every ion source has a characteristic pressure onset beyond which the ionization efficiency begins to precipitously drop. For example, the limiting vapor pressure is $\sim 2 \times 10^{-4}$ Torr for the Electron Beam Plasma Ion Source (EBPIS) used at the Holifield Radioactive Ion Beam Facility (HRIBF). The limiting vapor pressure method, along with diffusivity information for the particular radioactive species/target material combination, is routinely used in the selection of candidate target materials for use at the HRIBF. The material selection/evaluation process is greatly facilitated by the use of data based thermo-chemistry and thermodynamic codes such as ThermoCalc,[1] ChemSage,[2] and HSC[3] to calculate vapor pressures, thermal equilibrium compositions, dissociation temperatures, chemical reactions, etc. This method has been experimentally validated for several targets used at the HRIBF including Ni, Ge, Al_2O_3, ZrO_2, HfO_2 and UC_2. It has been used to select all target materials used to date at the HRIBF as well as a list of refractory candidate target materials for production of radio-nuclei with high-energy proton beams. Table I and Table II, provide, respectively, lists of target materials and their limiting temperatures for the production of proton-rich and neutron–rich radio-nuclei with 1 GeV proton beams. Although the product species listed for a given target material can be produced through the respective nuclear reactions, not all of the species can be efficiently diffused from the particular target material because of unfavorable physical and chemical properties of particular species/target material combinations.

Table I. A partial listing of candidate target materials for spallation production of proton-rich radio-nuclei with 1 GeV protons.

Target Material	Limiting Temp. °C	Product Species
BeO	2230	He → F
C	1975	He → N
Al_2O_3	1725	He → Si
SiC	1700	He → P
VC	1930	He → Cr
Sc_2O_3	1775	He → Ti
Zr	2030	P → Mo
ZrC	2375	P → Mo; He → N
Y_2O_3	1950	He → F; Al → Zr
ZrO_2	2050	He → F; Si → Nb
ZrC	2180	He → N; Si → Nb
Nb	2080	P → Mo
NbC	2220	He → N; P → Mo
CeC_2	2390	He → N; Cu → Nd
CeO_2	1900	He →O; Cu → Cu
HfO_2	2200	He → Re
Ta	2650	He → Os
TaC	2340	He → Os
W	2863	He → Ir
WC	2480	He→ Ir
Re	2600	He → Pt
ThC_2	2650	He → U
UC_2	2100	He → Pu

Table II. A listing of neutron-rich radio-nuclei produced by proton induced fission reactions in UC_2 and ThC_2. Proton energy: 1 GeV.

Target Material	Limiting Temp. °C	Product Species
UC_2	2100	As → Dy
ThC_2	2650	As → Dy

[1] ThermoCalc is a data based software package for calculating thermodynamic chemical reactions and phase diagrams developed by the Royal Institute of Technology, Stockholm, Sweden.
[2] ChemSage is a data based computer code for solving a variety of thermo-chemical equilibrium problems marketed by GTT- Technologies, Herzogenrath, Germany.
[3] HSC is a data based thermodynamics and thermo-chemistry code for calculating a variety of chemical reaction, heat balance, equilibrium composition, and phase diagram problems and is a product of Outokumpu Research, Oy, Pori, Finland.