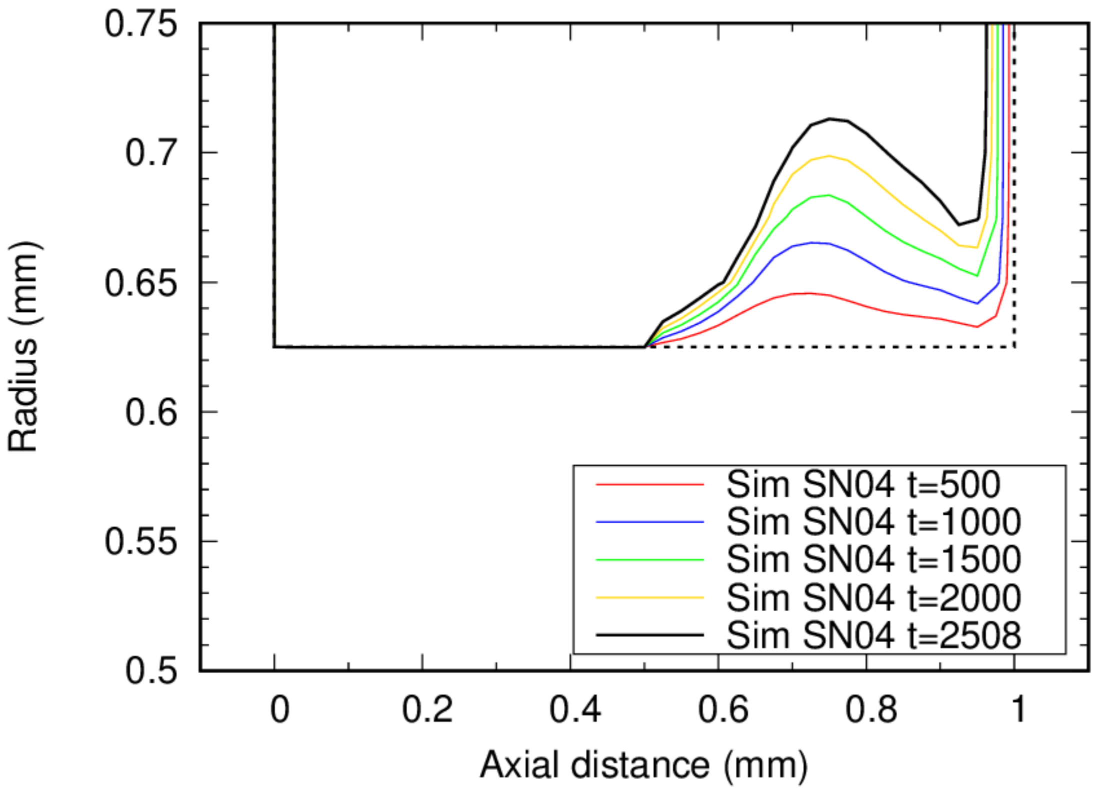

Lifetime Evaluation of Low-Power Ion Thrusters

Final Presentation: Numerical Part

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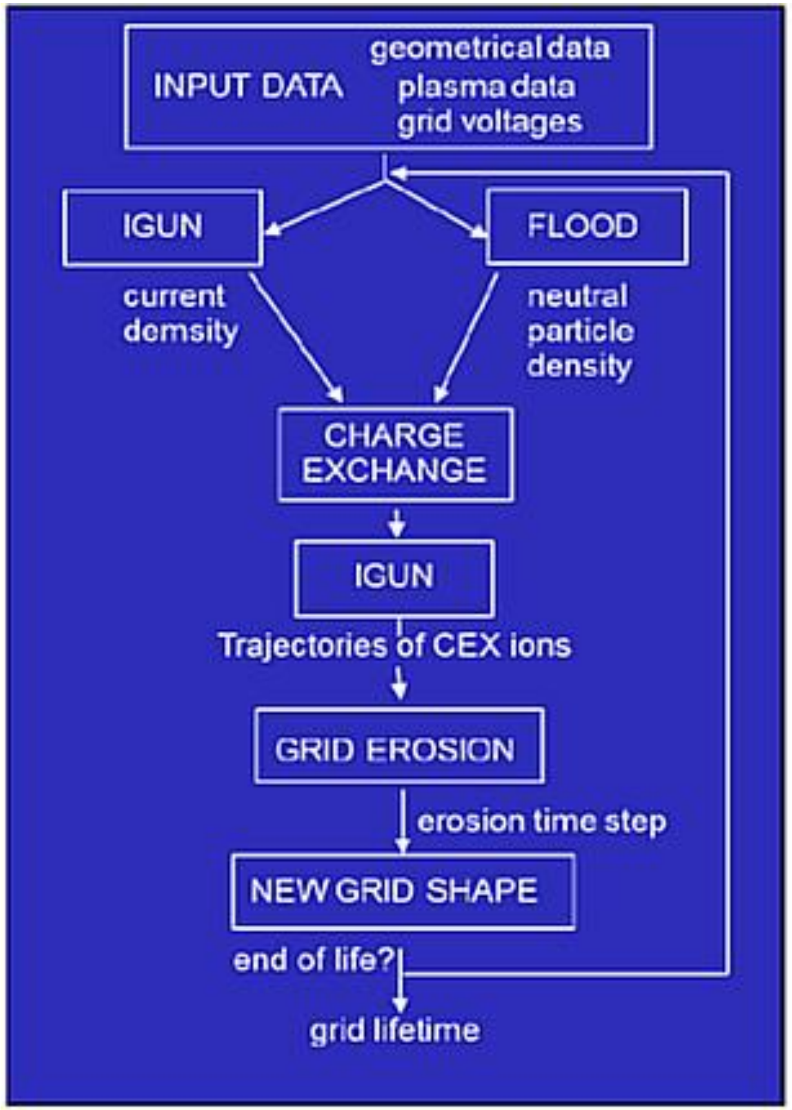
Leibniz Institute of Surface Engineering (IOM)

ESA contract no. 4000127019/19/NL/RA/va

Overview: Dynasim

- DynaSim combines
  - Commericially available IGUN [1,2] **ion trajectory code**
  - IOM-developed FLOOD **neutral flow module**
- Characteristics
  - 2D approach assuming axis symmetry
  - Single ion extraction channel, apertures in polygon coordinates
  - IGUN includes self-consistent model for plasma sheath and space charge simulation
  - FLOOD neutral expansion in molecular flow regime, diffusive reflection
  - Sputter database including IOM measured data, various materials may be apllied (molybdenum, graphite, titanium,…)
  - Comprehensive set of input parameters can be specified (flows, grid and particle temperatures, background pressure…)
  - Erosion modelling of screen, accelerator and deccelerator grids



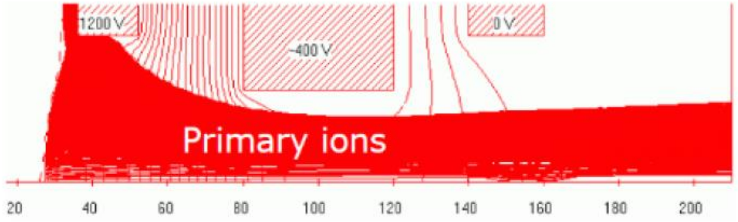
[1] Becker, Review of Scientific Instruments **67** (1996) 1132
[2] Becker and Herrmannsfeldt, Review of Scientific Instruments **63** (1992) 2756

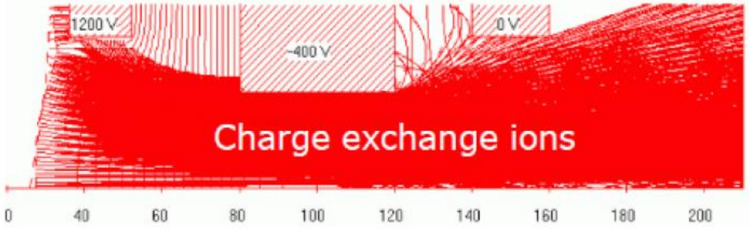
Overview: Dynasim

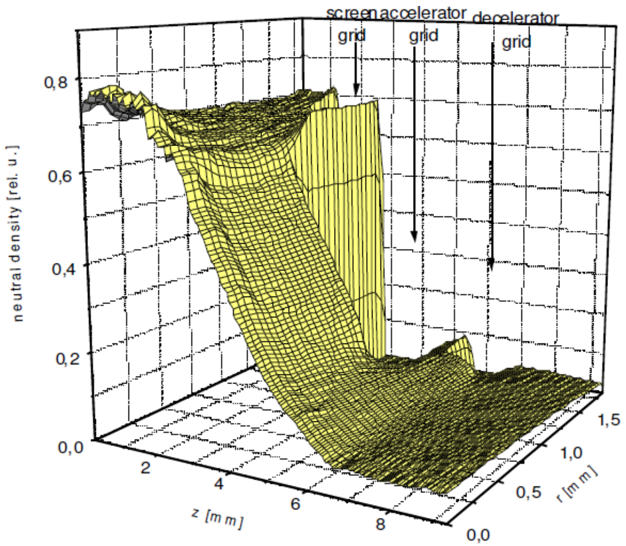
- IGUN
  - Computes primary ion trajectories
  - Computes secondary ion(charge exchange) trajectories

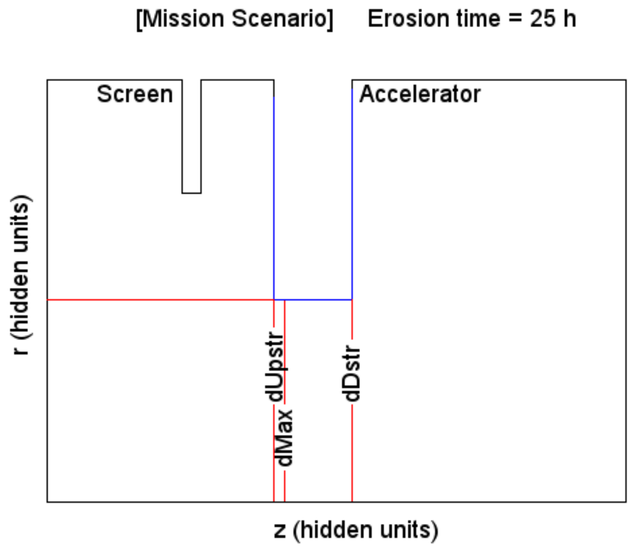
- FLOOD
  - Computes neutral density flow
  - Computes starting points of charge exchange trajectories

- Erosion computation based on sputter yields for trajectories impinging aperture surfaces
- Generation of new grid aperture polygon for next time step









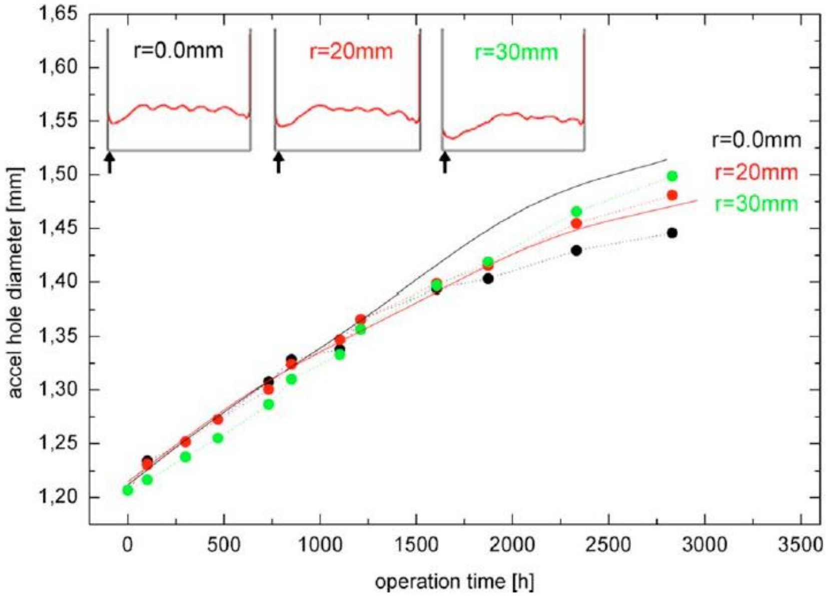
IOM

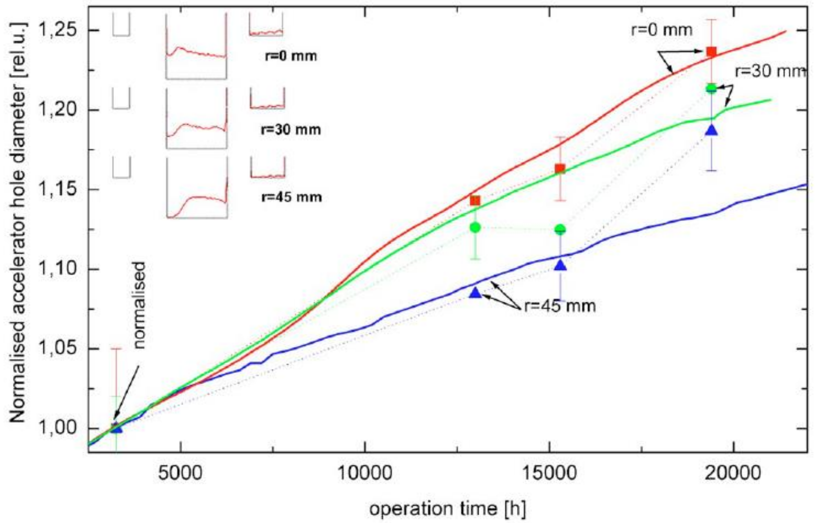
Overview: Dynasim [Validation]

Several validation approaches for Dynasim have been carried out in the past:

- 2800h accelerated wear test
  - Use of ISQ40RF ion source under „accelerated“ erosion conditions
  - Three grid system
  - Inspections each 200-500h using light microscopy and a high precision microbalance
  - Radial variation based on plasma density estimation

- 20000h RIT-10 ARTEMIS lifetime test
  - Life test performed by EADS ST
  - Two grid system
  - Precise mechanical hole measurement at three times
  - Radial variation based on plasma density estimation



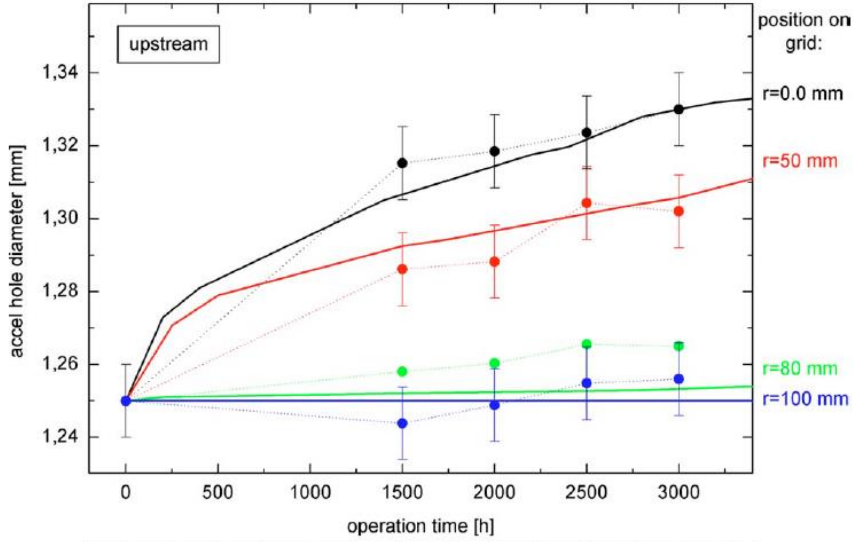


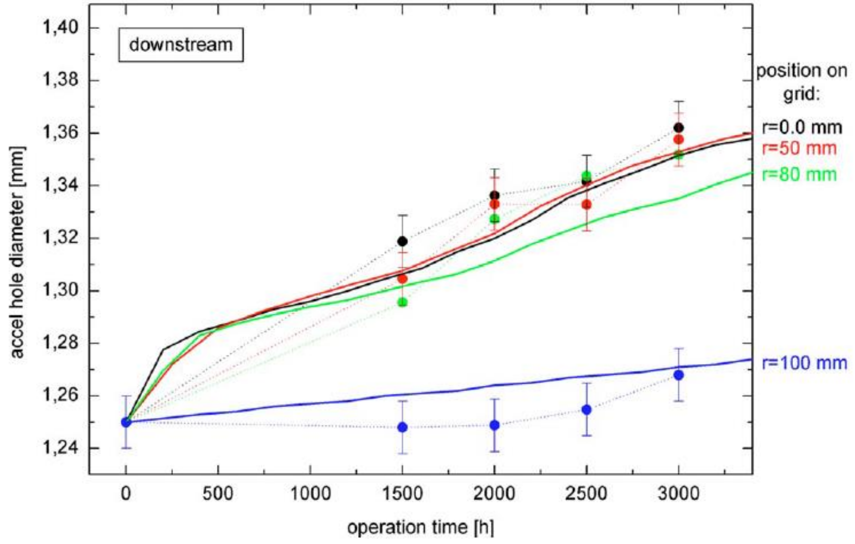
[3] Tartz, Hartmann and Neumann, Review of Scientific Instruments **79** (2008) 020000

Overview: Dynasim [Validation]

Several validation approaches for Dynasim have been carried out in the past:

- 3000h RIT-22 endurance test
  - Life test performed by EADS ST
  - Two grid system
  - Inspections starting at 1500h, then every 500h using optical imaging
  - Radial variation based on plasma density estimation at four radial positions

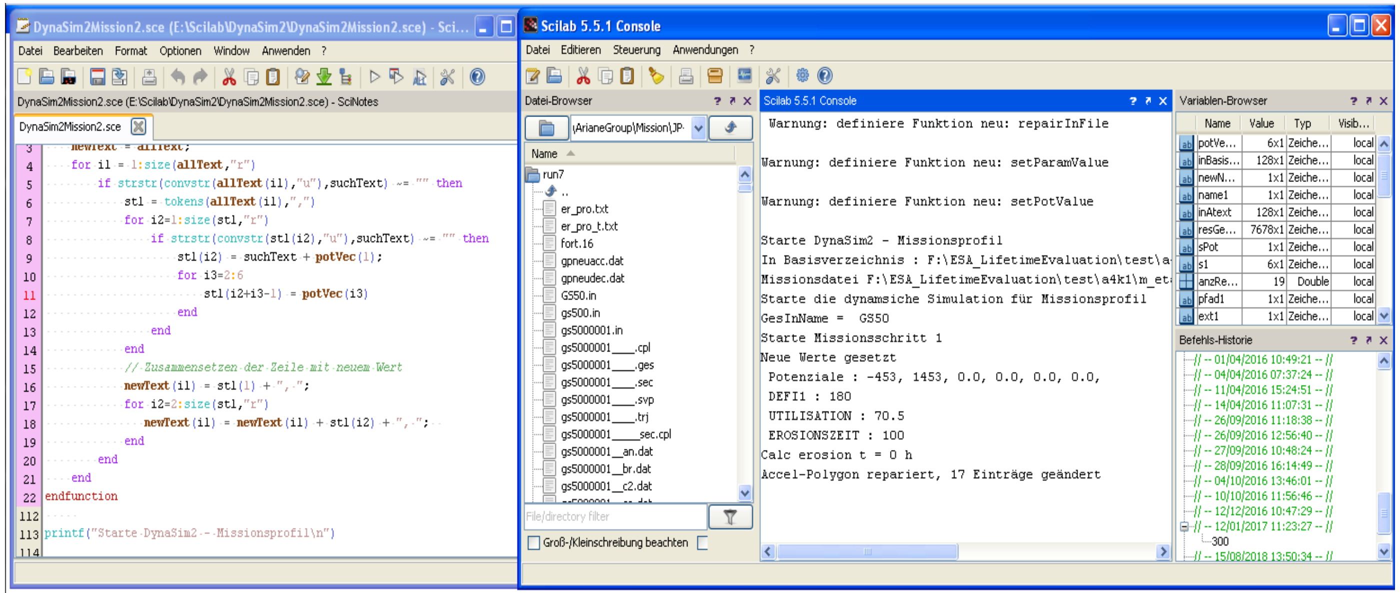




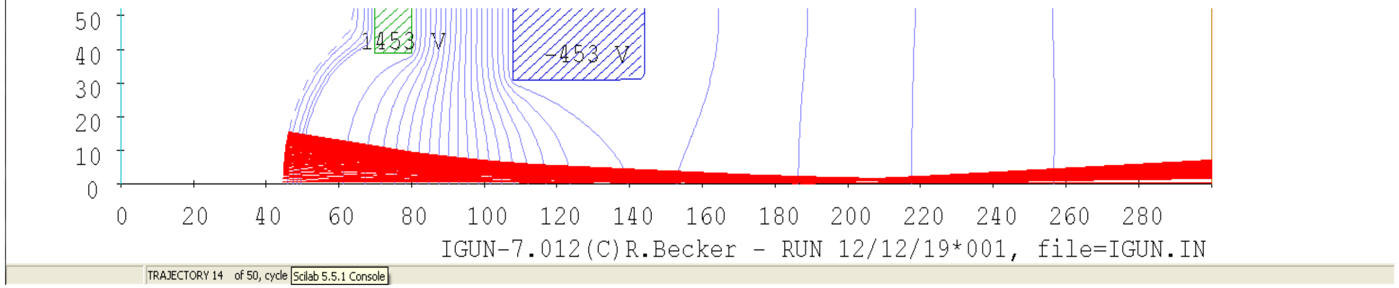
[3] Tartz, Hartmann and Neumann, Review of Scientific Instruments **79** (2008) 020000

Extending Dynasim Capabilities

- New Dynasim Package (Scilab) `Dynasim2Mission2.sce` allows for adjusting parameters with each timestep
  - Screen grid voltage
  - Accelerator grid voltage
  - Beamlet current
  - Mass utilization efficiency
  - Others can easiliy be added if required (e.g. facility background pressure)



- Simulation timesteps can be appropriately set and altered
- Extended routines for data analysis have been programmed



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Parameter	common unit	Input vs. simulation time
Screen grid voltage	V	variable
Accelerator grid voltage	V	variable
Decelerator grid voltage	V	constant
Beamlet current	µA/hole	variable
Mass efficieny	%	variable
Background chamber pressure	Pa	constant
Screen grid temperature	K	constant
Accelerator grid temperature	K	constant
Decelerator grid temperature	K	constant
Electron temperature (discharge)	eV	constant
Ion temperature (discharge)	eV	constant
Neutral temperature (discharge)	K	constant
Initial screen grid radius	mm	N/A
Screen grid thickness	mm	N/A
Initial accelerator grid radius	mm	N/A
Accelerator grid thickness	mm	N/A
Initial decelerator grid radius	mm	N/A
Decelerator grid thickness	mm	N/A
Screen-accelerator grid spacing	mm	N/A
Accelerator-decelerator grid spacing	mm	N/A

Simulation preparation

Input file generation

- Input variables based on TPS log files of SN03/SN04 thruster tests
  → only small number of changes in operation conditions applied
- Initial grid hole geometry identical for both thrusters
- Timestep 4h, accumulating to 628 simulation steps
- Electron temperature based on PPA measurements
- Facility pressure set to measured values, but turns out to be ngligible in current simulations

Simulation parameter	unit	SN03	SN04
Screen grid voltage	V	1000[a]	1400[a]
Accelerator grid voltage	V	-160[a]	-180[a]
Beamlet current	μA/hole	79.2[a]	134.1[a]
Mass efficiency	%	36.8[a]	52.2[a]
Screen grid temperature	deg C	150	150
Accelerator grid temperature	deg C	100	100
Electron temperature (discharge)	eV	4.5	as SN03
Ion temperature (discharge)	eV	0.03	as SN03
Neutral temperature (discharge)	deg C	set to screen grid temp.	as SN03
Initial screen grid radius	mm	0.950	as SN03
Screen grid thickness	mm	0.250	as SN03
Initial accelerator grid radius	mm	0.625	as SN03
Accelerator grid thickness	mm	1.000	as SN03
Screen-accelerator grid gap	mm	0.500	0.550

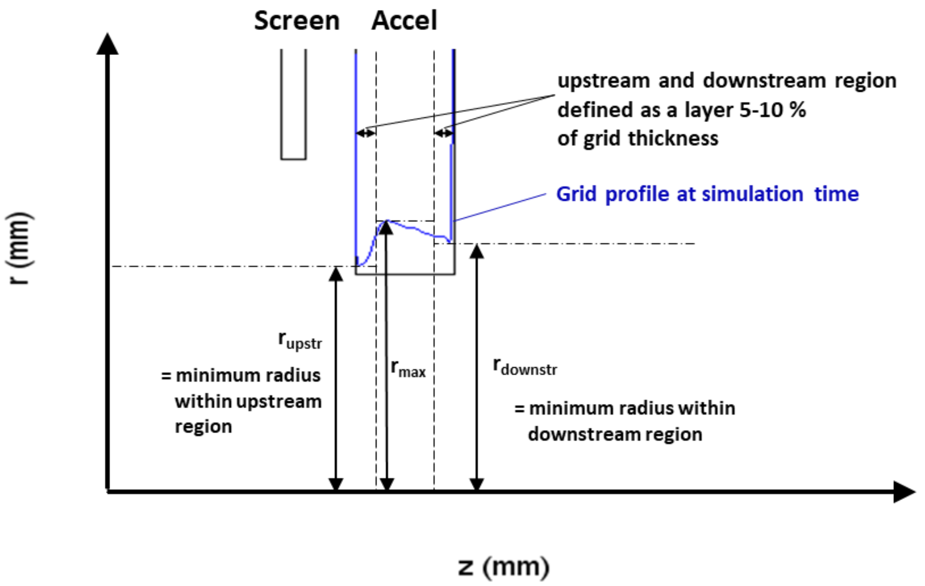
[a] variable with every timestep, see Listing 1

```
TPS 1 / SN 03
time Uscr Uacc  Ibl  etaM step
   0 1000 −160 79.2 36.8 4
   4 1000 −160 79.2 36.8 4
  20 1000 −160 79.2 36.8 4
  36 1000 −160 79.2 36.8 4
  60 1000 −160 79.2 36.8 4
  83 1000 −160 79.2 36.8 4
...
```

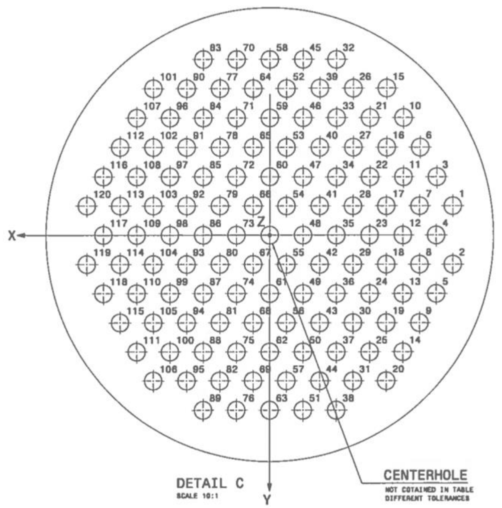
```
TPS 2 / SN 04
time Uscr Uacc   Ibl  etaM step
   0 1400 −180 134.1 52.2 4
   8 1400 −180 134.1 52.2 4
  30 1400 −180 134.1 52.2 4
  54 1400 −180 134.1 52.2 4
  76 1400 −180 134.1 52.2 4
 100 1400 −180 134.1 52.2 4
...
```

Simulation preparation

- Grid hole diameter definitions
  - Maximum hole radius is the maximum over the grid thickness, neglecting an upstream/downstream layer of 10%
  - Upstream radius is the minimum radius in the 10% upstream region
  - Downstream radius is the minimum radius in the 10% downstream region



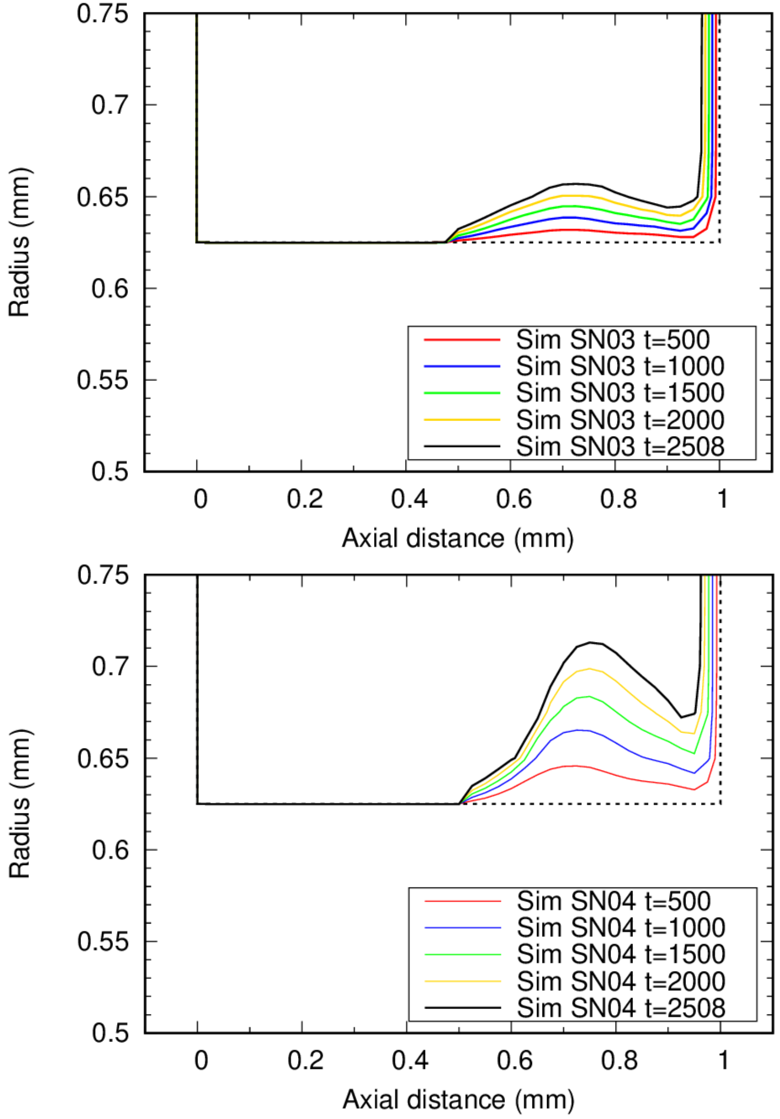
- Which grid holes are simulated?
  - Extracted beamlet currents may differ over the grid radius due to non-constant plasma density distribution
  - Resulting different hole erosion across the grid
  - Common approach:
    - Quadratic plasma density distribution
    - „Average“ beamlet current extracted at r = R/√2, here Ref. 12/109



Summary of Simulation Results I

Axially resolved temporal erosion along the accelerator grid hole channel

- Erosion moves forward smoothly for both thrusters/operation conditions
- Erosion rates for the higher-current operation condition (SN04) exceeds lower current operation (SN03)
- Simulated erosion concentrates on the „downstream-handed“ half of the accelerator grid channel
- As it is observed in other simulations with comparable operation conditions, a „tongue“ remains on the downstream side over the complete simulation period



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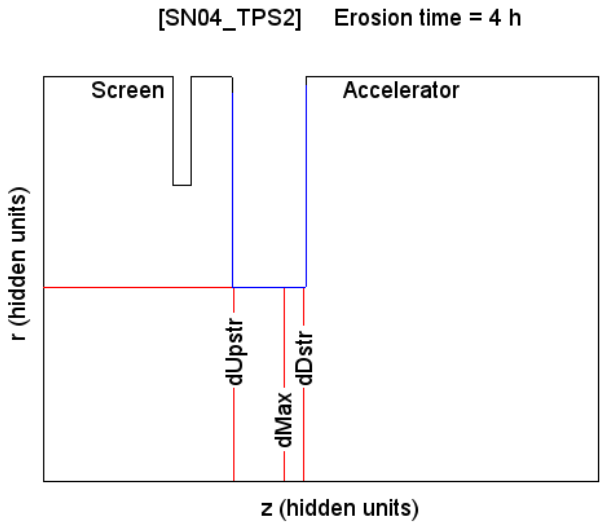
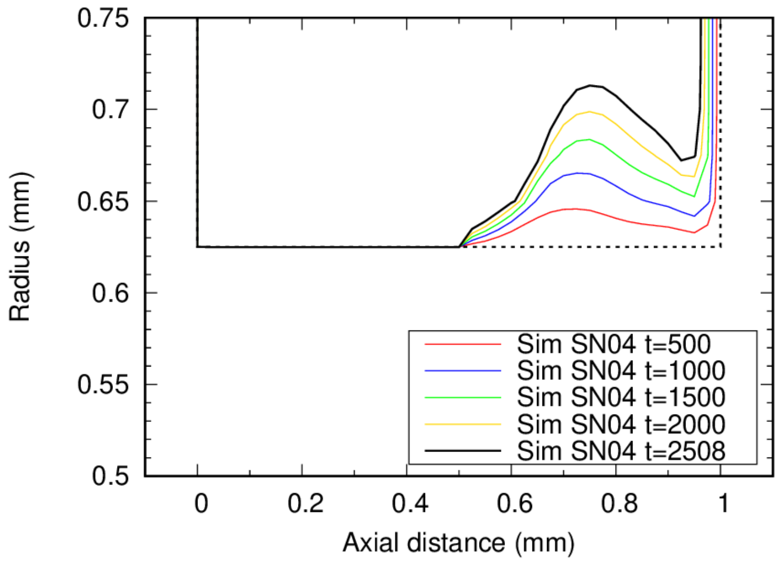
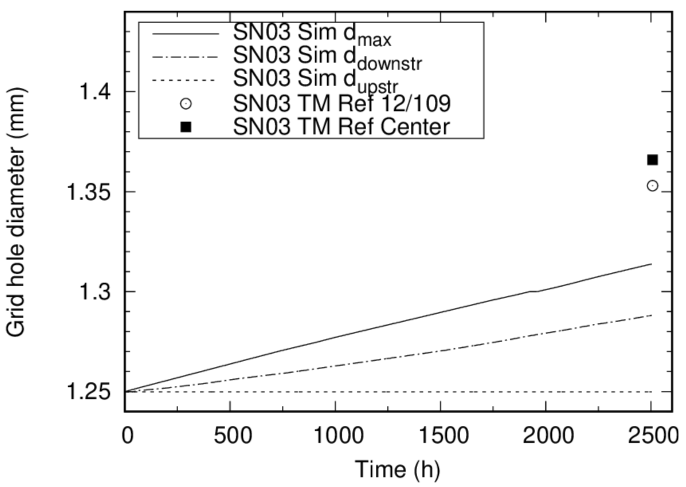


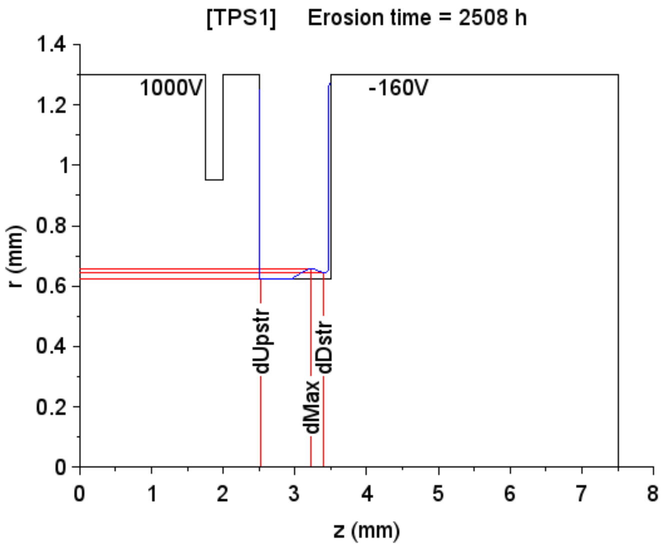


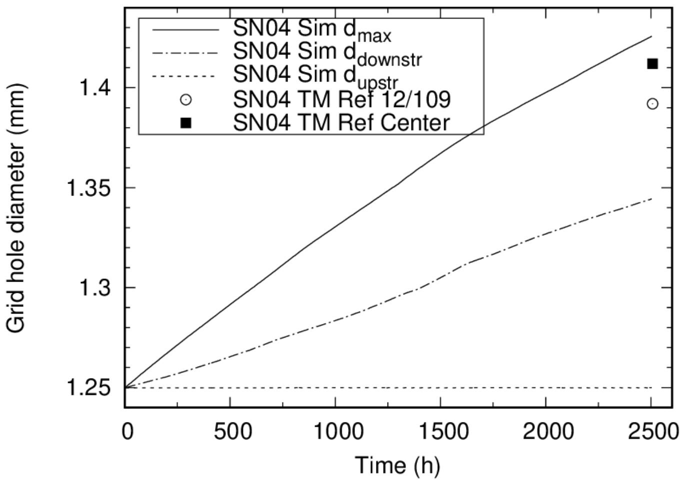
Summary of Simulation Results II

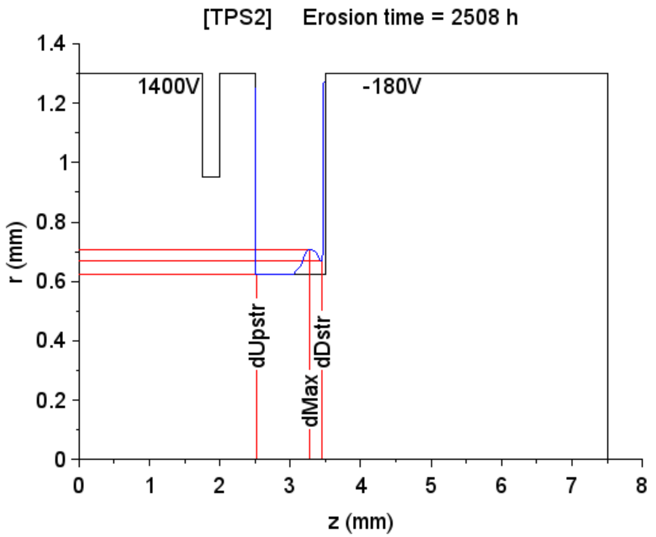
Temporal evolution of the maximum erosion radius: Main results after 2500h

- Comparison to tactile measurements by ArianeGroup GmbH
- Radii of maximum erosion in reasonable agreement, change of radius
  - Underestimated by 38% for SN03
  - Overestimated by 24% for SN04
- Simulation shows no noteworthy upstream erosion
- Underestimation of the totally eroded material for both simulations SN03/SN04





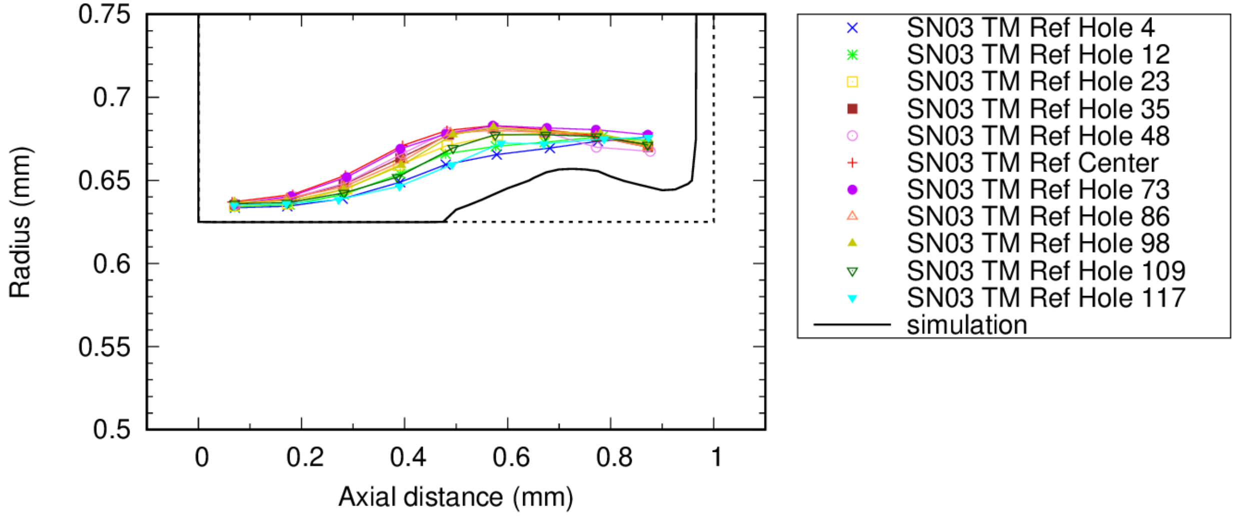


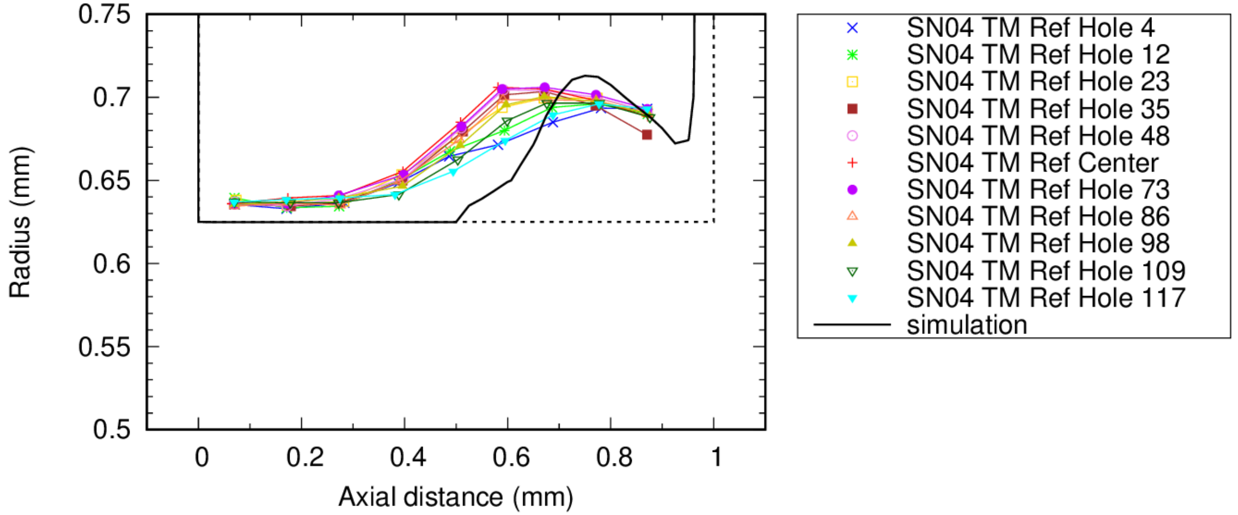


Summary of Simulation Results III

Comparison of eroded grid hole channel profiles to tactile measurements

- Good agreement of the erosion shape, but
  - Moderate axial shift of the maximum radius position (~20% of the grid thickness)
  - Predicted eroded mass significantly lower for SN03
- Numerous variations of input parameters (sensitivity study) do not change the main results
- Main cconclusions from parameter variations:
  - Increasing the electron temperature would lead to flatter erosion profiles, but not substantially increase total eroded mass
  - Increasing the beamlet current would shift the maximum to the upstream side, and also increase the eroded mass

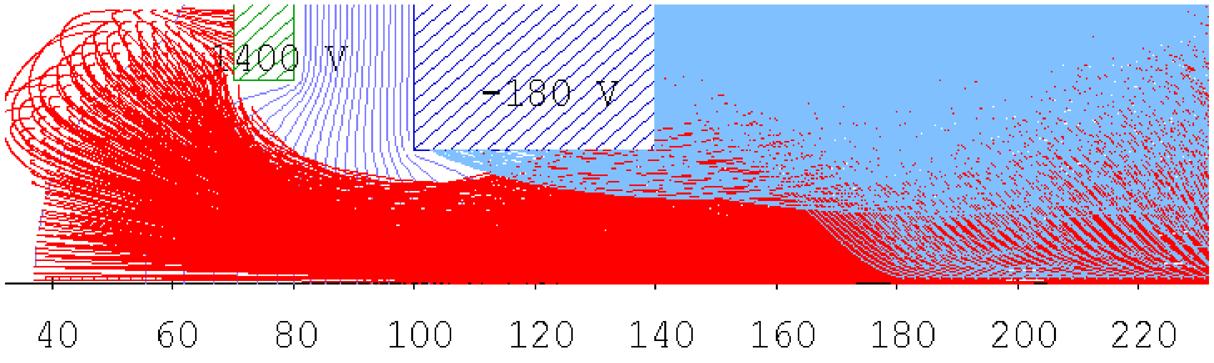


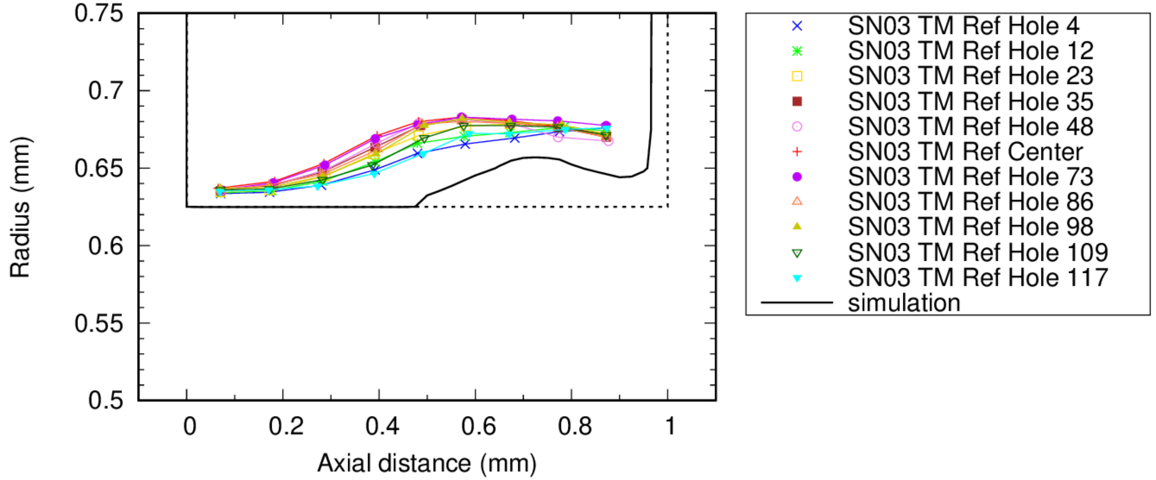


Summary of Simulation Results IV

More detailed view on the origin of CEX ion trajectories:

- Erosion is predominantly triggered by CEX ions from the inter-grid region (red trajectories)
- „Plume“ CEX ions (blue trajectories) impinge nearly along the complete length channel axis, but corresponding CEX currents are too small to cause significant erosion
- No reasonable thruster operation conditions could be identified that would generate an „radial shift“ of the channel erosion profile
- This kind of discrepancy not observed in simulations with larger beamlet currents and/or mass efficiencies:
    - For SN03-like operation conditions, further investigations needed





Thank you for your attention

Back-up

- Back-up material: Additional simulations, parameter variations

Back-up

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