Runaway electrons in SPARC V0

RA Tinguely\textsuperscript{1}, O Embréus\textsuperscript{2}, T Fülöp\textsuperscript{2}, L Hesslow\textsuperscript{2}, M Hoppe\textsuperscript{2}, P Svensson\textsuperscript{2}, O Vallhagen\textsuperscript{2}, S Newton\textsuperscript{3}, P Helander\textsuperscript{4}, AJ Creely\textsuperscript{5}, D Garnier\textsuperscript{1}, RS Granetz\textsuperscript{1}, N Howard\textsuperscript{1}, P Rodriguez-Fernandez\textsuperscript{1}, R Sweeney\textsuperscript{1}, and the SPARC team

\textsuperscript{1} MIT Plasma Science and Fusion Center, Cambridge, USA
\textsuperscript{2} Chalmers University, Gothenburg, Sweden
\textsuperscript{3} Culham Centre for Fusion Energy, Oxon, UK
\textsuperscript{4} Max Planck Institute for Plasma Physics, Greifswald, Germany
\textsuperscript{5} Commonwealth Fusion Systems, Cambridge, USA


APS-DPP, Ft. Lauderdale, October 2019, CO5.10, MF: SPARC & C-Mod
Status + trajectory

Assess disruptions in SPARC: halo currents, heat loads, runaway electrons, etc.

Inform engineering and design

This talk:

1D modeling of runaway current / density \( j_r(r, t) \)

3D modeling of runaway distribution function \( f(r, \mathbf{v}, t) \) (preliminary)
**SPARC V0 explores new parameter space for runaway electron generation and dynamics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Opportunities and challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_0$</td>
<td>12 T</td>
<td>Intense synchrotron radiation</td>
</tr>
<tr>
<td>$&lt;n_e&gt;$</td>
<td>$4 \times 10^{20}$ m$^{-3}$</td>
<td>High collisional damping</td>
</tr>
<tr>
<td>$R_0$, $a$</td>
<td>1.65 m, 0.5 m</td>
<td>Short thermal quench, current quench, and transport times</td>
</tr>
<tr>
<td>$&lt;T_e&gt;$</td>
<td>10 keV</td>
<td>Large primary generation/hot-tail mechanism</td>
</tr>
<tr>
<td>$I_p$</td>
<td>7.5 MA</td>
<td>Large avalanche multiplication, good runaway confinement</td>
</tr>
</tbody>
</table>
GO* self-consistently evolves the runaway current and electric field diffusion

Total current density
\[ j_\parallel = \sigma E + n_r e c \]

Runaway density
\[ \frac{\partial n_r}{\partial t} = \frac{dn_r}{dt}\bigg|_{n_e,E,T}^{\text{Dreicer}} + \frac{dn_r}{dt}\bigg|_{n_r,E,T}^{\text{avalanche}} + \frac{dn_r}{dt}\bigg|_{n_T}^{\text{tritium}} \]

Temperature profile
\[ T(t, r) = (T_i(r) - T_f(r)) e^{-t/t_0} + T_f(r) \]

! Hot-tail effects and transport are not included here! 

*H Smith et al 2006 PoP 13
The effect of elongation* is to reduce the induced electric field and runaway generation rate

Electric field diffusion

\[ \mu_0 \frac{\partial j_\parallel}{\partial t} = \frac{1 + \kappa^{-2}}{2} \frac{1}{r} \frac{\partial}{\partial r} r \frac{\partial E}{\partial r} \]

Avalanche multiplication

\[ j_r \propto \exp \left( \frac{I_P}{I_A \ln \Lambda} \times \frac{2}{\kappa + \kappa^{-1}} \right) \]

**JO6.00010: T Fülöp, Self-consistent modelling of electron runaway during tokamak disruptions**

3:48 PM–4:00 PM, Tuesday, 22 October 2019, Room: Grand D, Session JO6: MF: MHD and Disruption Physics

SPARC V0 plasma profiles input into GO

Pre-disruption:

\[ n_0 [10^{20} \text{ m}^{-3}] \]

\[ n_e(r, t) = n_e(r) \]

\[ T_f(r) = 20 \text{ eV} \]

\[ \kappa(r) = 1, 1.45 \]

\[ Z_{\text{eff}} = 1 \]

\[ t_0 = 1 \text{ ms} \]

Post-disruption:

CO5.00004: P Rodriguez-Fernandez, Physics-Based Integrated Modeling and Exploration of Fusion Performance in SPARC Plasmas

CO5.00005: NT Howard, Investigation of Core Physics in the SPARC Tokamak
Increased elongation leads to longer resistive diffusion times and lower induced electric fields
Increased elongation reduces the total expected runaway current, which is negligible for SPARC V0.
Current conversion % decreases with elongation, final temperature, and thermal quench time
GO + CODE* (kinetic equation solver) indicates that hot-tail generation is substantial

* No particle losses or synchrotron/bremsstrahlung are considered here!

*M Landreman et al 2014 CPC 185; A Stahl et al 2016 NF 56
• GO used to model runaway electron evolution during disruptions in SPARC V0
• Plasma elongation slows resistive diffusion and reduces electric fields
• Low plasma-to-runaway current conversion ( < 0.1%) is expected for elongated SPARC V0 plasmas
• Hot-tail effects (in GO+CODE) substantially increase runaway current conversion (~30%)
• However, particle transport from disruption MHD still needs to be assessed and is underway

JO6.00010: T Fülöp, Self-consistent modelling of electron runaway during tokamak disruptions
3:48 PM–4:00 PM, Tuesday, 22 October 2019, Room: Grand D, Session JO6: MF: MHD and Disruption Physics
SPARC and the Fast Track to FUSION ENERGY

- Tuesday, October 22
- 5:00–7:00PM
- Grand Ballroom B
Bonus
Preliminary GO+CODE simulations indicate runaways with average energy $\sim 15$ MeV
SPARC V0 plasma profiles input into GO

Pre-disruption:

\[ j_0 \text{ [MA/m}^2\text{]} \]

\[ n_0 \text{ [10}^{20}\text{ m}^{-3}\text{]} \]

\[ T_0 \text{ [keV]} \]

\[ \kappa \]

Post-disruption:

\[ n_e (r, t) = n_e (r) \]

\[ Z_{\text{eff}} = 1 \]

\[ T_f (r) = 20 \text{ eV} \]

\[ t_0 = 1 \text{ ms} \]

\[ \kappa (r) = 1, 1.45 \]