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A CURRICULUM FOR ENGINEERING EDUCATION IN STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY

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The paper outlines a course on structural mechanics in reactor technology taught to graduate students of mechanical engineering at Delft University of Technology. The course consists of three main parts, viz. criteria for allowable stresses, stresses and deformations in plates, shells and rings and analysis of pressure vessel components.

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DISCUSSION

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In Nuclear Engineering, a detailed study of nuclear power reactor performance, basic to all questions of design, operation, optimization and economics, resolves ultimately to the consideration of four sub-systems: nuclear, thermal, hydraulic and structural - and their interactions. Hence in the design of a Master of Engineering Science formal graduate program in Nuclear Engineering, a 42 hour course in Reactor Structural Mechanics has been included as an elective. A candidate wishing to pursue this aspect would have studied, or be studying concurrently, reactor theory, heat generation, heat transfer and transport, single and two phase fluid dynamics, reactor dynamics, and reactor systems analysis, all of which bear on the mathematical modelling of structural problems in the reactor context. More significantly he would have completed 84 hours devoted to Mathematical Analysis and Computation, and Matrix Theory and Computation. As a result he would come to Reactor Structural Mechanics with a good background in mathematical and numerical techniques relevant to Nuclear Engineering, with special emphasis on spectral theory of self-adjoint and non self-adjoint linear operators, direct and interative techniques for the solution of high order sets of equations arising in the numerical solution of elliptic and parabolic partial differential equations, and the associated error analysis theory. In Reactor Systems Analysis he would have studied the general question of the reduction of field problems to finite vector formulations, e. g. , variational principles, and modal, nodal, finite difference and finite element methods within the general framework of weighted residual approximations.

The course in Reactor Structural Mechanics is therefore able to concentrate on physical phenomena, formulations, and analytical and numerical approaches, using the most relevant and concise mathematical development without inhibition. .In addition to the formal course, a candidate may choose, as his compulsory 168 hour individual project, a topic in Structural Mechanics for more detailed investigation. A recent example was the finite element analysis of high speed rotating systems, e. g. , neutron choppers, with interference problems and anisotropic material.

The basic approach in the discussion of structural problems of nuclear reactors is the derivation of working equations from general thermoelasticity theory with critical examination of explicit assumptions. By commencing with the decomposition of stress and strain tensors into mean and deviatoric components, and the use of operator formalism for rheological properties, a simple logical treatment of linear elasticity, viscoelasticity, and the extension of non-linear uniaxial creep data to triaxial states is possible. Also,reflecting the real situation, and a particular interest of the School in probabilistic models, the random elements in Reactor Structural Mechanics, both uncertainty and random processes, are emphasized. The course is designed to cover a number of realistic and representative reactor problems, pertaining to the prediction of operational performance and structural crises, e. g. , rupture, instability, thermal fatigue, etc. , under static and dynamic conditions, for basic elements, simple components and ultimately non-linear multi-component systems. Thus problems range from simple analytical linear one dimensional static thermoelasticity of cylinders, through flow induced vibrations, to three dimensional finite element approaches to real pressure vessel problems. The methodology of approach to a problem follows the scheme:

a) Problem identification - relevant structural phenomena and physical processes,

b) General mathematical statement of equations and boundary conditions,

c) Reduction to a feasible, soluble, relevant problem by explicit simplification - reduction of dimensionality, choice of empirical laws, leading to working equations of the mathematical model,

d) Choice of formulation, analytical and/or numerical approach,

e) Problem solution and associated computer programming,

f) Interpretation of results of mathematical model analysis in relation to the real problem.

The emphasis on basic principles, breadth of view, flexibility of approach, and a reasonable degree of mathematical and computational sophistication, is a reflection of the "engineering science" nature of the Nuclear Engineering course. The lack of a national nuclear power program gives freedom to range over a variety of reactor types, in selection of problems for educational and research purposes, and the opportunity to consolidate such an approach.

In conclusion, the particular viewpoint adopted in the School of Nuclear Engineering to Reactor Structural Mechanics is characterised by:

a) An emphasis on stress and displacement as essential constituents in the definition of the state of a nuclear reactor system, in addition to neutron flux, nuclide concentration, geometry, temperature, pressure and flow rates.

b) The key role of structural mechanics in the delineation of real constraint boundaries in the optimization of reactor design and operation.

c) The existence of real physical interactions and feedback loops coupling the nuclear, thermal, fluid dynamic and structural aspects, and the need therefore for breadth and depth of knowledge in non specifically structural subjects.

d) The common frame of reference provided by the mathematical formulations, approximation methods and numerical techniques of neutron diffusion, heat conduction, fluid dynamics and elasticity.

Associated research activities tend, by circumstances, to be of a theoretical and computational nature. Of particular interest is the coupled fluid dynamics, heat transfer, structural mechanics problem of fuel pins and fuel rod clusters in channels. A powerful digital data acquisition system, developed for reactor noise research may enable small scale experimental research into random structural dynamics problems associated with boiling to be initiated.