National Research Centre
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Experimental study of electrostatic residual ion dump

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Reference design of the Residual Ion Dump (RID) for the ITER NBI system is based on an electrostatic deflection of the residual negative and positive ions to in-line dump panels.

According to 4-channels beam line concept, RID forms four narrow (about 100 mm in width) vertical channels with the aid of 5 panels (1.8 m long and 1.7 m in height). Two middle panels are negatively biased with about -20 kV.

This concept has the advantage of compact design with quite moderate power density (PD) load onto the panels – peak PD is less 8 MW/m2.

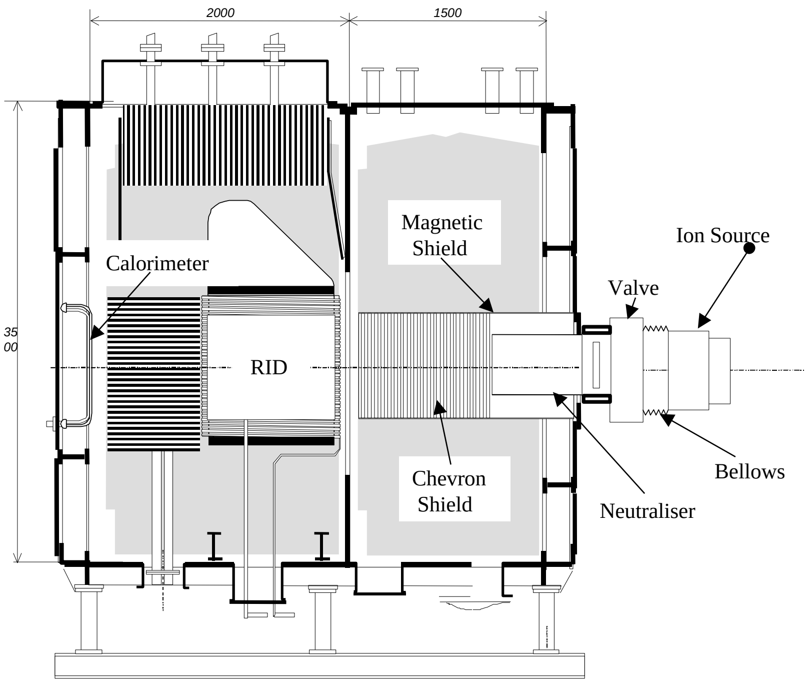
However, such a concept has never been earlier tested in any operating NBI system, all of them used magnetic deflection systems with remote ion dumps.

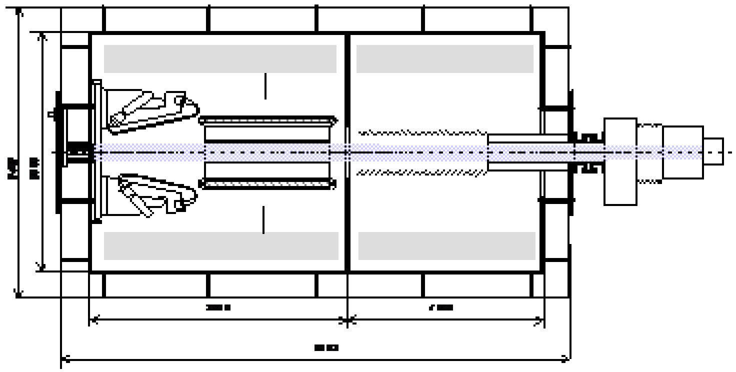
Experimental investigation of the electrostatic RID concept was done at the test stand IREK in the Kurchatov Institute.

- positive hydrogen and helium ion beam;
-one RID channel with two panels, one panel under negative potential;
-magnetic system which produces rather uniform vertical magnetic field in the RID volume.

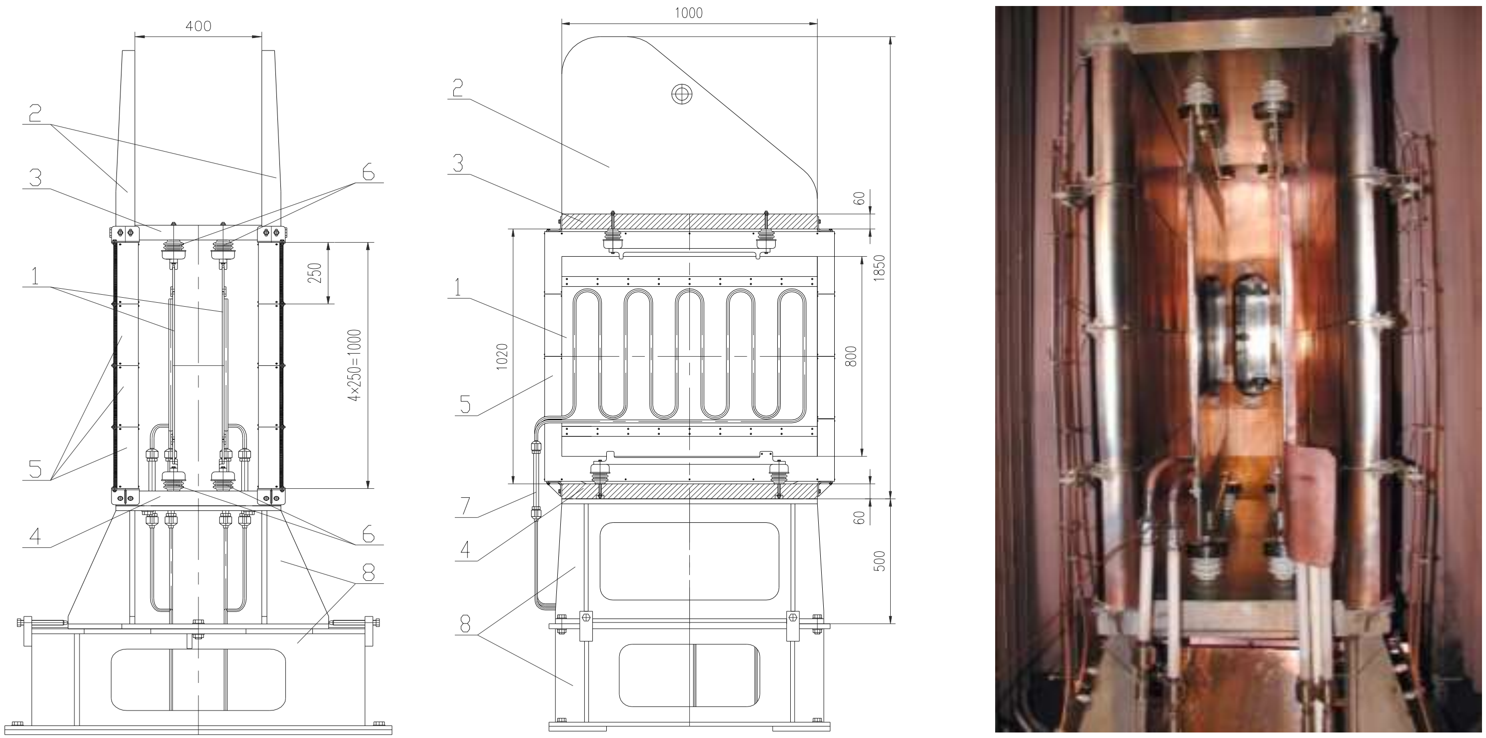
The main physical questions are:

- influence of the ion beam space charge on the RID deflection properties;
- secondary electrons production and their behaviour in the crossed electric and magnetic fields, that can have an influence on the high voltage holding and state of operability.





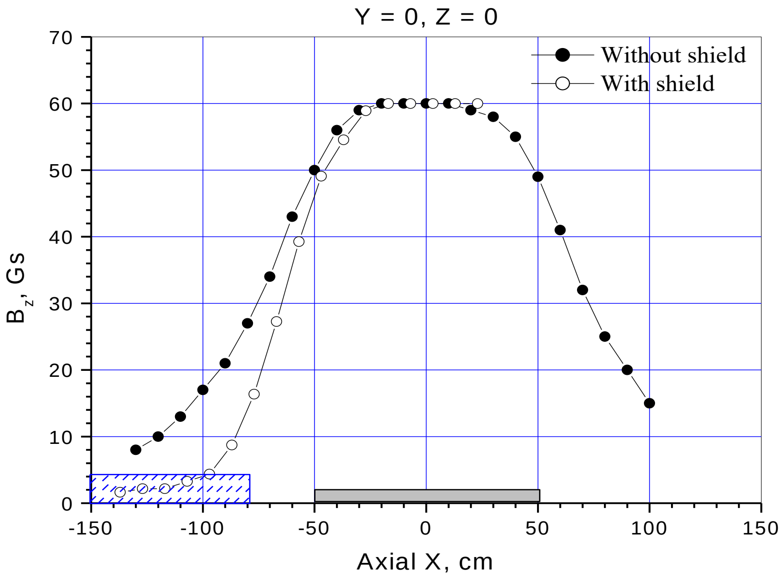
The experimental RID model layout in vacuum vessel of the IREK test injector. Ion source with multi-slit extractor 12x36 cm can produce a beam of positive hydrogen ions with maximum parameters 60 A/60 keV/1.5 s.

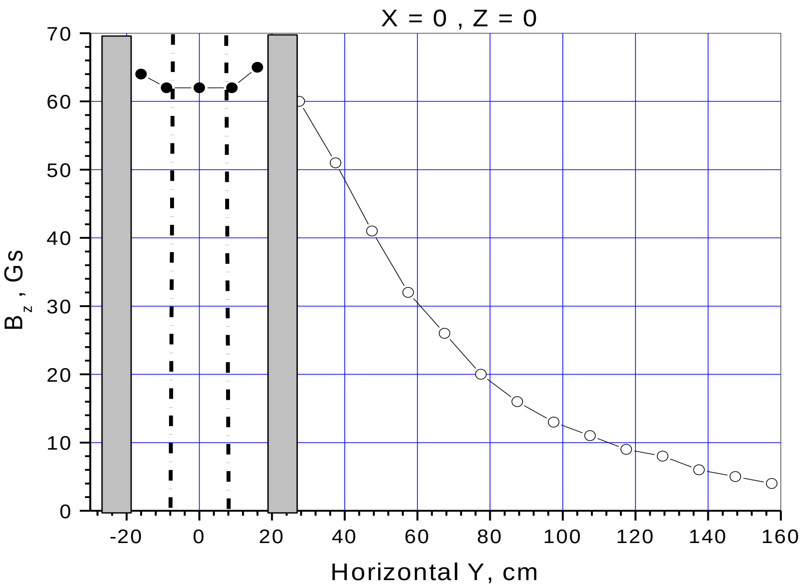


The experimental RID model axial and side views.

1 – RID panels; 2 – Magnetic box side plates – electromagnet cores; 3, 4 – Top and bottom magnetic conductors; 5 – Electromagnetic coils; 6 – Support insulators with screen caps; 7 – Cooling water tube insulation insert; 8 – Support frames.
RID inside the IREK vacuum vessel (view to the ion source, dumping panel under negative potential is on the right).

Vertical magnetic field distributions in the RID MS (total current in 8 coils - 110 A).





Vertical magnetic field profiles in the RID area along and across beam axis (8 electromagnet coils total current is 105 A, local coordinate system origin is in the RID centre)

Advantage of such MS configuration - very uniform B_z inside the “magnetic box”.
Disadvantage - quite high magnetic flux at the both sides of the box.

The RID magnetic system (MS) is to provide a vertical magnetic field (B_z) to simulate the ITER NBL conditions.

Secondary electrons drift in the crossed **ExB** fields occurs when a cycloid height becomes less than the channel width.

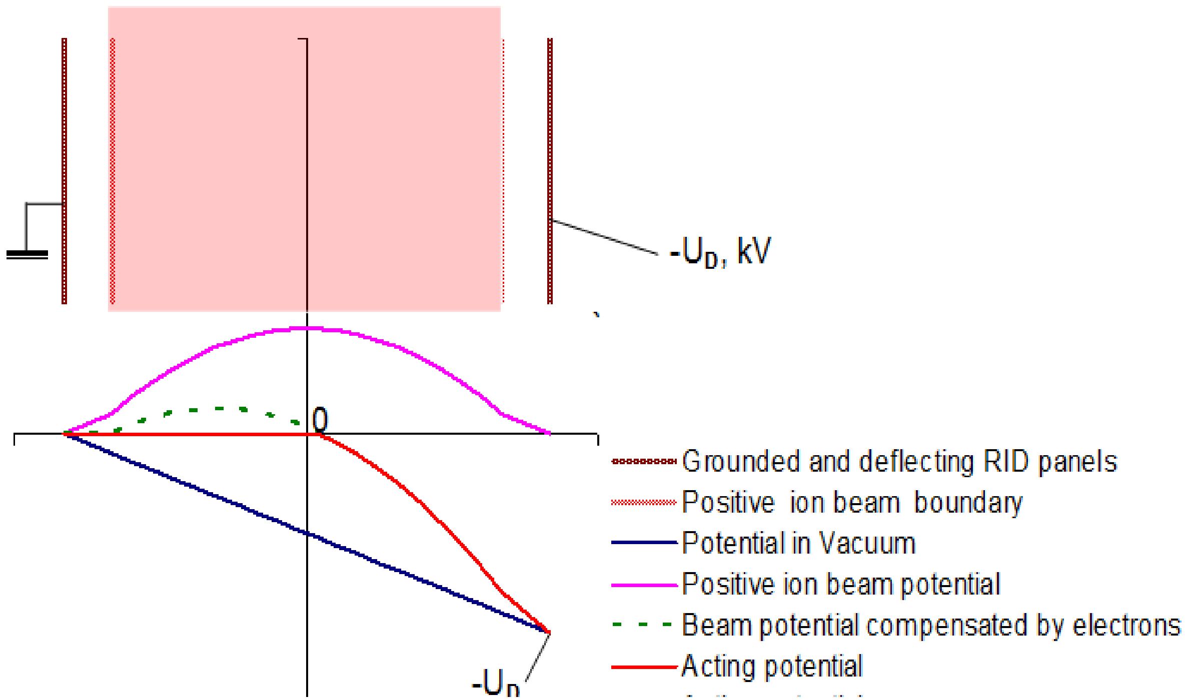
$$h = 11.4\ E/B^2 < d \quad [\text{cm, V/cm, Gs}]$$

For U_d = -9 kV this requires B_z > 21.5 Gs.

Moreover, the MS is designed to produce B_z up to 130 Gs.
This gives an ability to carry out an investigation of the residual ion beam deflection in horizontal plane and its damping on the panels with use of the magnetic field only (Magnetic RID).

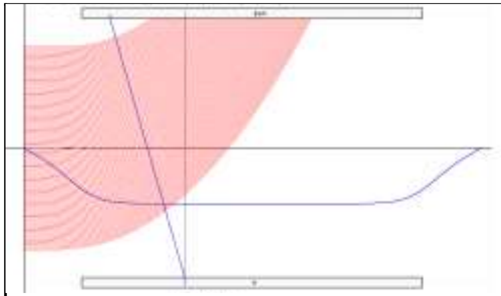
INFLUENCE OF THE BEAM SPACE CHARGE ON THE RID DEFLECTION PROPERTIES

In a case when 1 A of 50 keV He^{+} ions with an average current density of 1 mA/cm^2 enters the RID and its SC becomes decompensated estimation of the beam maximum potential gives a value of about 1.6 kV. Such potential can noticeably influence on the beam deflection.

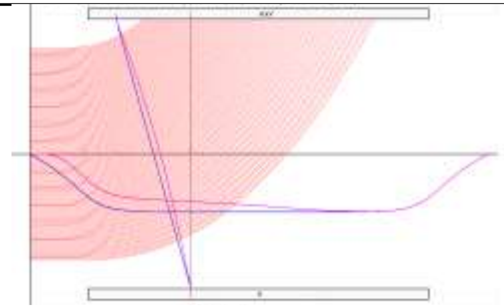


BEAM DEFLECTION MODELING

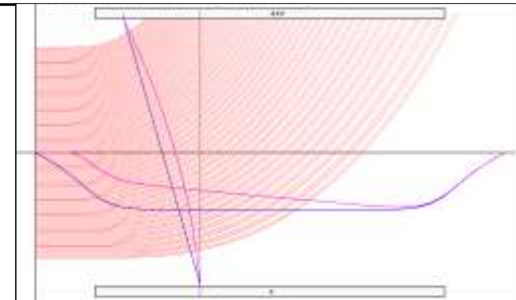
Modeling code is developed to calculate a self-consistent electric field in the RID model volume and trajectories of deflecting ions with taking into account the beam SC



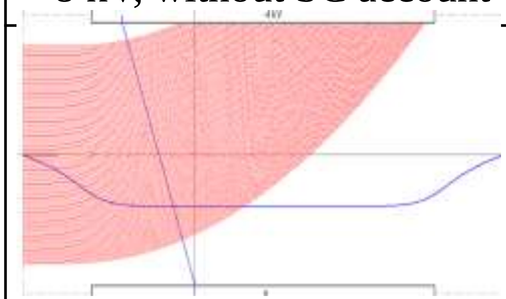
-8 kV, without SC account



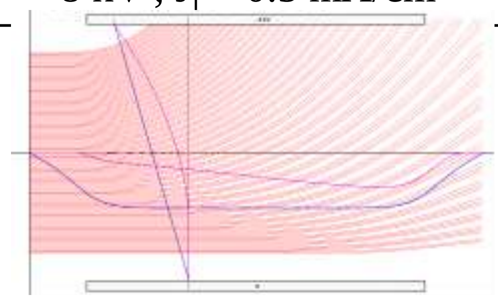
-8 kV , J_i = 0.5 mA/cm^2



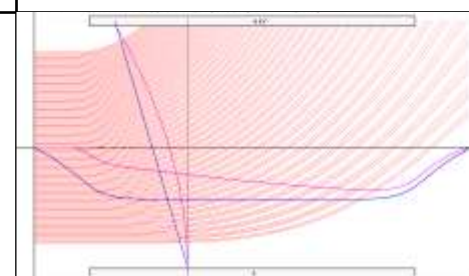
-8 kV , J_i = 1 mA/cm^2



-4 kV, without SC account



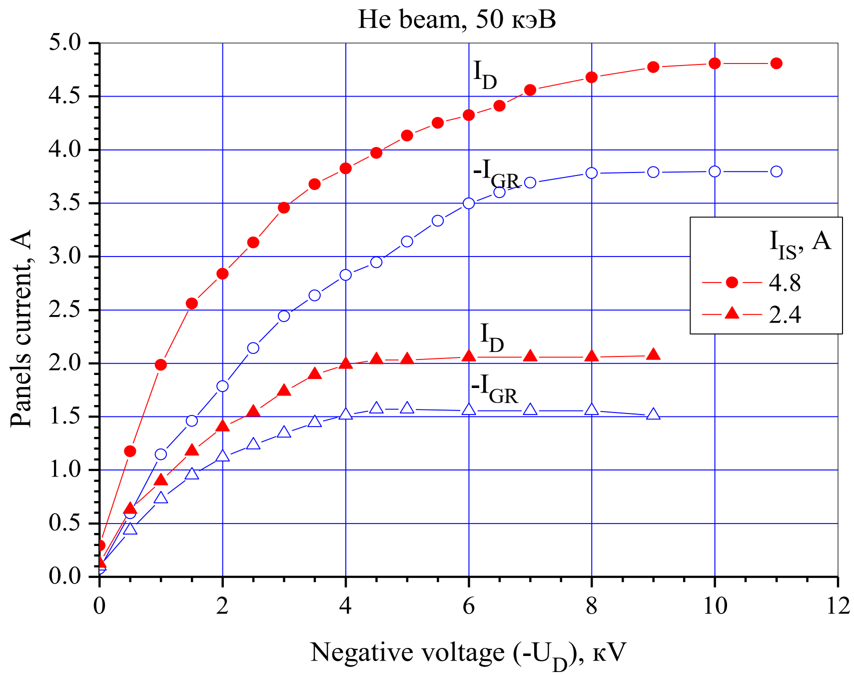
-4 kV , J_i = 1 mA/cm^2



-6 kV , J_i = 1 mA/cm^2

Calculated relative potential profiles along the RID model axis and across axis and trajectories of 50 keV He^+ ions

EXPERIMENTAL RESULTS.

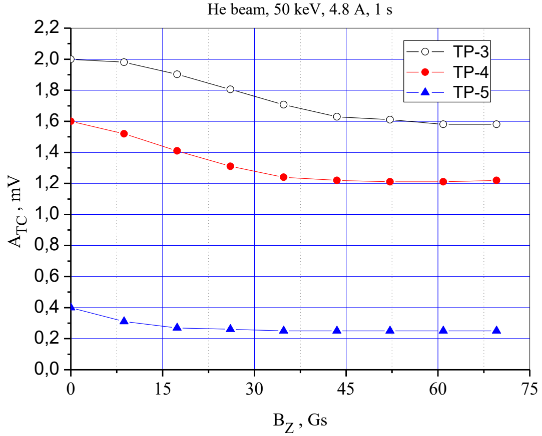


Dependence of currents onto the RID deflecting (I_D) and grounded (I_{GR}) panels on the applied negative potential for different currents of the He^+ ion beam from the ion source (I_{IS}).

The beam SC influence was studied more thoroughly using the thermo-probes (TP) arranged on the water cooled tubular calorimeter placed 80 cm downstream the RID exit, where additional beam dump with a set of ion collectors was located

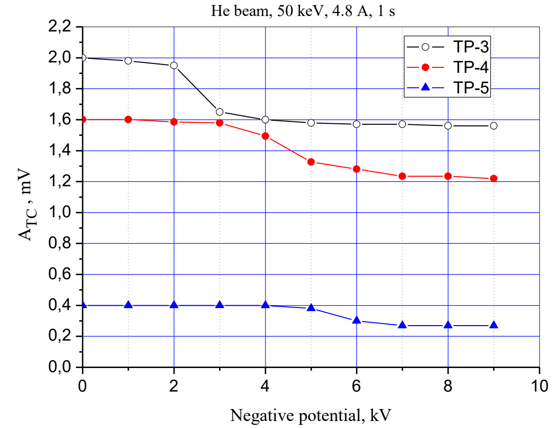
View of the beam calorimeter with ThermoProbes. Pitch between probes centers is 37 mm. Electrostatic deflection of ions is to the left (in the TP-1 direction) where additional beam dump with a set of ion collectors is located

Magnetic deflection

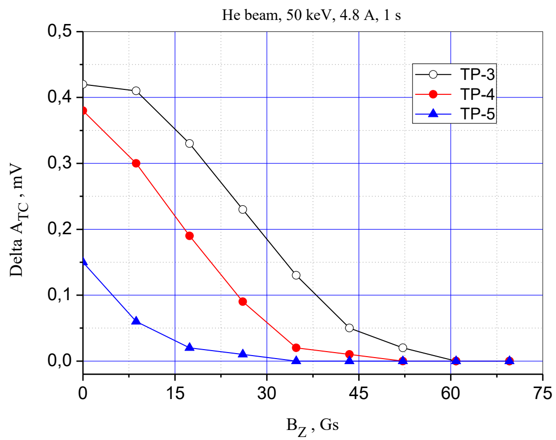


Ions + atoms

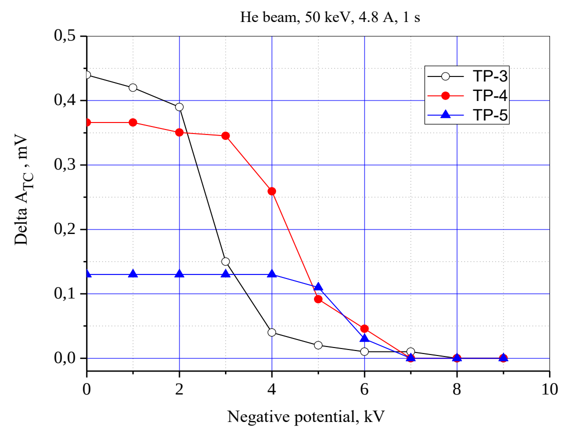
Electrostatic deflection



Ions + atoms



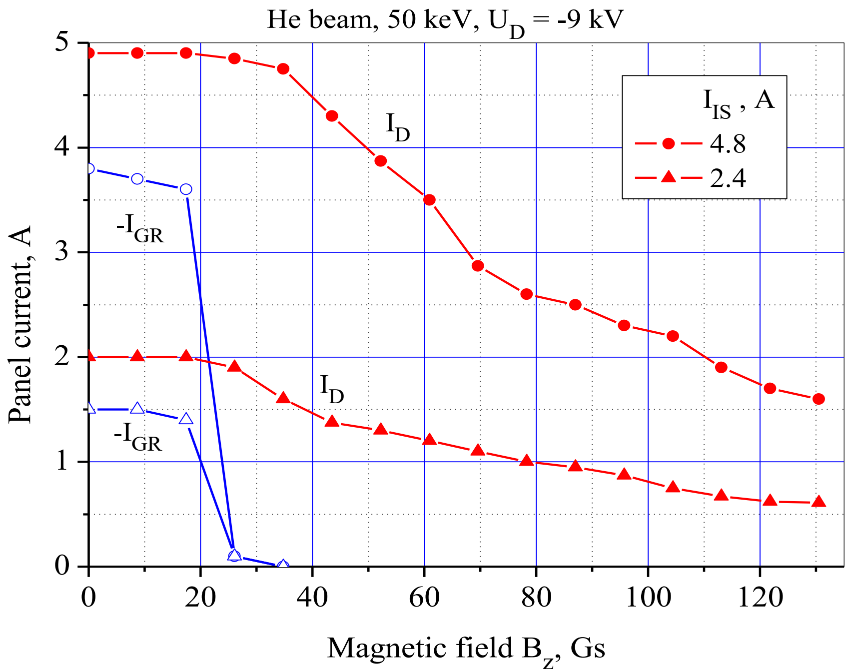
Ions



Ions

Dependence on the RID vertical magnetic field and on the RID negative deflecting potential of the ThermoProbes signals. 50 keV He beam, ion source current is 4.8 A, ion current density in the RID is about 1 mA/cm^2.

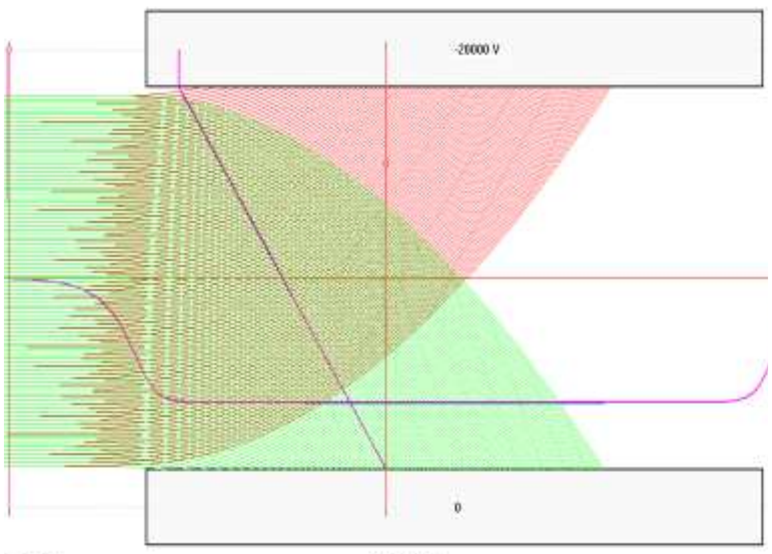
Influence of external magnetic field on the RID operation conditions

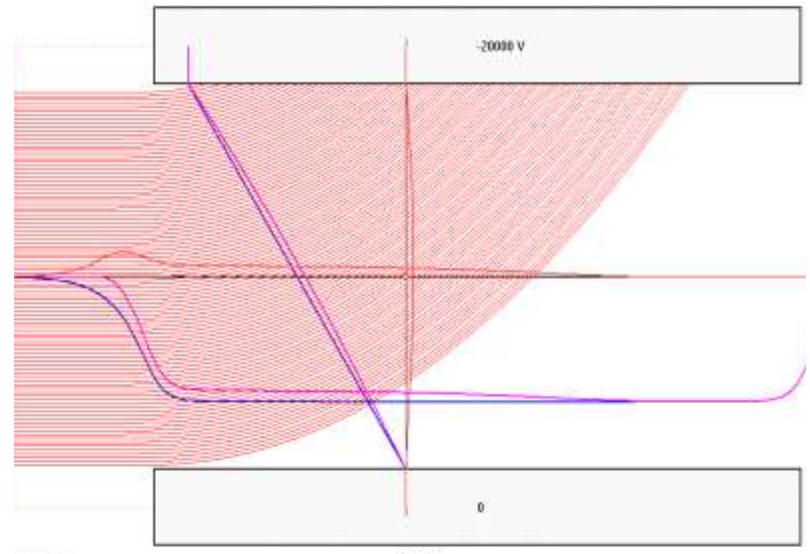


Dependence of the RID panels current on the vertical magnetic field value at U_D =-9 kV for different He^+ currents from the ion source.

The main result–secondary electrons drift around the negative panel does not deteriorate the RID operation, even at relatively high background pressure of 0.5 mTorr in the vacuum vessel

Modeling of the space charge influence on the ITER injector RID operation





Mixed beam of D^- and D^+ ions with 2 A current each (current density about 1.3 mA/cm^2). Deflection voltage is -20 kV

10 A D^+ ion beam (current density about 6.5 mA/cm^2) in an extreme case of superfluous gas input to the neutralizer

CONCLUSION

Experimental investigation of the residual ion dump model with electrostatic deflection of He^+ ions has shown the following:

- The space charge of the beam with current density at a level of 1 mA/cm^2 significantly affects the actual deflecting field, thus the necessary value of the deflection voltage should be increased up to two times in comparison with unperturbed field (i.e. without the beam).
- Secondary electrons drift in the crossed ExB fields does not lead to noticeable impact on the RID high voltage holding.
- The computer simulations of self-consistent electric potential in the RID volume with ion beam tracing are in good agreement with experimental results. The same code is used for modeling of the RID operation for the ITER beam line. It is shown that SC of the residual deuterium ions current density of 2 mA/cm^2 at energy of 1 MeV is rather small, besides positive and negative ions almost compensate SC of each other. Moreover, even in the emergency case of non-neutralized 10 A beam SC in not too high, and applied -20 kV deflecting voltage is enough to fully intercept the ion beam. Thus, negative deflecting voltage of 20÷25 kV will be enough for stable work of the ITER RID.