POWER EXHAUST IN FUSION PLASMAS

Nuclear fusion research is entering a new phase, in which power exhaust will play a vital role. This book presents a comprehensive and up-to-date summary of this emerging field of research in fusion plasmas, focusing on the leading tokamak concept.

Emphasis is placed on rigorous theoretical development, supplemented by numerical simulations, which are used to explain and quantify a range of experimental observations. The text offers a self-contained introduction to power exhaust, and deals in detail with both edge plasma turbulence and edge localized modes, providing the necessary background to understand these important, yet complicated phenomena.

Combining an in-depth overview with an instructive development of concepts, this is an invaluable resource for academic researchers and graduate students in plasma physics.

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Preface

Power exhaust, by which we mean the safe removal of power from a burning plasma, is an essential requirement for the successful operation of any fusion reactor. Specifically, plasma thermal energy must be conveyed across the first wall without undue damage to plasma facing components (divertor and limiter tiles) by heat load related plasma–surface interactions (ablation, melting, erosion). Unlike other ‘technological’ problems related to fusion reactor design, e.g. tritium retention in plasma facing materials, neutron damage to structural components or non-inductive current drive, power exhaust is intimately linked to plasma confinement and thus a perennial concern for any fusion reactor. While only a minor issue in existing tokamaks, it will be critical for ITER (the next step plasma-burning experiment) and even more so for DEMO (the demonstration fusion power plant). Even non-burning, superconducting machines, such as EAST, KSTAR, JT60-SA, W7-X, etc. will be forced to tackle this problem due to their long pulse capabilities.

This monograph is an attempt to draw a unified and up-to-date picture of power exhaust in fusion plasmas, focusing primarily on the leading tokamak concept. Emphasis is placed on rigorous theoretical development, supplemented by numerical simulations when appropriate, which are then employed to explain and model a range of experimental observations. The objective is not just to provide the reader with a reliable map of the conquered territory and a guided tour over its many hills and valleys,[1] but also to supply him or her with the tools necessary to embark on independent, and hopefully fruitful, journeys into the uncharted regions, the white spaces on the map, *la terra incognita*. In this respect, the book is aimed both at graduate students of magnetically confined plasmas and at researchers already working in the field wishing to develop a deeper understanding of plasma exhaust physics – a quickly emerging area of fusion research.

[1] This function being well served by regular review articles appearing in topical journals.

Broadly speaking, the text is organized into two parts. The first (Chapters 2 to 4) is dedicated to developing the theoretical framework necessary to describe the equilibrium and stability properties of magnetically confined plasmas, the second (Chapters 5 to 8) deals with plasma transport phenomena necessary to understand power exhaust in real experiments. After a brief examination of charged particle motion, the two basic orderings of plasma dynamics (MHD and drift) are introduced and the corresponding guiding centre kinetic and fluid equations are derived. These are then used to investigate the equilibrium, stability and transport properties of magnetically confined plasmas. Energy transport in the radial, diamagnetic and parallel directions due to collisional (classical and neoclassical) and turbulent (drift-Alfvén and interchange) processes is examined with special emphasis on plasma turbulence in the boundary (edge) plasma and the scrape-off layer (SOL). Next, the relevant experimental results from tokamaks and the modelling approaches typically used to interpret these results are reviewed. Finally, the tools developed hereto are applied collectively to study power exhaust in low and high confinement regime plasmas in tokamaks, in particular to edge / SOL turbulence and edge localized modes (ELMs).

The idea for this book originates with my early inroads into power exhaust on JET and owes much to the difficulties I encountered in finding relevant material in the topical literature. During this period I was, and indeed still am, fortunate enough to benefit from the vibrant scientific environment of the Culham Science Centre. I thus feel highly indebted to my many colleagues and friends at JET and in other labs around the world, without whom this project would certainly not have succeeded. In particular, I would like to thank A. Alonso, P. Andrew, N. Asakura, M. Beurskens, J. Boedo, S. Brezinsek, D. Campbell, C. S. Chang, A. Chankin, J. Connor, G. Corrigan, D. Coster, G. Counsell, T. Eich, S. K. Erents, M. Fenstermacher, O. E. Garcia, B. Gonçalves, P. Helander, T. Hender, C. Hidalgo, G. Huysmann, S. Jachmich, A. Kirk, S. Krashenninikov, A. Kukushkin, B. LaBombard, B. Lipschultz, S. Lisgo, A. Loarte, G. F. Matthews, G. McCracken, W. Morris, D. Moulton, V. Naulin, A. Nielsen, V. Philipps, R. A. Pitts, J. Rapp, R. Schneider, B. Scott, S. Sipilä, P. C. Stangeby, M. Tokar, D. Tskhakaya, S. Wiesen, M. Wischmeyer, G. S. Xu, R. Zagórski and S. Zweben. I would also like to thank UKAEA, EFDA-JET, EPSRC and Imperial College, London, for their support and the many research opportunities which they supplied.