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To: Members of ORSORT Faculty Date: July 13, 1951

From: F. C. VonderLage

Subject: Training for Reactor Engineers

Attached is a paper on the above subject. I would be delighted to receive comments, preferably in written form, from the ORSORT faculty members.

F. C. VonderLage

FCV/hlm

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TRAINING FOR NUCLEAR ENGINEERS ..... F. C. VonderLage, Director
Oak Ridge School of Reactor Technology

ASEE MEETING, East Lansing, Michigan

June 25, 1951

Nuclear engineering at present can be divided into four huge segments; Engineering associated with (1) the production of new materials, with the production of fissionable isotopes holding the central position; (2) the development of powerful nuclear particle accelerators for use, to date at least, principally as tools for scientific research and engineering testing; (3) the improvement of atomic weapons; and (4) the development of nuclear reactors for power; for the conversion and breeding of fissionable materials, and, to a lesser extent, for the production of radioisotopes; and for the production of free neutrons for use in research. There are requirements in technology peculiar to each of these segments of nuclear engineering, but in the interest of brevity and without a significant sacrifice in completeness, the meaning of nuclear engineering can be restricted to mean reactor engineering in a discussion on the "Training of Nuclear Engineers."

Reactor technology is one of the few technologies that sprang up primarily out of the prompt application of a single scientific discovery-- namely, nuclear fission. With the application of nuclear fission to reactor development, nuclear properties of materials of construction suddenly became important to engineering-- and there was introduced to engineering a new, primary, concentrated source of high-grade energy of potentially greatly increased specific power.

The exploitation of the favorable characteristics of this energy source, together with the limitations set by nuclear properties on the

choice of construction materials, has led to a tremendous development program, the detailed character and scope of which are not well known by those outside the project. It includes the development of the use of chemical elements heretofore only identified on the periodic chart, from the search for ores through reduction, refining, metallurgical treatment, and fabrication into reactor components. It includes the design of novel components such as valves, pumps, heat exchangers, of high capacity and leakproof, as well as the design of control systems of unfailing response in times measured in milliseconds. It includes development in the field of chemical technology and of techniques for remote control of huge plants, together with radiation protection for personnel. The need for these primary developments are multiplied to what appears almost a limitless extent by the need for secondary developments. It does not appear appropriate here to describe the work in more detail. It must suffice to say that, although reactor engineering is large in size of effort, it is in its early development stage; it is almost completely development engineering and is of broad scope, perhaps the broadest of all modern technologies, intimately encompassing all branches of engineering.

Reactor technology, in its earlier infancy, was concerned chiefly with finding a method to sustain a nuclear-fission chain reaction, and the application of nuclear physics was prominent. The understanding of the operation of nuclear reactors in terms of more basic physical concepts is now sufficiently complete to make significant progress possible, and by far the major effort now being applied lies in the extension of familiar fields of engineering and chemical technology.

Nuclear engineering is characterized by a synthesis of the technology of all branches of engineering, rather than an extension of engineering into a new branch. Materials, methods, devices, components, and systems of these elements unique to reactors certainly have not yet been developed even to their near optimum. These elements are generally unavailable commercially. Costs and performance characteristics of components and systems are not extensively codified and tabulated. Designing a reactor is not simply the problem of selecting components whose characteristics are known, as in the case of a steam plant. For these reasons, it is perhaps premature to introduce the concept of "nuclear engineering." Reactor engineering is not, at present, engineering in the same sense as steam-power engineering is engineering, and the training required of a reactor engineer is that required of a development engineer.

The training of development engineers for nuclear engineering, for guided-missiles engineering, and for modern aircraft engineering, to mention only some of the large technologies of wide scope which have arisen in recent years, presents a newly recognized challenge to university engineering educators. The basic essentials for one to perform professionally as an engineer is a foundation of knowledge in science and the engineering arts, and the ability for logical analysis (mathematics) to serve as tools in the design and evaluation of machines, devices, systems, etc., to perform a given utilitarian function. For a development engineer it will not suffice in his design that he know simply the engineering practice in an established engineering field, since he is working in fields in which the practice is not yet established; and it is indeed, his job, in part to contribute to the establishment of sound new practices on a wholesale scale.

The challenge to engineering educators is to recognize the need for educating development engineers, and to so educate them that they will be effective in areas of engineering for which no engineering practice has been established. This requires a strengthening of knowledge in basic fundamentals and a development of a keen inventive instinct to apply this knowledge. It is clear that these two cannot be done completely in a four- or even five-year undergraduate period, and so the design of a curriculum for the development engineer must recognize the need for a new compromise in emphasis between that placed on fundamentals and that placed on design.

TRAINING OF THE NUCLEAR DEVELOPMENT ENGINEER

The development engineer, in order to perform adequately, is required to have training embracing all the branches of engineering. Knowledge of all branches of science is required, both basic and applied, which is broad and in depth as a foundation for modern analysis, design, and evaluation. Study of engineering courses of general applicability needs to be emphasized, necessitating the abandonment of specialized engineering courses of limited applicability. Specialization must, in the main, be deferred until the student reaches the graduate level, or, alternately, until he is employed following the baccalaureate degree. Specialization in the technology and current practice unique to an industry, especially one of large scope in its early development stage, must be deferred until after he completes his university student career.

THE UNDERGRADUATE CURRICULUM*

The emphasis on training of the development engineer at the undergraduate level should be of such a nature as to provide the student with a broad and thorough knowledge in the basic sciences, in the applied sciences, in engineering, and of the continuity between them, and to develop the attitude that each bit of such knowledge has, or has a potential for, application to engineering development.

At the undergraduate level, a broad and sturdy foundation must be laid covering each of the basic sciences, mathematics, physics, chemistry, and biology. Knowledge in these should proceed to a sufficiently advanced level to permit deep understanding and their application to the applied and engineering sciences. Mathematics, for example, should proceed to partial differential equations and LaPlace transforms so that these can be applied to analysis in the study of diffusion and heat transfer, to mention only two. Kinetic theory should proceed to the point of integrating it with thermodynamics, and the phenomenological knowledge of the existence of martinsite, pearlite, etc., in steel should be understood in terms of physical chemistry.

Modern sciences (for example, nuclear physics) should be included in the undergraduate curriculum. The newer topics in science, which

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*Views presented here grew out of experience in training graduate engineers in the Oak Ridge School of Reactor Technology. All members of the faculty have contributed in discussion, including Professor Trevor R. Cuykendall of Cornell, who spent his sabbatical leave during the fall semester of 1950-51 with the school, and has reported his views and experiences on an undergraduate curriculum for development engineers to us.

had not been applied in engineering to an appreciable extent, were omitted from engineering curricula in the past. The current rate of progress of development engineering will no longer permit this omission; what is today scientific knowledge only, may be utilized in design tomorrow.

What has been said about the basic sciences applies in general to the applied or engineering sciences. The scope of study should include a wide variety of subjects such as mechanics, elasticity, fluid mechanics, thermodynamics and heat transfer, electric-circuit analysis, and the like. Courses should not be confined to those commonly associated with a single branch of engineering(for example, mechanical engineering), since modern devices and systems often combine in their design intimate integration of knowledge from all branches of engineering.

An adequate number of general engineering courses containing topics which are frankly phenomenological or engineering practice in nature (for example, properties of engineering materials, machine design, structures, shop practice and fabrication methods) should be included. Topics covered should be selected to serve in future years to provide the development engineer with sufficient general information and concepts of this type so that he can conform in the world of engineers, will have them available for introduction into his inventive imagination when applicable, and can avoid the effort of new invention when a suitable solution is already available.

Non-technical, cultural subjects such as history, english, economics, and political science should be included in the undergraduate curriculum to insure that the student is educated as well as trained. The importance

of this cannot be overemphasized, but will not be elaborated on here, since many appropriate papers have been written on the subject.

DESIGN ABILITY AT THE UNDERGRADUATE LEVEL

Engineering design ability holds a central position in the definition of the activities of professional engineering. Ability for this can be developed, in a measure, in the laboratory courses associated with the more advanced applied-science courses. There possibly is room for a very few courses devoted exclusively to design, perhaps in the form of an undergraduate thesis. Other than the thesis, it is unlikely that time will permit design experience to progress much beyond a simple selection-of-components type of design such as, for example, the selection of suitable components for the assembly of an oscillator curcuit of given frequency range. An undergraduate thesis on developing a design incorporating a novel arrangement of components, or a simple design incorporating a new application of a scientific principle for the first time, would be desirable. But, in the main, experience and growth in design ability for the student of development engineering must await the graduate-school period, or alternately, employment in a development laboratory.

NUCLEAR OPTIONS AT THE UNDERGRADUATE LEVEL

A few universities might offer nuclear options. This would take the form of special emphasis on nuclear physics and radiochemistry in the basic sciences. In the applied sciences, emphasis should be placed on fluid mechanics and heat transfer. A new subject, reactor theory, might be introduced. Nuclear instrumentation might be singled out for special attention in an electrical engineering course. Radiobiology and health protection might be included.

It would be a mistake to specialize on nuclear technology to the point of crowding out the broad program of training for the development engineer as outlined earlier. Rather the selection of topics and the emphasis on training should be focused on a presentation of the material which will be necessary to support analysis and design ability later. It is hopeless, for reasons outlined earlier, to attempt to train a student in nuclear engineering in the same sense that he is trained in heat-power engineering. Topics on technology peculiar to nuclear technology should not occupy more than, say, 10 per cent or less of the student's time.

PLACEMENT OF EMPHASIS AT THE UNDERGRADUATE LEVEL

Whether the future nuclear engineering student is to be enrolled in a nuclear option or not, care must be exercised in a development-engineering curriculum to insure that the engineer's motivation is not lost because of the emphasis on the sciences in the curriculum.

In the science courses, the primary emphasis should be placed on application, and the potential application, of the science to new design. Emphasis on the scientist's urge to increase the body of knowledge contained in science should be submerged in the former. This can be done in the course of selecting problems, suitably chosen from the applied sciences or engineering fields, to illustrate the application of the scientific theory or facts as they occur in the course. It does not mean omitting topics from the science course which have no presently existing applications. This leads to fragmentation of the unity of science, rote-learning, and the omission of topics which may prove to have great potential for future application. Nor does it mean that the logic of science should be diluted by shallow analysis which may arise from deficiency in mathematical preparation.

On the other hand, the applied-sciences and engineering courses must be taught with the background of underlying basic science always within clear view of the student. The abstract phenomenological quantities should be understood in terms of more basic concepts; for example, entropy in terms of a statistical measure of the degree of lack of order.

GRADUATE-LEVEL TRAINING

At the graduate level, more specialized and more advanced training in science would occur to the point of sophistication in areas supporting the chosen engineering specialty. It was stated earlier that, in the main, because of the need for a more thorough training in fundamentals, the development of the ability for design must await the graduate-school level of training, and this could be done best by an engineering thesis. The thesis would be on the application of a well-established scientific (either basic or applied) principle, theory, or knowledge to the development of a new device or component. Or it might be the extension of applied science by analysis or synthesis of scientific principles or theories basic to an applied problem. Work on the thesis may include, due to the paucity of information, the carrying out of scientific experiments, performance of tests, or the gathering of data, say, on physical properties of a material. But the emphasis on these knowledge-gathering functions should be as a means to an end, with the principal emphasis placed on design and evaluation.

At the graduate level of training of the engineer, the main emphasis should be on developing the ability and the ingenuity to apply the basic and applied sciences and engineering knowledge to the design and development of a component or system to perform a prescribed utilitarian function.

THESIS RESEARCH ON REACTOR PROBLEMS

The undertaking of research on reactor systems or on major components unique to reactors, except for reactors of low power, is generally precluded from the university campus because of the magnitude of such problems, of the facilities required, and of the security problem. A large laboratory on campus suitable for such work tends to become a business operated by the university rather than a training ground for students.

The urgency for results at an AEC laboratory does not offer many components problems suitable for university development. There are, however, problems which arise in reactor development and which are suitable for university research. These are of longer-range interest. The extension of the theory of fluid mechanics to the fluid dynamics of solutions containing energy sources is an example, to mention only one, now of interest.

To aid universities in becoming acquainted with the existence of such problems, and also to aid in evaluating the need and desirability for establishing a nuclear-option curriculum, the Oak Ridge School of Reactor Technology has established places for university professors to attend the school for a limited period of time. Further information can be obtained by writing to the Director, Oak Ridge School of Reactor Technology, P. O. Box P, Oak Ridge, Tennessee.

CAMPUS REACTORS

The construction of a low-power research reactor on a campus is feasible and not beyond the means of a university. It lends itself to training in the unclassified areas of reactor technology and will be a very valuable and worth-while research tool, since it will furnish a copious supply of neutrons and nuclear radiations. However, the technological features of classified and high-powered reactors are not present,

and the campus reactor is not of great value in demonstrating the features of main interest to the development of the modern reactor technology.

UNIVERSITY TRAINING IN THE TECHNOLOGY, ARTS, AND PRACTICES UNIQUE TO A SPECIAL INDUSTRY

An attempt to train a university engineering student in the technology, arts, and practices unique to an industry, in an effort to allow him to compete at an advantage in that industry, is fraught with grave danger of disappointments. Time spent in this leads to dilution of training in those subjects basic to engineering. The vagaries of future employment opportunities, or a shift of interest during the formative years, may preclude a student's final entry into the industry and the sought-for advantage becomes a serious disadvantage.

Courses consisting of topics unique to industries which are in a period of rapid technological growth runs the risk of rapid obsolescence, since what is important today can be profitably forgotten tomorrow to make way for something that replaces it. A continual revision of the topical content would be particularly difficult, especially if there are security barriers to prevent complete and ready access to information.

Suggestions to set up a nuclear-engineering option in the sense of the present discussion leads to the question, "Why not a guided-missiles option, or a jet engine option, or a rocket option?" The multiplicity of courses required for this would be enormous, and limitation to a selected specialized technology runs the risk of a university's narrowing the market for its students product.

GROWTH OF TRAINING PROGRAMS WITHIN INDUSTRIAL ORGANIZATIONS

Traditionally, the knowledge unique to an industry has been obtained by growth of the individual through experience within the industry after graduation. But growth by on-the-job experience tends to be hopelessly slow in large industries encompassing unique technology, and many industrial organizations have instituted some training method to accelerate this growth for the engineer newly hired into the company. That the burden for this type of training should fall upon the industry itself seems eminently fitting and proper. It is most rapidly and efficiently acquired in an environment wherein the work is being done. Universities must maintain their emphasis on education, not training. Inclusion of this type of training in universities leads to trade-schooling at the expense of education in the broader arts, sciences, and engineering, and leads more and more to control by the dictates of the needs of a single industry.

Training periods for employees of organizations or industries of the type under discussion last from six months to two years. Frequently, they are assigned administratively to a training department during the period. The training may take several forms, such as temporary assignment to various jobs as trainees, night classes, or in some cases, a special night school supported by the company, or perhaps a combination of these. Other industries send their new employees part-time to a special school supported and conducted by the company, and supplement this by job rotation. The latter more thorough method is indicated for industries whose technology is large or in its early development stage.

The Oak Ridge School of Reactor Technology is such a school, supported by the Atomic Energy Commission for the purpose of training reactor

engineers in the technology peculiar to reactors. Recently graduated students are employees of the laboratory while at the school, and it serves as a central agency for training of reactor engineers for the commission's reactor development program. The student employees transfer to the payroll of contractors of the commission's reactor development program at the end of their training.

ESTABLISHMENT OF A DEPARTMENT OF DEVELOPMENT ENGINEERING

Because of the emphasis that has been placed here on the importance of training development engineers, it appears appropriate to comment on the importance of continuing the training of engineers in the traditional university engineering curricula. There are powerhouses to be built, bridges and highways to be designed and constructed, new waterworks, ships, power systems, communications systems, automobiles to be produced and developed--and all the myriad creations of engineers continue to be needed and at an increasing rate. The nuclear-engineering programs also require these things, and many components of the development program itself are reduced to engineering design, lying wholly within one of the several branches of engineering. The conventional engineer is expert, adept, and eminently qualified for this work, and his services are in demand on the nuclear-engineering program. Recognition of the continuing need for the conventional engineer does not, however, weaken the argument for the need for education for the development engineer.

The establishment of a developing engineering curriculum with a college of engineering is likely to lead to some problems. The achievement of proper content and scope of courses, the integration and timing between basic-science courses, applied-science courses, and the courses

in the several branches of engineering, or between courses within each of these, is apt to pose coordination and administrative problems.

It is not likely that a simple set of courses bearing appropriate titles chosen from among those now existing in several departments of a university will serve as an optimim in forming an undergraduate curriculum for development engineers, nuclear option or not. The coordination and organization of a set of courses suitable for this is a problem which would in many colleges require an administrative instrument for coordination. The creation of a department of development engineering might be necessary to achieve this. The demand for development engineers will continue to expand sufficiently to warrant the establishment of a department of development engineering within many of the engineering colleges of universities in this country.