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What is Detachment? Data Analysis Techniques to Understand and Control Detachment in Tokamaks

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A degree of detachment is critical for the sustainable operation of a fusion energy plant within stringent safety limits [1]. Consequently, it is essential to develop a thorough and practical understanding of divertor detachment and control to move the technology readiness level of the tokamak from development to deployment. This topical review will cover the data analysis techniques and numerical methods applied in the field, with guidance on assessing the appropriateness of a statistical approach in the field of detachment physics with a focus on the main diagnostics using this field: Langmuir probes, atomic and molecular spectroscopy, filtered cameras, and bolometry [2]. A comparative analysis will be made with analysis techniques used in the field of divertor control, and a critique of the applicability of the reviewed material to reactor-scale devices will be made.

There are specific complexities to diagnosing divertors compared to the core due to the open magnetic topology, low levels of symmetry, and large variation in geometric configuration and spatial location within the device. It follows that the symmetry-based parameter mapping and tomographic inversions that are common in core physics have reduced application in the study of detachment. Experimental investigations are further complicated by the need to quantify the atomic and molecular processes that elucidate the power, particle, and momentum balance in the divertor and hence determine the state of detachment [3]. As a result, a rich field of data analysis and uncertainty quantification has developed to characterise detachment in a range of machines using both Bayesian inference and inverse problem solving [4]. These problems are solved with a diverse range of numerical solutions from Least Squares Regression and Monte Carlo sampling to Broyden–Fletcher–Goldfarb–Shanno (BFGS) and gradient-based conditional sampling to genetic algorithms.

Sensor fusion (or integrated data analysis) has been a growing trend to optimise the increasing level of accessible computational resources and to utilise the growing set of diagnostics and coverage on current devices [5]. This is somewhat contrary to the needs for a reactor which, for engineering and safety reasons, will have the absolute minimum required set of diagnostics [6]. Additionally, the actuator control times will be significantly larger than for current day devices. In preparation for reactor-scale devices, analysis schemes will need to be developed that accommodate limited diagnostics and diagnostic coverage, and for detachment control to operate within the narrow tolerances of a reactor [7].

References

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