Beam penetration and photoemission benchmark

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Consultancy Meeting on the Evaluation of Data for Neutral Beam Modelling, 18-20 May 2022, IAEA Headquarters
## Benchmark progress

### I. Constant profile test cases

**Calculation length: 2m**

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Beams:</th>
<th>Energies:</th>
<th>Densities (n_e):</th>
<th>Temperatures:</th>
<th>Available codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. H(+) 100%</td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>0.1, 1, 20 keV</td>
<td>RENATE, RENATE-OD, FIDASIM, CHERAB</td>
</tr>
<tr>
<td>2. H(+) 100%</td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>0.1, 1, 20 keV</td>
<td>RENATE, RENATE-OD, FIDASIM, BBNBI (good stat.), CHERAB, CRM-stat</td>
</tr>
<tr>
<td>3. D(+) 100%</td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>0.1, 1, 20 keV</td>
<td>RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB</td>
</tr>
<tr>
<td>4. He(2+) 100%</td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>0.1, 1, 20 keV</td>
<td>RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB</td>
</tr>
</tbody>
</table>
## Benchmark progress

<table>
<thead>
<tr>
<th></th>
<th>Beams:</th>
<th>Energies:</th>
<th>Densities ((n_e))</th>
<th>Temperatures:</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
<td>D(+) 95% + Be(4+) 5% ((n_i), %)</td>
<td>Te = Ti</td>
<td>RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H, D, T</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>1, 20 keV</td>
</tr>
<tr>
<td>6.</td>
<td>D(+) 95% + C(6+) 5% ((n_i), %)</td>
<td>Te = Ti</td>
<td>RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>1, 20 keV</td>
</tr>
<tr>
<td>7.</td>
<td>D(+) 99.9% + W(64+) 0.1% ((n_i), %)</td>
<td>Te = Ti</td>
<td>RENATE, RENATE-OD, new W cross-sections?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>20 keV</td>
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<tr>
<td>8.</td>
<td>D(+) 50% + T(+) 50% ((n_i), %)</td>
<td>Te = Ti</td>
<td>RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>20 keV</td>
</tr>
<tr>
<td>9.</td>
<td>D(+) 40% + T(+) 40% + He(2+)15% + Be(4+) 4.5% +C(6+) 0.2% + Ne(10+) 0.29% + W(64+) 0.01%</td>
<td>Te = Ti</td>
<td>RENATE, RENATE-OD, new W cross-sections?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>30, 100, 1000 keV</td>
<td>1E19, 1E20 m-3</td>
<td>20 keV</td>
</tr>
</tbody>
</table>
## Benchmark progress

### II. Plasma profile test cases

<table>
<thead>
<tr>
<th>Profiles along beam provided</th>
</tr>
</thead>
</table>

1. **ITER scenario**
   - **Beams:** H, D, T
   - **Energies:** 30, 100, 1000 keV

2. **ITER scenario with blob**
   - **Beams:** H, D, T
   - **Energies:** 30, 100, 1000 keV

3. **Island divertor**
   - **Beams:** H
   - **Energies:** 30, 100, 1000 keV

### Li and Na beams:

RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB

RENATE, RENATE-OD
Most standard:
pure H (case 2)

Scenario: 2
Density: 1E+20 1/m³
Temperature: 1 keV

Beam energy: 30 keV
Beam energy: 1 MeV
### Gergő Pokol: Beam penetration and photoemission benchmark

#### Meeting on Data for Neutral Beam Modelling, 18-20 May 2022, IAEA Headquarters

#### Attenuation coefficient (1/m)

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</thead>
<tbody>
<tr>
<td>1E+19</td>
<td>100</td>
<td>30</td>
<td>H</td>
<td>2</td>
<td>0,543</td>
<td>0,588</td>
<td>0,589</td>
<td>0,562</td>
<td>0,595</td>
<td>0,544</td>
<td>0,562</td>
<td>0,569</td>
</tr>
<tr>
<td>1E+19</td>
<td>1000</td>
<td>30</td>
<td>H</td>
<td>2</td>
<td>0,494</td>
<td>0,499</td>
<td>0,504</td>
<td>0,510</td>
<td>0,526</td>
<td>0,495</td>
<td>0,510</td>
<td>0,506</td>
</tr>
<tr>
<td>1E+19</td>
<td>20000</td>
<td>30</td>
<td>H</td>
<td>2</td>
<td>0,364</td>
<td>0,382</td>
<td>0,399</td>
<td>0,377</td>
<td>0,407</td>
<td>0,365</td>
<td>0,376</td>
<td>0,381</td>
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</table>

#### Attenuation coefficient deviation from average (%)

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</tr>
</thead>
<tbody>
<tr>
<td>1E+19</td>
<td>100</td>
<td>30</td>
<td>H</td>
<td>2</td>
<td>-4,6</td>
<td>3,3</td>
<td>3,5</td>
<td>-1,3</td>
<td>4,7</td>
<td>-4,4</td>
<td>-1,2</td>
<td>-1,2</td>
</tr>
<tr>
<td>1E+19</td>
<td>1000</td>
<td>30</td>
<td>H</td>
<td>2</td>
<td>-2,2</td>
<td>-1,2</td>
<td>-0,2</td>
<td>0,8</td>
<td>4,0</td>
<td>-2,0</td>
<td>0,9</td>
<td>0,9</td>
</tr>
<tr>
<td>1E+19</td>
<td>20000</td>
<td>30</td>
<td>H</td>
<td>2</td>
<td>-4,6</td>
<td>0,2</td>
<td>4,5</td>
<td>-1,2</td>
<td>6,8</td>
<td>-4,3</td>
<td>-1,4</td>
<td>-1,4</td>
</tr>
</tbody>
</table>
Case 2 (pure H plasma) general conclusions

Matching attenuation coefficients within a few percent. → quantify statistics?
1. BBNBI and CHERAB use the effective attenuation coefficients calculated by ADAS. BBNBI data features stochasticity due to its Monte-Carlo nature. → fit exponential on BBNBI?
2. Both RENATE and RENATE-OD are based on the ALADDIN database and solve bundled-n CRM, so no significant difference is observed for pure plasmas. → RENATE-OD fixed for high energy!
3. FIDASIM and CRM-stat (by O. Marchuk) also solves bundled-n CRM but based on ADAS – their agreement is very good.
4. nl-model needed! nlm-model needed?
5. New bundled-n cross-sections?
6. …?

All codes agree on a tendency of a significant effect of plasma temperature and appear to produce reliable results.
Pure ions – H plasma (case 1)

Scenario: 1
Density: 1E+20 1/m³
Temperature: 20 keV
Beam energy: 30 keV

**Beam energy ~ ion temperature extreme case.**
RENATE and FIDASIM use similar methods to integrate rates.
(Input from ADAS and Marchuk CRM?)
Isotope effects – H vs D plasma (case 2-3)

Scenario: 2-3 relative
Density: 1E+20 1/m³
Temperature: 20 keV
Beam energy: 30 keV

Comparison of H and D plasma showed a small isotope effect, at high temperature and low beam energy.
(Need to check CHERAB, BBNBI.)
Impurities – Be impurity (case 5)

Scenario: 2-5 relative
Density: $1E+20$ 1/m3
Temperature: 20 keV
Beam energy: 30 keV

The **effect of impurities** – provided the same electron density and quasi-neutrality – is a **increase in the attenuation rate**.
Impurities – C impurity (case 6)

Scenario: 2-6 relative
Density: 1E+20 1/m³
Temperature: 20 keV
Beam energy: 30 keV

More scatter of results for C impurity – requires further investigation.
Mixed plasma D-T (case 8)

Scenario: 2-8 relative
Density: 1E+20 1/m³
Temperature: 20 keV
Beam energy: 30 keV

The effect of is like the H-D isotope effect.
(Need to check CHERAB, BBNBI.)
Plasma profile: ITER with SOL blob

Beam type: H
Beam energy: 100 keV
(ITER DNB)

Good agreement of all codes
With the CRM-solvers (FIDASIM and RENATE(-OD)) featuring a slightly delayed response to the density changes.
Plasma profile: ITER with SOL blob

Beam type: H
Beam energy: 100 keV
(ITER DNB)

Not all codes can calculate.
With the CRM-solvers (FIDASIM and RENATE(-OD)) featuring a significantly delayed response to the density changes.

Photoemission
Summary

1. Benchmark was already very useful for code development – preliminary results published at [EPS2021, Pokol et al.].

2. RENATE Open Diagnostics got a new rate calculation module – corrected rates calculation at beam energy $\gg 100$ keV.

4. Some constant profile test cases were challenging: 7 (W impurity), 9 (with W impurity) – new W data could be added to RENATE-OD.

5. Plasma profile test cases show expected results, but small effects – more pronounced effects in photoemission!

6. Sufficient input data only for beams of Hydrogenic species.

7. Benchmark could be more complete with the missing codes and nl-resolved models.

8. Another direction would be to test the effect of the new cross-sections $\rightarrow$ add Be data $\rightarrow$ rather in CRP summary paper?