Commun. Comput. Phys.
doi: 10.4208/cicp.190810.080211a

Vol. **10**, No. 3, pp. 716-741
September 2011

A Code that Simulates Fast-Ion D_α and Neutral Particle Measurements

W. W. Heidbrink[1,*], D. Liu[1,3], Y. Luo[1,4], E. Ruskov[1] and B. Geiger[2]

[1] *Department of Physics and Astronomy, University of California, Irvine, California, CA 92697, USA.*
[2] *Max-Planck Institute für Plasmaphysik, Garching, Germany.*
[3] *Department of Physics, University of Wisconsin-Madison, Madison, WI 53706, USA.*
[4] *Tri Alpha Energy Corporation, 27211 Burbank, Foothill Ranch, CA 92610, USA.*

Received 19 August 2010; Accepted (in revised version) 8 February 2011

Available online 1 June 2011

Abstract. A code that models signals produced by charge-exchange reactions between fast ions and injected neutral beams in tokamak plasmas is described. With the fast-ion distribution function as input, the code predicts the efflux to a neutral particle analyzer (NPA) diagnostic and the photon radiance of Balmer-alpha light to a fast-ion D_α (FIDA) diagnostic. Reactions with both the primary injected neutrals and with the cloud of secondary "halo" neutrals that surround the beam are treated. Accurate calculation of the fraction of neutrals that occupy excited atomic states (the collisional-radiative transition equations) is an important element of the code. Comparison with TRANSP output and other tests verify the solutions. Judicious selection of grid size and other parameters facilitate efficient solutions. The output of the code has been validated by FIDA measurements on DIII-D but further tests are warranted.

PACS: 52.55.Pi, 52.65.Pp, 52.70.Kz

Key words: Fast ions.

1 Introduction

Supra-thermal populations of energetic ions play an important role in magnetic fusion research. These "fast ions" are created by neutral-beam injection, by RF heating, and in fusion reactions. The distribution function that describes these populations generally is a

*Corresponding author. *Email addresses:* `Bill.Heidbrink@uci.edu` (W. W. Heidbrink), `dliu29@wisc.edu` (D. Liu), `yluo@trialphaenergy.com` (Y. Luo), `eruskov@uci.edu` (E. Ruskov), `bgeiger@ipp.mpg.de` (B. Geiger)

complicated function of velocity and configuration-space variables. Measuring the fast-ion distribution function in the harsh magnetic fusion environment is a major diagnostic challenge.

One approach is to exploit charge exchange reactions between energetic deuterium ions and an injected neutral beam. Collection of escaping neutrals is the basis of neutral particle analysis (NPA) [1], a technique that has been applied to tokamak plasmas for nearly five decades [2]. A more recent technique is to analyze the visible photons emitted by hydrogenic fast ions that neutralize in the injected beam [3]. A review of these fast-ion D_α (FIDA) measurements was recently published [4].

Both NPA and FIDA diagnostics provide valuable information about the fast-ion distribution function but also depend sensitively on other plasma parameters and on atomic cross sections. One way to relate the measured signals to theory is to construct a phase-space weight function for each measurement [5]; the signal is the convolution of the fast-ion distribution function with the weight function. As illustrated by the examples in [4], this approach is quite useful for rapid qualitative interpretation of the measurements. It can also be the basis for an inversion algorithm. Although the processes are too complicated for a unique inversion [6], a least-squares minimization scheme that utilizes a weight function can determine which model distribution function agrees best with the data. An example of inference of the distribution function from collective Thomson scattering data was recently published [7].

Alternatively, one can use forward modeling. In this approach, the distribution function is a given quantity supplied by theory. The code described in this paper, dubbed FIDASIM, takes this approach. FIDASIM accepts a theoretical distribution function as input and predicts FIDA and NPA spectra for comparison with the data. The code is designed to compute "active" signals produced by an injected neutral beam. (In reality, collisions with edge neutrals also produce FIDA and NPA signals but the code does not treat these "passive" reactions.) To date, the code has been used to model measurements on the DIII-D and ASDEX-Upgrade conventional tokamaks and on the NSTX and MAST spherical tokamaks. An early version of the code was described in the Appendix of [3]. This paper describes version 3.0 and is organized as follows. Section 2 presents the assumptions and organization of the code. Section 3 describes tests that verify that the code correctly solves the desired equations. Section 4 explains the optimal selection of numerical parameters in terms of physical processes. Section 5 summarizes validation by experiment. Section 6 provides an outlook for further tests and improvements.

2 Model

The code has four main sections (Fig. 1). The first section prepares the data and the second calculates the neutral populations. The third and fourth sections both rely on the first two sections but are independent of each other. One section computes the NPA flux and the other computes the FIDA radiance.