A. Background Information on Control Engineering

1. Philosophical Problems

Control engineering is essential to the safe efficient operation of any large-scale process such as a nuclear power plant. Yet, the control of these processes usually receives little attention during the design and construction phases. This has resulted in some hard lessons. For example, the only reactor ever launched by the United States into space, the SNAP-10A, failed after only 44 days because of an instrument malfunction. The Three Mile Island accident was in large measure the result of a control failure in that the man-machine interface was poorly designed. This situation is not unique to the nuclear industry. Modern aircraft are designed to fly entirely by computer. Yet, there have been several crashes because a pilot didn't fully understand the preprogrammed instructions in the software or because a ground-based computer couldn't supply the needed data to the airborne one. Control engineering merits more attention that it currently receives. In particular, it should be an integral part of a plant or system's design and not, as is often the case, an add-on.

What accounts for the failure to recognize control issues as fundamental to process design and development? A large measure of the problem originates in the way that control engineering is taught and practiced in the United States. Some specifics:

a) Less than a half-dozen (2 or 3 at last count) colleges or universities offer degrees in control engineering. The field is not recognized as a discipline.

b) Control engineering courses are usually offered as an elective in each of the major engineering departments. For example, the MIT Departments of Mechanical and Chemical Engineering as well as the Aero/Astro department all offer courses, each with its own distinct emphasis. Aerospace engineers focus on optimal control, mechanical engineers tend to use the more conventional feedback techniques, while those dealing with chemical systems stress system models. Why the differences? Each discipline has certain unique problems and hence it emphasizes aspects of control engineering that are most relevant to these problems. Chemical engineers, for example, deal with transport lags (time delays while fluids move through a pipe) and hence lack current information for use in generating feedback. Hence, they rely on system models.

c) There is an enormous gap between theory and practice in the field of control. The theoretical people write articles in which mathematics are often applied in a manner that can't be translated to the real world. Practitioners have, as a result, largely ignored the advances of the last thirty years and are still applying proportional-integral controllers of a type available during World War II to most industrial problems.

d) The gulf between theory and practice in control engineering is accentuated in the nuclear industry because of the long lead-times for plant construction, regulatory inertia, and the lack of new plant orders. The long lead-times (ten years) mean that the control technology selected for a plant will be obsolete by the time the plant is built. The regulatory process is so demanding that few licensees are willing to invest the man-power (woman-power) needed to obtain approval of new equipment. Some plants that have tried to implement digital (i.e., software-based) control and safety system have experienced delays of years and losses of enormous sums of money. The lack of new plant orders means that new technologies are not incorporated in plant designs as they evolve. Thus, instead of an incremental assimilation of new ideas, there will be a step change when and if a new plant is ever ordered in the United States. This will further exacerbate the regulatory issues because the regulatory agencies will not have developed expertise in the new technology.

All engineers, and nuclear ones in particular, need to recognize the importance of overcoming the above hurdles of the effective implementation of the latest advances on control theory.

2. Sources of Information

Table One lists useful references for information on control engineering. Table Two lists text books on the control of nuclear reactors. None of these books is recent. Five universities currently have research programs in progress that deal with reactor control. The MIT program, which started in 1978, is the oldest and is only one that has demonstrated its results on actual reactors — The MIT Research Reactor and the Annular Core Research Reactor at the Sandia National Laboratories in New Mexico. Table Three lists the major reports that have come out of the MIT program. The other universities with reactor control programs are:

Penn State	–	Robust Techniques
University of New Mexico	–	Spacecraft Control
University of Tennessee	–	Signal Validation/Neural Nets
Ohio State	–	**Instrumentation and Man-Machine Interface**

Table One

Sources of Information on Control Engineering

1. IEEE Transactions on Control – An excellent journal but the emphasis is on theory.
2. IEEE Transactions on Control Technology – An excellent journal started in 1992 to complement the above one on theory.
3. IEEE Control Systems Magazine – This journal is highly recommended for its readable, relevant articles on all aspects of control theory and practice.
4. Proceedings of the American Control Conference (ACC) – An excellent conference which usually draws from academia, industry, and government laboratories. It is held annually.
5. IEEE Conference on Decision and Control – Similar to the ACC but usually more theoretical.

Barker Library has an excellent selection of textbooks on control engineering. Also the Coop stocks many books on control engineering. Recommended are:

An* – Model-Based Control of Robot Manipulators

Asada*/Slotine* – Robot Analysis and Control

Astrom – Adaptive Control

Dorf – Modern Control Systems(1)

Franklin – Feedback Control of Dynamic Systems(1)

Friedland – Control System Design – An Introduction to State-Space Methods

Ogata – Modern Control Theory(1)

Schultz/Melsa – State Functions and Linear Control Systems

Seborg – Process Dynamics and control(1,2)

Shinsky – Process Control Systems(3)

*Slotine/Li – Applied Non-Linear Control

*MIT Author

Notes: (1) Text covering fundamentals

(2) Oriented for chemical engineers

(3) Oriented toward applied problems

Table Two

Books on the Control of Nuclear Reactors

1. Ash, M.S., *Nuclear Reactor Kinetics*, 2nd ed., New York, N.Y., McGraw-Hill Book Company, Inc., 1979.

2. Christensen, G.S., Soliman, S.A., and Nievo, R., *Optimal Control of Distributed Nuclear Reactors*, New York and London, Plenum Press, 1990.

3. Hetrick, D.L., *Dynamics of Nuclear Reactors*, Chicago and London, The University of Chicago Press, 1971.

4. Hetrick, D.L., ed., *Dynamics of Nuclear Systems*, Tuscon, AZ, University of Arizona Press, 1972.

5. Keepin, G.R., *Physics of Nuclear Kinetics*, Reading, MA, Addison-Wesley Publishing Company, Inc., 1965.

6. Kerlin, T.W., *Frequency Response Testing in Nuclear Reactors*, New York and London, Academic Press, 1974.

7. Lewins, J., *Nuclear Reactor Kinetics and Control*, Oxford, Pergamon Press, 1978.

8. Mohler, R.R. and Shen, C.N., *Optimal Control of Nuclear Reactors*, New York and London, Academic Press, 1970.

9. Schultz, M.A., *Control of Nuclear Reactors and Power Plants*, 2nd ed., New York, NY, McGraw-Hill Book Company, Inc., 1961.

10. Stacey, W.M., *Space-Time Nuclear Reactor Kinetics*, New York and London, Academic Press, 1969.

11. Weaver, L.E., ed., *Reactor Kinetics and Control*, AEC Symposium Series, Vol. 2, U.S. Atomic Energy Commission, 1964.

12. Weaver, L.E., *System Analysis of Nuclear Reactor Dynamics*, an AEC Monograph, U.S. Atomic Energy Commission, 1963.

13. Weaver, L.E., *Reactor Dynamics and Control*, New York, NY, American Elsevier, 1968.

Table Three

MIT Reports on Reactor Control

1. Bernard, J.A. and D.D. Lanning, Fault-Tolerant Systems Approach Toward Closed-Loop Digital Control of Nuclear Power Reactors, CPE-8317878, National Science Foundation, Washington, D.C., Jan. 1988.

2. Bernard, J.A., Formulation and Experimental Evaluation of Closed-Form Control Laws for the Rapid Maneuvering of Reactor Neutronic Power, Report No. MITNRL-030, Massachusetts Institute of Technology, Cambridge, MA, Sept. 1989.

3. Bernard, J.A. and T. Washio, Expert Systems Applications Within the Nuclear Industry, American Nuclear Society, La Grange Park, IL, Oct. 1989.

4. Bernard, J.A., Startup and Control of Nuclear Reactors Characterized by Space-Independent Kinetics, Report No. MITNRL-039, Massachusetts Institute of Technology, Cambridge, MA, May 1990.

5. Bernard, J.A., Henry, A.F., Lanning, D.D., and J.E. Meyer, Closed-Loop Digital Control of Nuclear Reactors Characterized by Spatial Dynamics, Report No. MITNRL-041, Massachusetts Institute of Technology, Cambridge, MA, Mar. 1991.

6. Bernard, J.A., Henry, A.F., Lanning, D.D., and J.E. Meyer, Studies on the Closed-Loop Digital Control of Multi-Modular Reactors Report No. MITNRL-049, Massachusetts Institute of Technology, Cambridge, MA, Nov. 1992.