Grant Continuation: Code Development Incorporating Environmental, Safety and Economic Aspects of Fusion Reactors (FY94)

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This is a proposal to continue our work on the Environmental, Safety and Economic (ESE) aspects of fusion reactors under DOE contract DE-FR03-89ER52514 ending October 31, 1994. Tasks proposed here are for the period FY94, the final year under the current three-year contract.

Objectives

The overall objectives continue to be those stated in the FY 92-94 grant proposal. In summary, they are:

1. Completion of first-generation Environmental, Safety and Economic (ESE) computer modules suitable as integral components of tokamak systems codes.
2. Continuation of work on special topics, in support of the above and in response to OFE requests.

Recent Progress (As of April, 93)

Considerable progress was made during the first three-year grant period ending October 31, 1991 on the above described tasks. This work is summarized in the Final Report covering that period ("Final Report: Code Development Incorporating Environmental, Safety and Economic Aspects of Fusion Reactors (FY 89-91)," S.K. Ho, T.K. Fowler, and J.P. Holdren, Editors, UC-BFE-027, November, 1991). Here we focus on progress during the twelve months since the last proposal was submitted in April, 1992.

Interactions with the ARIES and ITER teams have continued. We have maintained good communication with the design teams on ESE related issues. We will continue our participation in the ITER EDA and post-ARIES (PULSAR and STARLITE) design activities in the areas of fusion

environment and safety. We have regularly participated in their project and informal meetings.

Continued work in the development of environmental and safety indices for fusion systems-code application is being carried out in accordance with the long-term plan. Several modifications in the characterization of the indices and the enhancements of graphical illustrations have been made. A paper describing this progress is in preparation for submission to journal publication.

We have collaborated with INEL, the TSTA group at LANL, and UCLA in modeling the tritium system for ITER. As part of this cooperative effort, a graduate student spent last summer at TSTA working on realistic models of systems components. Our work involves two levels of tritium modeling. The first one, a simple system-level inventory evaluation which is linearly proportional to residence times, has been completed. Currently, we are working at the second-level modeling with the utilization of physicochemical models of intermediate detail (pressure balance, equation of state, etc.), thus, producing more accurate and informative simulation results. The intermediate level of complexity, as opposed to a detailed model, makes it possible to integrate all fuel cycle units in a consistent manner, resulting in an integrated dynamic modeling of all the fuel cycle units that has the capability for overall optimizations. The analyses should also provide better estimation of residence times for the system-level modeling.

We have maintained a strong effort in developing fast calculational schemes for activation inventory evaluation. We studied the collective effects of variations in the fusion reactor components (i.e. various combinations of structural materials, breeding materials, reflectors, coolants, etc.) that can significantly modify the neutron spectrum and the resulting activation inventory. As a result, we have formulated scaling equations to approximate the activation radioactivity of a silicon carbide first wall by data regression of the numerical neutronics database from the parametric scoping studies. This work has been completed, resulting in a paper to be published in the journal of Fusion Technology. We are currently extending the approach to examine similar calculational scheme for the activation behavior of steel structures and tungsten divertors. These scaling equations for fast calculation of activation radioactive inventory are being implemented into ESE computer modules.

We have also made a significant progress in the adaptation of existing transport and activation codes for the purpose of numerical calculations of radioactive inventories in a fusion reactor with the primary goal of minimizing the computation time while assuring adequate generality and accuracy. The DABL69 cross-section library for transport calculations was adopted, and a scheme for processing point-energy ACTL activation library

into group cross-sections has been developed for use in the neutronics code ANISN. We developed an efficient procedure for flux-weighting the group activation cross-sections to generate one-group fluxes and activation cross-sections. The ANISN-based computational system was benchmarked against the reference LLNL system used in our activation calculations with good agreement. We investigated a number of schemes for reducing the calculational time, and managed to reduce the reference time for getting the effective one-group fluxes and activation cross sections by nearly two orders of magnitude.

In collaboration with LLNL, we are in the process of implementing safety features in SuperCode. We have studied and became familiarized with the modularization structure and computational algorithms of SuperCode. Currently, a module of tritium permeation in the plasma-facing components based on the model developed by G. Longhurst at INEL has been installed and benchmarked.

We have developed a simplified environmental and safety computational systems module, ultimately as a first version to be incorporated into SuperCode. This work will provide insights in the coupling and trade-off of environmental and safety factors with other aspects of fusion reactor design via a consistent overall systems module. Our goal here is to provide a working code in a timely fashion while detailed models are not yet available.

The problem of plasma burn control and rapid shutdown is being studied with the application of SuperCode. Our previous work with zero-dimensional plasma power balance has been extended to include plasma radial profile effects.

We have completed the development of a methodology in decision analysis utilizing influence and decision diagrams to model fusion reactor design problems. We have applied the methodology to assess an optimal design of an experimental facility based, under uncertainty, on the attributes of technical performance, cost, safety, and time schedule. The analysis also presented some rationales and options applicable to the construction of the SSAT.

Prof. John Holdren as a member of the FEAC is involved in the capacity of providing programmatic guidance to the U.S. fusion program, particularly in the area of fusion safety and environmental issues.

A master thesis analyzing the fusion blanket transient temperature profile in accidents was completed last summer. An invited paper on safety and environmental issues in the strategy for fusion development was presented by Prof. Holdren in the last Topical Meeting on the Technology of Fusion Energy in Boston. A paper about the modeling of the tritium fuel

system and a paper concerning the simplified scaling activation calculational scheme for steel structures were presented at the 17th Symposium on Fusion Technology at Rome, in September, 1992.

Proposed Tasks for FY94

1. Continue development of safety-environment indices and graphical representations and the applications of these to illuminate the characteristics of evolving fusion-reactor designs. Emphases will include:
 - (a) Incorporating into safety-index calculations a more sophisticated set of linkages relating materials properties and reactor-design features to severe-accident release fractions, disaggregated by major reactor components (i.e., first wall, rest of inner blanket, shield, coils);
 - (b) Improved characterization of radioactive wastes and waste hazards from fusion and (for comparison) fission, including "low-level" and "medium-level" wastes;
 - (c) Development of uncertainty and sensitivity analyses for ESE indices and feasibility study of using perturbation theory for generating the sensitivity of ESE indices to data and design uncertainties.
2. Development of fast methods for calculating neutron activation induced radioactive inventories. Two different approaches are expected to be completed during FY 94:
 - (a) The formulation of approximate scaling laws, with major focus on tungsten-divertor and stainless-steel-structure fusion reactor designs;
 - (b) The adaptation and streamlining of the ANISN code to fusion safety calculations with emphasis on minimizing the radioactive inventory computational time.
3. Complete development of a dynamic tritium systems code in collaboration with LANL and INEL. This model is at an intermediate level of detail compared to commercial chemical processing models, with the objective of integrating all fuel cycle units consistently.
4. Complete an integrated environmental and safety systems module linking the plasma and engineering aspects of fusion reactor design. This work is an extension of a simplified version currently being developed .

5. Participate actively in implementing ESE and other subsystem modules into the SuperCode, the ITER EDA systems code developed at LLNL.
6. Investigate the rapid control of plasma shutdown with profile effects and its implications in fusion safety.
7. Explore innovative schemes to improve fusion-reactor ESE performance via the investigation and illumination of ESE impact of alternative materials and design choices.
8. Continue participation in PULSAR and STARLITE design activities.
9. Collaborate with INEL, LLNL, and ITER JCT on applications of the ESE computer modules.

Publications

The following includes only publications issued during the last twelve months (since the last proposal submitted in April, 92).

1. R. Levinson, "An Ordinary Differential Equation Solution for the Transient Temperature Profile of a Fusion Reactor Blanket Following a Loss of Flow Accident" M.S. Thesis, University of California, Berkeley, May 1992.
2. J.P. Holdren, "The Role of Safety and Environmental Issues in the Strategy for Fusion Development," invited presentation at the 10th Topical Meeting on the Technology of Fusion Energy, Boston, June 1992.
3. S.K. Ho and T.K. Fowler, "Fast, Approximate Scheme of Activation-Induced Radioactivity Evaluation for Fusion Reactor Systems Studies," Proc. 17th Symp. on Fusion Technology, Rome, Italy, September (1992).
4. D. Sarigiannis, T.K. Fowler, S.K. Ho, and J.P. Holdren, "Tritium Process Modeling: A System Approach," Proc. 17th Symp. on Fusion Technology, Rome, Italy, September (1992).
5. R.W. Conn, D.E. Baldwin, K.H. Berkner, F.L. Culler, R.C. Davidson, S.O. Dean, D.A. Dreyfus, J.P. Holdren, R.L. McCrory, N.F. Ness, D.O. Overskei, R.R. Parker, B.H. Ripin, M.N. Rosenbluth, J. Sheffield, R.E. Siemon, P. Staudhammer, and H. Weitzner, "Report on Program Strategy for U.S. Magnetic Fusion Energy Research," Report of the Fusion Energy Advisory Committee of the U.S. Department of Energy, DOE/ER-0572T, September 1992.

6. Z. Covaliu, "A Multi-attribute Analysis of a Fusion-Energy-Program Decision under Large Uncertainties", 15th Annual Industrial Liaison Program, University of California, Berkeley, California, March 1993.
7. S.K. Ho, F. Brechtel, and T.K. Fowler, "A Simple Scaling Approach to Calculate Activation Radiological Hazards in a Silicon Carbide First Wall," to be published in Fusion Technol. (1993).

Project Organization

In FY 94, an additional Principal Investigator will be added, Dr. Ehud Greenspan. Dr. Greenspan, a well-known expert in neutronics applications, was recently appointed Professor-in-Residence in the Berkeley Department of Nuclear Engineering. As such, he has already begun participating in the supervision of graduate student research. The recent major reduction in computer time to carry out neutron transport calculations with the ANISN code was accomplished by a student under his direction. Otherwise our research group maintains the same level as last year, as follows:

Principal Investigators:

T. Kenneth Fowler,

Ehud Greenspan,

John P. Holdren;

1 Assistant Research Engineer, Shu K. Ho, funded by the grant;

3 graduate students funded by the grant.

Funding

The requested funding for this period is \$300,000, per OFE guidelines. To hold costs to this level and honor our commitments to graduate students, it will be necessary to cancel the subcontract to LLNL included in the budgets in prior years. We will however maintain an informal relationship with Dr. John Perkins and others at LLNL. A copy of the FY 94 budget request is attached.

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