Atomic Physics Effects on IEC Ion Radial Flow

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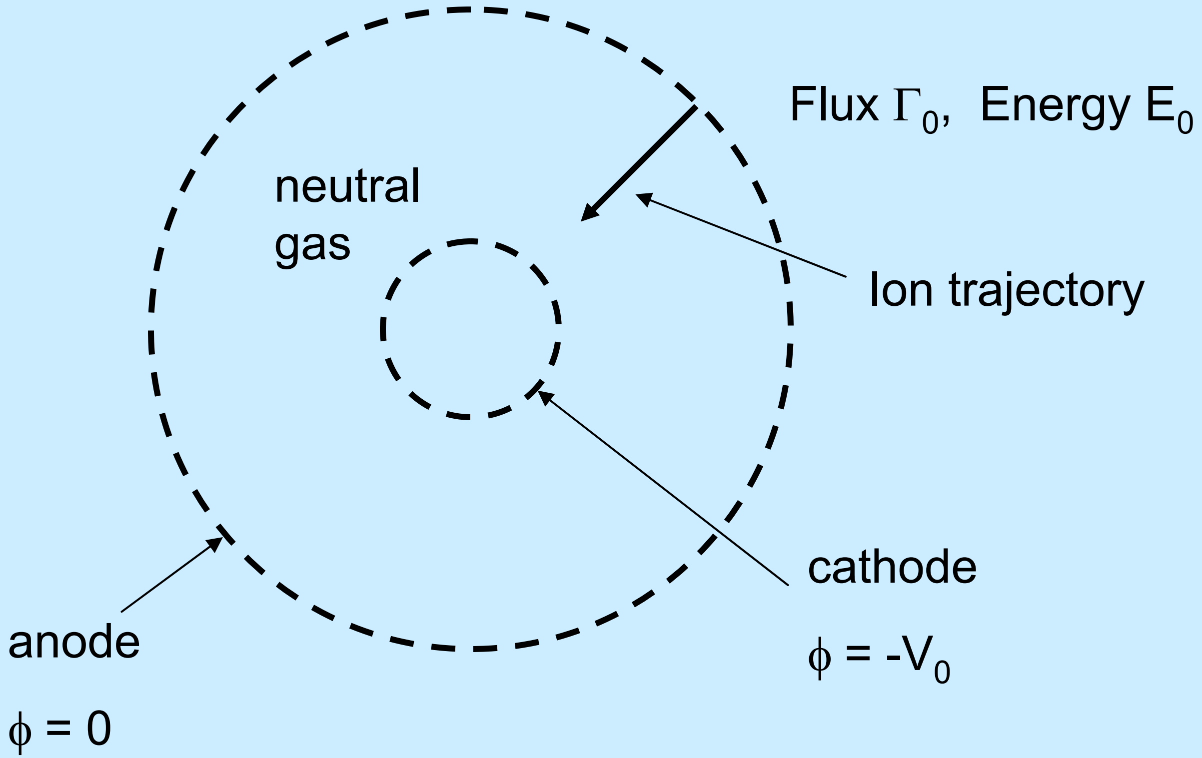
The Goal of this Research

- Understand the role of atomic physics on the flow of ions in gridded spherical IEC devices

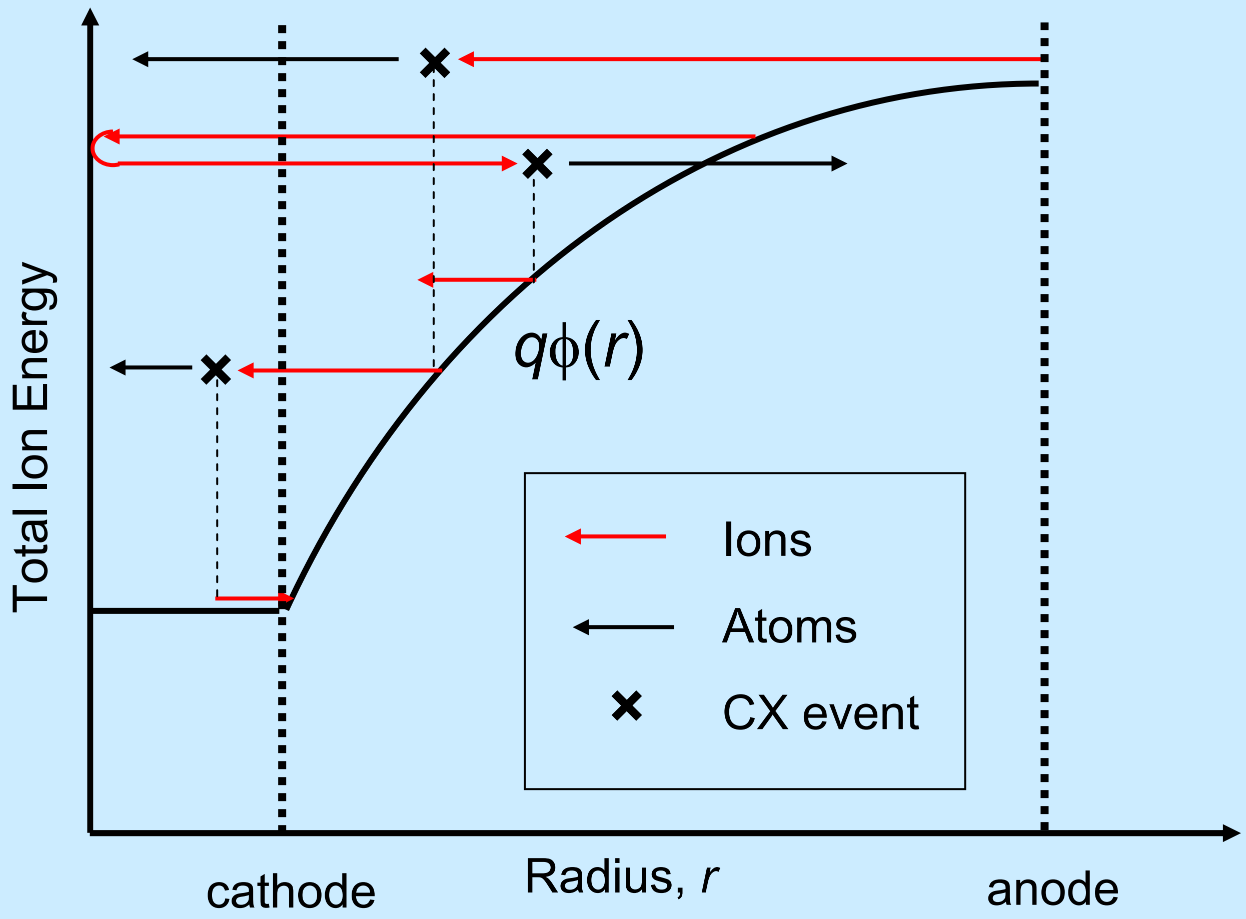
- Develop a model to predict the performance of these devices

IEC Model

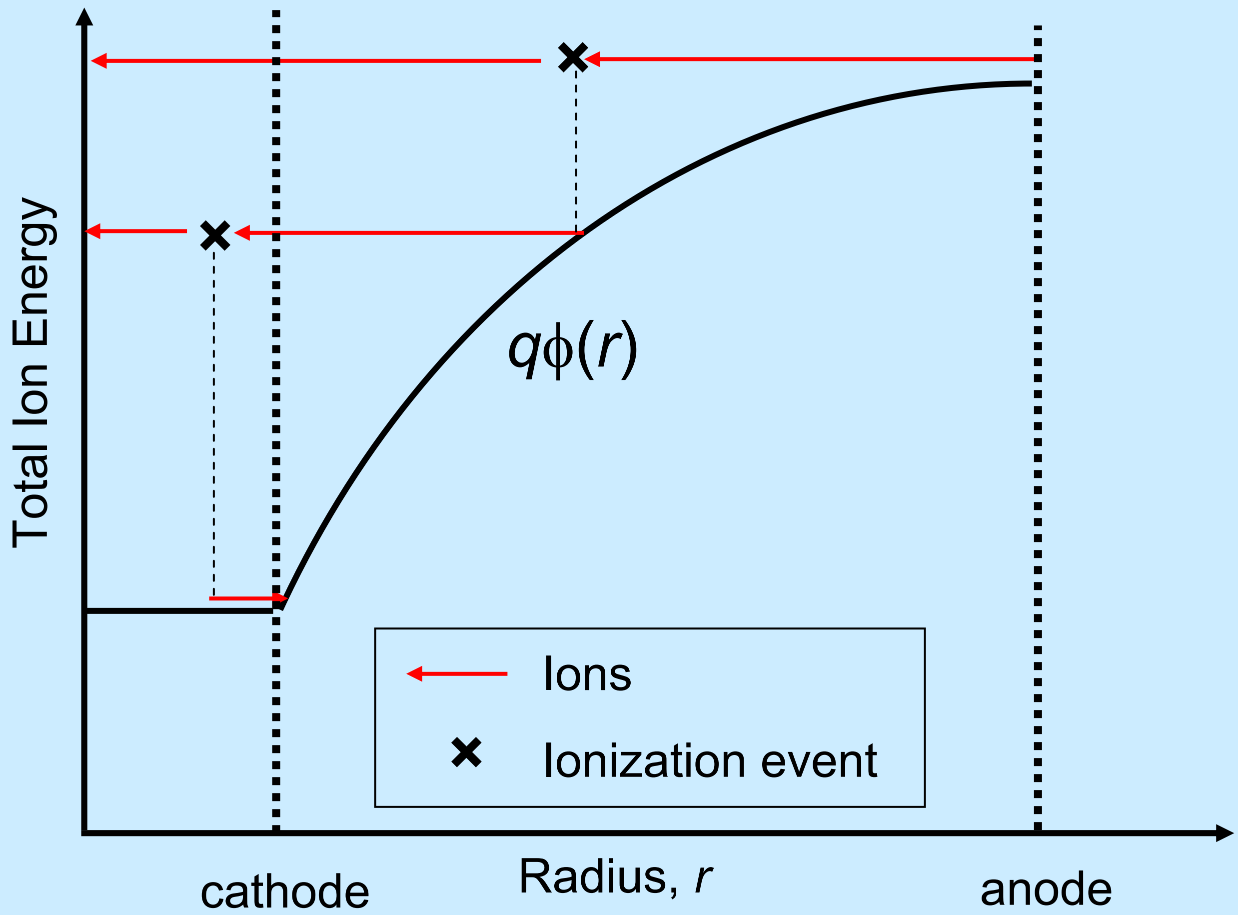


Flux Γ_0, Energy E_0
neutral gas
Ion trajectory
cathode
$\phi = -V_0$
anode
$\phi = 0$

Charge Exchange Produces Fast Atoms and Cascading Down of the Ion Energy



Ionization Produces Cold Ions without Loss of Energy



Basic Assumptions of the Model

- Background D_2 gas
- Deuterium ions (no molecular ions)
  - Collisionless motion except for charge exchange and ion impact ionization interactions
- Fast deuterium atoms
  - Collisionless motion
- Prescribed electrostatic potential profile
  - Child-Langmuir or vacuum in intergrid region
  - Flat in the cathode region
- Spherical symmetry – ignore stalk and defocusing
- Electron – atom interactions neglected.

Formalism

- Cold ion source function = $S(r)$
- Attenuation function = $g(r, r')$

$$g(r,r') = \exp\left(-\int_r^{r'} n_g \sigma_{cx}\left(E\left(r''\right)\right) dr'' \right)$$

gas density   charge exchange cross-section

- Ion flux $d\Gamma(r)$ at r due to ions born at r'

$$r^2 d\Gamma\left(r\right) = r'^2 g\left(r,r'\right) S\left(r'\right) dr'$$

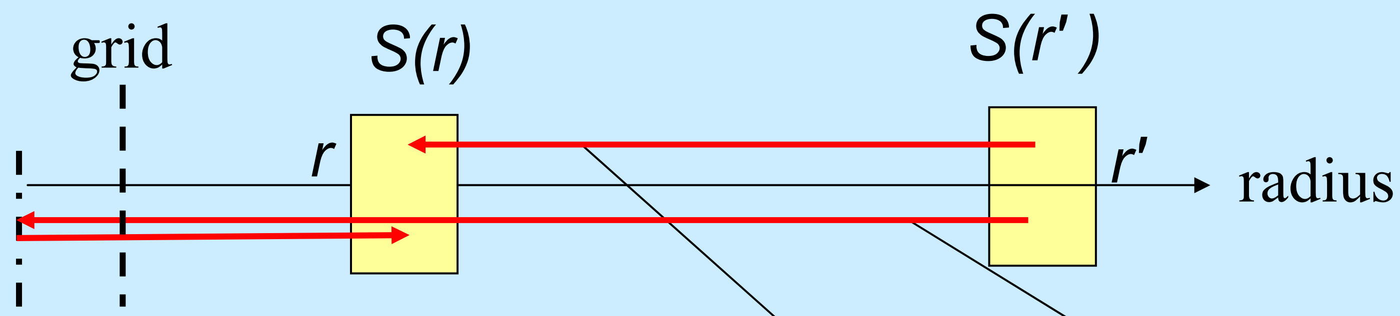
Particle Conservation in the Intergrid Region

Sum over all generations of cold ions and all ion passes

$$S(r) = A(r) + \int_{r}^{\text{anode}} K(r, r')S(r')dr'$$

$A(r)$ = cold ion source due to ions from the anode

Kernel relates the Source at one Radius to the Source at another Radius



$$K(r,r') = n_g \sigma_{tot}\left(E(r,r')\right)\left(\frac{r'^2}{r^2}\right)\frac{\boxed{g(r,r')} + \boxed{\gamma_c^2 \frac{g_{cp}(r')}{g(r,r')}}}{\boxed{1-\gamma_c^2 g_{cp}(r')}}$$

gas density

total cross-section

cathode transparency

sum over passes

complete pass probability

Solution Method

- Set up a mesh in the intergrid region (the Volterra equation is only defined there)
- Calculate the attenuation coefficients in the intergrid region numerically and in the cathode region analytically
- Solve the Volterra equation by finite difference methods

Given $S(r)$ We Can Calculate:

- Energy spectrum of the fast ion flux, $f_i(r,E)$
- Energy spectrum of the fast neutral flux, $f_n(r,E)$
- Ion current collected by the cathode
- Neutron production rate
- etc

The “Catch”

- The ion current Γ_0 leaving the anode is unknown experimentally and therefore is an adjustable parameter.
- We adjust it to match the calculated cathode current with the measured value.
- We then compare calculated and measured neutron generation rates.

Example Calculation

Input:

Cathode voltage	166 kV
Gas pressure	2 mTorr
Inward anode current	12.3 mA

Cathode Current:

energetic ion current striking cathode	16.4 mA
cold ion current striking cathode	23.7 mA
secondary electron emission	27.8 mA
Total Cathode Current	**68 mA**

Example Calculation - II

- Neutron Generation (model)
  - by ion-gas fusion 8.1×10^6 n/s
  - By fast atom-gas fusion 3.8×10^7 n/s
  - Total **4.6×10^7 n/s**

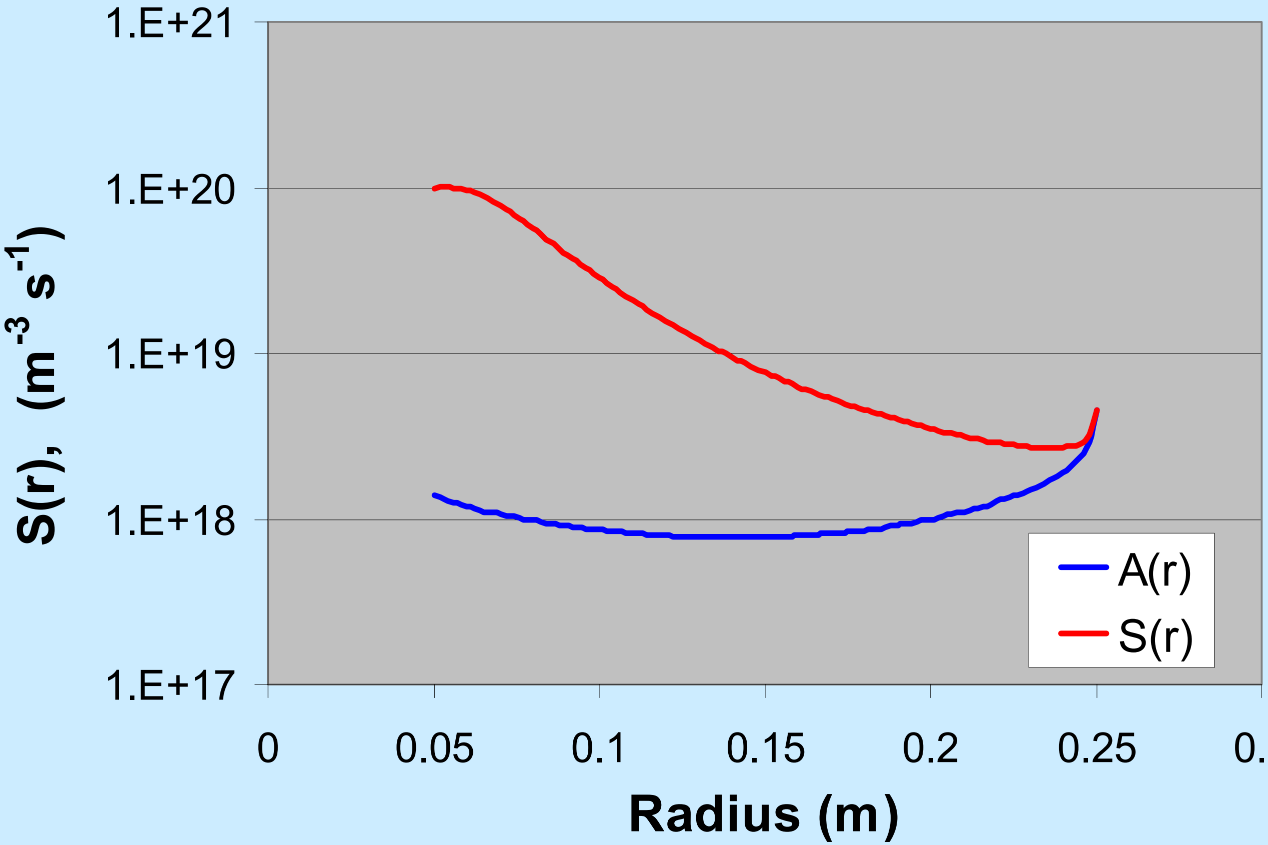
- Neutron Generation (exp.) **1.8×10^8 n/s**

Neutron generation processes not calculated:

Ion-ion fusion

Implantation in cathode grid

Cold Ion Source Function

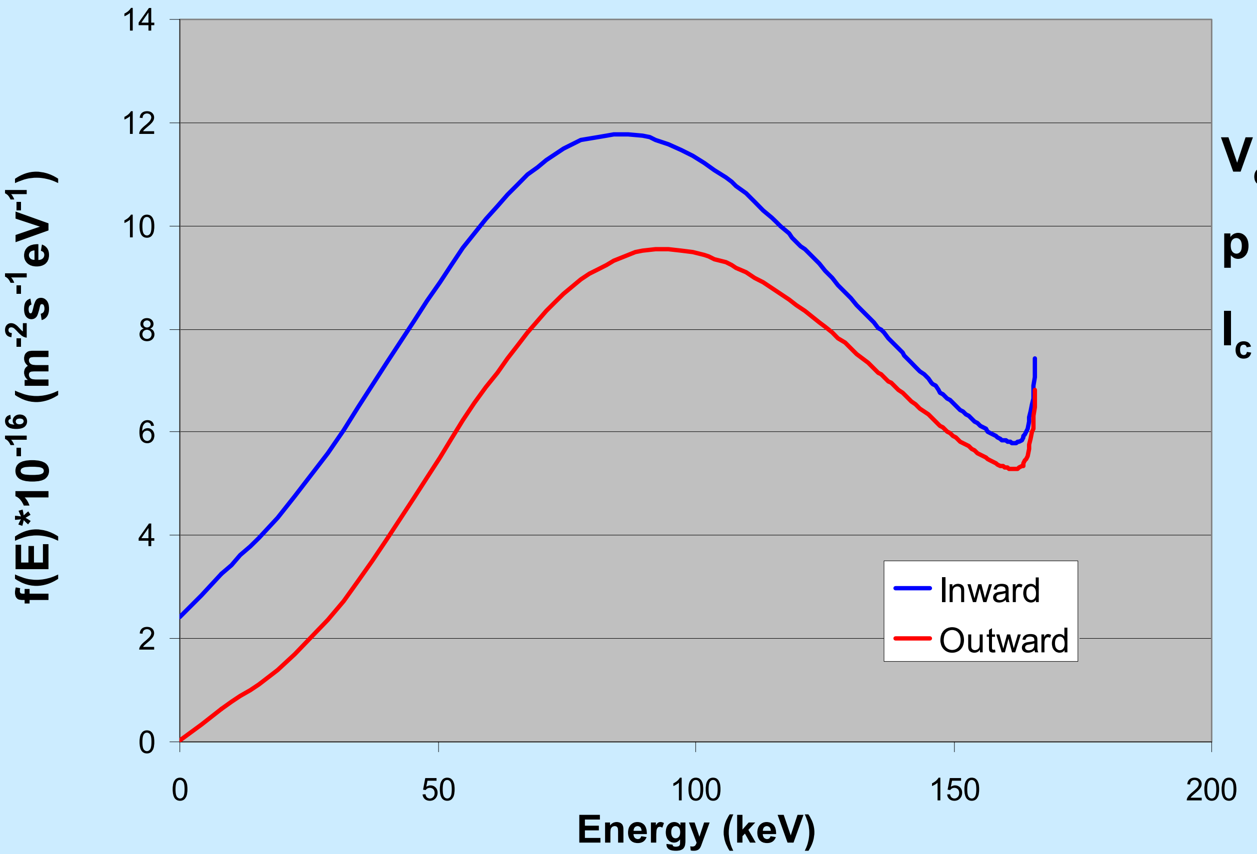


V_c = 166 kV

p = 2 mTorr

I_c = 68 mA

Energy Spectrum at Cathode

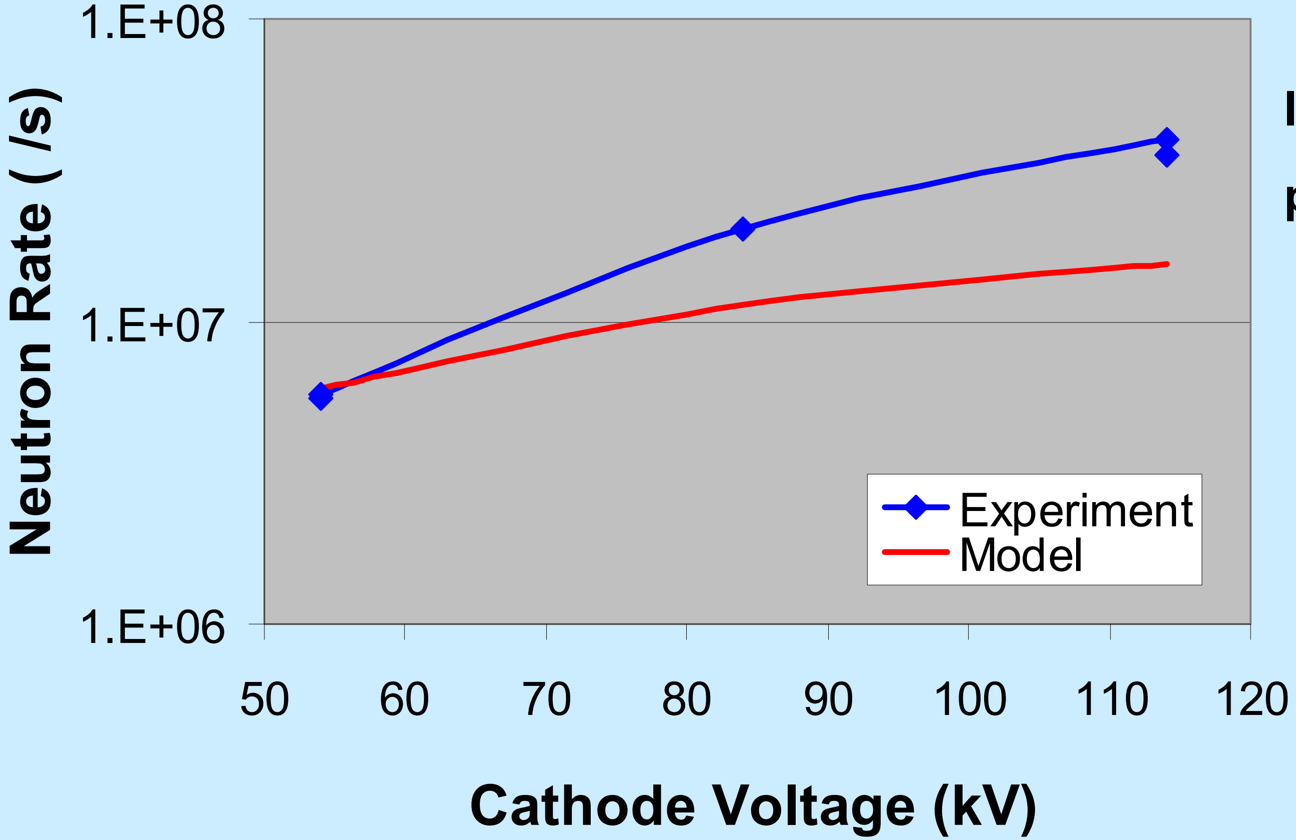


V_c = 166 kV

p = 2 mTorr

I_c = 68 mA

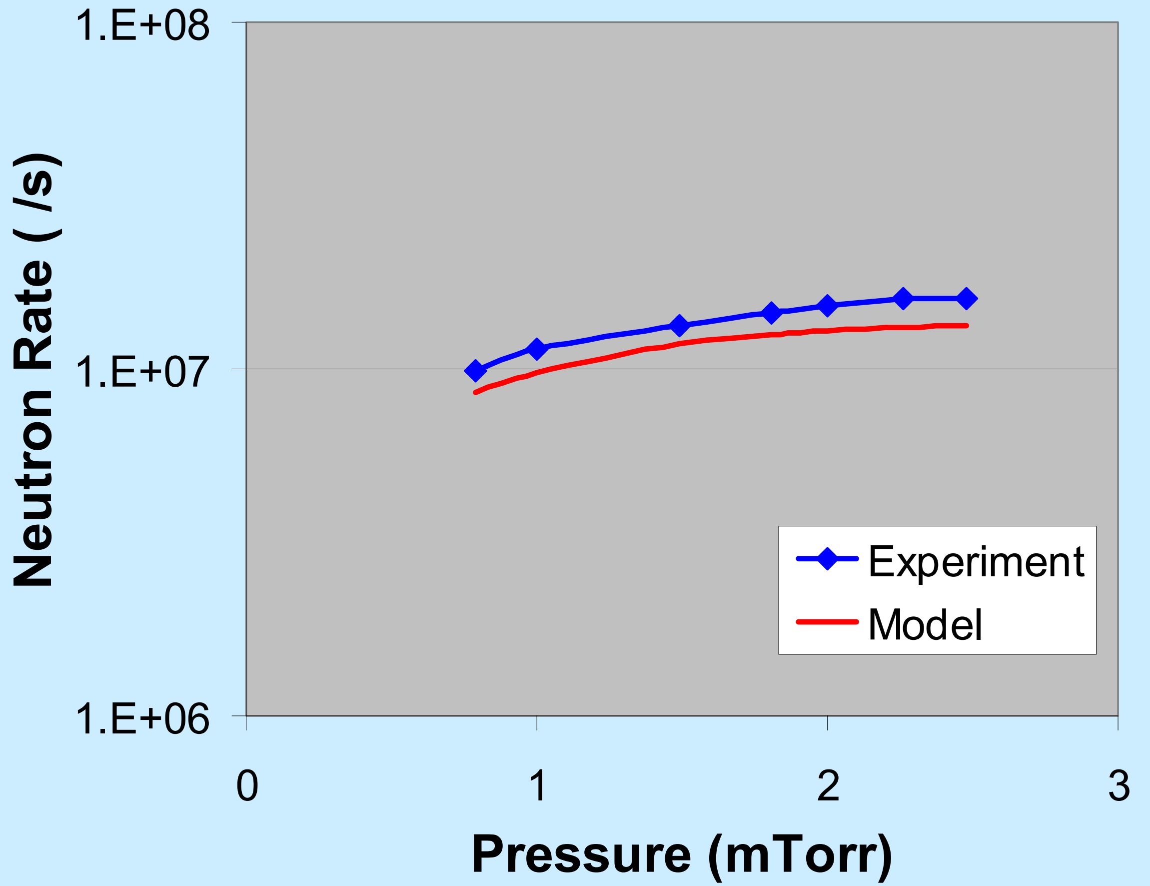
Voltage Scan



I_c = 30 mA

p = 2 mTorr

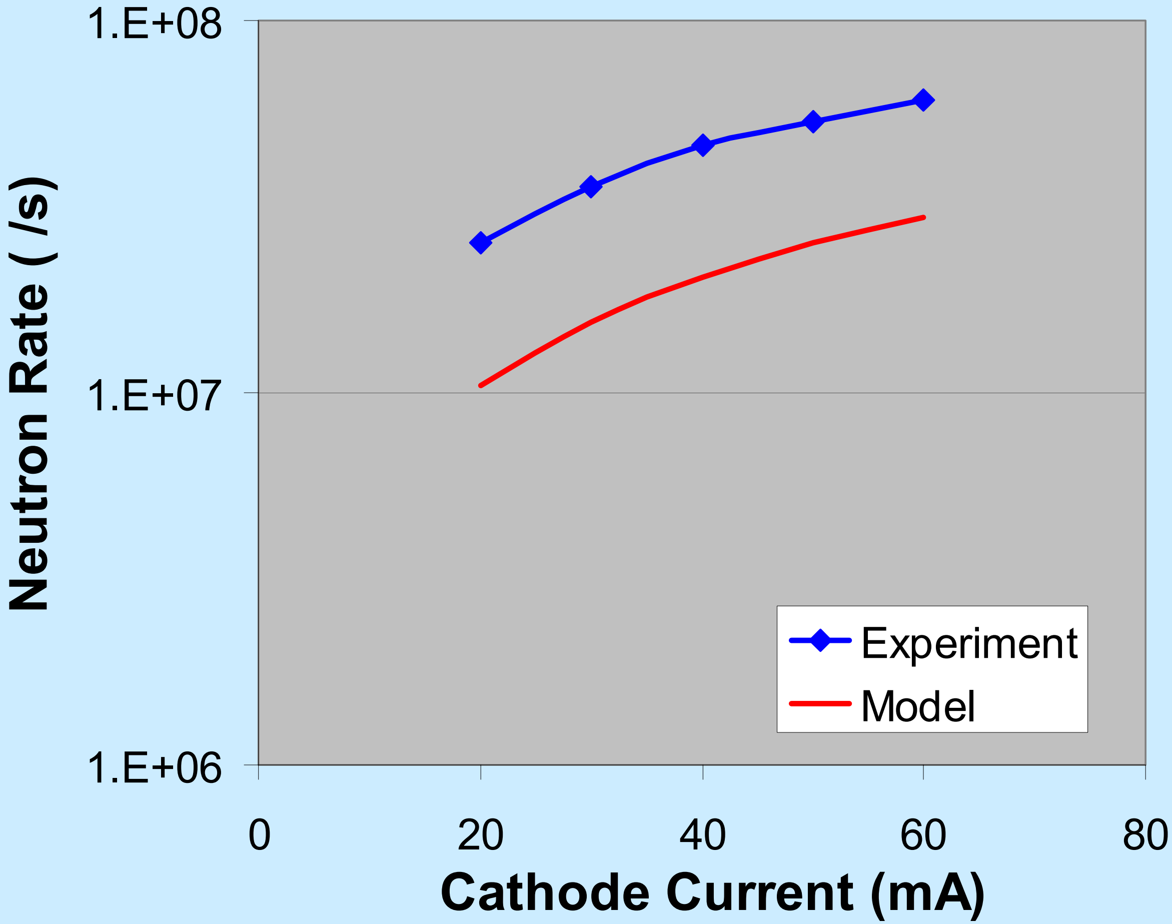
Pressure Scan



V_c = 94 kV

I_c = 30 mA

Current Scan



V_c = 112 kV

p = 2 mTorr

Conclusions

- The model reproduces the general trends of neutron production rate with changes in cathode current, cathode voltage, and gas pressure.

- The calculated neutron production rates are close to the measured values at low voltage and about a factor of 4 low at high voltage.

Possible Improvements

- Add molecular effects
- Calculate potential profile self-consistently
- Add potential “hill” in the cathode region
- Add multi-species, e.g. D-^{3}He
- Other suggestions?

Acknowledgement

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