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The New Discipline of Nuclear Engineering

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I. Introduction

Like many nuclear engineering departments throughout the United States, the department at MIT has been carefully analyzing and planning its future strategy in order to maintain a strong and viable program. This planning, which by now has extended over approximately half a decade, is far more encompassing than the normal evolution of engineering curriculum. Extensive long range planning has been required because of the particular problems facing the nuclear engineering community.

The primary problems are by now well known. There is declining interest in nuclear power in the United States with no new orders in the foreseeable future. Similarly, fusion research has been significantly curtailed in recent years by the Congress and the United States Department of Energy leaving the program with an unstable and somewhat unpredictable future. The net result has been a reduction in the number of students entering the nuclear engineering profession. Since strong student enrollment is the lifeblood of any academic department, these problems threaten the well being, and in some cases the actual existence, of nuclear engineering departments throughout the country. A related problem concerns university research reactors. With declining student interest and many reactors due for relicensing, university administrators are often tempted to shut down and decommission such facilities.

Nuclear engineering departments have responded to these problems with a number of new initiatives which have been somewhat, but not completely, successful. For example, in the fission area there are substantial efforts underway to study methods of improving performance and to extend lifetimes of existing power plants. Also, although the fusion budget has been reduced, the new emphasis on basic fusion science and engineering should benefit university programs to the extent that a stable future can be maintained. These initiatives and trends have helped to stem the tide of reduced student interest but have not, by themselves, led to increased student enrollment.

By and large the most popular and successful strategy to generate increased student interest in nuclear engineering is the new emphasis placed on non-power applications of radiation for societal benefits, particularly those related to medicine and biology. This general area of research is referred to as “radiation science and technology (RST).” The sub-area related to medicine and biology is sometimes called “radiological sciences,” or “bionuclear technology.” By whatever name the combination of an intellectually rigorous curriculum, coupled with the prospects of helping fellow human beings in a fairly direct one-on-one basis, is a very enticing option for many students. Nuclear engineering departments that have initiated such programs have shown growth in this area. However, the area is still not sufficiently well defined and cohesive to have established a nationally recognized presence as compared, for instance, to fission research. This remains for the future.

In analyzing these problems and trends the Department of Nuclear Engineering at MIT has observed that the resulting responses, which involve substantial efforts, have been moderately successful but are nonetheless reactionary in nature. As a result we have attempted to step back and develop a more global view of a nuclear engineering education, a view that should suggest the proper strategy for a healthy survival in the coming century.

There are two main insights that have been developed towards this goal. First, we have come to recognize that the time is now right for a basic nuclear engineering education to make a transition from a single technology driven curriculum based on nuclear power to a curriculum based on a universal core discipline valid for each of the many specialized areas of research. Second, we have come to recognize that nuclear engineering research is not a mature, saturated field. Indeed there is a new, largely unexplored, frontier involving fundamental physical, chemical, and biological phenomena characterized by mesoscale science (corresponding to the intermediate regime between the atomic and practical macroscopic engineering length scales).

A more detailed description of these two insights represents the main contribution of the remainder of the paper.

II. A Nuclear Engineering Core Curriculum

As a starting point we reiterate that until recently a nuclear engineering education has been predominantly defined in terms of a single technology, nuclear power. In analogy, during the early years of their existence many other engineering departments were also dominated by single technologies; for example, the petroleum industry for chemical engineering, the electric power machinery industry for electrical engineering, and the steam engine industry for mechanical engineering. As these industries matured the corresponding departments expanded into a variety of new areas making use of the same basic core knowledge. The resulting diversification is by now so wide that one no longer associates a particular industry with, for instance, electrical engineering but instead expects technical expertise over a broad range of core electrical engineering fundamentals. The assertion here is that the most successful engineering departments are those that have successfully made the transition from a single technology driven curriculum to a basic discipline driven education. The time is now right for nuclear engineering to make this transition.

The transition to a discipline driven curriculum offers a new view of RST. The fact that there are a wide variety of RST applications as opposed to a single focus should in fact be viewed as a strength and not a weakness. We are only at the beginning of a new era in which nuclear processes will play a critical societal role in bionuclear, environmental, and industrial applications. Although the research applications are diverse, the crucial point is that there exists a “glue” which holds together and defines the discipline of nuclear engineering. This “glue” is the common educational core of material, fundamental to all these applications. The core can be defined as “applied nuclear science” and includes low energy nuclear physics, the interaction of ionizing radiation with matter, and plasma science and technology.

A word of caution is in order. While the diversity of RST is a definite advantage, the fact that most nuclear engineering departments are relatively small suggests that care must be exercised not to over diversify. Within RST, choices must be made to create a critical mass of faculty and student interest in one, or perhaps two, sub-areas. In this way a national identity can be established in these sub-areas which will serve to promote a well recognized visibility for a nuclear engineering education. At MIT, as well as other universities, bionuclear technology appears to be one sub-area of choice.

Although bionuclear technology is a sub-area of RST it, nevertheless, represents a wide range of research. To establish a reasonably complete bionuclear activity probably requires at least six or seven committed faculty members covering the three basic classes of applications; (1) the treatment of illnesses (e.g. BNCT, development of pharmaceuticals), (2) medical and biological diagnostics (e.g. imaging techniques) and (3) health physics issues (e.g. the linear extrapolation hypothesis). University programs of this size or larger, focusing on the related nuclear engineering technology rather than the pure biological sciences, will help to create an identity for bionuclear technology and establish that such activities should naturally reside in nuclear engineering departments.

Towards the goal of establishing a unified discipline we have instituted a four subject core requirement for all of our Ph.D. students, regardless of research area of interest. These subjects are as follows: (1) Applied Nuclear Physics, (2) Engineering Principles in a Nuclear Environment, (3) Microscopic Theory of Transport, and (4) Nuclear Measurements Laboratory. With this
background students should be prepared to start research in any of the traditional nuclear engineering areas: fission, fusion, or RST.

The disciple thus defined represents a rigorous course of study which has evolved naturally from our combined research activities. It is unique in the School of Engineering and resides most appropriately in the Department of Nuclear Engineering. As the department evolves along this disciplinary path there will be less and less reason to support, as we have until recently, the three independent and only weakly interacting tracks of fission, fusion and RST**.** Ultimately, these sub-areas will be viewed as particular applications of the basic discipline “applied nuclear science.”

III. The New Frontier in Nuclear Engineering Research

During the course of our long range planning discussions it has become apparent that there exists a common thread linking much of the ongoing research in the department. This thread is the recognition that the important physics describing many of the phenomena under consideration corresponds to the regime of mesoscopic science. The number of applications in which this occurs is sufficiently large and general in scope that we have been led to the conclusion that for the foreseeable future, mesoscopic science is the new frontier in nuclear engineering research.

To put mesoscopic science in context, note that for much of the early part of the century a major effort in engineering research was devoted to the study of macroscopic fluid-like models. As nuclear physics developed, there was a corresponding activity aimed at understanding microscopic phenomena at the atomic and nuclear levels. This activity, among other things, led to the measurement and understanding of nuclear cross-sections, information vital to the development of nuclear power. Mathematical models were also developed showing how to conceptually and sometimes practically move from the micro to macro regimes.

Although it was recognized that research on the intermediate mesoscopic scales could be very interesting and important for many applications, until recently little effort has been devoted to such projects. The reasons are twofold. First, the basic micro and macro phenomena had to be well enough understood before proceeding to the more complex intermediate scales. Second, the technological tools and computing capabilities required for such research were just not available.

The situation is now changed. In the engineering sense, both micro and macro phenomena represent matured subjects. Furthermore, recent progress and new inventions in nuclear technology, as well as greatly improved modeling and computing capabilities, now provide access to the regime of mesoscopic physics.

New opportunities exist in each of the three traditional areas of nuclear engineering research, fission, fusion, and RST. Consider the following examples. In the bionuclear area it is now possible to produce micro-beams of particles whose cross-section is smaller than the size of a single cell. Such particles can deliver a precise, known dose of radiation to a single cell. Coupled with spectacular advances in imaging resolution it will soon be possible to discover, by direct measurement, how radiation interacts with and affects the behavior of living cells. This level of knowledge would greatly increase our fundamental understanding of radiation treatment over traditional methods which deliver larger doses over many cells and then requires various statistical averaging procedures. Such technology will be invaluable in the development of tailor-made radiation treatments and the accurate determination of the effects of radiation related to health physics issues.

In the area of fission research, one long standing problem of great practical importance is the formation and development of cracks. Such phenomena occur on length scales much smaller than the macro scale but much larger than the single atomic scale. Recent innovations in computer modeling, as well as new advances in imaging techniques, are beginning to provide access to this important class of mesoscopic physics problems.

Fusion, from its outset, has been concerned with mesoscopic physics. Basic plasma physics, with its large number of dimensionless parameters gives rise to a correspondingly large number of widely separated length and time scales. In the practical sense, one can think of the macroscopic scale as corresponding to machine size (e.g. meters) and the microscopic scale as the electron and ion gyro radii (e.g. 0.0001 cm and 0.5 cm). Perhaps the most outstanding problem in fusion physics is the prediction of the anomalous heat conductivity of a plasma. This anomaly is believed to be generated by small scale plasma instabilities with wavelengths and frequencies intermediate to the micro and macro scales. Sophisticated modeling techniques and increases in computing capabilities are now beginning to make this mesoscopic physics problem tractable.

The recognition that mesoscopic physics is a new frontier with applications across all areas of nuclear engineering research should provide new opportunities for cross interactions between different sub-groups within the department. The science and technology has a considerable degree of overlap and it is of interest to the future well being of nuclear engineering that the existing separate tracks of fission, fusion, and RST increase collaborations with one another to form a larger, more unified discipline of nuclear engineering.

IV. Conclusions

As Bob Dylan said: "The times, they are a-changing." If nuclear engineering departments are to survive and contribute to the well being of society they must change, and on a relatively fast time scale, because of reduced interest in nuclear power. Our plan is to focus our educational curriculum about a core discipline based on applied nuclear physics. Our research will expand in the area of RST, bionuclear in particular, while we attempt to maintain our efforts in fission and fusion. A common thread linking the traditional sub-areas of nuclear engineering research is the identification of mesoscopic physics as a new frontier, which should hopefully encourage stronger overlap projects and lead to a more unified discipline.

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