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| SRC “KURCHATOV INSTITUTE” MOSCOW |
| BTR INPUT GUIDE |
| Version 4.0 (free geometry) |
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| **01.06.2013** |

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| * Helps the user to make a quick start and gives the main idea of BTR model and features |

*“One day I will find the right words,*

*and they will be simple.”*

*―* [*Jack Kerouac*](http://www.goodreads.com/author/show/1742.Jack_Kerouac)*,* [*The Dharma Bums*](http://www.goodreads.com/work/quotes/827497)

# BEAM TRANSMISSION CODE (BTR)

# *USER’S GUIDE (INPUT)*

# Jun 2013, E. Dlougach

# INTRODUCTION

BTR-code for neutral beam injectors design is typically used for power loading analyses in ITER heating and diagnostic NBI systems. It takes into account the detailed neutral beam structure and the NB injector geometry with realistic gas & fields background. BTR is supplied with a graphical user interface which allows to play with the input data, to follow the beam particles tracks, and to look through the resulting load maps. Basically a BTR user is not expected to be a expert in injectors design and physics, as running the code itself provides basic training for its advanced usage.

BTR implements a discreet model of beam simulation, i.e. it traces “big particles”, taking into account particles transformations based on given cross-sections data.

BTR 4.0 is a parallel multi-thread Win32-application, created with help of MS Visual C++ 2008. The physical amount of big particles is not limited, up to 108 big particles can be traced on modern systems within one BTR run. The only restriction is the memory of the machine.

BTR is supplied by a Windows-like User Interface (GUI). It allows the user to set interactively the NBI configuration, environment and beam tracing options, displays all the information on the screen through data plots and tables. Beam tracing is visualized during calculation, and the intermediate results of power density (PD) are available any time.

The work with BTR normally includes the following steps:

1. Input NBI geometry;
2. Input Beam structure and optics;
3. Input Options, Preferences;
4. Input Gas profiles, Fields data;
5. Input Additional settings;
6. Run the Beam;
7. Results post-processing;
8. Save the results.

This document gives a short review of BTR model, and provides Input guide-lines for customary BTR-tasks:

1. Beam Transport (*Direct Interception* task);
2. Residual ions power (*RID* task);
3. Re-ionized power (*Reion* task).

The purpose of the document is to help a user to make a quick start and get the main idea of BTR model and features. It’s recommended - at least for the beginners - not to mix different BTR-tasks in one run, because each Task normally requires its own suite of options and parameters.

If you face any persistent problem with BTR, you are kindly asked to inform the BTR support service by e-mail (edlougach@nfi.kiae.ru).

*Acronyms in BTR and BTR-documentation*

*AS – Active Surface (i.e. Surf activated by the user’s mouse-click);*

*BP – Big Particle, a model particle, carrying an integral current (power);*

*BS – Beam Source;*

*BTR – “Beam TRansmission” code (initially “Beam Transport with Re-ionization”);*

*CS – Coordinate System;*

*DI – Direct Interception (typically referred to atom power fallen at Surf);*

*FW – First Wall of the Tokamak (more rarely - Far Wall);*

*GG – Grounded Grid of the Beam Source;*

*GP – Green Panel, the main BTR input tool;*

*MF – Magnetic Field;*

*NB – Neutral Beam;*

*NBI – Neutral Beam Injector;*

*NBL – Neutral Beam-line;*

*PD – Power Deposition at Surf;*

*Reion – re-ionized particle, i.e. positive ion H+/D+ born from atom H0/D0;*

*Surf – any surface (physical or virtual), included into the Task geometry;*

### *BTR coordinates and units*

BTR uses NBL coordinates, i.e. right-handed CS with origin is at the BS GG centre. Axis *X* is directed along the NBL major horizontal axis, it is NOT inclined with the beam and/or NBL components. The values of NBL components inclination, beam tilting, misalignments, shifts are given with respect to this nominal axis. Axis *Y* is horizontal right in GG plane (if seen from Tokamak), axis *Z* – vertical up in GG plane.

All the values are indicated by default in SI (international units system), unless other specified.

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### *BTR Limitations*

* ITER-like NBI configuration is assumed Standard;
* Particle sorts traced: D-, D+, D0, H-, H+, H0;
* Source Beam starts from X = 0 (emitted from BS GG);
* No account of BS space charge while tracing the particles;
* Gauss divergence is applied to all beamlets (along Y and Z);
* All the surfaces are flat (but can be non-rectangular);

# BTR INTERFACE

*NBI screen*

* Top-Left window;
* displays the geometry of NBI in horizontal (XY-plane) view and vertical (XZ-plane) view. Also the beamlets axes are shown according to their aimings (violet lines). In Standard geometry mode the positions of “diaphragms” (PDP term) are shown blue. During the beam tracing, if the Option Show Particles is ON, the screen shows BP tracks calculated: blue – atoms, red – positive ions, green – negative ions. When Show Particles is OFF, no tracks are shown, but the calculation runs 2-3 times faster. When the calculation is finished, BTR-message appears, and the surfaces met power are marked by red spots. To calculate power load on a Surf the user catches the red spot on the Surf (selects it) and then calls Pop-up menu by right mouse button. The Pop-up menu allows to get the results for the Selected Surf and display them on the other screens (Load screen, Status/Prof screen).

*Green Panel (GP)*

* Bottom-Left window;
* is the main input tool of BTR, which displays the set of options and parameters defining the task and allows the user to directly modify the input data before running the calculation. The filenames indicated in the Options are updated automatically when the user reads a correspondent text-file.

Green Panel has the following sections (data groups):

1. TASK CAPTION

BTR INPUT date 00:00:0000 time 00:00:00

TITLE: to be defined

COMMENTS: do be defined

1. TASK OPTIONS

Source Beam: MAMuG or SINGAP

OPTIONS:

Magnetic Field: file <filename.txt> - ON /OFF

Gas Profile: file <filename.txt> NOT LOADED

First Wall 2D-profile: <filename.txt> NOT LOADED

PDP-input: file <filename.txt> NOT LOADED

Beamlets: file <filename.txt> NOT LOADED

Source Particle: H- /D-

Neutralization: THIN /THICK

Residual Ions tracing after Neutralization: ON /OFF

Atoms tracing after Neutralization: ON /OFF

Reflected ions tracing in RID: ON /OFF

Re-ionization: ON (percent) - / OFF

Re-ionized particles tracing: ON /OFF

Solid Surfaces accept: TOTAL power

Active rows : 1 2 3 4

Active channels : 1 2 3 4

1. BEAM TRACING
2. NBI CONFIGURATION
3. TOKAMAK AREA
4. BEAM ARRAY (REGULAR)

Sections 3 – 6 contain the list of parameters organized as follows

*parameter description BTR internal name = value*

Note. In FREE input mode, when NBI geometry is defined by Surfaces array, the sections 4 and 5 are skipped (not displayed in the GP).

*Load screen*

* Top-Right window
* has several view modes. Basically it is used for the results display.

1. When no Surf is Selected the screen shows the summary of power loads calculated by this moment;
2. When the user selects a Surf and chooses in Pop-up menu one of the load-map display mode (*Multi-colour* or *Contour* map) - the correspondent map is shown in the Load screen. If the user chooses *Load Info* in Pop-up menu, the selected Surf load summary (incl. total power, load peak, peak’s position, etc.) appears in the screen.

*Status/Prof screen*

* Bottom-Right window;
* is multi-functional too:

1. When the beam tracing is in progress, it shows the calculation status, which is updated every second (the frequency depends on the task and the system). It shows the total amount of particles in the task, the total number of beamlets, and the number of beamlets calculated by the moment. Also it shown the memory available in the system and the memory currently in use (captured by BTR).
2. When the user selects a Surf and chooses (in Pop-up menu) *Load Profiles* or *Load Info* – the screen shows the Load Profiles corresponding to the map.
3. When the user selects a Surf and chooses (in Pop-up menu) *3D-view*, the screen shows the 3D-view of the Load.

# BTR menu

*Main menu commands*

|  |  |  |
| --- | --- | --- |
| *File* | *New* | Not active |
| *File* | *Open* | Open a text file in GP |
| *File* | *Save* | Save the text in GP as a file |
| *File* | *Save as* | Save the text in GP as a file |
| *File* | *Exit* | Close BTR session |

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| --- | --- | --- |
| *Edit* | *Title* | Set the Task Title |
| *Edit* | *Comments* | Set the Task Comments (multi-line) |
| *Edit* | *Mag Field* | Set MF profile or 3D matrix |
| *Edit* | *Gas profile* | Set Gas profile or 2D matrix |
| *Edit* | *First Wall* | Set FW 2D profile |
| *Edit* | *Plasma* | Set Plasma Profiles N/T/Z and Ψ-matrix |

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| --- | --- | --- |
| *View* | *Toolbar* | Show/Hide the Toolbar |
| *View* | *Status bar* | Show/Hide the Status bar |
| *View* | *Split* | Resize the Windows |
| *View* | *Fit On/Off* | Toggle on/Off the Config scaling |
| *View* | *Neutralizer* | Zoom to show the Neutralizer |
| *View* | *RID* | Zoom to show the RID |
| *View* | *Full Area* | Show the NBI total |
| *View* | *Fields/Gas* | Show/Hide Fields and Gas profiles in the Config view |
| *View* | *Beam* | Show/Hide beamlet axes |
| *View* | *Surf labels* | Show/Hide Surfaces hot spots and ID |
| *View* | *Particles* | Show/Hide Particles tracks during beam calculation |

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| --- | --- | --- |
| *Tasks* | *Neutralization* | Set the model & parameters for Neutralization |
| *Tasks* | *Re-ionization* | Set the parameters for Re-ionization |
| *Tasks* | *RID field* | Calculate 2D RID U-field |
| *Tasks* | *Transport* | Beam Transport Task settings |
| *Tasks* | *Beam-Plasma* | Beam stopping in Plasma settings |
| *Tasks* | *Run PDP* | PDP launching tool |
| *Tasks* | *Trace BP* | Trace a test Big Particle (Atom or Ion) |

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| --- | --- | --- |
| *Options* | *Input* | Toggle between Standard and Free input mode |
| *Options* | *Beam* | Beam tracing options and parameters |
| *Options* | *NBI config* | Standard NBI components parameters |
| *Options* | *Fields /Gas* | MF, RID field and Gas profiles management |
| *Options* | *Plasma* | Beam stopping in Plasma settings |
| *Options* | *Surfaces* | Add/Read/Calculate All commands |
| *Options* | *Threads* | Threads number setting |

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| --- | --- | --- |
| *Data* | *Update* | Apply the settings in the GP to the Task |
| *Data* | *Read Config* | Read the input settings from file and apply it |
| *Data* | *Show Active* | Show the settings currently used (Active) |
| *Data* | *Save* | Save the active settings in a text file |
| *Data* | *Import* | Read NBI Stand Geom and Beam in PDP-format |
| *Data* | *Export* | Convert BTR Config to PDP input (Geom&Beam) |
| *Data* | *Read Surf* | Read Free Surfaces from Surf-file |
| *Data* | *Save Surf* | Save the active Free Surfaces in a file |

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| --- | --- | --- |
| *Results* | *Save All* | Save All Active Loads in a folder |
| *Results* | *Read All* | Read Config with Loads from a folder |
| *Results* | *Save Summary* | Save Load Reasults summary in a file |
| *Results* | *Read one* | Read a single Load-map |
| *Results* | *PDP output* | Read PDP output load-matrix |
|  |  |  |
| *Plot* | *SINGAP pos* | Irregular beamlets array positions at GG |
| *Plot* | *MAMuG pos* | Regular beamlets array positions at GG |
| *Plot* | *Beamlet Profile* | Beamlet angular profile and splitting |
| *Plot* | *Beamlet Image* | Beamlet BPs image at the area Xmax |
| *Plot* | *Neutralization* | Neutralization profiles along X |
| *Plot* | *Re-ionization* | Re-ionization profile along X |
| *Plot* | *Beam Exit Foot* | Beamlets axes image at the area Xmax |
| *Plot* | *Plasma Stopping* | Beam Intensity profile in Plasma |
| *Plot* | *Beam in Plasma* | Horiz and Vert plane maps of the beam |
| *Plot* | *Multi-colour Map* | Multi-colour Load map for Selected Surface |
| *Plot* | *Contour Map* | Contour Load map for Selected Surface |
| *Plot* | *3D-view* | 3D-view of Load for Selected Surface |
| *Plot* | *Profiles* | Maximal Profiles of the Load for Selected Surf |
| *Plot* | *Angular distr* | Angular distr of Power Load on Selected Surf |
| *Plot* | *Combine* | Show several Loads on one map |
| *Plot* | *Gas profile* | Active Gas Profile |
| *Plot* | *Magnetic Field* | Active MF profiles |
| *Plot* | *PD-prof along X* | Re-ionized and Neutral Load profile along X |

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| --- | --- | --- |
| *PDP* | *NBI geom* | Read NBI Standard geom. from PDP-input |
| *PDP* | *Beam* | Read Beam Array in PDP-input format |
| *PDP* | *Run* | Run PDP-code |
| *PDP* | *Results* | Show PDP output load-matrix |
| *PDP* | *Export Data* | Convert BTR Config to PDP input (Geom&Beam) |

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| --- | --- | --- |
| *Help* | *Help Topics* | List Help topics |
| *Help* | *About BTR* | Display Information about BTR version |
| *Help* | *Manual* | BTR User’s Manual |
| *Help* | *What’s This?* | Display Help for interface tools |

*Pop-up menu (called by right mouse button click in Config screen)*

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| --- | --- |
| *Zoom In* | Increase the scale of Config view |
| *Zoom Out* | Set the default scale of Config view |
| *Modify Surf* | Call for Modify Surf dialog-box for Selected Surf |
| *Add New Surf* | Call for Add New Surf dialog-box |
| *Delete Surf* | Delete a Surface (remove it from Configuration) |
| *Delete All Free* | Remove All Free Surfaces created before |
| *Clear Selection* | Unselect All the Selected Surfaces (except the last) |
| *Load Info* | Display the selected Load Parameters and Summary |
| *Load Profiles* | Maximal Profiles of the Load for Selected Surf |
| *Load Steps /Limits* | Set parameters for Load calculation on Selected Surf |
| *Multi-colour Map* | Multi-colour Load map for Selected Surface |
| *Contour Map* | Contour Load map for Selected Surface |
| *3D-view* | 3D-view of Load for Selected Surface |
| *Angular Distr* | Angular distr of Power Load on Selected Surf |
| *Show Load Data* | Display the Selected Load (or Surf) file in GP |
| *Add /Remove Load* | Add or Remove the Load in the Loads Summary |
| *Combine Loads* | Show several Loads on one map |
| *Save Load* | Save the Load data in a file |
| *Smooth Load* | Apply smoothing to Selected Load data |
| *Clear Load* | Set Zero Load at the Selected Surface |
| *Calculate All* | Calculate All non-zero Loads |

*BTR start /stop buttons (Toolbar)*

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|  | *“blue comb”* | Start multi-thread (parallel) beam calculations |
|  | *“red cross”* | Pause or Stop the beam calculations |

# BTR INPUT

When running BTR the user makes a selection between 3 branches:

1. New task

2. Results review

3. Demo

According to the selection made, the user has to pass through the sequence of dialogs which make him put his preferences, and to read appropriate files. The user may choose to skip the Directed Input procedure any moment and to return back to the standard input procedure.

Running Demo might be useful for the beginners – to see what is the code about.

## New task

New task means the user wants to play with the input data and run the beam (or some part of it, at least one BP) - to get new results.

Typically the following groups of parameters should be specified before running the beam:

1. NBI geometry;
2. Beam structure and optics;
3. Options, Preferences;
4. Gas profiles, Fields data;
5. Additional settings.

*INPUT: NBI geometry*

There are two options to specify NBI geometry in BTR – Standard and Free. *Standard* input is based on the standard set of components essential for NB injectors. The main components are Beam Source, Neutralizer, RID, Calorimeter, Duct. Some of the components have multi-channel structure for beam passage (Neutralizer, RID). Other (Duct) can be represented by a set of box-shape tubes. Each standard component (position and size) is defined by a small number of parameters, but the standard component structure is fixed. As opposed to Standard option, BTR allows to set NBI geometry in *Free* manner. Free geometry means there are no fixed components, but plane Surfaces which can be set by their corner-points positions.

*How to set Standard NBI configuration*

Standard NBI geometry is plotted in Config screen. The geometry is defined by a set of input parameters united in the Green Panel section – “NBI CONFIGURATION”. The input parameters can be modified directly - either through the Green Panel (F2 for update), or by using the dialog tools (Main Menu). The list of parameters is shown below.

*parameter description BTR internal name value*

……………................... NBI CONFIGURATION ........................................................................

Beam Axis Horiz. Misalign Angle, rad BeamMisHor = -0.002

Beam Axis Vert. Misalign Angle, rad BeamMisVert = 0

NBL Axis Vert. Inclination Angle, rad VertInclin = -0.0492

Beam Axis Vert. Tilting Angle, rad BeamVertTilt = -0.01

Calc. area Length, m AreaLong = 26

Calc. area Horiz. min, m AreaHorMin = -1.8

Calc. area Horiz. max, m AreaHorMax = 1.8

Calc. area Bottom, m AreaVertMin = -2.4

Calc. area Top, m AreaVertMax = 1.2

Neutralizer Channels number NeutrChannels = 4

Neutralizer Entry Coord. X, m NeutrInX = 1.9

Neutralizer Exit Coord. X, m NeutrOutX = 4.9

Neutralizer Height, m NeutrH = 1.7

Neutralizer Channel Entry Width, m NeutrInW = 0.1051

Neutralizer Channel Exit Width, m NeutrOutW = 0.0952

Neutralizer Panel Entry Thickness, m NeutrInTh = 0.043

Neutralizer Panel Exit Thickness, m NeutrOutTh = 0.034

Neutralizer Entry Vertical Bias, m NeutrBiasInVert = 0

Neutralizer Exit Vertical Bias, m NeutrBiasOutVert = 0

Neutralizer Entry Horizontal Bias, m NeutrBiasInHor = 0

Neutralizer Exit Horizontal Bias, m NeutrBiasOutHor = 0

RID Channels number RIDChannels = 4

RID Entry Coord. X, m RIDInX = 5.4

RID Exit Coord. X, m RIDOutX = 7.2

RID Height, m RIDH = 1.7

RID Channel Entry Width, m RIDInW = 0.1061

RID Channel Exit Width, m RIDOutW = 0.0948

RID Panel Thickness, m RIDTh = 0.02

RID Potential, kV RIDU = -20

RID Entry Vertical Shift, m RIDBiasInVert = 0

RID Exit Vertical Shift, m RIDBiasOutVert = 0

RID Entry Horizontal Shift, m RIDBiasInHor = 0

RID Exit Horizontal Shift, m RIDBiasOutHor = 0

Calorimeter Entry Coord. X, m CalInX = 7.555

Calorimeter Exit Coord. X, m CalOutX = 10.395

Calorimeter Entry Width, m CalInW = 0.48

Calorimeter Exit Width, m CalOutW = 0.48

Calorimeter Height, m CalH = 1.7

Dia 5 Dist X, m PreDuctX = 10.75

Dia 5 Width, m PreDuctW = 0.45

Dia 5 Height, m PreDuctH = 1.5

Dia 5 Vertical Shift, m DiaBiasVert = 0

Dia 5 Horizontal Shift, m DiaBiasHor = 0

Dia 6 Dist X, m DDLinerInX = 11.6

Dia 6 Width, m DDLinerInW = 0.45

Dia 6 Height, m DDLinerInH = 1.25

Dia 6 Vertical Shift, m LinerBiasInVert = 0

Dia 6 Horizontal Shift, m LinerBiasInHor = 0

Dia 7 Dist X, m DDLinerOutX = 12.6

Dia 7 Width, m DDLinerOutW = 0.54

Dia 7 Height, m DDLinerOutH = 1.5

Dia 7 Vertical Shift, m LinerBiasOutVert = 0

Dia 7 Horizontal Shift, m LinerBiasOutHor = 0

Dia 8 Dist X, m Duct1X = 14.9

Dia 8 Width, m Duct1W = 0.546

Dia 8 Height, m Duct1H = 1.49

Dia 8 Vertical Shift, m Duct1BiasVert = 0

Dia 8 Horizontal Shift, m Duct1BiasHor = 0

Dia 9 Dist X, m Duct2X = 19

Dia 9 Width, m Duct2W = 0.546

Dia 9 Height, m Duct2H = 1.4

Dia 9 Vertical Shift, m Duct2BiasVert = 0

Dia 9 Horizontal Shift, m Duct2BiasHor = 0

Dia 10 Dist X, m Duct3X = 19.6

Dia 10 Width, m Duct3W = 0.56

Dia 10 Height, m Duct3H = 1.2

Dia 10 Vertical Shift, m Duct3BiasVert = 0

Dia 10 Horizontal Shift, m Duct3BiasHor = 0

Dia 11 Dist X, m Duct4X = 20.8

Dia 11 Width, m Duct4W = 0.54

Dia 11 Height, m Duct4H = 1.15

Dia 11 Vertical Shift, m Duct4BiasVert = 0

Dia 11 Horizontal Shift, m Duct4BiasHor = 0

Dia 12 Dist X, m Duct5X = 22

Dia 12 Width, m Duct5W = 0.54

Dia 12 Height, m Duct5H = 1.08

Dia 12 Vertical Shift, m Duct5BiasVert = 0

Dia 12 Horizontal Shift, m Duct5BiasHor = 0

Dia 13 Dist X, m Duct6X = 23.81

Dia 13 Width, m Duct6W = 0.54

Dia 13 Height, m Duct6H = 1.07

Dia 13 Vertical Shift, m Duct6BiasVert = 0

Dia 13 Horizontal Shift, m Duct6BiasHor = 0

Dia 14 Dist X, m Duct7X = 24.65

Dia 14 Width, m Duct7W = 0.54

Dia 14 Height, m Duct7H = 1.06

Dia 14 Vertical Shift, m Duct7BiasVert = 0

Dia 14 Horizontal Shift, m Duct7BiasHor = 0

Dia 15 Dist X, m Duct8X = 24.7

Dia 15 Width, m Duct8W = 0.54

Dia 15 Height, m Duct8H = 1.08

Dia 15 Vertical Shift, m Duct8BiasVert = 0

Dia 15 Horizontal Shift, m Duct8BiasHor = 0

Standard NBI geometry also can be taken from so called PDP-file. This is a special text format for PDP-code, its structure being described in relevant PDP-documentation. The file can be read by Main menu command *Data-Import-NBL geom (PDP).*

*How to set Free NBI configuration*

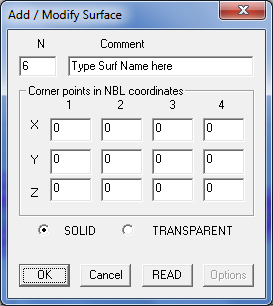
When *Free Surf mode* is selected, BTR initially shows the default beam array (i.e. beamlets axes) in empty geometry. The only Free Surfaces defined by default are *Calculation Area Limits*. To configure the task there are two steps needed.

First, you read Config-file which has the same format as in the Standard geometry. But when you are working in the Free mode, the data section *NBI Configuration* is not used (skipped by BTR). Only the *Beam Regular Array* and *Beam Tracing*, including the limits of Calculation Area are taken by BTR from Config-file in Free Surf mode. The beamline geometry should be created separately by adding the Free Surfaces.

*Free Surf Direct Input and Modification*

To add a Surface manually use the command Options->Surfaces->Add New. In the Surf Dialog (see below) define the corner-points, the Comment line and set Solid/Transparent property.

BTR 4.0 Dialog - for input or modification of Free Surf data



The newly created Free Surface is displayed on pushing OK.

To Modify a Free surface Select it (left mouse click on the hot-spot), then click the Pop-up menu (right mouse button) and choose Modify Surf command. The same Add/Modify dialog will reappear with the Surf actual data (old corner-points, ID-number and Comment). Set the new data and push OK – the Surface will be updated at once. (Note: Surf ID is assigned automatically, its manual change is not safe).

*Read Free Surf from a file*

You can read one or multiple Surfaces from external text files. Use the Menu command Data->Read Surf, then specify the path for the input Surf-file. You can repeat this operation as many times as needed and read as many Surf-files as you need.

The example of Surf-file format is given below

\*Each Surface is defined by 4 Planar Corner Points (X Y Z)

\*This geometry file uses the NBDI Grounded Grid coordinate system

# |ABSOLUTE\_VALVE|LOWER\_SURFACE solid

13.624 -0.309 -1.379

13.624 0.31 -1.379

12.376 0.31 -1.379

12.376 -0.309 -1.379

# |ABSOLUTE\_VALVE|UPPER\_SURFACE solid

13.624 0.309 0.1

13.624 -0.31 0.1

12.376 -0.31 0.1

12.376 0.309 0.1

*Delete Free Surf*

You may want to delete any Surf created (or all of them). Use the Pop-up menu command Delete Surf (or Delete All Free).

*INPUT: Beam structure and optics*

Source Beam is represented by a finite array of beamlets (elementary beams extracted from GG apertures). Each beamlet has individual position on GG, horizontal and vertical aiming.

BS beamlets’ positions & aimings are defined by BS accelerator type and can be either regular (“MAMuG” option) or non-regular (SINGAP option).

The input procedure for regular beam differs from non-regular model.

*Regular beam*

Basic regular MAMuG accelerator configuration is described in DDD 5.3.

By default GG has 4×4 groups (segments) of apertures. Horizontal and vertical steps between group centers are defined by *SegmStepHor* (160mm) and *SegmStepVert* (396mm). There are 5×16 apertures in each group. Within the group the steps between apertures are defined by *AppertStepHor* (20mm) & *AppertStepVert* (22mm). Beamlet groups’ axes are focused at *BeamAimHor* and *BeamAimVert* - in horizontal and vertical planes. Within each group the beamlets are focused at *AppertAimHor* (7.2 m) in horizontal plane and are parallel in vertical plane (*AppertAimVert* = 999m).

Here is the list of input parameters for regular beam array:

*parameter description BTR internal name value*

………………………................... BEAM ARRAY (regular) .................................................

Beam Groups (Segments): Total Horiz. Number NofChannelsHor = 4

Beam Groups (Segments): Total Vert. Number NofChannelsVert = 4

Beam Groups (Segments): Horiz. Step, m SegmStepHor = 0.16

Beam Groups (Segments): Vert. Step, m SegmStepVert = 0.396

Beam Groups (Segments): Horiz. Aiming Dist, m BeamAimHor = 25.5

Beam Groups (Segments): Vert. Aiming Dist, m BeamAimVert = 25.5

Beamlets: Horiz. Number per Segment NofBeamletsHor = 5

Beamlets: Vert. Number per Segment NofBeamletsVert = 16

Beamlets: Horiz. Step, m AppertStepHor = 0.02

Beamlets: Vert. Step, m AppertStepVert = 0.022

Beamlets: Horiz. Aiming Dist, m AppertAimHor = 7.2

Beamlets: Vert. Aiming Dist, m AppertAimVert = 999

Each beamlet is assumed to have Gauss-type angular profile in horizontal and vertical planes, defined by horizontal and vertical divergences. The beamlets of Regular beam have equal divergence across the total array (though vertical and horizontal values can be set independently).

Typically each beamlet consists of 2 fractions - “Core” and “Halo”. Core part carries the most beam power (~85%) with the divergence 3 – 7 mrad. The Core divergence can be set differently in horizontal and vertical plane. Halo fraction is a small part of a beamlet power (~15%) with wider angular distribution (15-30 mrad) assumed to be isotropic.

Here is the list of input parameters to set beamlet optics:

Beamlet Core Horizontal Diverg, rad (>0) BeamCoreDivY = 0.003

Beamlet Core Vertical Diverg, rad (>0) BeamCoreDivZ = 0.003

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

The following 2 parameters define BS Current and Energy:

Source Beam Current, A IonBeamCurrent = 40

Source Beam Energy, MeV IonBeamEnergy = 1

*Non-regular beam*

Non-regular beam array can be read from text file. BTR supports 2 input formats to set individual properties of beamlets array extracted at BS GG, i.e. start point position, aiming, divergence.

1. CEA input data file (“Bert-file”) contains 10 data columns (Note: parameter “beamlet radius” is not used by BTR):

1 2 3 4 5 6 7 8 9 10

START POS-X WID-X ALF-X DIV-X POS-Y WID-Y ALF-Y DIV-Y FRACTION

... … … … … … … … … …

Dimensions are mm and mrad.

X is horizontal, Y is vertical.

POS-X POS-Y Horizontal/Vertical position of beamlet in mm

WID-X WID-Y Horizontal/Vertical width (=radius) of beamlet in mm

ALF-X ALF-Y Horizontal/Vertical angle in mrad. Positive angle is pointing upwards.

DIV-X DIV-Y Horizontal/Vertical beamlet core divergence in mrad.

FRACTION Fraction of power in this beamlet.

1. EXCEL input file. Another format of non-regular beamlets file can be prepared in EXCEL and should contain 7 data columns:

1 2 3 4 5 6 7

Yo Ay Acy Zo Az Acz rI

… … … … … … …

POS-Y ALF-Y DIV-Y POS-Z ALF-Z DIV-Z FRACTION

Dimensions are mm and mrad.

Y is horizontal, Z is vertical.

POS-Y POS-Z Horizontal/Vertical position of beamlet in mm

ALF-Y ALF-Z Horizontal/Vertical angle in mrad. Positive angle is pointing upwards.

DIV-Y DIV-Z Horizontal/Vertical beamlet divergence in mrad.

FRACTION Fraction of power in this beamlet.

In both non-regular files the parameter beamlet divergence refer to beamlet Core fraction. Halo divergence and Halo fraction are specified in the Green Panel, like in regular beam array. These parameters are shown below:

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

For non-regular beam BS total Current and Energy are similar to regular case:

Source Beam Current, A IonBeamCurrent = 40

Source Beam Energy, MeV IonBeamEnergy = 1

*INPUT: Options, Preferences*

*Beamlet model*

BTR uses the discrete model for beamlet simulation. Each beamlet is represented by a finite, large enough, number of big particles (BPs) emitted within a cone in Polar beamlet model (or pyramid in Cartesian beamlet model). The beamlet current is divided to angular groups (2-dimensional), and each group is represented by a single BP. This BP carries the current (power) integrated within the angular group limits. Polar model performs 2D splitting along polar and azimuth directions, while Cartesian model applies 2D splitting along horizontal and vertical directions.

Beamlet splitting to angular groups is done with accordance to the beamlet divergence and Core/Halo ratio.

*Cut-Off ratio* means the lower limit of BP current which is traced during the beam run. When the splitting procedure is complete, BPs with the current lower than Cut-Off current are thrown away (cut-off).

*Polar Split model*

Beamlet splitting is done with regular step along Polar and Azimuth angular directions. Specific parameters for this model are:

Beamlet Polar Split Number (Polar) PolarNumber = 10

Beamlet Azimuth Split Number (Polar) (>3) AzimNumber = 12

If *Polar Split Number* is set 0, all beamlet current (power) is carried by a single BP, emitted along the beamlet axis from the aperture centre.

*Cartesian Split model*

Beamlet splitting is done with regular step along Horizontal (Y) and Vertical (Z) angular directions. Specific parameters for this model are:

Beamlet Hor. Split Number (Cartesian) (>0) BeamSplitNumberY = 10

Beamlet Vert. Split Number (Cartesian) (>0) BeamSplitNumberZ = 10

If both numbers are set 0 or 1, all beamlet current (power) is carried by a single BP, emitted along the beamlet axis from the aperture centre.

*Particles Tracing model*

Ion path is calculated step-by-step by Euler integration of dynamic equation

.

Ions trajectory steps are given by

Source ions Trajectory Step, m TraceStepL = 0.1

Reionized/Residual Ions Trajectory Step, m IonStepL = 0.05

Secondary atoms (born in the Neutralizer) are not traced stepwise but directed straightforward till meeting the area boundary or any solid surface.

BPs are traced until meeting the calculation area boundary or any solid surface. If BP is transformed along its path (Neutralized or ionized) some part of its current (power) is taken away by newly born particles, as described further.

*Particles Transformations*

Neutralization is a process of source beam stripping (for negative ions) on a gas target in the Neutralizer channels. Due to the reactions in the Neutralizer volume (for H-/D- source beam essential processes are stripping, re-ionization, double-stripping, and charge-exchange), the beam generally consists of 3 fractions at the Neutralizer exit: atoms (H0/D0), positive ions (H+/D+), and negative ions (H-/D-).

Two models of beam neutralization are used in BTR – *Thin* and *Thick.*

*Thin neutralization*

Thin model is simple. It means each source BP is split when reaching some bound, defined by X-coordinate (*NeutrXmax*) to 3 secondary BPs: positive ion, negative ion, atom). Usually this bound is set close to the Neutralizer exit plane (X ≈ NeutrOutX), but this is not necessary.

The Current fractions of secondary particles after splitting are given by the fractions of atoms and positive ions, which are set before calculation. The parameters relevant to Thin Neutralization are:

Neutralization End, m NeutrXmax = 4.91

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.6

Residual Positive Ions fraction PosIonPart = 0.2

Residual negative ion fraction is calculated as (*1* - *NeutrPart - PosIonPart*)

If BS ions are positive (H+/D+), the parameter *PosIonPart* is ignored. The source BP is split to 2 secondary particles (positive ion and atom), according to the *NeutrPart* value*.*

*Thick neutralization*

Thick model is working along the region of neutralization which is typically set to Neutralizer channels length. Thick model can be applied only with the gas profile specified in the region of neutralization. It works as following. After entering the region the source ion (BP) is traced step-by-step (*NeutrStepL*) as described above, but after each step it “delivers” additional BPs, which are traced too. The current taken away by the new BPs is calculated as solution of linear system of balance equations for current densities, the coefficients are defined by the local values of gas density, cross-sections and trajectory step (*NeutrStepL*). The procedure continues until the source BP gets out of the region. The region limits are defined by parameters *NeutrXmin* and *NeutrXmax*. Unlike for the Thin model with user-defined *NeutrPart* and *PosIonPart*, within Thick model is active the actual values of *NeutrPart* and *PosIonPart* are evaluated by BTR for the given gas profile and shown in the Green Panel.

The parameters relevant to Thick neutralization are:

*parameter description BTR internal name value*

Cross-Section H- >> Ho (stripping), m-2 NeutrSigma = 1.3e-020

Cross-Section Ho >> H+ (re-ionization), m-2 ReionSigma = 4.2e-021

Cross-Section H- >> H+ (2-stripping), m-2 TwoStripSigma = 7.0e-022

Cross-Section H+ >> Ho (Q-exchange), m-2 PosExchSigma = 3.0e-023

Neutralization Start, m NeutrXmin = 1.8

Neutralization End, m NeutrXmax = 4.91

Neutralization Step, m NeutrStepL = 0.5

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.56071

Residual Positive Ions fraction PosIonPart = 0.227177

### *Neutral Beam Re-ionization*

Downstream the Neutralizer the residual ions (positive and negative) are deflected by electrostatic RID field and accepted by RID panels. The neutral beam continues its path to plasma through the beam Duct. Still a certain part of neutral current (3-12%) is lost due to re-ionization which takes place on background gas downstream the Neutralizer. Re-ionization model is similar to Thick neutralization, but takes into account only re-ionization process. The region of Re-ionization is defined by the limits *ReionXmin* and *ReionXmax*. The step of current decrease – *ReionStepL*.

The basic parameters are

*parameter description BTR internal name value*

Cross-Section Ho >> H+ (re-ionization), m-2 ReionSigma = 4.2e-021

Re-ionization Start, m ReionXmin = 4.91

Re-ionization End, m ReionXmax = 25.61

Re-ionization Step, m ReionStepL = 0.2

Reionized/Residual Ions Trajectory Step, m IonStepL = 0.05

The parameter *IonStepL* is applied to all secondary ions tracing after neutralization, i.e. to all residual (deflected in RID) and born in re-ionization downstream RID.

*INPUT: Gas profiles, Fields data*

### *Gas Density profile*

BTR supports 2 text formats of gas density data: 2 and 3 columns.

1. Gas Density file along NBL-axis is defined as 2 columns data

|  |  |
| --- | --- |
| X, m | Gas Density, m-3 |
| X1 | D1 |
| X2 | D2 |
| … | … |
| Xn | Dn |

There is no restrictions for X-data step – it can be constant or variable.

1. 3 columns file contains 2D gas density distribution

|  |  |  |
| --- | --- | --- |
| X, m Gas | Z, m | Density, m-3 |
| X1 | Z1 | D1 |
| X2 | Z2 | D2 |
| … | … | … |
| Xn | Zn | Dn |

The steps may vary but they should form a rectangular grid.

### 

### *Magnetic Field distribution*

BTR supports 2 types of text formats of MF data.

1. MF components (Bx, By, Bz) can be defined similarly to gas density profile - along the NBL axis. The data is arranged as follows

|  |  |  |  |
| --- | --- | --- | --- |
| X, m | Bx, T | By, T | Bz, T |
| X1 | Bx1 | By1 | Bz1 |
| X2 | Bx2 | By2 | Bz2 |
| … | … | … | … |
| Xm | Bxm | Bym | Bzm |

There is no restrictions for X-data step – it can be constant or variable.

2. 6-columns format. BTR can also read MF spatial distributions arranged in 6(7) data columns:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| X, m | Y, m | Z, m | Bx, T | By, T | Bz, T | Babs, T |
| X1 | Y1 | Z1 | Bx1 | By1 | Bz1 | Babs1 |
| X2 | Y2 | Z2 | Bx2 | By2 | Bz2 | Babs2 |
| … | … | … | … | … | … | … |
| Xm | Ym | Zm | Bxm | Bym | Bzm | Babsm |

The steps along X, Y, Z may vary but they should form a brick-like grid.

### *Electrostatic Field in RID*

Electrostatic Field in RID by default is set uniform within each RID channel and horizontally directed (along Y). Due to the voltage distribution across the RID panels E-vector is directed oppositely in adjacent RID channels. Usually some of the panels are grounded, while the rest carry non-zero potential, given by parameter

RID Potential, kV RIDU = -20

*INPUT: Additional settings*

*Neutral beam stopping in Plasma*

BTR code allows to calculate the NB ionization in tokamak plasma and to get the shine-through power on the FW surface. The tangential injection point is defined by tokamak centre position in NBI frame (origin at the GG centre, X - horizontal along the beam, Y - horizontal across the beam, Z - vertical up).

Attenuation of the neutral hydrogen beam injected into a plasma is brought about by ionization and charge-exchange processes in collisions of hydrogen with the plasma constituents such as electron, proton, and impurity ions. In the case of homogeneous plasmas, the ratios among the intensities *In* of the subbeams converge at a given value of *x*, irrespective of the initial condition of *In*. In such a condition, the beam intensity (or Current) satisfies

, with

Here is the beam stopping cross-section. The equation is also used to estimate the shine-through power.

The beam stopping cross-section is calculated using Janev-Suzuki model (analytical fits) of beam ionization, so that is a function of the following variables: *E* (beam energy), *ne* (electron density), *Te* (electron temperature), and *Zeff* (effective ionic charge). In order to estimate for the plasma impurities involved, a weighted sum of the stopping cross-sections for single-impurity plasmas is used (Janev et al [1]). For pure hydrogen plasma an improved analytical formula of stopping cross-section () proposed by Suzuki is applied.

The plasma profiles *ne /Te /Zeff* are taken from an external text file, the data should be formatted in 4 columns as follows:

|  |  |  |  |
| --- | --- | --- | --- |
| Pol. Flux (Ψ)  normalized | Te,  keV | Ne,  1019, m-3 | Zeff |
| 0 | 23.92 | 7.269 | 2.236 |
| 0.005289 | 23.83 | 7.241 | 2.234 |
| 0.01058 | 23.83 | 7.241 | 2.234 |
| 0.9626 | 1.219 | 5.103 | 2.018 |
| 0.9732 | 0.938 | 4.533 | 2.025 |
| 0.9997 | 0.2814 | 3.022 | 1.686 |

The normalized polodial flux Ψ(R,Z) matrix should be taken from standard EQDSK files (IDM, EP section), where R,Z are given in tokamak reference CS. In BTR-code Ψ is used as a reference radial coordinate in setting the *ne /Te /Zeff* profiles. The impurity content can be set with respect to *ne*, so that the user can change directly the number and weights of plasma species. For multi-impurities case the profile *Zeff* is not used. For single impurity case the profile *Zeff* is applied (the impurity weight is ignored). At present version the number of impurities for input is limited to 8.

The parameters to set tokamak geometry and position (in NBI CS) are:

*parameter description BTR internal name value*

.................. TOKAMAK area ..................

Tokamak Centre X in NBI frame, m TorCentreX = 32

Tokamak Centre Y in NBI frame, m TorCentreY = -5.31

Tokamak Centre Z in NBI frame, m TorCentreZ = 0

Tokamak Sectors Number TorSegmentNumber = 36

Target Plane A Position X, m MovX = 38.4

Target Plane A Half-Width, m MovHor = 0.5

Target Plane A Half-Height, m MovVert = 1

Target Plane A Vertical Shift, m MovShiftVert = 0

Target Plane B Position X, m Mov2X = 28.7

Target Plane B Half-Width, m Mov2Hor = 0.5

Target Plane B Half-Height, m Mov2Vert = 1

Target Plane B Vertical Shift, m Mov2ShiftVert = 0

Target Plane C Position X, m Mov3X = 31.9

Target Plane C Half-Width, m Mov3Hor = 0.5

Target Plane C Half-Height, m Mov3Vert = 1

Target Plane C Vertical Shift, m Mov3ShiftVert = 0

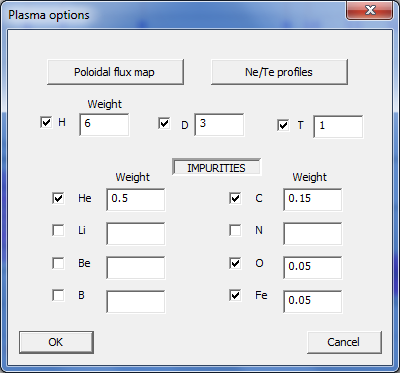
Target Plane D Position X, m Mov4X = 35.1

Target Plane D Half-Width, m Mov4Hor = 0.5

Target Plane D Half-Height, m Mov4Vert = 1

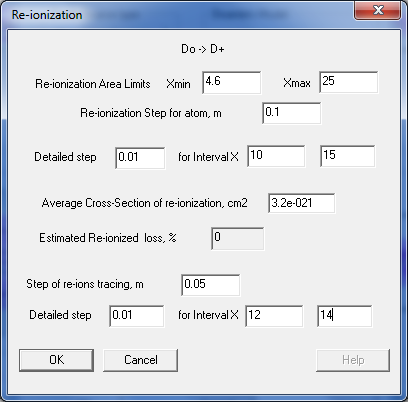
Target Plane D Vertical Shift, m Mov4ShiftVert = 0

BTR dialog used to set the plasma content for beam stopping:



*Steps refinement*

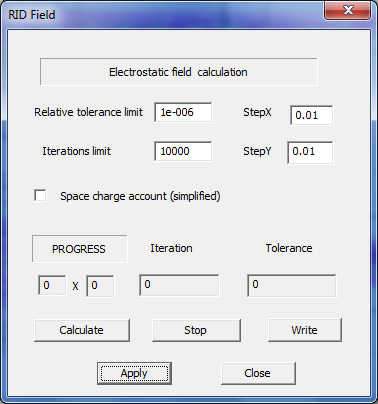
The basic steps used to calculate NB re-ionization and re-ions tracing are *ReionStepL* and *IonStepL.* Still if the user needs to calculate some interval (within the region of Re-ionization, defined by *Xmin/Xmax*) with more detailed steps, it’s possible set/modify them in the dialog Re-ionization:



*RID 2D field calculation*

Electrostatic Field in RID by default is set uniform within each RID channel and horizontally directed (along Y). Additionally, a fast calculation of the realistic 2D U-field distribution in one channel can be made, and then applied to the beam tracing. The U-field can be calculated either with space charge (Poisson solution) or without space charge account (Laplas).

To implement this option BTR dialog-box RID Field is used:

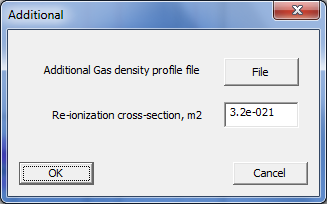


StepX and StepY define the grid-step for numerical solution.

When you press Calculate button, the iterations are started and proceed until the Iterations limit or tolerance limit is achieved.

*Additional Gas profile for Re-ionization*

Additional gas profile and the cross-section can be defined for re-ionization. Menu command Options->Fields/Gas invokes a Fields/Gas dialog-box, where the button (Gas)”*Advanced*” allows to set the input data file and appropriate cross-section for the new gas. The resulting Re-ionization rate and percentage will be calculated as a sum across the two gas profiles – basic and additional.

****

# BTR INPUT GUIDELINES - for 3 main tasks

## Beam Transport (*Direct Interception* task)

Run BTR and choose New Task branch.

**STEP 1** Input NBI geometry

Choose between Standard and Free mode of NBI geometry input.

*In Standard mode:*

* read the Config-file (Data->Read Config), if you already have it;
* you may also create a new Configuration directly in the Green Panel (press F2 to update data!);
* Save the new configuration in Config-file (Data->Save).

*In Free mode:*

* read the Surfaces input files (Data->Read Surf), if you have them;
* or add new Surfaces directly by Add Surf command;
* Save the new surfaces in a Surf-file (at least every 5-10 surf).

**STEP 2** Input Beam structure and optics

* Regular beam (MAMuG): change the data in the Regular Beam Array section of the Green Panel (press F2 to update);
* Set the value of Beamlet Core Divergence (common for all the beamlets) - typiclally 3 values are considered: 3, 5, and 7 mrad:

.................. BEAM TRACING ..................

Beamlet Core Horizontal Diverg, rad (>0) BeamCoreDivY = 0.003 (or 0.005/0.007)

Beamlet Core Vertical Diverg, rad (>0) BeamCoreDivZ = 0.003 (or 0.005/0.007)

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

* Irregular beam (SINGAP): read the beam array from a Beam-file. The beam-file data table contains among other properties individual core divergence for each beamlet, so the GP parameters *BeamCoreDiv* will be ignored. But still the Halo is not taken from the beam-file and it should be defined directly in GP, for example:

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

Always press F2 for update.

**STEP 3** Input Options, Preferences

First, set the source particle (H-/H+/D-/D+), and check the beam groups (horizontal and vertical) to involve into the calculation. At least 1 beam group should be checked for tracing, in our example all the groups (4x4) are traced (totally 16 groups):

OPTIONS:

Source Particle: D-

Active rows : 1 2 3 4

Active channels : 1 2 3 4

Next, set the source beam Current and Energy.

.................. BEAM TRACING ..................

Source Beam Current, A IonBeamCurrent = 40

Source Beam Energy, MeV IonBeamEnergy = 1

Finally, carefully steer you beam according to the selected NBI geometry (differently for Standard and Free!):

.................. BEAM TRACING ..................

Beam Axis Horiz. Misalign Angle, rad BeamMisHor = -0.002

Beam Axis Vert. Misalign Angle, rad BeamMisVert = -0.01

Beam Axis Vert. Tilting Angle, rad BeamVertTilt = -0.0492

The main purpose of beam transmission calculations is to evaluate the neutral beam losses caused by the beam power direct interception. It requires the beam should be modeled with very high accuracy. Every beamlet has to be represented by large amount of BP, and the Cut-Off should be small enough.

The recommended values for the beam model are:

.................. BEAM TRACING ..................

Beamlet Splitting Type (0 - Polar, 1 - Cartesian) BeamSplitType = 0

Beamlet Polar Split Number (Polar Splitting) PolarNumber = 100

Beamlet Azimuth Split Number (Polar Splitting) (>3) AzimNumber = 120

…

Beamlet Current Cut-Off ratio (<<1) CutOffCurrent = 1.00e-004

(Always press F2 for update!)

Further you have to choose the Neutralization model, as it can affect the NB transmission.

*Thin Neutralization*

Thin model is fast and simple, and it doesn’t require Gas profile or MF-data to be involved into the calculation. Thin model is good for fast and usually optimistic evaluation of NB losses.

To use the Thin model set the following Options in GP

OPTIONS:

Neutralization: THIN

Residual Ions tracing after Neutralization: OFF

Atoms tracing after Neutralization: ON

Note: Within this task we don’t want to trace the residual ions after Neutralization, as we do it in the RID task. We need to trace only the neutral specie, the ions will be stopped (discarded).

Then put *NeutrXmax* close to (or exactly at) your Neutralizer exit position (we have the exit at X = 4.9m), and set the known beam fractions after Neutralization:

.................. BEAM TRACING ..................

Neutralization Start, m NeutrXmin = 1.8 (not used)

Neutralization End, m NeutrXmax = 4.91

Neutralization Step, m NeutrStepL = 0.5 (not used)

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.6

Residual Positive Ions fraction PosIonPart = 0.2

The parameters shown in grey are not used by the Thin model.

(Always press F2 for update!)

🡪 Thin Neutralization is done.

*Thick Neutralization*

Thick model is more complex and takes more time, it requires Gas profile, and it can be really useful with MF-data involved into the calculation. Thick model allows to simulate the processes going within the Neutralizer with high accuracy and to understand the influence of MF on the NB direct losses.

To use the Thick model set the following Options in GP

OPTIONS:

Neutralization: THICK

Residual Ions tracing after Neutralization: OFF

Atoms tracing after Neutralization: ON

Then define the region of Neutralization: *NeutrXmin* and *NeutrXmax.* The 1st limit can be set, like in our example, at the Neutralizer front (entry) position - or at X = 0 (GG), depending on the gas conditions. The 2nd limit is close to (or exactly at) the Neutralizer exit position (we have the exit at X = 4.9m). The *TraceStepL* should be small vs the *NeutrXmin* distance – 10 cm will do here. NeutrStepL means the step along the source ion BP trajectory upon which the source ion BP “splits” to 3 particles (atom, positive ion, and negative ion). With reducing this step we increase the accuracy (and increase the time). The Cross-Sections are depending on the BS energy (*IonBeamEnergy*) and particle sort (or more exactly on the energy/nucl) The beam fractions after Neutralization are calculated by BTR for the given gas profile and cross-sections defined, their preset values are ignored:

.................. BEAM TRACING ..................

Source ions Trajectory Step, m TraceStepL = 0.1

Cross-Section H- -> Ho, m2 NeutrSigma = 1.30e-020

Cross-Section Ho -> H+, m2 ReionSigma = 4.20e-021

Cross-Section H- -> H+, m2 TwoStripSigma = 7.00e-022

Cross-Section H+ -> Ho, m2 PosExchSigma = 3.00e-023

Neutralization Start, m NeutrXmin = 1.8

Neutralization End, m NeutrXmax = 4.91

Neutralization Step, m NeutrStepL = 0.1

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.56071 (calc by BTR)

Residual Positive Ions fraction PosIonPart = 0.22717 (calc by BTR)

(Always press F2 for update!)

🡪 Thick Neutralization is done.

And finally we choose the *Re-ionization* preferences.

If you don’t have any Gas for input, or simply don’t want to calculate the re-ionization loss of the NB, set the following options:

OPTIONS:

Re-ionization: OFF

Re-ionized particles tracing: OFF

Then just press F2 to update and you’ve finished with Re-ionization.

Otherwise, if you have defined the Gas profile which covers the area downstream the Neutralizer (up to the NBI exit window), you can involve the account of re-ionization loss if the NB as following:

OPTIONS:

Re-ionization: ON

Re-ionized particles tracing: OFF

Note: here we don’t trace the re-ions, we need to know only the power lost by NB due to re-ionization on the background gas.

The re-ionization Cross-section is the same as used for Thick model

Cross-Section Ho -> H+, m2 ReionSigma = 4.20e-021

The region of re-ionization is defined by the limits *ReionXmin* (it’s reasonable to make it equal to *NeutrXmax*) - and *ReionXmax* (limited either by the end of gas profile or by the NBI exit). The ReionStepL should be small compared to the region length.

.................. BEAM TRACING ..................

Re-ionization Start, m ReionXmin = 4.91

Re-ionization End, m ReionXmax = 25.61

Re-ionization Step, m ReionStepL = 0.2

Reionized/Residual Ions Trajectory Step, m IonStepL = 0.05 (not used)

(Always press F2 for update!)

🡪 Re-ionization is done.

At this point you have configured your Task.

Next you’ll add Gas and MF profiles and run the beam.

We recommend to Save all the modifications you’ve made in Config-file (Data->Save). So you’ll be sure you can return back to this input set any moment by calling Data->Read Config.

**STEP 4** Input Gas profiles, Fields data

Gas Profile (1D) can be directly defined in a dialog-box, called by Edit->Gas Profile -> X, Density. You simply type the values of X,m and the Gas Density, m-3 in the correspondent fields. Then push the Plot-button and see the result profile to be involved. To Save it in a text-file push Save-button within the dialog-box. To make it active use OK-button.

But more often you’ll have the ready input file with gas profile, prepared by other codes. Use the Read-button in the Gas dialog-box to load the data and then plot it (Plot-button). You can make changes in the profile directly within the dialog box (and this is the reason behind the menu caption “Edit”).

*Magnetic Field*

MF 1D profile can be defined exactly the same manner as 1D Gas profile, by calling the MF dialog-box via Edit->Mag Field->X,Bx,By,Bz.

The direct input and file reading are working similarly.

But if you want to read 3D MF matrix (file with 6(7) columns), choose the menu command Edit->Mag Field->X,Y,Z,Bx,By,Bz. Then specify the file path/name in the system dialog opened.

**STEP 5** Input Additional settings

The additional settings are not used for this task.

**STEP 6** Run the Beam

If you have already Saved your Config-file, push the Start button (blue comb) on the Toolbar. Before starting the beam BTR will ask if you are sure you want to see the particles tracks on the screen, as the drawing lead to several times longer calculation. This is up to you to decide.

It is better that first you look at BP tracks, realize they are OK, and you’ve chosen the correct tracing options. Then you can interrupt the beam any time by pushing the Stop-button on the Toolbar (red cross). During the pause just go to View->Particles and uncheck the option. Then restart the beam tracing (blue comb), and you’ll not see the tracks any more, but the calculation will be ended very soon. BTR will notify about the number of beamlets finished. Due to multi-thread operation, the beamlets don’t come simultaneously. You have to wait until all the beamlets in the task finish.

If you want to Stop the beam completely before its self-stop, push the red cross two times. The first click will pause, the second will stop the beam. After stopping the calculation you can make changes and configure a new task. Or close BTR session.

When all the beamlets finish, you can get the Load results and work with them. At first, for safety do Save the Results by calling Results->Save All.

## Residual Power (*RID task*)

Run BTR and choose New Task branch.

**STEP 1**  Input NBI geometry

In fact, by this moment BTR Free hasn’t got a function to apply fields of complicated structure (like RID field) in the gaps between Free Surfaces, because the surfaces are actually “free” and not follow any rule. But in Standard NBI mode the RID field is still active (the rules are still working for standard components).

There is no choice – you have to use Standard NBI geometry input.

*In Standard mode:*

* read the Config-file (Data->Read Config), if you already have it;
* you may also create a new Configuration directly in the Green Panel (press F2 to update data!);
* Save the new configuration in Config-file (Data->Save).

**STEP 2** Input Beam structure and optics

* Regular beam (MAMuG): change the data in the Regular Beam Array section of the Green Panel (press F2 to update);
* Set the value of Beamlet Core Divergence (common for all the beamlets) - typiclally 3 values are considered: 3, 5, and 7 mrad:

.................. BEAM TRACING ..................

Beamlet Core Horizontal Diverg, rad (>0) BeamCoreDivY = 0.003 (or 0.005/0.007)

Beamlet Core Vertical Diverg, rad (>0) BeamCoreDivZ = 0.003 (or 0.005/0.007)

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

* Irregular beam (SINGAP): read the beam array from a Beam-file. The beam-file data table contains among other properties individual core divergence for each beamlet, so the GP parameters *BeamCoreDiv* will be ignored. But still the Halo is not taken from the beam-file and it should be defined directly in GP, for example:

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

Always press F2 for update.

**STEP 3** Input Options, Preferences

First, set the source particle (H-/H+/D-/D+), and check the beam groups (horizontal and vertical) to involve into the calculation. At least 1 beam group should be checked for tracing, in our example only one RID channel (#2) is calculated (with all 4 groups along vertical):

OPTIONS:

Source Particle: D-

Active rows : 1 2 3 4

Active channels : 2

Next, set the source beam Current and Energy (the Current is set for the entire Source, i.e. for all the 16 beam groups).

.................. BEAM TRACING ..................

Source Beam Current, A IonBeamCurrent = 40

Source Beam Energy, MeV IonBeamEnergy = 1

Finally, carefully steer you beam according to the selected NBI geometry

.................. BEAM TRACING ..................

Beam Axis Horiz. Misalign Angle, rad BeamMisHor = -0.002

Beam Axis Vert. Misalign Angle, rad BeamMisVert = -0.01

Beam Axis Vert. Tilting Angle, rad BeamVertTilt = -0.0492

The main purpose of RID task is to get the power distributions (load maps) on the RID panels. The source beam model can be less accurate than for the Transport task. Every beamlet has to be represented by ~1000 BP, and the Cut-Off can be moderate.

The recommended values for the beam model are:

.................. BEAM TRACING ..................

Beamlet Splitting Type (0 - Polar, 1 - Cartesian) BeamSplitType = 0

Beamlet Polar Split Number (Polar Splitting) PolarNumber = 30

Beamlet Azimuth Split Number (Polar Splitting) (>3) AzimNumber = 36

…

Beamlet Current Cut-Off ratio (<<1) CutOffCurrent = 1.00e-002

(Always press F2 for update!)

The Neutralization model affects the results not so much as for NB transmission. The reason is simple: when the ions are deflected in RID field, their footprint on a RID panel becomes more distributed and the details of the primary beam footprint are smoothed.

*Thin Neutralization*

Thin model is fast and simple, and it doesn’t require Gas profile or MF-data to be involved into the calculation. Thin model is good enough for RID power analysis.

To use the Thin model set the following Options in GP

OPTIONS:

Neutralization: THIN

Residual Ions tracing after Neutralization: ON

Atoms tracing after Neutralization: ON

Note: Here in the RID task we are interested in residual ions even more than in tracing atoms after Neutralization, so actually we can set the option of tracing atoms OFF (the atoms will stop after Neutralization).

Then put *NeutrXmax* close to (or exactly at) your Neutralizer exit position (we have the exit at X = 4.9m), and set the known beam fractions after Neutralization:

.................. BEAM TRACING ..................

Neutralization Start, m NeutrXmin = 1.8 (not used)

Neutralization End, m NeutrXmax = 4.91

Neutralization Step, m NeutrStepL = 0.5 (not used)

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.6

Residual Positive Ions fraction PosIonPart = 0.2

The parameters shown in grey are not used by the Thin model.

(Always press F2 for update!)

🡪 Thin Neutralization is done.

*Thick Neutralization*

Thick model is more complex and takes more time, it requires Gas profile, and it can be really useful with MF-data involved into the calculation. Thick model allows to simulate the processes going within the Neutralizer with high accuracy. In RID task, however, you’ll notice a little difference when comparing the load results obtained for Thin and Thick model.

To use the Thick model set the following Options in GP

OPTIONS:

Neutralization: THICK

Residual Ions tracing after Neutralization: ON

Atoms tracing after Neutralization: ON or OFF

Then define the region of Neutralization: *NeutrXmin* and *NeutrXmax.* The 1st limit can be set, like in our example, at the Neutralizer front (entry) position - or at X = 0 (GG), depending on the gas conditions. The 2nd limit is close to (or exactly at) the Neutralizer exit position (we have the exit at X = 4.9m). The *TraceStepL* should be small vs the *NeutrXmin* distance – 10 cm will do here. NeutrStepL means the step along the source ion BP trajectory upon which the source ion BP “splits” to 3 particles (atom, positive ion, and negative ion). With reducing this step we increase the accuracy (and increase the time). The Cross-Sections are depending on the BS energy (*IonBeamEnergy*) and particle sort (or more exactly on the energy/nucl) The beam fractions after Neutralization are calculated by BTR for the given gas profile and cross-sections defined, their preset values are ignored:

.................. BEAM TRACING ..................

Source ions Trajectory Step, m TraceStepL = 0.1

Cross-Section H- -> Ho, m2 NeutrSigma = 1.30e-020

Cross-Section Ho -> H+, m2 ReionSigma = 4.20e-021

Cross-Section H- -> H+, m2 TwoStripSigma = 7.00e-022

Cross-Section H+ -> Ho, m2 PosExchSigma = 3.00e-023

Neutralization Start, m NeutrXmin = 1.8

Neutralization End, m NeutrXmax = 4.91

Neutralization Step, m NeutrStepL = 0.1

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.56071 (calc by BTR)

Residual Positive Ions fraction PosIonPart = 0.22717 (calc by BTR)

(Always press F2 for update!)

🡪 Thick Neutralization is done.

Then we set the step for ions – small as compared to the RID channel width:

Reionized/Residual Ions Trajectory Step, m IonStepL = 0.01 (or less)

Finally you can modify RID potential in the section NBI Configuration

RID Potential, kV RIDU = -20

At this point you have configured your Task.

Next you’ll add Gas and MF profiles and run the beam.

We recommend to Save all the modifications you’ve made in Config-file (Data->Save). So you’ll be sure you can return back to this input set any moment by calling Data->Read Config.

**STEP 4** Input Gas profiles, Fields data - This step fully repeats the one for Transport task.

**STEP 5** Input Additional settings

Within RID task you can use the additional feature of calculating the real U-field in a gap between 2 RID panels, and then apply it to the RID channels. This feature is available only in Standard geometry mode.

**STEP 6** Run the Beam - This step fully repeats the one for Transport task.

## Re-ionized Power (*Reion task*)

Run BTR and choose New Task branch.

**STEP 1** Input NBI geometry

Choose between Standard and Free mode of NBI geometry input.

*In Standard mode*:

* read the Config-file (Data->Read Config), if you already have it;
* you may also create a new Configuration directly in the Green Panel (press F2 to update data!);
* Save the new configuration in Config-file (Data->Save).

*In Free mode*:

* read the Surfaces input files (Data->Read Surf), if you have them;
* or add new Surfaces directly by Add Surf command;
* Save the new surfaces in a Surf-file (at least every 5-10 surf).

**STEP 2** Input Beam structure and optics

* Regular beam (MAMuG): change the data in the Regular Beam Array section of the Green Panel (press F2 to update);
* Set the value of Beamlet Core Divergence (common for all the beamlets) - typiclally 3 values are considered: 3, 5, and 7 mrad:

.................. BEAM TRACING ..................

Beamlet Core Horizontal Diverg, rad (>0) BeamCoreDivY = 0.003 (or 0.005/0.007)

Beamlet Core Vertical Diverg, rad (>0) BeamCoreDivZ = 0.003 (or 0.005/0.007)

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

* Irregular beam (SINGAP): read the beam array from a Beam-file. The beam-file data table contains among other properties individual core divergence for each beamlet, so the GP parameters *BeamCoreDiv* will be ignored. But still the Halo is not taken from the beam-file and it should be defined directly in GP, for example:

Beamlet Halo Divergence, rad BeamHaloDiverg = 0.03

Beamlet Halo Fraction BeamHaloPart = 0.15

Always press F2 for update.

**STEP 3** Input Options, Preferences

First, set the source particle (H-/H+/D-/D+), and check the beam groups (horizontal and vertical) to involve into the calculation. At least 1 beam group should be checked for tracing, in our example all the groups (4x4) are traced (totally 16 groups):

OPTIONS:

Source Particle: D-

Active rows : 1 2 3 4

Active channels : 1 2 3 4

Next, set the source beam Current and Energy.

.................. BEAM TRACING ..................

Source Beam Current, A IonBeamCurrent = 40

Source Beam Energy, MeV IonBeamEnergy = 1

Finally, carefully steer you beam according to the selected NBI geometry (differently for Standard and Free!):

.................. BEAM TRACING ..................

Beam Axis Horiz. Misalign Angle, rad BeamMisHor = -0.002

Beam Axis Vert. Misalign Angle, rad BeamMisVert = -0.01

Beam Axis Vert. Tilting Angle, rad BeamVertTilt = -0.0492

The main purpose of Reion power calculations is to evaluate the neutral beam losses caused by re-ionization and to calculate the detailed re-ionized power maps on the NBL surfaces. It doesn’t require high accuracy of source beam model. But the amount of re-ionised particles should be large enough in order to produce smooth distributions on multiple surfaces along the region of re-ionization. Another requirement for this task is that the re-ions tracing step should be small vs the Larmor radius of the Magnetic Field, which is essentially non-uniform along the NBL.

The recommended values for the beam model are:

.................. BEAM TRACING ..................

Beamlet Splitting Type (0 - Polar, 1 - Cartesian) BeamSplitType = 0

Beamlet Polar Split Number (Polar Splitting) PolarNumber = 10

Beamlet Azimuth Split Number (Polar Splitting) (>3) AzimNumber = 12

…

Beamlet Current Cut-Off ratio (<<1) CutOffCurrent = 5.00e-002

(Always press F2 for update!)

Neutralization model doesn’t affect on Re-ionization losses and power depositions. Thin model will be OK.

To use the Thin Neutralization model set the following Options in GP

OPTIONS:

Neutralization: THIN

Residual Ions tracing after Neutralization: OFF

Atoms tracing after Neutralization: ON

Note: Within this task we don’t want to trace the residual ions after Neutralization, as we do it in the RID task. We need to trace only the neutral specie, the residual ions will be stopped (discarded). In fact these ions are deflected and dumped by RID.

Then put *NeutrXmax* close to (or exactly at) your Neutralizer exit position (we have the exit at X = 4.9m), and set the known beam fractions after Neutralization:

.................. BEAM TRACING ..................

Neutralization Start, m NeutrXmin = 1.8 (not used)

Neutralization End, m NeutrXmax = 4.91

Neutralization Step, m NeutrStepL = 0.5 (not used)

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.6

Residual Positive Ions fraction PosIonPart = 0.2

The parameters shown in grey are not used by the Thin model.

(Always press F2 for update!)

🡪 Thin Neutralization is done.

*Thick Neutralization*

Thick model is more complex and takes more time, it is not good for use within Re-ionization task. However, if you want to use it – set the following Options in GP:

OPTIONS:

Neutralization: THICK

Residual Ions tracing after Neutralization: OFF

Atoms tracing after Neutralization: ON

Then define the region of Neutralization: *NeutrXmin* and *NeutrXmax.* The 1st limit can be set, like in our example, at the Neutralizer front (entry) position - or at X = 0 (GG), depending on the gas conditions. The 2nd limit is close to (or exactly at) the Neutralizer exit position (we have the exit at X = 4.9m). The *TraceStepL* should be small vs the *NeutrXmin* distance – 10 cm will do here. NeutrStepL means the step along the source ion BP trajectory upon which the source ion BP “splits” to 3 particles (atom, positive ion, and negative ion). With reducing this step we increase the accuracy (and increase the time). The Cross-Sections are depending on the BS energy (*IonBeamEnergy*) and particle sort (or more exactly on the energy/nucl). The beam fractions after Neutralization are calculated by BTR for the given gas profile and cross-sections defined, their preset values are ignored:

.................. BEAM TRACING ..................

Source ions Trajectory Step, m TraceStepL = 0.1

Cross-Section H- -> Ho, m2 NeutrSigma = 1.30e-020

Cross-Section Ho -> H+, m2 ReionSigma = 4.20e-021

Cross-Section H- -> H+, m2 TwoStripSigma = 7.00e-022

Cross-Section H+ -> Ho, m2 PosExchSigma = 3.00e-023

Neutralization Start, m NeutrXmin = 1.8

Neutralization End, m NeutrXmax = 4.91

Neutralization Step, m NeutrStepL = 0.1

Neutral fraction (Neutr. Efficiency) NeutrPart = 0.56071 (calc by BTR)

Residual Positive Ions fraction PosIonPart = 0.22717 (calc by BTR)

(Always press F2 for update!)

🡪 Thick Neutralization is done.

And finally we choose the Re-ionization preferences.

To involve Re-ionization you need to define a Gas profile which covers the Re-ionization area – it typically starts at the Neutralizer exit and ends at the NBI exit window. It can also be limited by Gas profile limits. Still you can reduce the Re-ionization region, e.g. to look thoroughly at some part of it. Set the following options in GP:

OPTIONS:

Re-ionization: ON

Re-ionized particles tracing: ON

As mentioned above, the amount of re-ionised particles should be large enough in order to produce smooth distributions on multiple surfaces along the region of re-ionization. It means the ReionStepL should be small enough to ensure the high rate of re-ionization acts along each neutral BP track. Another important requirement is that the re-ions tracing step IonStepL should be small vs the Larmor radius of the Magnetic Field, and the field is essentially non-uniform along the NBL.

With account of these considerations set the following parameters for Re-ionization in GP:

.................. BEAM TRACING ..................

Cross-Section Ho -> H+, m2 ReionSigma = 4.20e-021

Re-ionization Start, m ReionXmin = 4.91

Re-ionization End, m ReionXmax = 25.61

Re-ionization Step, m ReionStepL = 0.1

Reionized/Residual Ions Trajectory Step, m IonStepL = 0.01

(Always press F2 for update!)

🡪 Re-ionization is done.

At this point you have configured your Task.

Next you’ll add Gas and MF profiles and run the beam.

We recommend to Save all the modifications you’ve made in Config-file (Data->Save). So you’ll be sure you can return back to this input set any moment by calling Data->Read Config.

**STEP 4** Input Gas profiles, Fields data - This step fully repeats the one for Transport task.

**STEP 5** Input Additional settings

For re-ionization calculations you can use the additional option of Steps Refinement. To do it call the Reionization dialog box and specify the intervals with particular steps.

Also the additional Gas profile (with additional Cross-Section) can be defined for Re-ionization. Use the command Options->Fields/Gas to call the dialog-box, then push the Advanced button in the Gas section, set the additional Cross-section value and read additional Gas profile.

**STEP 6** Run the Beam - This step fully repeats the one for Transport task.