ADAS in FAFNER and TRANSP/NUBEAM

Implementation and Benchmark

Michael Kraus[1] (michael.kraus@ipp.mpg.de),
Jörg Stober[1], Giovanni Tardini[1], Douglas McCune[2],
Marina Gorelenkova[2], Martin O'Mullane[3]

[1]Max-Planck-Insitut für Plasmaphysik, Garching
[2]Princeton Plasma Physics Laboratory
[3]University of Strathclyde

ADAS Workshop 2009

FAFNER and TRANSP/NUBEAM

- Monte Carlo codes for NBI physics
- NUBEAM[1]: time-dependent, developed at PPPL
- FAFNER[2]: stationary, developed at IPP
- atomic data used:

FAFNER

- Freeman & Jones: Atomic Collision Processes in Plasma Physics Experiments (1974)
- Riviere: Nuclear Fusion 11, p363 (1971)
- Olson et al.: Physical Review Letters 41, p163 (1978)

TRANSP/NUBEAM

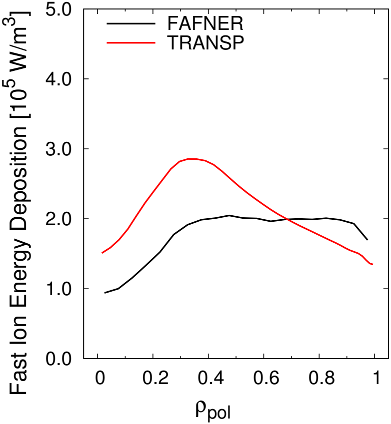
NTCC PREACT[a]:

- Barnett: ORNL Redbook 1 (1990)
- Phaneuf et al.: ORNL Redbook 5 (1987)
- Janev et al.: Elementary Processes in Hydrogen-Helium Plasmas (1987)

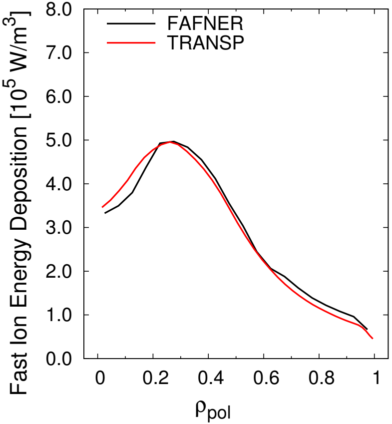
[a] http://w3.pppl.gov/ntcc/PREACT/

[1] Pankin et al.: Computer Physics Communications 159, p157 (2004)
[2] Lister: FAFNER - A Fully 3D NBI Code Using Monte Carlo Methods (1985)

Comparison of FAFNER and TRANSP/NUBEAM

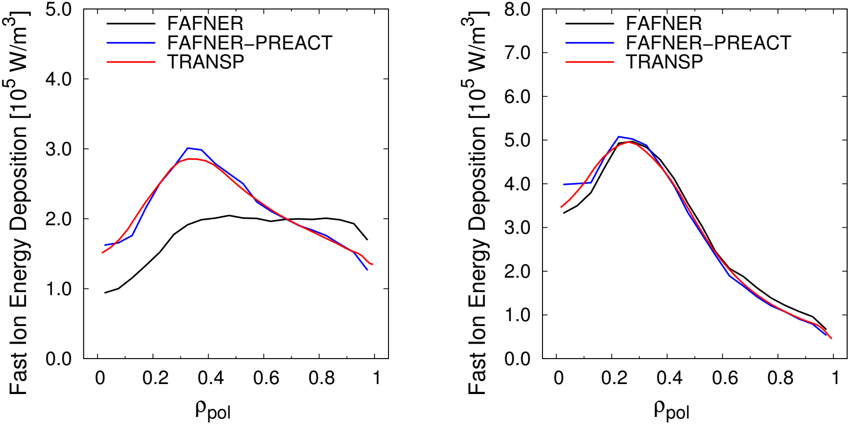


#17847, NBI Source 1
($n_0 \simeq 1.2 \times 10^{20}\ m^{-3}$)



#17870, NBI Source 1
($n_0 \simeq 0.8 \times 10^{20}\ m^{-3}$)

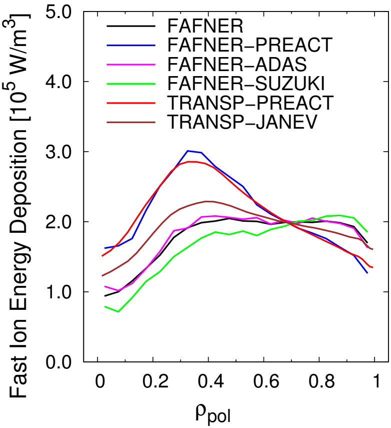
Implementing PREACT into FAFNER



#17847, NBI Source 1
($n_0 \simeq 1.2 \times 10^{20}\ m^{-3}$)

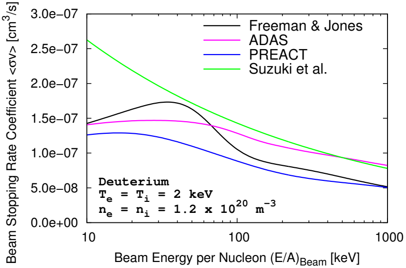
#17870, NBI Source 1
($n_0 \simeq 0.8 \times 10^{20}\ m^{-3}$)

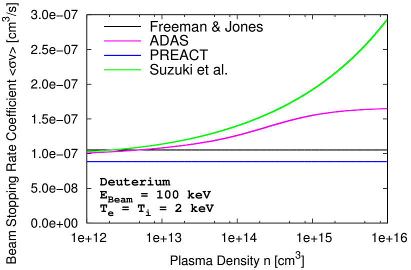
Benchmark of Ionisation Models



#17847, NBI Source 1

$(n_0 \simeq 1.2 \times 10^{20}\ m^{-3})$





Suzuki: Plasma Phys. and Contr. Fus. 40, p2097 (1998)
Janev: Nuclear Fusion 29, p2125 (1989)

Challenges Implementing ADAS into NUBEAM

- excited state beam stopping rate coefficient saved in `adf21` files within ADAS distribution
- tried to use `adf21` datasets with an adaption of the JET `qhioch7.f` routine
- problems:
  - no separate excited state data for electron impact, ion impact and charge exchange ionisation
  - but: separate ground state data available

    $\Rightarrow$ work around: enhancement factor η

$$\eta = \frac{<\sigma v>_{\text{exc}}\ n_{e,\text{eff}}}{<\sigma v>_{ei}\ n_e + (<\sigma v>_{ii} + <\sigma v>_{cx})\ n_i}$$

$$<\sigma v>_{ii,\text{exc}} = \eta <\sigma v>_{ii}$$

$$<\sigma v>_{cx,\text{exc}} = \eta <\sigma v>_{cx}$$

$\Rightarrow$ suitable solution?

Challenges Implementing ADAS into NUBEAM

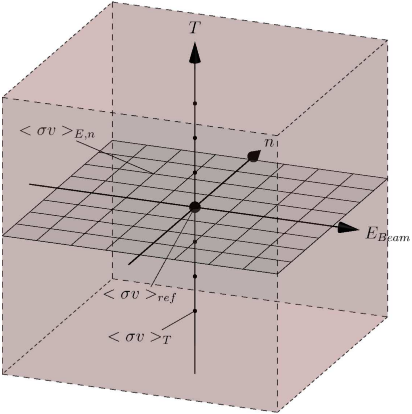
- problems (continued):
  - no dependence on T_e ($T_e = T_i$ assumed)
    - introduced error usually neglegible ($\simeq 1\%$)
    - but: special cases ($T_e \ll T_i$) resulting in quite high error e.g. for $T_e/T_i \simeq 0.2 \ldots 0.4$ error $\simeq 10 \ldots 20\%$

    $\Rightarrow$ unsolved (yet)
  - discontinuity between low and high energy dataset

    $\Rightarrow$ solution: calculation of a full 3D dataset
  - parameter ranges to small

    $\Rightarrow$ solved with the creation of the full 3D dataset

adf21 file format



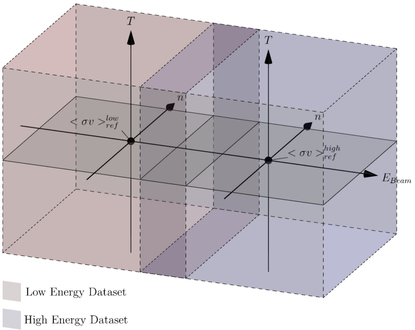
consists of:

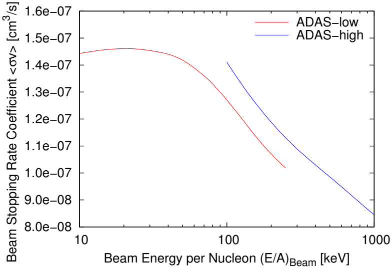
$$< \sigma v >_{E,n} \equiv < \sigma v > \left(E_{\text{Beam}},\ n_e,\ T_i^{\text{ref}} \right)$$
$$< \sigma v >_T \equiv < \sigma v > \left(E_{\text{Beam}}^{\text{ref}},\ n_e^{\text{ref}},\ T_i \right)$$
$$< \sigma v >_{\text{ref}} \equiv < \sigma v > \left(E_{\text{Beam}}^{\text{ref}},\ n_e^{\text{ref}},\ T_i^{\text{ref}} \right)$$

put together to:

$$< \sigma v > \left(E_{\text{Beam}},\ n_e,\ T_i \right) = $$
$$= < \sigma v >_{E,n} \frac{< \sigma v >_T}{< \sigma v >_{\text{ref}}}$$

adf21 file format: low and high energy dataset





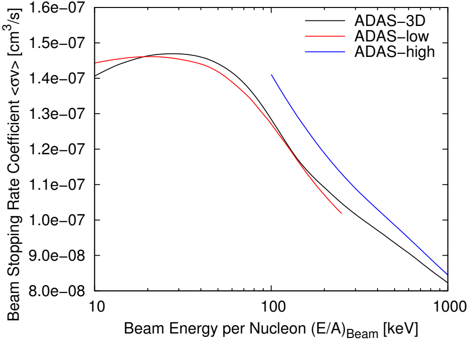
$$(n = 1.2 \times 10^{20}\ m^{-3},\ T = 2\ keV)$$

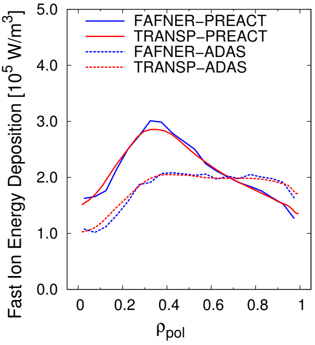
Problem:

gap between low and high energy dataset at $T \neq T^{\text{ref}}$

$\Rightarrow$ causes interpolation problems for the enhancement factor

Results





$(n = 1.2 \times 10^{20}\ m^{-3},\ T = 2\ keV)$

#17847, NBI Source 1
$(n_0 \simeq 1.2 \times 10^{20}\ m^{-3})$

$\Rightarrow$ data is smooth everywhere in the 3D grid
$+$ higher overall accuracy

Summary and questions open for discussion

- Achievements:
  - benchmark of FAFNER and TRANSP/NUBEAM
  - calculation of full 3D dataset for the ADAS excited state beam stopping rate coefficient
  - implementation into TRANSP/NUBEAM (with some limitations / approximations)
- Open questions:
  - enhancement factor accurate enough?
  - T_e/T_i as an additional parameter?

Calculation of the full 3D dataset

Create a logarithmic even spaced grid:

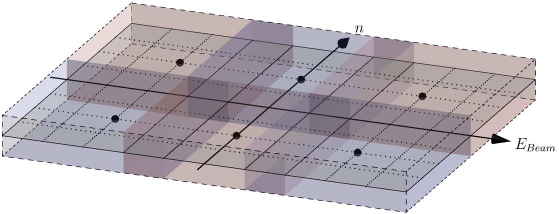
```
delta = 10^(1/12)

for i = 0, grid_size-1 do
    grid[i] = delta^i
endfor


1.0
1.21152765863
1.46779926762
1.77827941004
2.15443469003
2.61015721568
3.16227766017
3.83118684956
4.64158883361
5.62341325190
6.81292069058
8.25404185268
10.0
...
```

Parameter ranges:

	range			unit
beam energy	1×10^1	...	1×10^7	eV
plasma density	1×10^{12}	...	1×10^{16}	cm^{-3}
ion temperature	1×10^0	...	1×10^6	eV

$\Rightarrow$ $73 \times 49 \times 73$ grid points

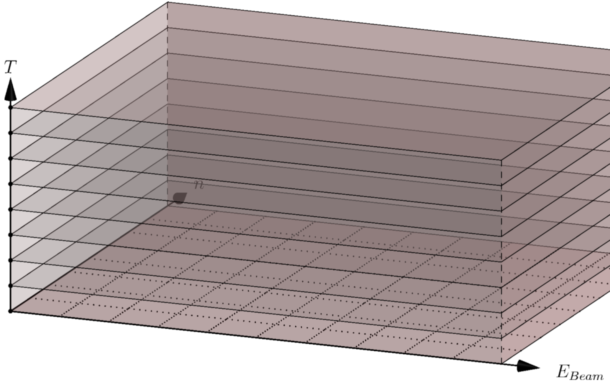
$\Rightarrow$ 6 files for the $E - n$ plane:



$\Rightarrow$ calculation of 73×6 `adf21` files using the `ADAS310` routine (only one T value each)

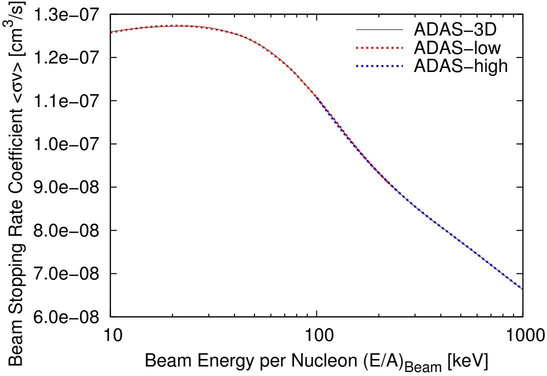
Calculation of the full 3D dataset

⇒ merge those 73 $E - n$ planes into one full 3D dataset



Comparison of the 3D dataset and the adf21 files

The 3D dataset perfectly matches the adf21 files from the ADAS dristribution at the reference temperature ($T_i^{ref} = 5keV/amu$):



(Deuterium, $n = 1.2 \times 10^{20}\ m^{-3},\ T = 10\ keV$)