PREFACE

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It is a pleasure to introduce to you this special edition of *Fusion Science and Technology* (*FS&T*) on Plasma Diagnostics for Magnetic Fusion Research, the fruit of the labor of many researchers over a period of 2.5 years.

High-temperature plasmas, of the type produced and studied in thermonuclear fusion research, are highly complex media with multiple, nonlinear interactions occurring simultaneously over a wide range of temporal and spatial scales. Great progress has been made in developing plasma theory, and we now have predictive capability in many areas of plasma behavior. But, we are far from reaching a complete understanding. From the very beginning fusion has been an experimentally driven science, and experiments, of course, necessitate measurements. The measurement techniques and instruments are known by the shortened term "diagnostics." The term is appropriate since it is derived from the Greek words "dia" and "gnosis," meaning "through knowledge." In fusion science our knowledge flows through the measurements.

Making measurements on high-temperature fusion plasmas is an extraordinarily difficult task. These plasmas can have volumes of up to hundreds of cubic meters and durations of minutes or even hours, and yet physical phenomena of importance can occur on size scales of millimeters and timescales of microseconds. Collective actions on size scales approaching a significant fraction of the plasma size, perhaps one-tenth of the plasma cross section, can also be important. Many parameters characterize plasmas, including magnetic fields, currents, densities and temperatures of electrons and ions, impurity type and influx, stored energy, and pressures. Some of the parameters have extreme values, for example, temperatures of up to 400 million °C. Accurate and reliable measurements of all these parameters are required to characterize the plasma and give the information needed to challenge the theories of plasma performance and phenomena. In addition, the interaction of the plasma with the material of the vessel surrounding it is known to have a major impact on the performance of the plasma and requires knowledge of a range of parameters (such as gas pressure and composition, and particle and energy fluxes) in the edge region of the plasma. Measurements of the consequences of this interaction, such as heating, local erosion, and deposition of eroded materials, are also traditionally included in plasma diagnostics.

Fusion plasmas are produced and contained in special machines, like tokamaks and stellerators, which by the nature of their construction limit access to the plasma. Access for the measurement systems is typically available only through small windows and ports. Some measuring sensors are mounted inside the machine vacuum vessels and can be subject to intense electromagnetic, neutron, and gamma radiation, as well as to particle bombardment. The fusion machines are contained in special experimental halls, and for safety reasons personnel cannot enter during operation. Frequently, the diagnostic instrumentation is housed in locations that cannot be accessed readily and so must be operated remotely, possibly for weeks or months without direct attention.

This difficult measurement challenge has inspired the creativity of thousands of experimental physicists. Almost all known interactions of the plasma with electromagnetic radiation (such as emission, absorption, refraction, reflection, and scattering) are exploited to probe the inner regions of the plasma using radiation from the hard-X-ray to the radio-frequency range. Probing beams from microwave to visible wavelengths are used in some techniques. Interactions of particles with the plasma achieved through the injection of gas, pellets, or beams of high-energy neutral particles are also deployed. Particles emitted by the plasma (neutrons, ions, and atoms) are measured in wide energy ranges. The measurements are made using an extensive array of measurement technology, including spectrometers, lasers, detectors, mixers, sources, and transmission systems. In many cases diagnostic requirements have driven the development of dedicated devices. The opportunities for creativity and ingenuity are almost limitless.

For the presentation in this special issue, we have divided the topic along the lines of the technology used in the different measurement techniques (magnetics, microwave, optical, passive and active spectroscopy, bolometry, neutral particles, fusion products, and operational and first wall), and a chapter has been prepared for each area. An introductory chapter relates the measurements of plasma parameters to the physics challenges faced on operating and planned devices and identifies the diagnostic techniques that are used to make these measurements. In diagnostics, a particular physical parameter of the plasma can frequently be measured by more than one technique using quite different technologies. A measurement matrix is included at the beginning of each chapter that shows the connection between the measurement technique and the physical parameter(s). The matrices can be used as convenient guides for measuring particular parameters. Two important and growing areas of fusion research are data validation and analysis. We have included a chapter on those areas. For each area, the basics of the measurement techniques are given, and examples of state-of-the-art applications are briefly described. The level of treatment is such that this special issue should serve both as an introduction to new graduates entering the field and as a comprehensive resource for experienced fusion researchers.

Within the last year a major decision has been taken on the future of fusion research: China, Europe, Japan, India, Korea, the Russia Federation, and the United States have decided to build the International Thermonuclear Experimental Reactor (ITER). This will be the largest tokamak ever built. It is designed to produce high fusion power for long durations—a first in fusion research. It is expected to generate fusion powers of the order of 500 MW for hundreds of seconds (although it will not have any direct electrical power output because the appropriate conversion equipment will not be installed).

The implementation of diagnostics on ITER will be a major challenge. In-vessel components will be exposed to much higher levels of neutron and gamma radiation than have been experienced previously, and there will be direct neutron heating of these components. At the end of ITER's life, the in-vessel diagnostic sensors will have experienced a neutron fluence of more than 10^5 times higher than that experienced on the most powerful fusion machines to date (JET and TFTR). As a consequence, many phenomena that relate to the physical properties of materials, and the ways in which they are altered by neutron and gamma radiation, must be taken into account in diagnostic design for the first time. These include radiation-induced conductivity and radiation-induced electromotive force in cables, and radiation-induced absorption and radioluminescence in optical materials. This is new territory for diagnostics. Indeed, it represents the current frontier of fusion diagnostic research. At the end of each chapter, there is a short section that looks forward to the diagnostic possibilities, and potential problems, of application to reactor-grade "burning" plasmas. There is also a chapter dedicated to summarizing the extensive research and development that has been undertaken, and that is still in progress, for the preparation of ITER. We develop this theme further in a concluding editorial perspectives. We take a virtual tour through the ITER complex as it will appear in the D-T burning phase, and we try to anticipate the advances in custom diagnostic design and supporting technology that will enable plasma measurements on ITER and on future "burning" plasma devices.

No work of this breadth and depth would be possible without the efforts of many. Established experts—all practitioners in the field—took on the substantial task of preparing the chapters. Through them, this edition is connected directly to the cutting edge of research in plasma diagnostics. The authors of the chapters have cooperated fully with the central guidelines that were necessary to achieve uniformity of treatment. We thank them for extending their cooperation and patience to us in generous measure at all times. We also thank the anonymous reviewers for their constructive comments. We can definitely state that the peer review process is alive and well in diagnostics! We thank the editorial team at *FS&T* for its efficient and professional production of this issue. Particular thanks are due Dr. Nermin Uckan, Editor of *FS&T*, for envisioning an issue in this topic area and for being a permanent source of guidance, help, and advice throughout the process of turning the vision into a reality.

During the preparation of this issue, two well-known and much-liked experimental plasma physicists, Ber de Kock and Gennadiy Razdobarin, passed away after long illnesses. Both made numerous and significant contributions to diagnostics throughout their long and successful careers, while working on several fusion machines and the preparations for ITER. We dedicate this special issue to their memory.