Wall distribution of ions externally injected for charge-breeding in ECRIS

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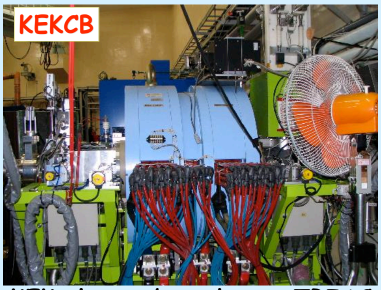


KEK charge breeder at TRIAC (18GHz ECRIS)

An isotope separator online (ISOL) based radioactive ion beam facility, named Tokai Radioactive Ions Accelerator Complex (TRIAC), is now operational under the collaboration between KEK and JAEA. KEKCB is a 18GHz ECR charge breeder operating at TRIAC. Employing the KEKCB, we have successfully converted singly charged ions of short-lived radioactive nuclei into the multi-charged ions with a charge-to-mass ratio of about 1/7. However, we observed large difference in charge breeding gaseous and non-gaseous ion species, i.e. in the injection optics and the resultant charge breeding efficiencies. In order to understand the difference, we investigated how the ions, externally injected to the ECR plasma of KEKCB for breeding their charge states but failed to be re-extracted, are distributed on the wall (surface) of the plasma chamber. To investigate the distribution, we had injected and charge-bred radioactive singly-charged ^{111}In ions with a half-life of 2.8 days. After the operation, we extracted the distribution of the ^{111}In by measuring the residual activity on the wall of the chamber. We have observed an azimuthally asymmetric distribution around the B_{min} of axial field configuration on the top of rather symmetric and isotropic distribution.

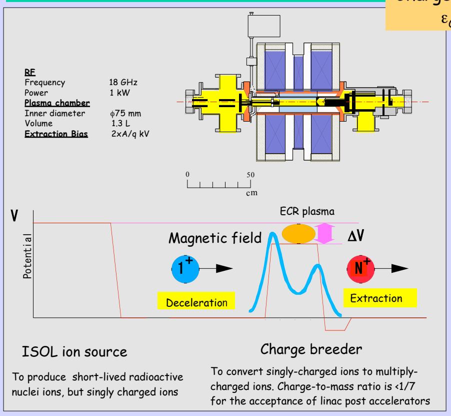
Motivation:

Why element-dependent charge breeding efficiencies; metallic or gaseous ?

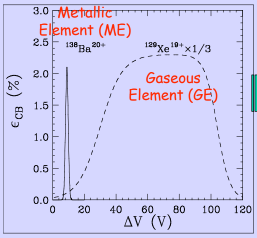
Charge breeding can be considered as two subsequently-separated processes.
(1) **Stopping:** Deceleration of ions to almost zero energy and capture by ECR plasma.
(2) **Ionization:** Step-by-step ionization of captured ions to multiply-charged ions.

Charge breeding efficiency (ε_{CB}) can be written as following;
$\varepsilon_{CB} \sim \varepsilon_{stopping} \times \varepsilon_{ionization}$.

Looking at ion loss distribution in ECR plasma, the "WHY" might be identified, i.e. which processes is rate-determining.
➔give us a good hint, essential for better understanding charge breeding in the ECR charge breeder and further development for higher breeding efficiencies



Electrical potential configuration (Deceleration and Extraction)



Charge breeding efficiencies vs. ΔV.
ΔV is the electric potential for fine-adjusting the energy of ions at injection into the ECR plasma, closely related to ECR plasma potential.

Element dependence

ΔV acceptance: very sensitive for metallic ions

Charge breeding efficiencies: $\varepsilon_{metallic} \sim 1/3 \varepsilon_{gaseous}$

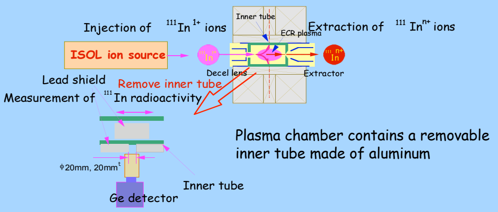
The difference might be due to the wall-loss during charge breeding. For GE, relatively free from the wall-sticking effect !? For ME, hardly to be recycled, once being sticked to the wall.

Question. When ? During stopping or Ionization ?

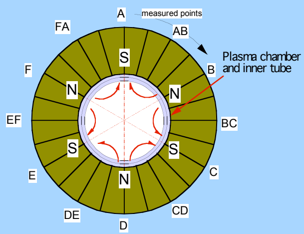
ION LOSS DISTRIBUTION : Strong asymmetric distribution might be caused by not-well optimized injection (deceleration) optics, while symmetric and/or isotropic distribution by not-well optimized plasma parameter for efficient capture and further ionization.

Charge breeding experiment for radioactive ion of ^{111}In ($T_{1/2}$~ 2.8d)

To investigate the behavior of ions injected for charge breeding, we measured γ-ray residual radioactivity of ^{111}In deposited on the wall of plasma chamber after charge breeding experiment.

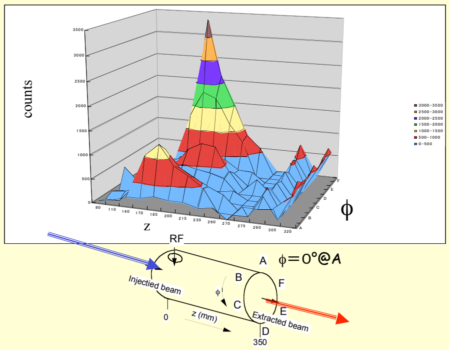


Experimental set-up for charge breeding and measuring the residual radioactivity of ^{111}In on the surface of inner tube.



Hexapole radial magnetic field and definition of measured points around the chamber. Viewed along the ion beam direction.

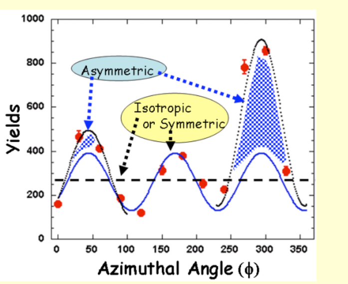
Experimental results (1)



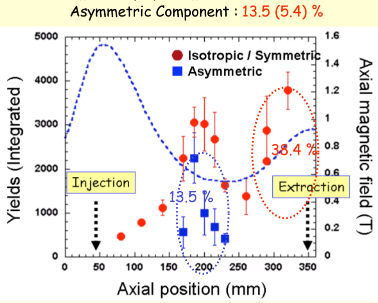
Contour plot of ^{111}In deposited on the surface of the inner tube. The interpolation is not rigorous, just for eye-guiding.

Experimental results (2)

Radial Loss Fraction
Isotropic / Symmetric Component : 86.5 (14.1) %
Almost half of them to extraction side !
Asymmetric Component : 13.5 (5.4) %



A typical azimuthal distribution of ^{111}In around Bmin. Decomposed into 3 components; azimuthally isotropic, symmetric (120 degree rotational symmetry), and asymmetric ones.



Longitudinal distribution of ^{111}In. Three components, as defined in the left figure, are shown separately. Axial magnetic filed configuration is also given for comparison.

Discussion & Summery

①Azimuthal Loss Distribution
Almost isotropic *around both end of plasma chamber*
Symmetric (120 degree Rotational Symmetry)
(possibly associated with hexapole radial field)
+ Asymmetric *around Bmin*
②Longitudinal Loss Distribution
Localized around Bmin and Extraction side (56 vs. 44)

△ ***Why & How localized around the extraction side ?*** (38.4 %)
➔Not enough stopping power of the present ECR plasma ?
➔Or, poor deceleration (causing large energy aberration) ?
➔Or, during the ionization ?
◎***Asymmetric component could be removed by more careful optimization for the injection?*** (13.5 %)