Theoretical Exploration of Some Issues Affecting IEC Fusion Rates

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Objectives

- Examine effect of voltage and background gas pressure on ion and fast neutral energy distributions.

- Investigate the effect of molecular species mix in the source region on the D-D neutron production rate.

- Extrapolate the D-T neutron production rate from D-D IEC parameters.

Objective 1

- **Examine effect of voltage and background gas pressure on ion and fast neutral energy distributions.**

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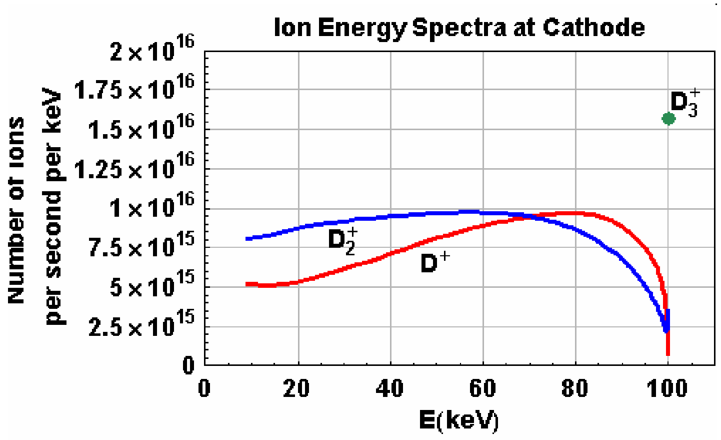
- Extrapolate the D-T neutron production rate from D-D IEC parameters.

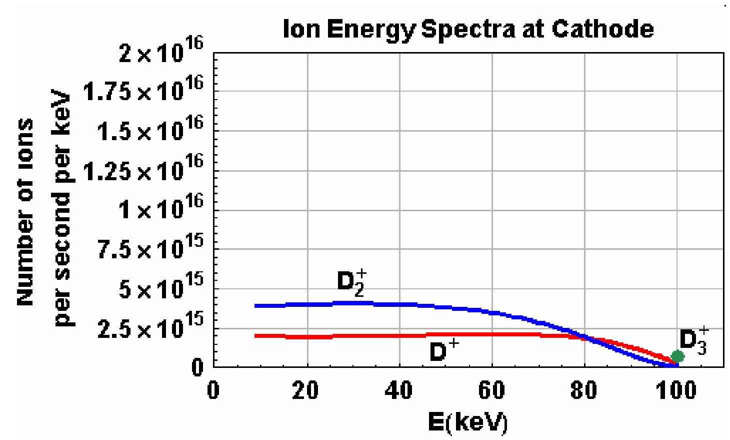
Increasing Neutral Gas Pressure Softens the Ion and Charge-Exchange Neutral Energy Spectra

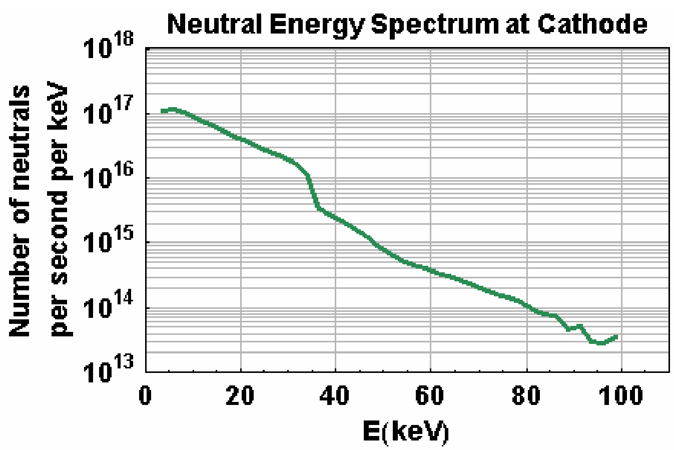
100 kV, 60 mA, r_c=0.05 m, r_a=0.25 m, Source: 0.1 D^+, 0.1 D_2^+, 0.8 D_3^+

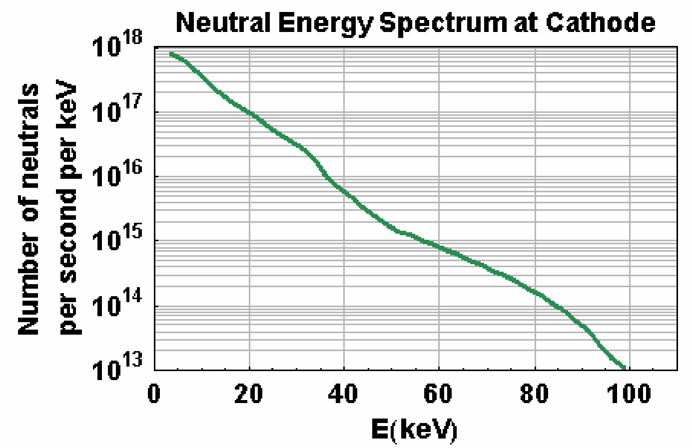
1 mtorr (0.13 Pa)

10 mtorr (1.3 Pa)









- Note: D_3^+ point is in total ions per second, not per second per keV.

Increasing Voltage Increases Neutron Production Rate and Affects the Origin of the Fusion Neutrons

2 mtorr (0.27 Pa), 60 mA, r_c=0.05 m, r_a=0.25 m, Source: 0.1 D^+, 0.1 D_2^+, 0.8 D_3^+

† "Neutrals" means the fast neutrals from charge-exchange or dissociation collisions.

Units of 10^7 n/s	**50 kV**	**100 kV**	**150 kV**
D^+ Neutrals† - Gas	0.84	1.54	2.04
D_2^+ Neutrals† - Gas	0.47	1.24	2.27
D_3^+ Neutrals† - Gas	5.78	5.11	5.31
D^+ - Gas	0.22	0.91	1.98
D_2^+ - Gas	0.09	0.54	1.36
D_3^+ - Gas	0.14	0.66	1.28
Total neutrons	7.54	10.0	14.2

Objective 2

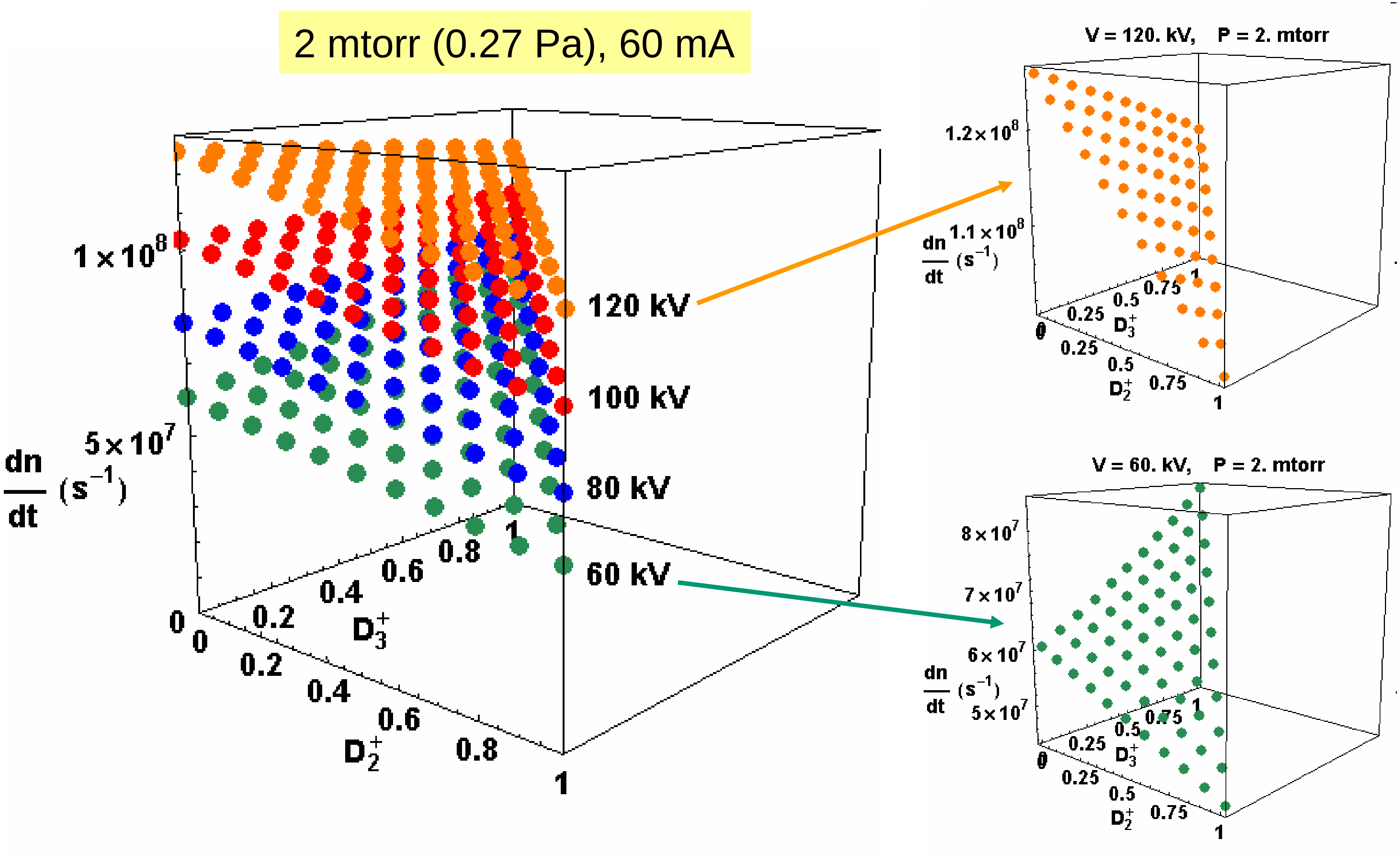
- Examine effect of voltage and background gas pressure on ion and fast neutral energy distributions.

- **Investigate the effect of molecular species mix in the source region on the D-D neutron production rate.**

- Extrapolate the D-T neutron production rate from D-D IEC parameters.

Increasing the Voltage Increases Neutron Production and Changes the Optimal Species Mix

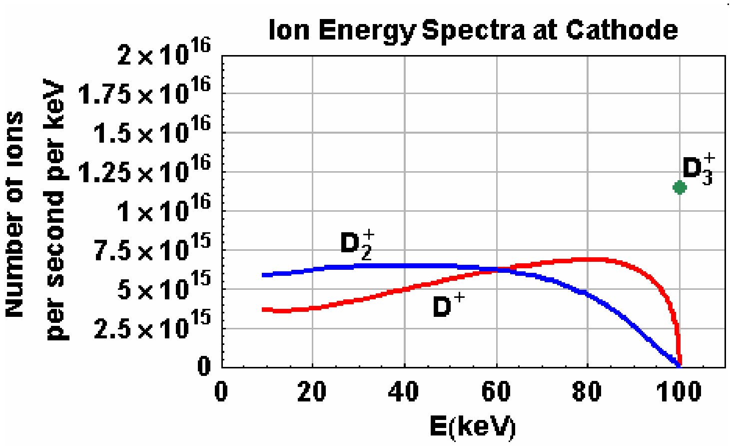
2 mtorr (0.27 Pa), 60 mA

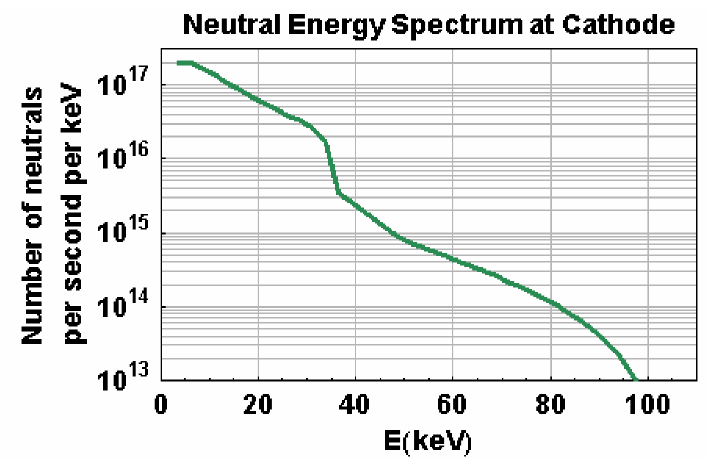


Source D^+ Gives a Faster Ion Spectrum than D_3^+, but the same neutron production rate

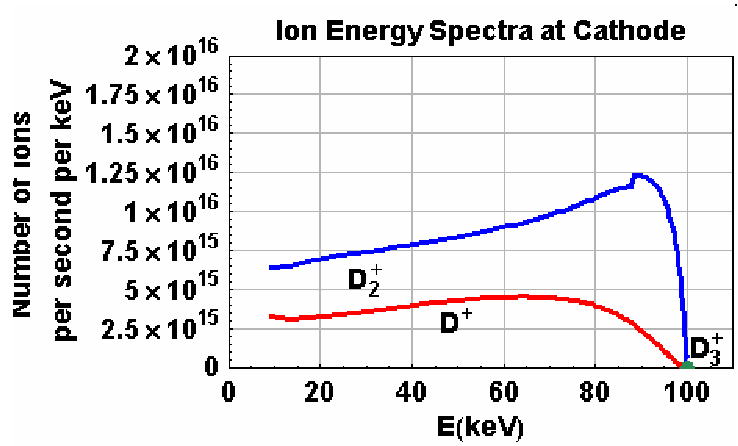
100 kV, 60 mA, 2 mtorr (0.27 Pa), r_c=0.05 m, r_a=0.25 m

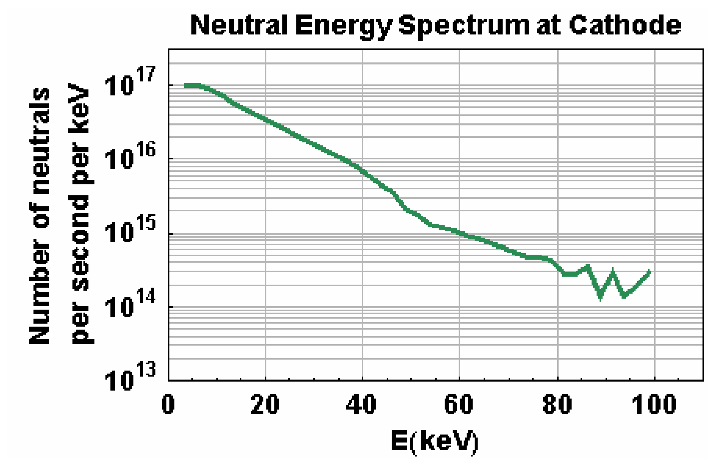
All D_3^+ in Source: 1.0x10^8 n/s





All D^+ in Source: 1.0x10^8 n/s



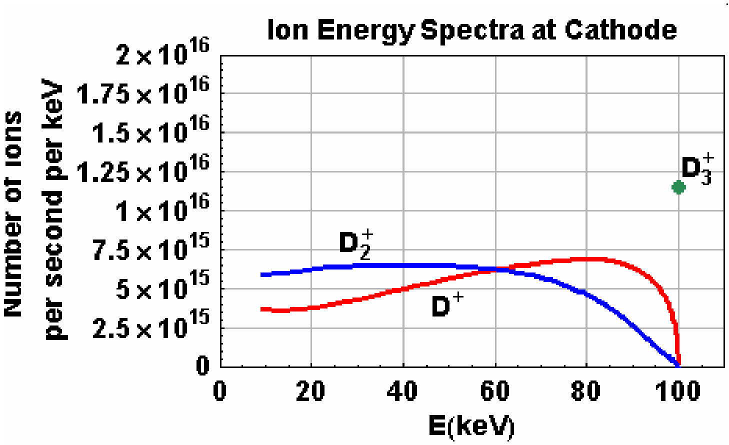


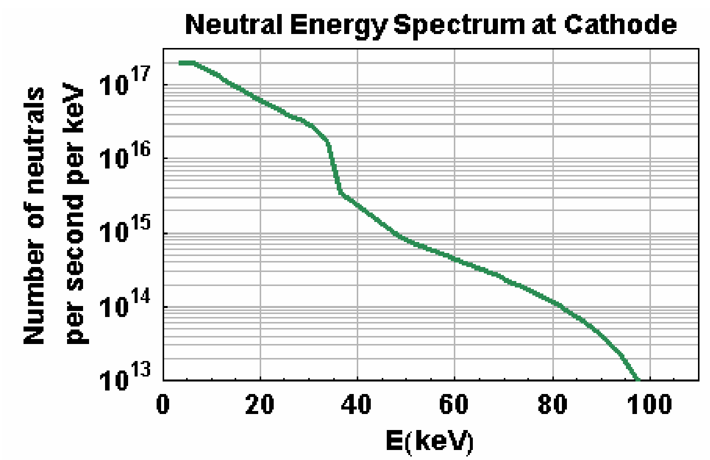
- Note: D_3^+ point is in total ions per second, not per second per keV.

Source D_2^+ Quickly Produces D^+ for the 100 kV, 60 mA, 2 mtorr Case

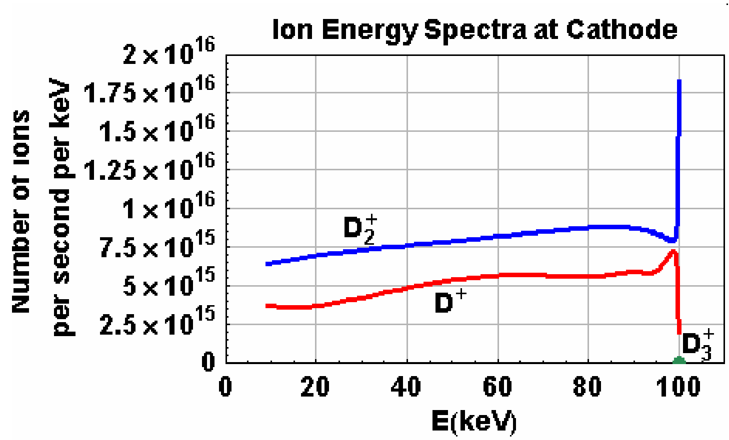
100 kV, 60 mA, 2 mtorr (0.27 Pa), r_c=0.05 m, r_a=0.25 m

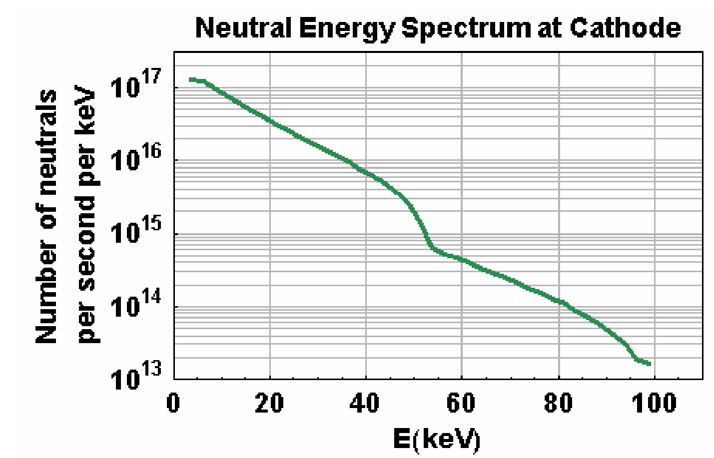
All D_3^+ in Source: 1.0x10^8 n/s





All D_2^+ in Source: 8.0x10^7 n/s





- Note: D_3^+ point is in total ions per second, not per second per keV.

The Origin of the Fusion Neutrons Depends Strongly on the Molecular Species Mix in the Source Region

100 kV, 2 mtorr (0.27 Pa), 60 mA, r_c=0.05 m, r_a=0.25 m

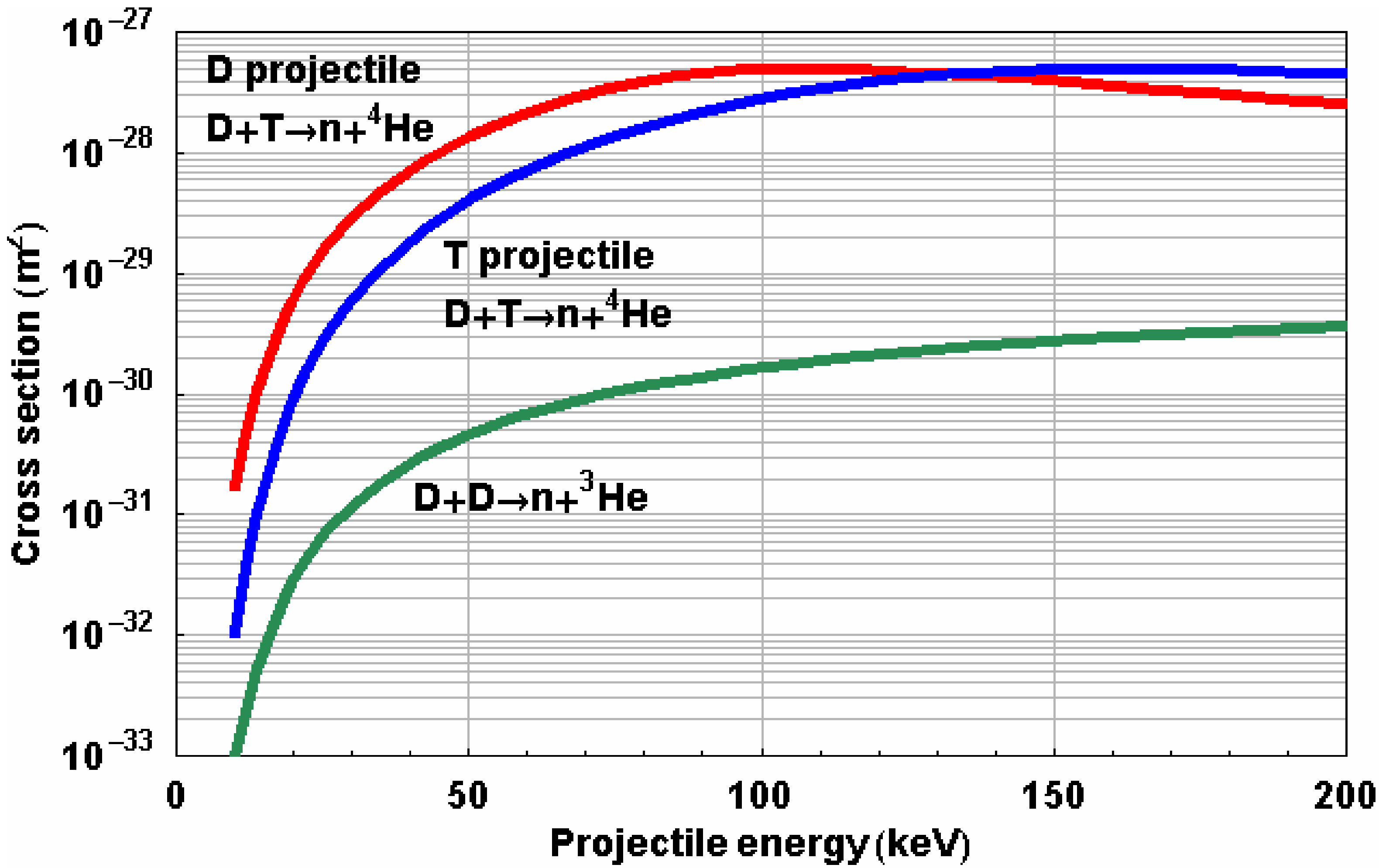
† "Neutrals" means the fast neutrals from charge-exchange or dissociation collisions.

Units of 10^7 n/s	D^+ Source	D_2^+ Source	D_3^+ Source
D^+ Neutrals† - Gas	6.2	0.9	1.0
D_2^+ Neutrals† - Gas	1.6	4.9	0.7
D_3^+ Neutrals† - Gas	0	0	6.6
D^+ - Gas	1.6	0.8	0.8
D_2^+ - Gas	0.9	1.4	0.4
D_3^+ - Gas	0	0	0.9
Total neutrons	10.3	8.0	10.3

Objective 3

- Examine effect of voltage and background gas pressure on ion and fast neutral energy distributions.
- Investigate the effect of molecular species mix in the source region on the D-D neutron production rate.
- **Extrapolate the D-T neutron production rate from D-D IEC parameters.**

Ratio of D-T to D-D(n+^{3}He) Fusion Cross Sections Depends on Energy and Which Species is the Projectile

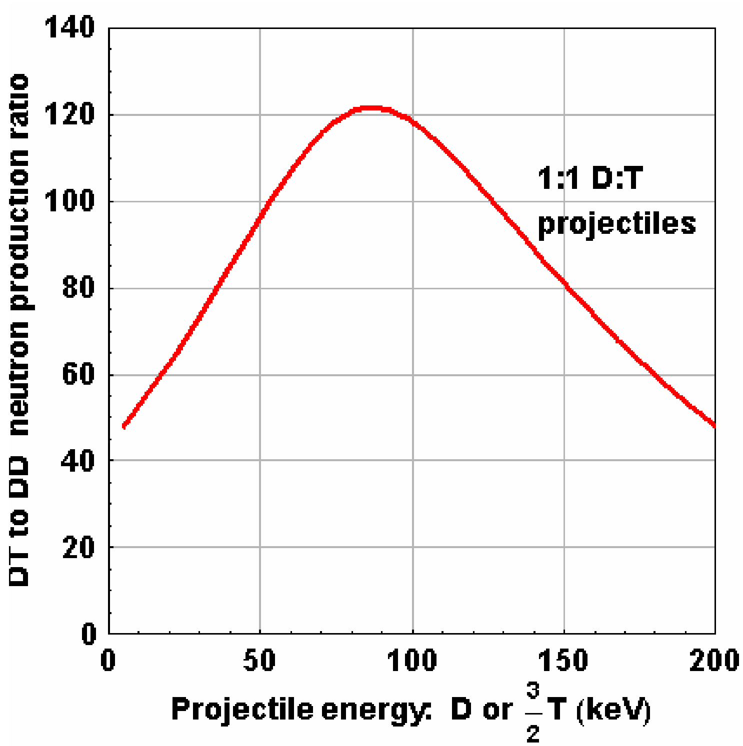


The D-T to D-D Neutron Production Rate Ratio Ranges from 50 to 120, Depending on Projectile Energy

- Define total fast neutral or ion density = n_{if} and total target neutral density = n_{it}.
- In a D-D plasma, the fusion rate for $D+D \Rightarrow n+{}^3He$ is $\Gamma_{DDn3} = n_{if} n_{it} <\sigma v>_{DDn3}$ where $<\sigma v>_{ij}$ means projectile species *i* colliding with background species *j*.
- In a D-T plasma, each species has half of its D-D density and the fusion rate for $D+T \Rightarrow n+{}^4He$ is $\Gamma_{DT} = \frac{1}{4} n_{if} n_{it} (<\sigma v>_{DT} + <\sigma v>_{TD})$
- Therefore, the ratio of D-T to D-D neutron production rate is

$$R = \frac{<\sigma v>_{DT} + <\sigma v>_{TD}}{4 <\sigma v>_{DDn3}}$$

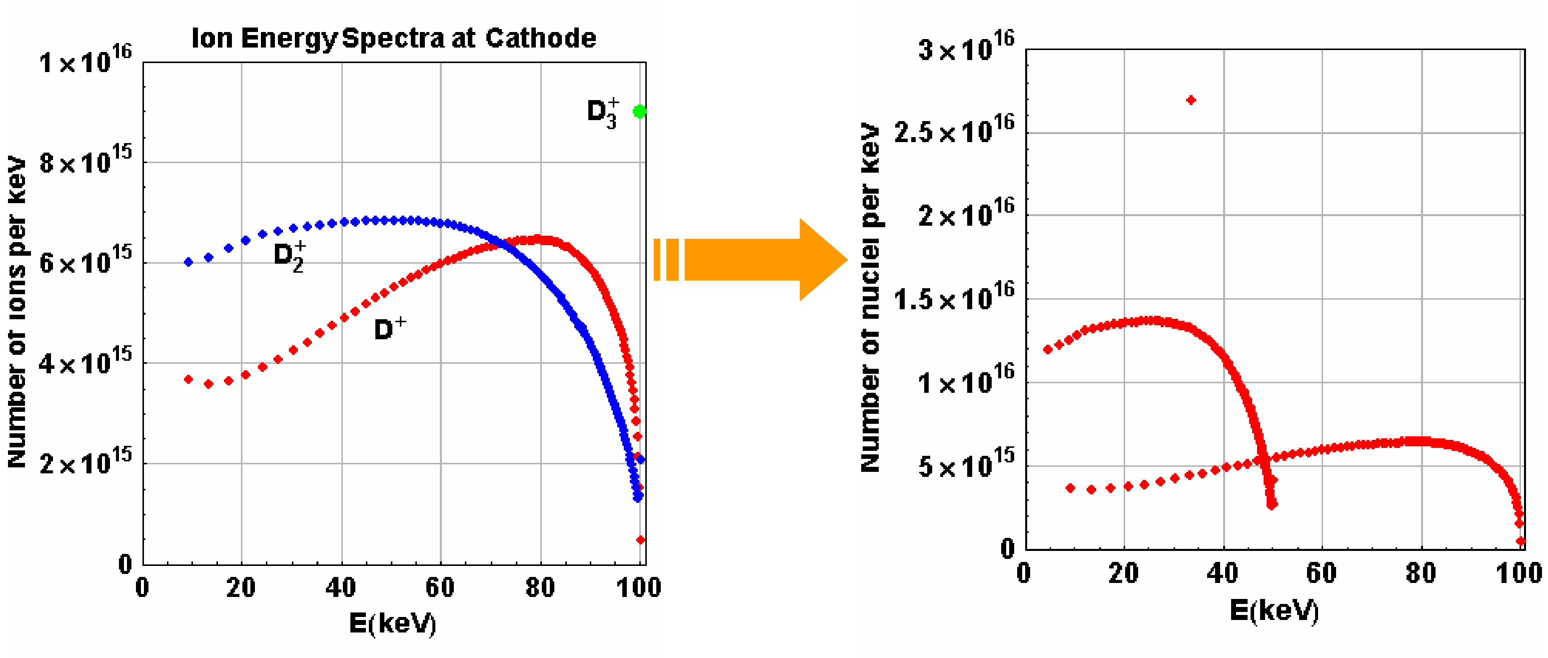
Weighting of D-T vs D-D Projectiles



Reference Case Increase for Replacing D-D by D-T is Factor of 83

100 kV, 60 mA, 2 mtorr (0.27 Pa), r_c=0.05 m, r_a=0.25 m, Source: 0.1 D^+, 0.1 D_2^+, 0.8 D_3^+

- The ion energy spectra at the cathode are translated into energy per nucleon:



- The ion and fast charge-exchange neutral nucleon distributions are weighted with the energy distributions and D-T:D-D fusion cross section ratios.
- Total weighting equation becomes

$$X = (f_{ion} \cdot w_\sigma)\frac{\dot{N}^{DD}_{ion}}{\dot{N}^{DD}_{total}} + (f_{neutral} \cdot w_\sigma)\frac{\dot{N}^{DD}_{neutral}}{\dot{N}^{DD}_{total}}$$

Conclusions

- For the parameter regimes investigated so far:
  - Increasing the neutral gas pressure softens the ion and charge-exchange neutral energy spectra, leading to an optimal background gas pressure.
  - Increasing the voltage increases the neutron production rate and increases the importance of reactions related to D+ and D2+.
  - The molecular species mix in the source region alters the ion spectra inside the anode, but the neutron production rate varies only slightly.
- Replacing D fuel by a D-T 50:50 mix should lead to D-T fusion neutron production rates ~80 times higher than the D-D rates.
  - Optimized parameters may increase this ratio slightly.