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Book Reviews

FUSION REACTOR PHYSICS, PRINCIPLES AND TECHNOLOGY

by

T. Kammash

Michigan: Ann Arbor Science Pub. Inc., 1975, 495 pp.

Intended primarily as a senior/graduate level textbook, this book doubles as an excellent overview of the interactive feedback between disciplines involved in the ongoing controlled fusion research program. Stressing basic principles, though going into much detail, the author aims at bringing into a common outlook the different aspects of the work in nuclear fusion: technological, physical, and economical.

The book consists of sixteen chapters, with references. No student exercises are included. However, going through the detailed derivations is an excellent exercise in itself. A previous course in plasma physics would facilitate easy grasp of the content.

In the first chapter the "rosy" incentives for the present fusion program are explained: unlimited fuel supply, inherent safety against explosions, decrease (but not "absence") of the radioactive wastes problem, and the expected lower biological hazard in case of accident. The different approaches to fusion are outlined: i) Magnetic confinement, including mirrors and toroidal devices; ii) Inertial confinement, including lasers and electron beams. The fusion fuel cycles, the Lawson criterion, magnetohydrodynamic and Micro-instabilities and their stabilization, and the fusion technology problems which are treated in the following chapters are briefly outlined. The author stresses the difference between the "scientific" and "technological" feasibility of the fusion power generation: "A successful fusion power feasibility demonstration in the early eighties will not, of course, gaurantee the possibility of power from controlled fusion," due to the many engineering and technological problems. He expects, however, a demonstration plant toward the end of the century: and a commercial one around the turn of the century. Is it a "hidden" message for those advocation the idea of going "solar and fusion" and to drop the "fission" program?

The second chapter is devoted to introducing basic physical concepts in fusion reactors. Expressions for energy balances for the electrons and ions, radiation losses as bremsstrahlung and cyclotron (synchrotron) radiation, D-D and D-T reactors, power densities, the burnup fraction, and the effective reaction parameter are deduced. The Gamow cross-section, the β-factor (ratio of plasma pressure to confining magnetic field pressure), and the concepts of ideal ignition temperature, confinement time, and Lawson criterion are discussed.

Chapter III treats the neutronics aspects of fusion reactors. Though its importance is recognized by the author (in the assessment of the heat extraction process and tritium breeding in the blanket, the shielding of the magnets, afterheat and activation calculations and estimation of the radiation damage to the various structural components) the area deserves a larger share of the treatment. A cylindrical geometry diffusion theory, two-group model with plasma as a line source, serves to crudely estimate the tritium breeding by L_i^6 and L_i^7 and the nuclear heating in a representative blanket. Though elegant, the treatment oversimplifies the real situation involving: high anisotropy in the neutron distribution which necessitates the use of transport theory with discrete ordinates or Monte-Carlo methods for adequate energy and space assessment, the geometrical effects of the toroidal shape, and the neutron source (plasma) resulting in hot spots on the chamber wall, the special design of the inner part of the torus due to its inaccessibility, the combined gamma-neutron shielding of the magnets, the cross-sections data handling, solid gas-cooled versus liquid-cooled blankets, and others. An expression for the doubling time is deduced. The physics of atomic displacement are used to assess the incremental damage by estimating the number of displaced atoms by 14 Mev neutrons, considering primary knock-on. Comparison to 1.41 Mev fissions neutrons is carried out. Cascading effects and inelastic and anisotropic scattering are not condidered: "The extent of radiation damage by neutrons on physical properties of materials is still a matter of considerable debate and speculation."

The next four chapters consider in much detail the different methods of heating (and possible fuelling), and maintaining the plasma at thermonuclear temperatures. The limitations on ohmic heating in Tokamaks: decrease of plasma resistivity with increasing electron temperature, increase in bremsstrahlung losses, preferential heating of electrons, and the necessity to use alternative heating methods is explained. The interaction of charged particles with the plasma in the presence of collective effects (incorporated through the use of Debye screening in the Coulomb cross-section) using Binary Collision Theory is treated in the context of analyzing of neutral beam heating. Plasma heating by relativistic electrons entails the study of the slowing down process of a particle through a cloud of charged particles using relativistic mechanics, and a comparison with Bethe's formula for the slowing down of a relativistic electron in a neutral gas. The best understood radiofrequency heating method: "Transit Time Magnetic Pumping" for frequencies in the 100 KHz range (corresponding to high plasma temperatures and low plasma density), and the interaction of charged particles with oscillating fields are studied. The current heating methods being unable to bring a D-T plasma to its ignition temperature (~4.5 kev), the importance of adiabatic compression as a second stage to bring a Tokamak reactor to ignition is studied.

Chapter VIII treats a simple model for a toroidal reactor in steady state to examine, from the dynamics equations, the stability of the system as a result of perturbations in particle density and temperature. By linearization, the stability criteria are deduced. Feedback stabilization using temperature dependence of the energy confinement time (and hence energy loss) is applied to measure deviations from operating values of temperature and density, and to suppress them. A more realistic model accounts separately for ions, electrons, exhaust components, Synchrotron and cyclotron radiation. Basic laws for neoclassical, anomalous drift wave turbulence, and trapped particle turbulence confinements are deduced.

The "environmental impact" of a mirror fusion reactor with direct conversion is analyzed in the ninth chapter. The efficiencies required for the different processes in the system to be competitive with regard to "thermal pollution" with other forms of competing power systems on the market are considered. The analysis yields that a D-T mirror reactor can compete with non-fusion power plants provided the direct conversion and injection efficiences prove realistic. The D-$H_e{}^3$ reactor (a "cleaner" system since the fusion energy is mostly in charger particles products, thus alleviating neutron activation problems) appears less promising unless the required injection power is greatly reduced.

Chapter X briefly treats the Fission-Fusion hybrid system. The advantages of greater power production, faster breeding than with pure fission, possible faster development of fusion reactor design, and safety (subcritical fission blanket) seem to be counterbalanced by the disadvantage of combining the hazards of both systems: tritium handling problem added to the radioactive wastes (fission products), and the geometry and cooling system problems becoming more severe than for either system. These considerations are not debated, but the technical principle is examined.

The inertial confinement fusion systems are analyzed in Chapter XI. The Lawson criterion is here replaced by the burn condition: $\rho r \sim 1$ gm/cm^3 for D-T fuel (product of material density and radius). The concept of a "microexplosion" using Taylor's similarity law and the Hugoniot relations for shock wave propagation are briefly discussed, as well as the "implosion" concept and the underlying energy break-even conditions, and laser coupling efficiency. The author warns: "The interaction of laser radiation with plasma is a complex phenomenon that has so far eluded exact and determiniotic assessment." Different processes for laser absorption are briefly discussed: inverse bremsstrahlung, and anomalous processes of absorption arising from electrostatic, electromagnetic and relativistic instabilities. A conceptual design for laser cavity module by the wetted L_i wall concept is outlined.

The next chapter treats the radiological problems of nuclear fusion power: "...expected to be less than the ones associated with fission power." These include: the magnets and biological shielding against primary and secondary neutrons and gammas, containment of radioactive material during normal operation (or during an accident), and storage of radioactive waste products. "It is evident that the biological shielding requirements of a D-T fusion will be greater than that required for a fission reactor: whereas 80% of D-T fusion reaction energy appears in neutrons, only 10% of fission energy appears as neutrons and gammas." However, fusion radioisotopes inventory (tritium and activation products) are a few orders of magnitude lower than those of fission reactors, and the afterheat is much less in fusion that in fission.

The major parameters needed to carry out a conceptual design of a fusion reactor are considered in Chapter XIII, with reference to a toroidal steady-state system: thermal wall loading, optimum power density, wall radius, total power, magnetic field strength, plasma density, confinement parameter ($n\tau$), full operation containment time, and other confinement parameters. The main design parameters of a mirror reactor, and a pulsed high β-staged reactor (Θ-pinch), are also considered.

Radiation damage, the most severe constraints on the engineering feasibility, is not treated. First, wall erosion due to evaporation, damage by sputtering and blistering are considered. A detailed analysis based on binary collisions yields a sputtering formula which is applied to estimate damage to first walls with comparison to some experimental results. Newly introduced concepts for the protection of first walls, such as graphite curtains, are not included.

Considering liquid lithium cooled blankets, the thermal aspects of fusion reactors are considered in Chapter XV: pumping of conducting fluid through magnetic fields and the ensuing high pumping power requirements, and the mechanical stresses limitations in reactor ducts. Other heat removal systems molten salts (flibe) and gas cooling (He) of solid blankets, deserve a share in the analysis.

The analysis is concluded in the sixteenth chapter by exposing a general formalism providing a basis for comparison for economic assessment of different fusion power systems based on a general power balance for four fusion concepts: mirrors, tokamaks, theta-pinch and laser-ignited. The analysis suggests that the fusion energy multiplication factor (Q), defined as the ratio of the rate of fusion energy produced to the rate of heating energy trapped by the plasma, appears to be a more fundamental measure of fusion power achievement that the Lawson number.

The book is recommended for research scientists desiring to acquire a general outlook on the different aspects of the fusion research program, and is a textbook for graduate fusion feasibility course work. The book complements the text by Rose and Clark.[(1)] Supplemental reading of conceptual designs reports [(2,3,4)] is needed to acquire a feeling of the "latest" in such a fast developing field, and gain more insight into the involved technological aspects.

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FINITE ELEMENT METHODS IN REACTOR PHYSICS ANALYSIS

by

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The paper is primarily concerned with the application of the finite-element methods for nuclear systems anaylsis. While the method has been initially developed and applied by structural engineers to their problems, it shows a great promise of application to Nuclear Systems analysis. The authors define the method of application towards obtaining approximate solutions to integro-differential equations which encompass most of the difficult dynamic processes[1,4,8] and transient performances of nuclear systems, including nonlinearities. They also bring out very well the valuable features of the method of application to problems of complex properties and geometries. The method seems to yield reasonably accurate results (though only a few of the applications results are available), besides being amenable to computer solutions[2,7,12] with minimum numerical difficulties.

The paper is comprised of six sections: Section I has a brief but interesting discussion of various forms of neutron diffusion problems. The details are considered in the later sections of the paper.

This introductory section deals with a brief summary of the current state of art in reactor calculations[3,5,6] and the areas where improvized developments are needed. The authors compare the methods of application in this section with a typical case of one group diffusion problems[1,10,11] with the results obtained by conventional finite difference formulations.

Section II develops various piecewise polynomial interpolations methods: initially for problems in one dimension and later for several-dimensions problems. The primary objective of the authors in this section is to obtain univariate and multivariate polynomial bases[9,10,13] in finding approximations to functions.

Sections III, IV and V concentrate on the central theme of the paper: which is to develop finite element methods for problems in neutron slowing down (Section III), static diffusion (Section IV) and reactor kinetics. Typical application and data for the methods are included: as obtained from experimental results for a typical four-group multiregion liquid-metal fast-breeder reactors. The designer's difficulties, particularly for power reactors and more specifically for fast reactors, are those of low degree of spatial symmetry, and demand multigroup models. The solutions to these are well-developed in this