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STUDY OF THE STRIPPING SCHEME FOR THE ISL FACILITY

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To achieve the acceleration of very low charged ions with good efficiency and low cost the charge to mass ratio must be increased by using stripper. In the ISL conceptual design two or more strippers are considered. The total voltage needed to reach the final energy depends on the stripping energy. Using the charge distributions, one can estimate the residual intensity at the end of the LINAC.

KEY WORDS: Stripping, radioactive beams, ISL, ISOL, charge state distributions

1 INTRODUCTION

The basic principle of the ISL facility is shown in Figure 1. The accelerator is composed in four sections. In this scheme there are strippers placed between the radio frequency quadrupole RFQ and the drift tube linear accelerator DTL, between the DTL and LINAC1, and finally between LINAC1 and LINAC2. The initial charge state of the ions coming from the ion source is assume to be 1^+ or 1^-. The charge to mass ratio must be greater than 1/20 after the first stripper, 1/6 after the second and 1/4 after the third one. In this paper the third stripper is not considered since the efficiency will be very high. Most of the light ions will be fully stripped.

2 CHARGE STATE DISTRIBUTION

The charge state distribution of an ion after passage through matter depends on the velocity and the atomic number Z. We assume that the initial charge state is much lower than the equilibrium charge state. There are many empirical formulae describing the charge state distribution after stripping. Betz *et al.*[3] has used the experimental data on many ions stripped in air and formvar foils at energies between 5 and 80 MeV to derive a semi-empirical relation for average charge state

$$\frac{\bar{q}}{Z} = 1 = C \exp\left[-v/(v_0 Z^{\gamma})\right] \tag{1}$$

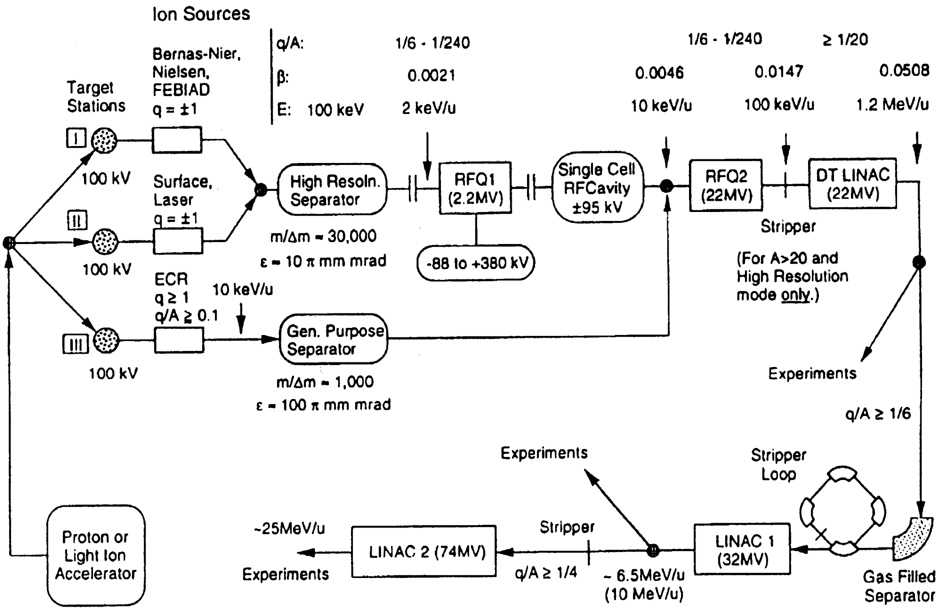

FIGURE 1: ISL Concept

where Z is the projectile atomic number, v its velocity, v_0 the Bohr velocity = c/137. C is a constant close to 1 and γ between .5 and .6.

This formula was modified by Baron et al.[1]

$$\frac{\bar{q}}{Z} = 1 - C \exp\left[-83.275\beta/Z^{\gamma}\right], \tag{2}$$

where β is the projectile velocity and light velocity ratio, C is a function of energy for energy. $C = 0.9 + 0.0769^{*}W$ for energy lower than 1.3 MeV/u, and $C = 1$ for energy higher than 1.3 MeV/U, and γ is fixed at 0.477

Supposing that no significant shell effects are present and $\bar{q}$ is not too close to Z, the distributions are assumed to be Gaussian with standard deviation d as proposed by Nikolaiev and Dmitriev[4]

$$d = \frac{1}{2}\sqrt{\bar{q}\left(1 - (\bar{q}/Z)^{1.67}\right)} \tag{3}$$

Small modifications where reported recently by Baron *et al.*[2] in order to take into account deviations observed for masses greater then Krypton.

For a gas stripper the relation is different. Using the data contains in Reference 3 we can express the average charge state to atomic number ratio for energy lower than 1.5 MeV/u by using a relation similar to Nikolaiev and Dmitriev[4] relation for foil stripper

$$\frac{\bar{q}}{Z} = \left[1 + \left(Z^{-.55} v/v'\right)^{-\frac{1}{.76}}\right]^{-1.12} \tag{4}$$

where $v' = 3.6 \times 10^8$ cm/s. In the case of a gas stripper the charge state distribution is not symmetric. It can be written in the following form

$$F(q) = \left(d\sqrt{2\pi}\right)^{-1} \exp\left(-|q - \bar{q}|^u / \left(2d^2\right)\right), \tag{5}$$

where d is the width and u the shape parameter of the distribution.

$$u = 2.24 \text{ if } (q - \bar{q}) \leq 0,$$
$$u = 1.83 \text{ if } (q - \bar{q}) \leq 0. \tag{6}$$

The distribution width in a wide range of both Z and particle velocity show great regularity. The distribution width can be approximate using the simple relation,

$$d = d_1 Z^w \tag{7}$$

Where the parameter d_1 and w have been determined empirically via the mean charge state and the amount to 0.32 and 0.45 in N_2 or Ar gas, and to 0.38 and 0.40 in C, respectively.

3 TOTAL VOLTAGE

Using these empirical relations, we can find the minimum voltage needed to reach a given final energy. The total voltage needed for the acceleration by the drift tube linacs up to the final energy depends on the Q/A from the ion source and on the charge state after stripping

$$E = (Q/A)_{\text{IS}} V_{\text{IS}} + E_{\text{RFQ}} + (Q/A)_{\text{Strip\#1}} V_{\text{DTL\#1}} + (Q/A)_{\text{Strip\#2}} V_{\text{DTL\#2}} \tag{8}$$

where

$(Q/A)_{\text{IS}}$ is the charge to mass ratio of the ion coming from the ion source,

V_{IS} is the high voltage of the ion source,

E_{RFQ} is the energy after the RFQ,

$(Q/A)_{\text{Strip\#1}}$ is the charge to mass ratio after the first stripper,

$V_{\text{DTL\#1}}$ is the voltage of the first drift tube linac,

$(Q/A)_{\text{Strip\#2}}$ is the charge to mass ratio after the first stripper,

$V_{\text{DTL\#2}}$ is the voltage of the first drift tube linac.

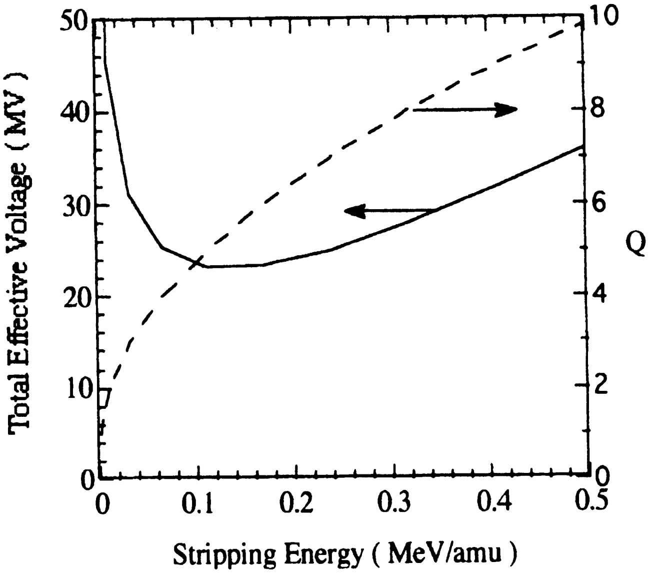

FIGURE 2: Total effective voltage needed to reach 1.5 MeV/amu for $^{60}Ni^{1+}$ as a function of the stripping energy using a gas stripper. The dashed curve shows the charge state after stripping.

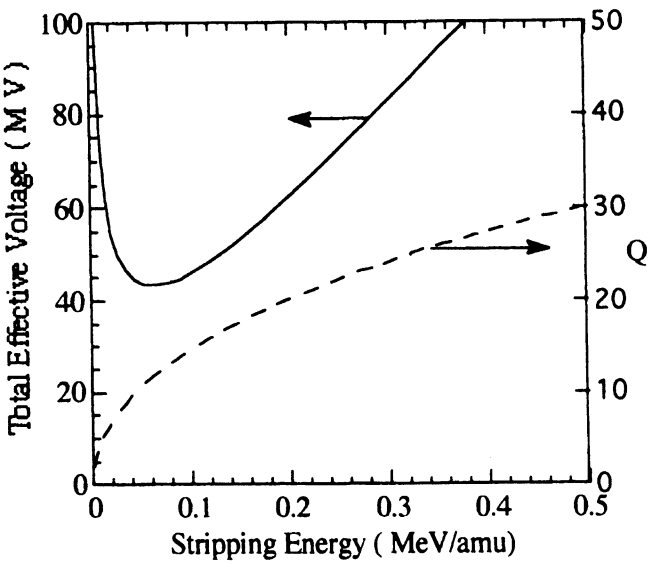

FIGURE 3: Total effective voltage needed to reach 1.5 MeV/amu for $^{238}U^{1+}$ as a function of the stripping energy using a carbon foil stripper. The dashed curve shows the charge state after stripping.

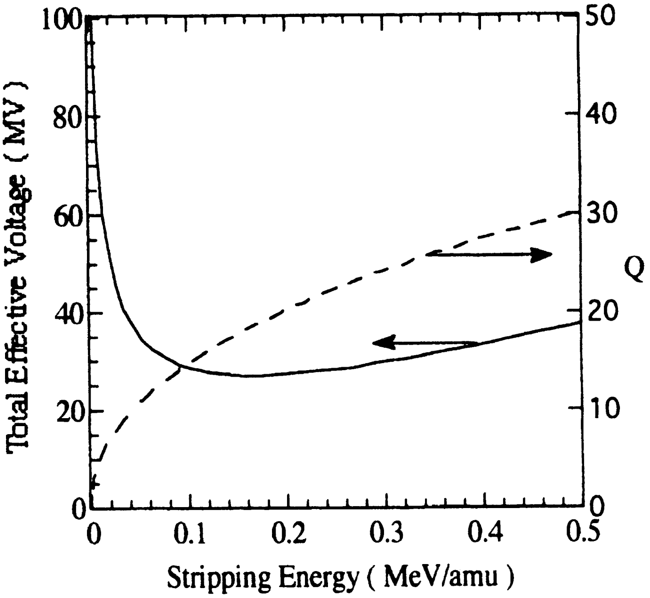

FIGURE 4: Total effective voltage needed to reach 1.5 MeV/amu for $^{238}U^{4+}$ as a function of the stripping energy using a carbon foil stripper. The dashed curve shows the charge state after stripping.

The minimization of the total voltage for the first stripper is not the only requirement, because if we want to use a carbon foil the energy must be high enough in order to use practical equilibrium thickness. If the energy is too low, a gas stripper must be used, but the charged states are lower.

3.1 First Stripper

For the first stripper the final energy of the DTL section is 1.5 MeV/u. This is mainly governed by the astrophysics and applied physics program. Figures 2 and 3 show the total voltage needs to reach 1.5 MeV/u as a function of the stripper energy for mass 60 and 238 respectively. The minimum is found to be around 0.140 MeV/u for mass 60 and 0.06 MeV/u for mass 238.

The used of multi-charged ions can decrease the total voltage needs to reach the final energy. Figure 4 shows the total voltage in the case of $^{238}U^{4+}$.The total voltage is decreased considerably, 26 instead of 42 MV. In this case the minimum is found around 175 keV/u for the first stripper.

3.2 Second Stripper

For the second stripper the final energy of the LINAC1 section is 10 MeV/u. Figures 5 and 6 show the total voltage necessary to reach this final energy as a function of the energy at the

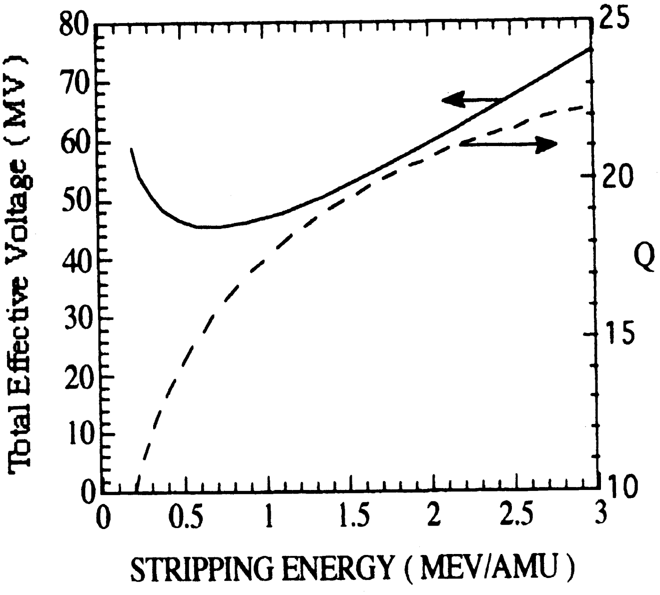

FIGURE 5: Total effective voltage needed to reach 10 MeV/amu for $^{60}Ni^{3+}$ as a function of the stripping energy using a carbon foil stripper. The dashed curve shows the charge state after stripping.

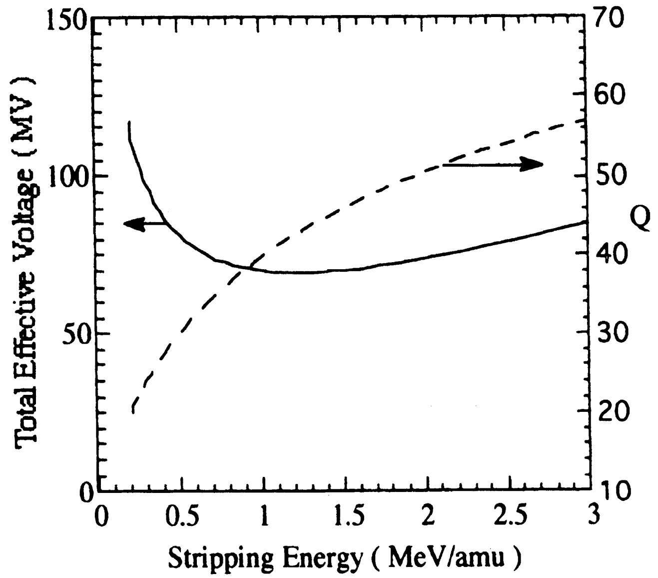

FIGURE 6: Total effective voltage needed to reach 10 MeV/amu for ^{238}U as a function of the stripping energy using a carbon foil stripper. The dashed curve shows the charge state after stripping.

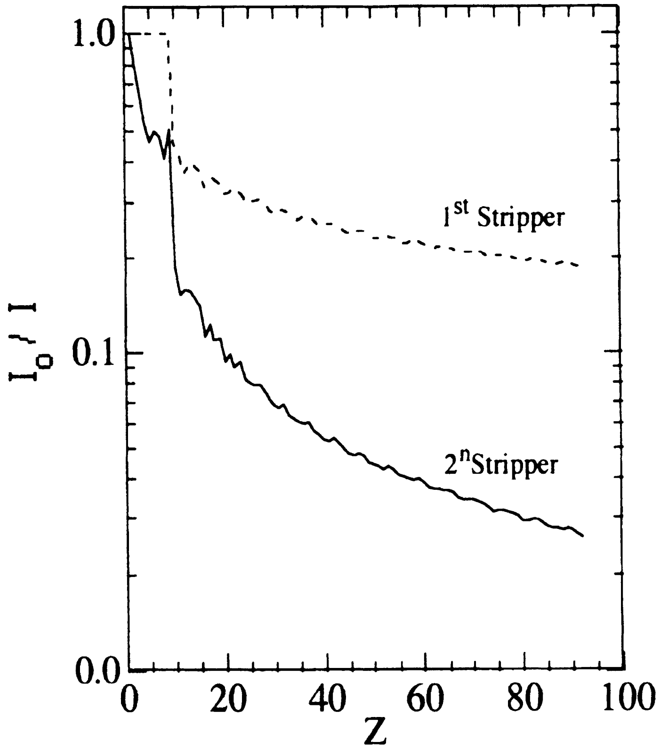

FIGURE 7: Residual intensity after the first and second stripper. The first stripper is a carbon foil and the stripping is done at 100 keV/amu. The second stripping is done at 1.5 MeV/amu using a carbon foil.

second stripper. The minimum is found to be around 1.2 MeV/u. This is in agreement with the natural break suggested to be around 1.5 MeV/u for astrophysics and applied physics programs.

4 RESIDUAL INTENSITY

The final intensity at the end of the accelerator will depend on the stripping scheme. Using the charge distributions 5) one can evaluate the residual intensity after stripping. Figure 7 shows the residual intensity as a function of the atomic number Z assuming that the first stripping is done at 100 keV/u and the second at 1.5 MeV/u. The dashed curve shows the relative intensity after the first stripper and the full line shows the relative intensity after the second stripper. The relative intensity after stripping decrease with the atomic number Z in the worst case the final intensity is about 3% of the initial intensity.

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